Effectiveness of Best Management Practices that Have Application to Forest Roads:
A LITERATURE SYNTHESIS

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ABSTRACT

Literature describing the effectiveness of best management practices (BMPs) applicable to forest roads is reviewed and synthesized. Effectiveness is considered from the perspective of protecting water quality and water resources. Both paved and unpaved forest roads are considered, but BMPs that involve substantial engineering are not considered. Some of the BMPs included are commonly used on roads; others are used less often. The synthesis focuses on quantitative BMP effectiveness and descriptions of processes or characteristics that influenced the effectiveness. Qualitative results and observations not supported by data are excluded. Most of the effectiveness results describe sediment losses and sediment delivery, but there is also some coverage of chemicals used as BMPs, such as dust palliatives and soil conditioners. Chapters and subheadings are based on how or where protection is provided, or type of BMP. The final chapter provides information on research needs and potential direction of BMP implementation in the future. Although there remains a great need to quantify BMP effectiveness more rigorously across more physiographic, topographic, climate, and soil conditions, the data provided in this synthesis give road and watershed managers and landowners a starting place for evaluating and selecting BMPs.

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Introduction

Every year, the U.S. Forest Service's San Dimas Technology and Development Center (SDTDC) sends out a Request for Proposals to agency field units to identify field personnel's priority needs that fall within SDTDC's mission areas. The need for a literature synthesis describing the effectiveness of road best management practices (BMPs) originated from such a request. Field personnel identified potential applications of a literature synthesis. One use would be to provide information that could be used for selecting appropriate BMPs and supporting mitigation strategies in environmental documents (for example, environmental impact statements and environmental analyses). Another would be to furnish material to support adaptive management for reducing problems associated with road construction and use.

Literature and associated data included in this synthesis come from a variety of sources; some of the references have been peer reviewed and some have not been. Journal papers; books; interim and final reports submitted to local, state, and federal agencies; graduate student theses; unpublished reports by research scientists, students, and companies; published state and federal documents; published and unpublished university documents; and information from Internet sites that we consider to be reputable (i.e., primarily federal, state, and university extension sites) are among the pieces of information that we reviewed. Data of unknown origin or data of obviously suspect quality found on the World Wide Web are not included. We have not attempted to rate or evaluate the quality of the data from the perspective of scientific rigor or statistical power. That analysis is outside the objectives and scope of this review, though the reader can pursue that objective if desired by returning to the originally cited sources. Instead, data are presented to provide the greatest breadth of information possible; this was

deemed important because the amount of effectiveness data available for many BMPs is relatively limited (Anderson and Lockaby 2011a, Moore and Wondzell 2005). International System (metric) and English units are employed in this synthesis, and with few exceptions the units used are those in the citations. For readers' convenience, English, metric, and gradient conversions can be found in the Appendix on pages 170 and 171.

BMP effectiveness is at the heart of this report; however, descriptions of the BMP characteristics or processes that reduce pollutants are provided to augment explanations of BMP success or failure in specific situations and to provide the reader with a better understanding of the appropriate applications or limitations of the BMP. Rarely are only qualitative or observational results given from a reference. Where they are used in this synthesis, they were extracted from research studies that included data, and the lack of data supporting the observation is noted. Some reports (especially those by agencies in state departments of highway or transportation) included comments or observations by motor-grader operators or other equipment operators on BMP effectiveness. We did not include these observations because they are subjective and lack measured data or any other type of quantified BMP information to support them. We are not suggesting such observations have no merit, but because they are not otherwise scientifically supportable, they have been excluded. Along this same line, we emphasize that this synthesis **does not** simply describe or summarize BMPs that are used on or are applicable to roads (e.g., from state BMP manuals), because our intent was to avoid implying that broad acceptance and implementation of a BMP guarantee effectiveness or that its performance is well supported by research.

To maximize the amount of available effectiveness data presented in this literature synthesis, studies and results are not restricted to road research or road applications.

BMP information and effectiveness results that have application to roads but originate from a variety of other resources, particularly agriculture, have also been included. As such, readers should be aware that levels of effectiveness reported in nonroad applications may not represent the degree of effectiveness if the BMP were applied to roads.

BMPs are discussed within this document only from the context of their effectiveness for controlling nonpoint source pollution. This was the original context of the term "best management practices" within the Federal Water Pollution Control Act (Clean Water Act) of 1972 as amended, even though the term "BMP" has since been appropriated and applied to management considerations far beyond nonpoint source pollution (Aust and Blinn 2004).

This review does not consider passage of aquatic organisms. Although aquatic organism passage clearly has application to the Clean Water Act, it is not central to the theme of nonpoint source pollution **control**. Readers interested in aquatic passage are directed to annotated bibliographies by Anderson and Bryant (1980) and Moore et al. (1999). Road decommissioning (including "putting skid roads to bed") also is explicitly excluded because the focus of this review is road construction, presence, and use. A wide variety of actions can be taken to decommission a road (e.g., for the U.S. Forest Service, see U.S. National Archives and Records Administration 2015), so this topic is sufficiently broad to warrant its own literature review in another outlet. However, some effectiveness information provided for BMPs associated with road construction/use may be applicable to decommissioned roads.

Forest roads are constructed to a wide range of standards. For example, the U.S. Forest Service has the largest single ownership of roads in the United States: about 370,000 mi of system roads (Foltz 1999, Peters and Peters 2009), which can be maintained at one of five different levels (Ruiz 2005) (Table 1). Most of these roads are typical of what people envision when they think of forest roads: unsurfaced or graveled roads. But the quality of those varies from low-standard roads passable only by high-clearance four-wheel drive vehicles to high-standard roads that can be traveled comfortably at moderate speeds. Some forest roads are paved because they have

high traffic volumes or high volumes of very heavy vehicles and thus require paving to protect the road surface from degrading. Most BMP studies included in this document involve lower-to-moderate standard roads, and skid roads when information is available. Because woods roads can include paved roads, however, there is some consideration of those roads (i.e., paving as a BMP) when effectiveness data were available. BMPs that require substantial design and engineering to implement and that are prescribed for very high volume roads (i.e., maintenance level 5 roads in Table 1) are beyond the scope of this synthesis.

The primary focus of BMP effectiveness in this synthesis is erosion and sediment control as sediment is the most common water pollutant associated with forest roads and forest operations (Stuart and Edwards 2006). Runoff and sediment also may carry other road- or traffic-derived pollutants (e.g., motor oil or other petroleum by-products), so other pollutants are discussed when applicable. For example, because road use can result in toxic metal contamination (Rogge et al. 1993), some BMPs have been evaluated for their effectiveness in reducing metal concentrations. Likewise, some chemicals that are used as BMPs (e.g., dust abatement chemicals, soil conditioners, deicing chemicals) have the potential to pollute nearby water bodies, so the pollution potential of such chemicals also is discussed. The effectiveness of BMPs at controlling nutrient losses, including phosphorus (P), which often is bound to mobile sediment, is not considered. Nutrients are excluded for two reasons: 1) Most nutrients are not pollutant concerns during road construction, use, or maintenance; and 2) in the case of P, focusing on sediment control typically is more informative in the context of BMP effectiveness—if sediment is controlled by a BMP, sediment-bound P usually is controlled.

Within the text, we sometimes use wording such as "the BMP was effective." In these instances we simply mean that the BMP resulted in greater reduction of a pollutant (usually sediment) compared to no implementation of the BMP or compared to another BMP. However, such broad use of the concept of "effectiveness" fails to address the more essential question: What level of effectiveness is sufficient to label the BMP as effective? That question is complicated because it does not have a single answer. For some uses, BMP effectiveness may be

Table 1.—Abbreviated descriptions of U.S. Forest Service road maintenance levels from Forest Service Handbook 7709.59, Chapter 60, 62.32 (U.S. Forest Service 2009)

Road maintenance level[a]	Associated road characteristics
1	These are roads that have been placed in storage between intermittent uses. The period of storage must exceed 1 year. Basic custodial maintenance is performed to prevent damage to adjacent resources and to perpetuate the road for future resource management needs. Emphasis is normally given to maintaining drainage facilities and runoff patterns. Planned road deterioration may occur at this level. Appropriate traffic management strategies are "prohibit" and "eliminate" all traffic. Roads receiving level 1 maintenance may be of any type, class, or construction standard, and may be managed at any other maintenance level during the time they are open for traffic. However, while being maintained at level 1, they are closed to vehicular traffic but may be available and suitable for nonmotorized uses.
2	Assigned to roads open for use by high clearance vehicles. Passenger car traffic, user comfort, and user convenience are not considerations. Warning signs and traffic control devices are not provided with the exception that some signing, such as "No Traffic Signs" may be posted at intersections. Motorists should have no expectations of being alerted to potential hazards while driving these roads. Traffic is normally minor, usually consisting of one or a combination of administrative, permitted, dispersed recreation, or other specialized uses. Log haul may occur at this level. Appropriate traffic management strategies are either to: a. Discourage or prohibit passenger cars, or b. Accept or discourage high clearance vehicles.
3	Assigned to roads open and maintained for travel by a prudent driver in a standard passenger car. User comfort and convenience are not considered priorities. Warning signs and traffic control devices are provided to alert motorists of situations that may violate expectations. Roads in this maintenance level are typically low speed with single lanes and turnouts. Appropriate traffic management strategies are either "encourage" or "accept." "Discourage" or "prohibit" strategies may be employed for certain classes of vehicles or users.
4	Assigned to roads that provide a moderate degree of user comfort and convenience at moderate travel speeds. Most roads are double lane and aggregate surfaced. However, some roads may be single lane. Some roads may be paved and/or dust abated. The most appropriate traffic management strategy is "encourage." However, the "prohibit" strategy may apply to specific classes of vehicles or users at certain times.
5	Assigned to roads that provide a high degree of user comfort and convenience. These roads are normally double lane, paved facilities. Some may be aggregate surfaced and dust abated. The appropriate traffic management strategy is "encourage."

[a] See Ruiz (2005) for photographs of roads in each maintenance level.

interpreted as we did in this document—any reduction in a nonpoint source pollutant. In other circumstances, BMP effectiveness may need to meet some minimum threshold of nonpoint source pollutant reduction before it is considered effective. The cost-to-benefit ratio of the BMP may be another factor in determining if a BMP is sufficiently effective for implementation. Due to the subjective nature of and many ways for defining and interpreting effectiveness, we intentionally have made no further attempt to define effectiveness throughout the chapters. Just as the reader is left to evaluate the rigor of the research and quality of the data and studies presented, the reader also is responsible for further interpretation of the pollutant reduction values cited from

these works. It is up to the reader to determine if the BMP is sufficiently effective to warrant implementation in the field or citation in written documents (e.g., environmental analyses).

In describing BMP effectiveness, the fundamental "unit" we have concentrated on is the individual BMP or a few bundled BMPs (i.e., several BMPs were grouped and effectiveness was reported for the group). Consequently, the focus is on studies where effectiveness of the individual or bundled practices was isolated and quantified. This approach thereby excludes many studies that conventionally are used to demonstrate overall BMP effectiveness on a watershed basis (e.g., Arthur

et al. 1998, Brown 2010, Kochenderfer and Hornbeck 1999, Kochenderfer et al. 1997, Lynch and Corbett 1990, Reinhart et al. 1963). These types of studies depend upon the examination of water quality (e.g., turbidity, sediment concentrations, or total suspended solid loads) at the mouth of a watershed. Thus, in addition to not being able to ascribe quantifiable levels of effectiveness to specific BMPs, readers are advised to use caution in interpreting the results of these studies. Hillside and in-channel storage of eroded sediment as well as lags in sediment delivery to the mouth of the watershed may result in incorrect interpretations or overestimations of BMP effectiveness (Edwards 2003).

The approach of examining individual BMPs clearly is at odds with how BMPs are applied within a project or watershed. Typically, multiple BMPs are planned and applied, with some BMPs even providing overlapping or redundant protection (Stuart and Edwards 2006). For example, cross-drain spacing requirements and road graveling both contribute to controlling overland flow energy and sediment transport. The interdependency and redundancy of some BMPs created some challenges to deciding how this literature synthesis should be organized. Ultimately we decided to define chapters and subheadings based on categories of how or where protection is provided or on types of BMPs. In the end, we strived to condense information from almost 800 references into a state-of-the-science document that will be useful to a diversity of landowners and forest resource specialists, and for a variety of applications, both within and outside the U.S. Forest Service.
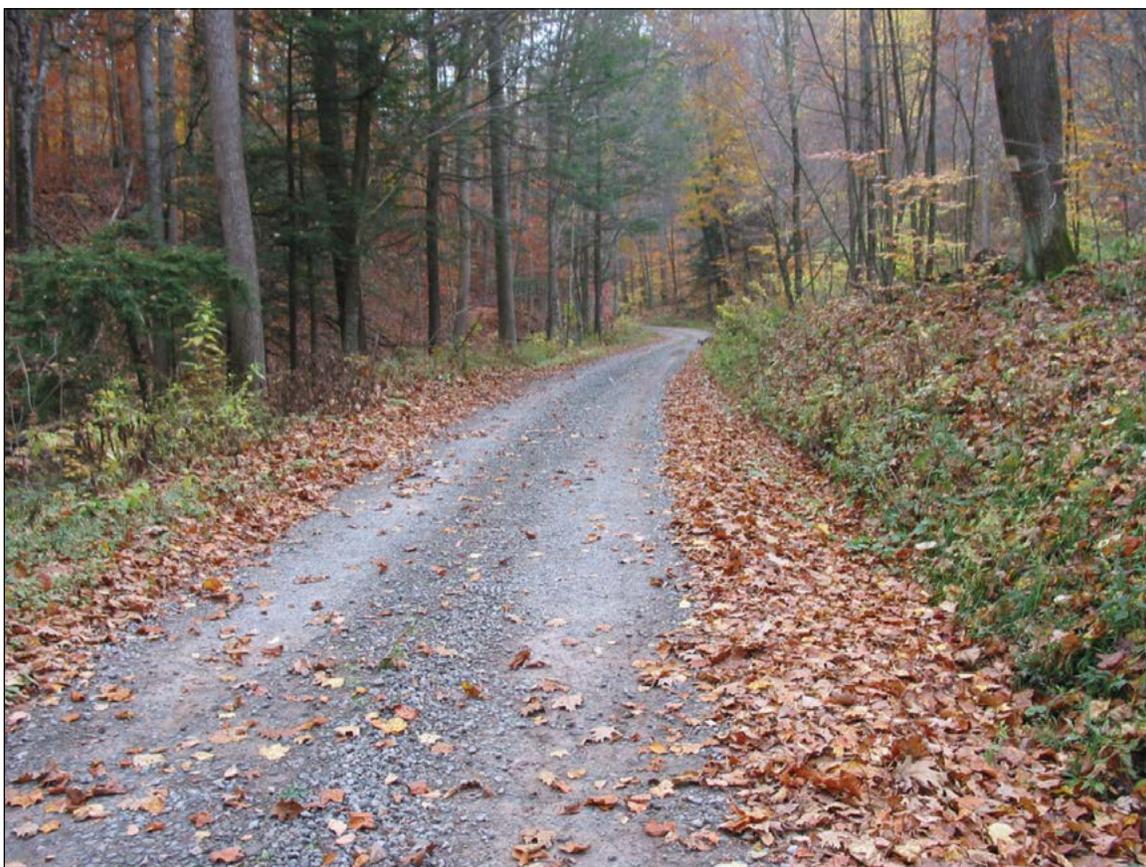
A forest road in West Virginia during autumn. (Photo by U.S. Forest Service, Northern Research Station.)

Road Planning

Research has consistently shown that roads increase erosion and sedimentation more than any other practice associated with forest management (Megahan and King 2004). This is the reason that road planning is repeatedly noted as the single most important BMP (Grace 2002b, Kochenderfer 1970). Through proper planning, most deleterious effects to soil and water resources are thought to be avoidable, thereby reducing the need for additional BMPs to mitigate less-than-optimally-planned roads. Planning is believed to provide greater environmental protection (versus without planning) while simultaneously controlling costs of road construction, BMP implementation, and long-term maintenance.

Road planning really involves all phases of road construction, including the pre- and post-activities to ensure the road meets objectives such as duration and level of use. As such, every chapter in this document could be included under the heading Road Planning. As stated in the Introduction (Chapter 1), however, BMP topics have been artificially separated to simplify presentation of material. Consequently, in this chapter, road planning topics are restricted to a subset of issues that would be defined during the preconstruction period. These are: road location, road profiles (i.e., construction designs, such as cut-and-fill or full bench), on-road drainage techniques (including drainage accomplished by road surface geometry and drainage structures), and cross-drain spacing. Note that road drainage considerations in this chapter focus only on BMPs associated with drainage **on** the driving surface. The effectiveness of BMPs used to control the effects of water diverted off the road is covered in Chapter 7.

Road Location

To the degree possible, well-located roads simultaneously 1) avoid high-risk areas (Megahan and King 2004), 2) maximize the distance between the road and water bodies (Megahan and King 2004), 3) minimize the number of water body crossings (Egan 1999, Megahan and King 2004), 4) minimize the total area disturbed by roads (miles and width of road) (Megahan and King 2004), and 5) control road grades at acceptable levels (Haussman and Pruett 1978, Packer 1967). The first four of these location criteria are considered within this section. Road grades are discussed later in this chapter within the context of cross-drain spacing. Road location, with respect to streams and stream crossings, is discussed from the more general perspective of whether distance acts as an effective BMP for controlling sediment delivery. More in-depth discussion of the effects of distance on sediment delivery with respect to buffer lengths can be found in Chapters 5 and 7.

No single optimal road location exists within any parcel of land because the final location depends on the importance (qualitatively or quantitatively) implicitly or explicitly assigned to each of the road location criteria during road layout. But no matter how each variable is weighted, planning can benefit all of these variables. For example, early research showed planning skid road locations reduced per-acre lengths an average of 37 percent, and reduced the total area in skid roads by 40 percent compared to allowing layout at the time of logging. Planned skid road grades also were an average of 33 percent less (Mitchell and Trimble 1959, Trimble and Weitzman 1953).

From the perspective of road BMPs and the Clean Water Act of 1972, high-risk areas are primarily three types of areas susceptible to mass failures (specific regions, specific geology or soil, steep terrain) and water bodies (predominantly streams). Mass failures are a concern because they can deliver excessive amounts of sediment to downslope streams and rivers (DeGraff 1990, Larsen and Torres-Sánchez 1992, Megahan et al. 1978), which can degrade aquatic habitats (Beschta 1978, Cederholm

et al. 1981, Eaglin and Hubert 1993, Harr and Nichols 1993) as well as water quality. Streams and other water bodies are critical because they are the objects of protection for the Clean Water Act, and because roads can act as channel extensions or provide direct conduits for sediment delivery. Furthermore, disregarding water bodies during road planning can make a road impassable periodically or even permanently.

Mass failures are not common everywhere. They tend to be more prevalent in specific regions, geologies, or soil types, and often in steep terrain with excess water (Anderson 1983, Beschta 1978, DeGraff 1990, Kingsbury et al. 1991, Maharaj 1993, Montgomery and Dietrich 1994). Duncan et al. (1987) showed the frequency of mass failures in parts of the Pacific Northwest increased exponentially with slope from 12 percent to ≥35 percent. Apparently, however, this relationship does not increase infinitely, as other characteristics of steeper slopes often make them less susceptible to landslides (Maharaj 1993, Megahan et al. 1978, Mehrotra et al. 1991). Not surprisingly, landslides also are often linked to the occurrence of large rain events or extremely wet periods (Anderson 1983, Chatterjea 1994, DeGraff 1990, Larsen and Torres-Sánchez 1992, Maharaj 1993, Moore et al. 1991, Scatena and Larsen 1991). In addition, many local naturally occurring variables contribute to landslide potential. The list of these is long, and an in-depth discussion of them is beyond the scope of this review. But some important factors are soil characteristics (Carrara et al. 1991, Maharaj 1993, Megahan et al. 1978, Sessions et al. 1987, Swanston 1974), lithology and bedrock characteristics (Carrara et al. 1991, DeGraff 1990, Maharaj 1993, Mehrotra et al. 1991, Swanston 1974), and hillside shape, including curvature and topographic convergence (Anderson 1983, Duncan et al. 1987, Montgomery and Dietrich 1994, Sidle et al. 1985). More uncommon events, such as seismic activity, also can trigger landslides (Brabb 1995, Moore et al. 1991).

The existence or construction of roads has been found to exacerbate landslide potential. Roads have more effect on landslide creation than does any other forest management activity (Megahan and King 2004, Moore et al. 1991). In Idaho, 88 percent of new winter and spring landslides surveyed over a 3-yr period (1974-1976) and 57 percent of new landslides inventoried after the

winter of 1995–1996 were associated with the presence of roads (McClelland et al. 1997, Megahan et al. 1978). In an unpublished 1965 U.S. Forest Service report, Jensen and Cole reported 90 percent of landslides surveyed in parts of the South Fork of the Salmon River in Idaho were associated with roads (Megahan et al. 1978). An analysis in the Olympic National Forest in Washington state showed that 90 percent of sites with slope failures or high risk for slope failures had road-related factors (Lewis 1995), and Amaranthus et al. (1985) found that 60 percent of debris slides inventoried in the Klamath Mountains of Oregon were associated with roads. Debris avalanche erosion was 25 to 340 times greater where roads were present in the Pacific Northwest than in unroaded forests (Swanston and Swanson 1976). In the northern Rocky Mountain province in Idaho, Megahan et al. (1978) used a number of reconnaissance techniques and estimated that roads were associated with 58 percent of landslides, whereas only 3 percent of landslides occurred on undisturbed hillsides. Road cuts were twice as likely to cause landslides as road fills, but the latter were more likely to reach streams downslope. In highly fractured and weathered bedrock and soils, roads with steep road cuts were the most common sites of landslides in Jamaica; more than 50 percent of the landslides were associated with road cuts (Maharaj 1993). In contrast to many other studies, in western Oregon landslide frequency was not strongly tied to the presence of roads, but road-associated landslides contributed far more sediment to stream channels than did landslides at all other locations (Fredriksen 1970). Mass failures most commonly affected locations where roads intersected stream channels.

In some instances, areas of landslide activity also contained other hillside disturbances associated with the road, such as logging. In the northern Rocky Mountain province of Idaho, 30 percent more mass failures occurred in the presence of logging or fires with roads than from roads alone (Megahan et al. 1978). Landslide frequency was 3 to 26 times greater on hillsides with road building and logging in northwestern California, compared to nearby undisturbed forest land (Wolfe and Williams 1986).

Because of the influence of soil wetness on mass failures, road drainage control is critical to reducing slope failures (Megahan and King 2004). Poor drainage

or the lack of drainage from roads concentrates flow (including intercepted interflow from upslope contributing areas), and has been responsible for hillslide failures after large rainfalls (Maharaj 1993, Sidle et al. 1985). Megahan et al. (1978) determined that lack of road drainage caused 27 percent of the landslides studied in Idaho. Dyrness (1967) reported that 4 of 47 slope failures in the Oregon Cascades, including the largest (in terms of material moved), were associated with blocked road drainage systems.

Relationships between mass failures and the presence of roads are illustrated by these and many other studies worldwide (for example, see Sidle et al. [1985] for a comprehensive review of mass failures and land use). Consequently, locating roads to avoid landslide-prone areas is a prudent BMP; however, the effectiveness of locating new roads outside these high-risk areas cannot be quantified directly. Thus, the existing known relationships, such as those described earlier, must be employed as surrogates of measurements of their effectiveness.

Locating roads to avoid landslide-prone areas can be achieved most successfully by identifying areas believed to be susceptible to mass failures based on local conditions and risk factors (Chatwin et al. 1994, Hammond et al. 1992, Larsen and Parks 1997, McClelland et al. 1997, Megahan et al. 1978, Montgomery and Dietrich 1994, Swanston 1974) and identifying the length (i.e., perpendicular to the contour) of the area typically influenced by mass wasting disturbance. This can be done with soil mapping, geotechnical investigations, and measurements of where roads have been constructed and landslides have occurred (Larsen and Parks 1997). Lower, middle, and upper landscape positions are all susceptible to mass failures (Amaranthus et al. 1985, Beschta 1978, Duncan et al. 1987, Fredriksen 1970, Megahan et al. 1978), so the analyses should include all slope positions. Roads outside of areas susceptible to mass failures still may trigger mass failure due to long lengths of influence, and alternatively, roads within the length of influence also may be affected by mass failures (e.g., covered by debris during failure) that other factors such as large precipitation events caused (Larsen and Parks 1997, Wemple et al. 2001).

Where roads cannot be avoided, the occurrence of mass failures can be reduced by controlling road width or length, or both dimensions. Widening an existing road in Malaysia resulted in a landslide during an intense rain event (Douglas 1967). Main access roads in Idaho had 3.4 mass failures per kilometer of road compared to narrower spur roads, which averaged only 0.8 mass failures per kilometer (Megahan et al. 1978). Sessions et al. (1987) found that using steeper roads with fewer miles across steep landslide-prone areas reduced landslide frequency as long as they were well maintained. This is because the shorter total road length resulted in two advantages: a greater proportion of the road system located on ridgetop areas, which are less susceptible to landslides, and smaller volumes of excavated material.

Although road-location BMPs for landslide-prone areas are focused primarily on entirely avoiding those areas, the objectives for reducing road impacts to streams in areas not prone to landslides are focused largely on maximizing distances between roads and streams, minimizing road length, and minimizing the number of stream crossings to the degree possible. There is broad acceptance that proper location of roads is critical to reducing stream sedimentation; roads are a major source of sediment and as much as 90 percent of sediment is attributable to roads (Megahan and King 2004, Packer and Christensen 1964). Much of the consensus about the importance of road location originates from the extensive amount of data that show the connection between the presence of roads and changes in watershed hydrology and sediment delivery, rather than from designed road location studies.

Differences in the degree of connectivity within different watersheds are due to topographic factors, road location and density, road drainage characteristics, and other conditions (Croke et al. 2005, Mockler and Croke 1999, Montgomery 1994, Skaugset and Allen 1998, Takken et al. 2008, Wemple et al. 1996), but road-to-stream connectivity is common. In the western Cascade Mountains, Wemple et al. (1996) found that 57 percent of the 350 km of road lengths surveyed were hydrologically connected to stream channels, so drainage density was effectively increased by 35 and 39 percent for two different basins. In Australia, Mockler and Croke (1999) estimated that hydrologic connections with the road system affected 44 percent of a stream network and 100

percent of the main channel of a 57-km^2 basin. Skaugset and Allen (1998) in Oregon and Bilby et al. (1989) in southwestern Washington state reported similar levels of road-to-stream connectivity: 31 to 39 percent and 34 percent, respectively. La Marche and Lettenmaier (2001) found 24 percent of ditch relief culverts in a 149-km^2 watershed in Washington were hydrologically connected to streams, and 33 percent of all culverts were stream crossing culverts that therefore were connected directly.

Because roads result in much greater sediment production than undisturbed hillsides, their hydrologic connection to streams consequently increases sediment delivery to levels much greater than would occur without roads (Mockler and Croke 1999). This is referred to as "sedimentological connectivity" (though it is not restricted to road-derived sediment) (Bracken and Croke 2007). However, the ubiquity of connectivity between roads and streams and consequent sediment delivery provide a more compelling argument for the effectiveness of minimizing road density (i.e., length per area) than for retaining maximum distance between roads and streams. If distance is important, evidence to support the latter should instead come from relationships between slope position and sediment delivery.

In the absence of roads, landscape position is not always related directly to hydrologic connectivity due to the complexities of hillslope, soil, and flowpath characteristics, but there is a greater probability of that connection if the transport distance is short (Bracken and Croke 2007). In the presence of roads, the potential for hydrologic and sedimentological connectivity is believed to increase as the distance between roads and streams becomes smaller (La Marche and Lettenmaier 2001), but illustrating that increasing the road-to-stream distance alone necessarily reduces hydrologic connectivity or sediment delivery is very difficult due to other factors such as slope and cover. This is because isolating the effectiveness of distance requires sediment reductions to occur solely from deposition on the hillside due to the increased opportunity for infiltration attributable to greater slope length. In reality many other natural hillside features and human-made structures reduce connectivity by slowing drainage or capturing sediment; these include natural obstructions, windrow filters, litter, vegetative cover, and designed erosion control structures (Burroughs and King 1989, Cook and King 1983,

Ketcheson and Megahan 1996, King 1979, Megahan and King 2004, Packer 1967, Packer and Christensen 1964, Wasniewski 1994) and can be at least as important as available distance between roads and streams.

Another problem with demonstrating the effectiveness of maximizing distance between roads and streams is the high variability in the amounts of sediment that originate from different road segments, as most sediment comes from only a small minority of road segments (Croke et al. 2005, Luce and Black 1999, Takken et al. 2008). Many problematic road segments are the result of inadequately spaced drainage features that allow concentrated flow from cross drains to reach streams (Skaugset and Allen 1998, Takken et al. 2008, Wemple et al. 1996). This is the principal source of connectivity aside from the direct connection at stream crossings. Skaugset and Allen (1998) found that 10 percent of drainage locations on roads that delivered sediment to streams (i.e., non-crossings) were from random, non-engineered points along roads in Oregon, whereas about twice that many origination points (19 percent) were cross drains. Wemple et al. (1996) reported that gullies which acted as stream channel extensions occurred below 25 percent of the cross drains surveyed. In a study by Croke et al. (2005), cross-drain culverts were 10 percent of all drain types surveyed, but 90.5 percent of them connected directly to streams by gullies. Because gullies can transport runoff and associated sediment almost unimpeded very long distances once they become established, even very long hillside distances between roads and water bodies can be rendered ineffective in preventing sediment delivery.

Even with acknowledging the difficulties of isolating hillside distance as an important variable in controlling sediment transport, it seems intuitive that decreasing the distance between roads and streams should increase the potential for road to stream connectivity. Some evidence supports high risk of sediment delivery from valley bottom roads that are close to parallel streams (Takken et al. 2008). In watersheds throughout several geographic regions in western Oregon, Skaugset and Allen (1998) reported that roads in lower valley segments constituted only 11 percent of the roads surveyed, but 59 percent of those delivered, or possibly delivered, sediment directly to streams. In these situations, advantages that distance could have provided are largely unavailable;

the flexibility and choices of other suitable mitigation strategies (e.g., erosion control structures between roads and water bodies) become much more limited, making sediment delivery very difficult to control (Swift 1985). It is also almost impossible to add enough cross drains on valley bottom roads to reduce runoff volumes enough to eliminate hydrologic and sedimentologic connectivity. Takken et al. (2008) calculated that cross-drain spacing in some situations on roads in valley bottom segments would have to be no more than 5 m, which is infeasible.

The relationship between distance and sediment delivery is not so clear for midslope and ridgetop positions. Skaugset and Allen (1998) rated about 30 percent of both midslope and ridgetop road segments as delivering or possibly delivering sediment to streams, though the total number of midslope road segments surveyed was much greater than the number of ridgetop segments (~2,450 versus 500, respectively). Midslope connectivity may be more common than often anticipated because these roads are most likely to intercept subsurface flow in cutbanks (Jones 2000b, Wemple et al. 2001), so more water must be handled by cross drains on midslope roads. Cutbanks can intercept subsurface flow when the depth of the cutslope extends below the permanent water table (O'Loughlin 1975, Parizek 1971), when there are transient (e.g., seasonal) water tables that rise above the base of cutslopes, or when discontinuous saturated zones (e.g., springs) exist above the water table (Dutton 2000, Tague and Band 2001, Wemple and Jones 2003). The locations where cutslopes will intercept subsurface flow is difficult to predict and plan for during road construction (Toman 2004). Experience in the physiographic region may be of limited usefulness in anticipating where problems might occur because seemingly similar road segments may not have similar potential for or amounts of cutbank interception (Toman 2004). Midslope roads contribute additional challenges during road location because they also tend to have more stream crossings than upper slope or lower slope roads due to the high drainage densities in midslopes (Takken et al. 2008). These provide a direct connection of runoff and sediment to streams (Weaver and Hagans 2004).

Locating roads in midslope and upslope positions may be somewhat more effective at controlling sediment than locating roads in valley bottoms immediately adjacent to streams, but the degree of protection often may

be overassumed, particularly for midslope locations. Concentrated road drainage from midslope roads can extend to streams, even for streams that are relatively far away (Croke and Mochler 2001, Ketcheson and Megahan 1996, Wemple et al. 1996). The length of such connectivity that is possible may be underestimated due to misconceptions about the objectives of road drainage BMPs. Most BMP cross-drain spacing recommendations in the United States are designed to control the energy of water at volumes small enough to control erosion and damage on the road surface (see Cross-Drain Spacing section). Maintaining concentrated road runoff at volumes that do not create hydrologic or sedimentologic connectivity once the water is diverted onto the hillside is not an objective of many recommendations, and the spacings required to meet these two different objectives are probably not equivalent in most instances (Edwards and Evans 2004). Therefore, control of hillside connectivity becomes dependent in part upon hillside erosion control, and also in part on limiting the volumes of water delivered at any one point from the road (described in Chapter 7).

Maintaining distance between roads and streams is probably most effective as a BMP when erosion or sediment transport is associated with dispersed road runoff, or with fillslope erosion from rainfall or dry ravel. In these situations, infiltration and sediment deposition can be achieved relatively easily in short distances because interrill and dry ravel erosion (versus rill and gully erosion) dominate sediment transport (Ketcheson and Megahan 1996).

The presence of stream crossings can strongly influence water quality and stream health because crossings directly contribute runoff and sediment (Kruetzweiser and Capell 2001, Lane and Sheridan 2002, Swift 1988, Weaver and Hagans 2004; also see Chapter 5), suggesting that planning to control the number of crossings can be an effective BMP. Croke et al. (2005) modeled runoff and sediment delivery from a variety of dispersive pathways to streams in a catchment in New South Wales, Australia, and found that the point with the greatest inputs of both was a stream crossing; other individual sources, such as cross drains, yielded substantially less sediment by dispersed pathways. Eaglin and Huber (1993) provide additional evidence of the effects of stream crossing density on sediment

delivery. Stream embeddedness and the amount of fine sediment in streams were both significantly and directly related to stream crossing density, and the amount of cobble substrate was significantly and indirectly related to crossing density. Bill (2005) also found stream crossing construction increased the percentage of fines downstream of the crossings and when compared to a stream in an unroaded watershed followed through several years of monitoring.

Road Profiles

The profile of a road refers to the general shape of the road prism and the driving surface. Most forest roads are constructed as cut-and-fill roads. A cut is made into the hillside and the removed material is side cast downslope (Fig. 1). About half of the road driving surface is built on residual soils in the cut portion and half is built on the side-cast fill material. The area from the top of the cutslope above the road to the bottom of the fillslope below the road constitutes the road prism.

Beyond the sediment associated with road driving surfaces (see Chapters 3 and 4) and with landslides or sediment delivery due to the location of roads, fillslopes and cutbanks of cut-and-fill roads have their own unique set of challenges with respect to erosion and sediment control. The design of cut-and-fill roads alters the surface and subsurface hydrology and oversteepens both cutbanks and fillslopes compared to the original hillside slope, though fillslopes tend not to be as steep as cutbanks (Burroughs and King 1989). Additionally, fillslopes generally are composed of unconsolidated material (Edwards and Evans 2004, Megahan and King 2004, Rothwell 1978). Together, these attributes make
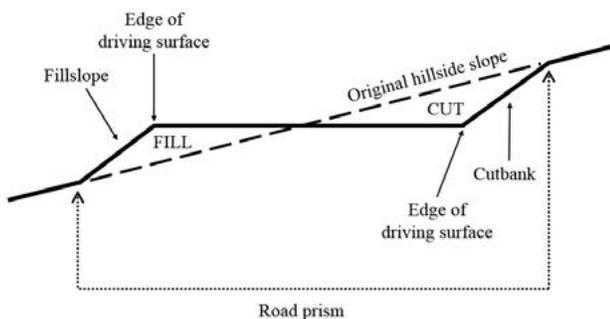
Figure 1.—Schematic of a cut-and-fill road. Soil removed from the cut is used to construct the fill. The road driving surface is composed of both cut and fill areas.

these areas susceptible to erosion until their soils become stabilized, usually through revegetation (see Chapter 6).

Through the life of the road, sediment contributions are generally much less from fillslopes and cutbanks than from an active driving surface (Croke et al. 2006, Reid and Dunne 1984, Swift 1984b). But fillslope and cutbank contributions can be substantial during construction, and they can be chronic in the long term if slope stabilization is not fully successful and concentrated flow from road surfaces is not controlled. Because fillslopes are on the downhill side of road prisms, they can deliver more sediment during construction than cutbanks. Stedman (2008) measured 1,178 kg of soil that was mechanically delivered to a stream from fillslope construction in the approaches[1] (a total of 152 m of length) of three stream crossings in West Virginia.

Even where road fills do not encroach on streams during construction, initial losses from fillslopes are elevated. This is because fillslopes are composed of unconsolidated material that is susceptible to water erosion and dry ravel (King 1984, Megahan 1974a). Conversely, the unconsolidated soil also provides high infiltration capacities (at least for nonconcentrated flow), reducing the potential for runoff and allowing rapid revegetation (Arnáez et al. 2004, Edwards and Evans 2004, Jordán-López et al. 2009). As a result, erosion rates on fillslopes typically decline relatively quickly once vegetation becomes established (Stedman 2008).

The primary situation in which fillslopes result in greater losses of soil than cutbanks after revegetation has become established is associated with fillslope failures. These can be large mass failures or small slides or slumps (Arnáez and Larrea 1995, Pitts 1992). As with other types of mass failures, fillslope failures commonly are related to poor road drainage control (Arnáez and Larrea 1995). Lewis (1995) reported that 70 percent of slope failures or locations where the risk for slope failure was high were on fillslopes, some of which were fillslopes where road drainage had failed and was destabilizing fills.

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[1]Approaches are defined as the length of road or ditch line from which water would drain directly to the crossing. The outer boundaries of an approach are usually definable by road-surface drainage features or grade changes on the road surface and ditch line.

Cutbanks can lose substantial amounts of soil during construction. Cerdà (2007) found soil erosion from cutbanks during construction was 30 times greater than previously constructed cutbanks that had about 35- to 55-percent vegetative cover. However, cutbanks tend to be more of a concern in the longer term than fillslopes because sediment production is more chronic due to gravity sloughing, undercutting, disturbance of cutbank vegetation with mowing, and bank failures. Several similarly designed experiments from existing cutbanks and fillslopes in the Mediterranean region of southern Spain illustrate this tendency. Using simulated rain events on 12 cutbanks (1 to 4 m high) and 12 fillslopes, Jordán-López et al. (2009) found cutslopes resulted in 18 times more total average soil loss (486.7 g m^{-2}) than fillslopes (27.2 g m^{-2}). On average, the cutbanks were 50 percent steeper (40-percent grade) than fillslopes (29-percent grade), but soil loss on the fillslopes was statistically ($p < 0.05$) explained only by soil texture and not by other soil cover or slope variables.

Arnáez et al. (2004) measured average total soil losses from simulated rain events on 12 cutbanks and 6 fillslopes of 160.7 g m^{-2} and 10.5 g m^{-2}, respectively. In their study, cutbank slope, which ranged from 60 to 120 percent, was significant (and positive) in explaining soil loss, and coarse fragment cover was significant (and positive) for the fillslopes. Rather than protecting the soil from erosion, increasing gravel content on the fillslope soil surface concentrated water and runoff locations between gravel particles; this is similar to processes noted for stone mulch (Poesen and Ingelmo-Sanchez 1992; also see Chapter 6). Jordán and Martínez-Zavala (2008) measured an average of 106 g m^{-2} from 10 cutslopes and 17 g m^{-2} from 10 fillslopes from simulated rain events, but neither slope gradient, rock cover, nor plant cover was statistically important in explaining the soil losses from either type of slope. Arnáez and Larrea (1995) used erosion pins and also found cutslope erosion exceeded fillslope erosion.

Although these Mediterranean studies do not consistently show cutslope gradient to be important in explaining erosion, it often is. For example, 0.75:1 (horizontal:vertical) slopes resulted in sediment reductions of just 32 to 47 percent over a 3-yr period after mulch, seed, and fertilizer treatments, compared to the 90-percent reductions estimated for more gentle slopes of

1.25:1 (Burroughs and King 1989). Diseker and Sheridan (1971) found steepness to be important in predicting roadside sediment yield in Georgia. For granitic cutslopes in Idaho, Megahan et al. (2001) reported that cutslope gradient was the most important variable when predicting cutslope sediment yield. Results from a road cutslope study by Odemerho (1986) in Nigeria showed a curvilinear relationship between cutslope gradient and sediment yield. Soil losses increased from about 35 tonne ha^{-1} yr^{-1} to 125 tonne ha^{-1} yr^{-1} as cutslope gradient increased from 2 percent to 7 percent, then decreased to less than 20 tonne ha^{-1} yr^{-1} as cutslope gradient continued to increase to approximately 50 percent.

Steep cutbanks are difficult to stabilize with vegetation and to keep vegetated for several reasons. Infiltration often is poor on cutbanks because of crusts that form due to erosion and low organic matter content in cutbank soils (Cerdà 2007). Runoff can wash seed, poorly established vegetation, and even mulch from cutbanks (Bochet and García-Fayos 2004, Buchanan et al. 2002, Burroughs and King 1989, Meyer et al. 1972) (also see Chapter 6). Freeze–thaw processes, frost heaving, and ground ice contribute by uprooting shallowly rooted vegetation and loosening soil, which continues the cycle of erosion (Arnáez and Larrea 1995). Intercepted subsurface flow can destabilize areas on the cutbank near where water comes to the surface and saturates the soil. Soil that has eroded and blocked drainage at the base of the cutbank can further saturate soil and contribute to destabilization of the cutbank (Arnáez and Larrea 1995). Cutslopes also are susceptible to small failures through undercutting or removal of the toe of the slope during ditch or road maintenance (Chatwin et al. 1994, Yee 1976).

Even after 10 yr, Cerdà (2007) found cutbanks at two locations in Spain generally had <50-percent vegetative cover. Bold (2007) also found revegetation was slow to occur on cutbanks with a mean slope of 96 percent in the moist climate of West Virginia. About 2 yr were required for moderate levels of vegetation to become established after cutbank construction and seeding, and after 4 yr the percent cover for cutbank sections with southern aspects averaged only 36 percent compared to 64 to 82 percent for other aspects. In eastern Spain, Bochet and García-Fayos (2004) reported almost no vegetation cover on road cutslopes greater than 100 percent, and <10-percent

cover on slopes less than 100 percent, for 6- to 8-yr-old roads; where vegetation did develop, cover was about twice as thick on north-facing versus south-facing cutbanks.

Several types of practices have been developed as BMPs to reduce some of the erosion and sedimentation problems associated with the fillslopes and cutbanks of cut-and-fill roads. These BMPs include using full bench construction and end hauling in place of cut-and-fill roads (at least in high-risk locations), compacting fillslopes, and terracing cutbanks (all of which are described in the following paragraphs) (Burroughs et al. 1976, Cameron and Henderson 1979, Chatwin et al. 1994, Gwynne 1950, Megahan and King 2004, Megahan et al. 2001, Stedman 2008) as well as a myriad of techniques to control drainage on fillslopes (Bethlahmy and Kidd 1966, Burroughs and King 1989, Cook and King 1983, Dudeck et al. 1970, Swift 1985) that are covered in Chapter 7.

Full bench construction involves constructing the driving surface fully from residual soil material so no material is side cast and no fillslope is created (Fig. 2). All of the excavated soil is used to supplement material where needed, including on the road surface and turnouts, and unneeded excess soil is stored in a location safe from sediment transport or taken offsite (i.e., end hauling) (Cameron and Henderson 1979). Thus, the primary advantage of full bench construction is that it eliminates fillslopes and problems associated with fillslope erosion and failure. A disadvantage of this alternative is that building a road of the same driving-surface width requires excavation farther into the upslope hillside, which typically results in a higher cutbank.
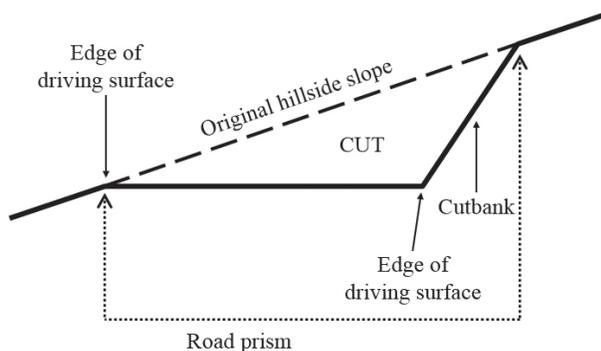
Figure 2.—Schematic of a full bench construction road. The road driving surface is entirely within the cut area since a fillslope is not developed in full bench construction.

Given that large mechanical additions of sediment to streams can result from cut-and-fill roads during construction where roads approach streams (Stedman 2008), and fillslopes are relatively common sources of hillside failures (Arnáez and Larrea 1995, Lewis 1995, Pitts 1992), full bench construction might be considered to be an effective means of reducing erosion and sedimentation in some situations. However, few studies have examined its effectiveness, so there is little direct evidence to support it as a BMP, to illustrate the improvement in effectiveness compared to cut-and-fill-roads, or to identify those situations where it is most effective. An analysis by Sessions et al. (1987) of landslide occurrence compared old construction techniques (late 1960s and early 1970s) using moderately sloped cut-and-fill roads to more modern construction techniques of steeper roads that included a subset of full bench roads (37 percent of new roads were full bench; the remaining were cut-and-fill). They found lower landslide occurrence in full bench roads, but attributed the reduction to the steepness of the roads and not to full bench construction, because steep roads, regardless of construction techniques, could reach ridgetop locations more quickly with shorter road lengths. They suggested construction of steeper cut-and-fill roads with adequate maintenance as an alternative to full bench construction to reduce landslide occurrence.

Whether roads are constructed using cut-and-fill or full bench techniques, cutbanks are created; therefore associated problems must be considered during road planning. In some locations, cutslope height has been associated with intercepted flow (Wemple and Jones 2003); in contrast, La Marche and Lettenmaier (2001) found no relationship between the two. Thus, designing roads to reduce cutbank heights to the degree possible will not guarantee that subsurface flow is not intercepted. Wemple and Jones (2003) found that road segments with the largest cutbank heights tended to respond rapidly to precipitation, resulting in higher unit area peak runoff, and hence, more energy for sediment production (Piehl et al. 1988). Skaugset and Allen (1998) reported that 72 percent of midslope road segments with cutbank heights more than 5 ft were rated as delivering or possibly delivering sediment to streams whereas 60 percent with cutslope heights less than 5 ft had those same ratings.

Much less information is available about other techniques that have been recommended as BMPs to reduce fillslope or cutbank erosion. There is little information in the literature to suggest that fillslope compaction reduces erosion. Instead, compaction may increase erosion. Fillslopes in Idaho were rolled and compacted, and runoff and erosion were compared to uncompacted fillslopes (Boise State University 1984). Compaction reduced infiltration rates and increased runoff and erosion. Sediment yields were 107 to 532 percent greater than for uncompacted fillslopes and averaged 282 percent more.

Similarly there is little information about or support for the effectiveness of terracing cutbanks. Terracing is rarely performed on forest road cutbanks, probably because on forest roads the cutbanks are usually not very tall. Creating terraces on short cutbanks with heavy equipment is difficult, especially in rocky soils. Terraces are more commonly used where cutbanks are relatively tall, and therefore vertical or nearly vertical walls would be unstable, such as along highways or U.S. Forest Service maintenance level 5 roadways. Gwynne (1950) described the appearance of 15-ft-high and 15-ft-wide step terraces that had been created in loess cutbanks that were up to 80 ft tall along an Iowa state highway. A year after construction, some of the risers had started to break apart. North-facing terraces underwent far more damage than south-facing terraces. In some instances so much of the risers had broken off that the cutbank slope had become an almost continuous slope with rills forming. The combination of spalling and water erosion was expected to eventually return the cutbanks to approximately 1:1 slopes. Megahan et al. (2001) found no significant differences in erosion rates of cutslopes treated with hydroseeding and mulch compared to cutslopes that were terraced, hydroseeded, and mulched. Rather than terracing or sloping cutbanks, Swift (1985) recommended building vertical cutbanks on roads that do not have ditch lines and letting them slump and settle to their natural angle of repose, as this technique can reduce both the width needed for the road prism (less distance for laying the slope back) and the size of fills because less material is excavated to create the cutbank. Swift (1985) did not report how much soil was eroded in this process when soil loosened during slumping. This technique is not possible with high vertical banks

because too much of the driving surface would be lost to accumulation of sloughing cutbank material, similar to that reported by Gwynne (1950).

The driving surface is the last major part of the road profile. Road shape is used to aid in road drainage to reduce the amount of erosion and sediment transport that occurs along with the amount of water discharged from a road's surface. Road drainage can be achieved with a variety of techniques. These include exploiting natural drainage attributable to road location or hillside shape (e.g., natural outsloping on the noses of ridges) and shaping the road surface (outsloping, insloping, crowning) or installing surface drainage structures (e.g., broad-bassed dips, open-top culverts, water deflection devices).

Outsloping has long been considered a simple and affordable technique to transversely drain water from along much of the road surface so that it cannot accumulate sufficiently to cause erosion or contribute to rutting (Swift 1985, Trimble and Weitzman 1953). An outsloped road is constructed so that the entire driving-surface road width is sloped away from the cutbank at about a 2- to 4-percent grade (Moll et al. 1997). This angle is considered to be sufficient to disperse the water and be safe enough to keep vehicles on the road at allowable speeds, particularly in wet or winter weather. However, slippage off outsloped roads has occurred under wet or icy conditions (Hafterson 1973). Analogously, insloping is designed to transfer all water toward the cutbank at a 2- to 4-percent grade (Moll et al. 1997) and transfer it into a ditch at the toe of the cutbank. The ditch parallels the road and then transfers drainage water (both road drainage and intercepted subsurface flow from upslope) under the road through cross-drain or relief culverts. Crowning includes both of these designs so that half of the drainage water is diverted to the outside of the road and half to the inside of the road. Taking advantage of both insloping and outsloping further reduces the risk of the vehicle sliding to the inside or outside of the road under wet or icy conditions. Crowning is probably the most common road surface shape used on roads (Skaugset and Allen 1998).

There are many claims in the literature about the benefits of each of these types of drainage in reducing erosion on the road surface because water is removed in small quantities, a primary tenet of controlling road erosion

(Croke and Hairsine 2006, Packer 1967). Unfortunately, no field data show that one road shape is preferable to another, or suggest in which situations each is most applicable (Elliot et al. 1999). Nor is there published research to indicate that any of these techniques generally is effective at draining water from roads in the way intended.

Each of these road surface drainage techniques works only if rainwater or snowmelt is effectively dispersed transversely from the road surface over the entire road length (or most of it). However, it is easy for the road surface to become deformed so that transverse drainage is inhibited, and instead, water runs down the driving surface, draining off only sporadically along the road length (Swift 1985). Road deformation and the loss of transverse (inslope or outslope) drainage can occur due to a number of processes. Longitudinal depressions are created in wheel tracks by vehicle loads being concentrated and translated to the road surface by the tires. Wheel tracks develop on all types of roads, including paved roads (Aycock 2009, Moll et al. 1997), where they contribute substantially to hydroplaning (Aycock 2009) and can concentrate flow meant to be dispersed or controlled in ditches. Unpaved roads are particularly susceptible to wheel track development when subjected to heavy equipment such as loaded log trucks. Wheel tracks can become ruts with continued heavy vehicle use during wet weather as the tracks retain water (Elliot et al. 2009). Berms also can form on the inside and outside edges of the driving surface (Swift 1985) and further exacerbate poor functioning of insloped, outsloped, and crowned roads.

Road Drainage Structures

Relief or cross-drain culverts that cross under the road from a ditch line adjacent to the road are the most common way to move water from roads (Piehl et al. 1988). Culverts are an efficient way to transfer drainage onto the hillslope below the road. However, several attributes can influence their effectiveness. Culverts are susceptible to plugging if cutslopes or hillsides fail and deposit soil or debris in the ditch line, or if they are not designed with sufficient slope to flush deposited sediment or organic debris, such as leaves and woody material. Plugging can be exacerbated by mechanical ditch cleaning because the toe of the slope is disturbed,

which can increase cutslope erosion or failure and provide a source of sediment. Ditch line cleaning also can disturb the cutbank proper, and remove established vegetation (Luce and Black 2001), which may increase erosion and culvert plugging. In Oregon, Skaugset and Allen (1998) found that 54 percent of cross-drain culverts surveyed were obstructed to some degree, and 60 percent of obstructed cross-drain culverts were blocked by sediment. Piehl et al. (1988) found that 48 percent of ditch relief culverts surveyed had inlets blocked by sediment (24 percent), physical damage (17 percent), or both. Careless road and ditch maintenance also can contribute to culvert failure by partially or fully crushing the inlet of relief culverts with heavy equipment. One-quarter of the relief culverts that had problems reported by Skaugset and Allen (1998) had crushed inlets.

Relief culverts are constructed from a variety of materials, but can have two basic designs: smooth-bored or corrugated. BMP manuals typically recommend corrugated culverts over smooth-bored culverts because the former provides roughness to the inflow, which reduces velocity and erosive potential of discharged water (on the outlet side). In a study of culvert hydraulics related to fish passage, Barber and Downs (1995) measured maximum pipe centerline velocities for a range of discharges and slopes for corrugated and smooth pipes of the same diameter. The smooth pipe produced maximum velocities that were 16 percent higher on average.

Incorrect cross-drain culvert installation and sizing are believed to result in increased sediment production. Improperly sized culverts can plug more easily, leading to culvert overtopping and road surface erosion. Culverts installed too deep at the inlet or at an incorrect gradient can cause sediment deposition, as can culverts installed more perpendicular (less skewed) to the road. Hanging culvert outlets that extend beyond the edge of the fillslope can cause increased scour and gullying. Guidelines for proper cross-drain culvert sizing and installation are widely available (e.g., Johansen et al. 1997, Keller and Sherar 2003, Kramer 2001, Rothwell 1978) and generally are based on federal design standards (Normann et al. 1985). However, research documenting the effectiveness of the guidelines is generally lacking in the literature. A survey by Piehl et al. (1988) of ditch-relief culverts in Oregon found that even though culvert skew angles

averaged half the recommended value of 30º, skew angle was not correlated with sediment accumulation at the culvert inlet.

Ditches are inherently a component of cross-drain culverts. The amount of sediment they provide can vary widely. Croke et al. (2006) found that road ditches, when isolated from the road surface and cutslope, contributed 17 to 45 percent of the total sediment yield from cut-and-fill insloping road segments in Australia. Ditch lines can become vegetated because they are moist and accumulate unconsolidated soil. But vegetation is not always effective at controlling ditch erosion, because grasses and herbaceous vegetation may be uprooted and scoured out when subjected to high amounts of energy from concentrated flow (Barrett et al. 1998b).

Ditch hardening with rock is presented commonly as a BMP to reduce ditch erosion (e.g., Berkshire Regional Planning Commission 2001, Elliot and Tysdal 1999), but only a few studies in the literature show how much of a reduction can be achieved with rock lining. Burroughs et al. (1984b) compared sediment production from cutslopes and rocked or unrocked ditches in Idaho. A 4-inch layer of 1.5-inch-diameter clean gneiss rock in ditch segments reduced sediment by 2.3 times compared to unrocked ditch segments. The characteristics of rock (e.g., size, compaction versus loose placement) that provide the most benefit are unknown. These characteristics may be very different from those of rock best suited for driving surfaces due to the amount of water that is intentionally concentrated in ditches.

A possible alternative to ditch hardening with rock is the use of soil conditioners for erosion control (also see Chapter 6). Soil conditioners have been shown to reduce erosion from irrigated agricultural furrows (Lentz et al. 1992; Zhang and Miller 1996a, 1996b), which may have some similarity with bare soil in roadside ditches. But there are no studies in which soil conditioners have been used specifically for erosion control in forest road ditch lines. Although soil conditioners are ideally suited for erosion control by concentrated flow, they are applicable only for the short term (e.g., during vegetation establishment). If long-term erosion control in ditches is possible with soil conditioners, it would be feasible only with repeated treatments.

Broad-based dip installation is another cross-drain technique used commonly on haul roads and other roads of comparable standard to overcome some of the problems associated with maintaining proper road surface shape for cross-drain culverts or for outsloping (Swift 1985). A broad-based dip (Fig. 3) is built as a gentle roll in the road centerline profile, which is carefully outsloped (Haussman and Pruett 1978, Swift 1988). The dip captures road surface drainage and directs it down the fillslope. Dip geometry—length and depth—must be designed to accommodate the traffic levels and vehicle types expected to use the road (Copstead et al. 1998, Hafterson 1973). The road surface contributing drainage to a broad-based dip is usually relatively flat (i.e., neither insloped nor outsloped) or slightly outsloped (Cook and Hewlett 1979). Broad-based dips are best suited for road segments that are no more than 8- to 10-percent grade (Cook and Hewlett 1979, Kochenderfer 1970, Swift 1985). On steeper roads, dips are difficult to build for effective drainage control (Kochenderfer 1995); dips on steeply sloped roads can become overtopped by water during large events so they become ineffective and create the potential for road gullying. If dips are deep enough to contain and drain water on steep roads, they are very difficult to drive over without vehicles bottoming out or high centering (Hafterson 1973).

Wheel ruts can form along the contributing road length of broad-based dips, but the dip itself theoretically compensates for that because water is meant to be turned off the road only at the dips. This suggests that

Figure 3.—A broad-based dip on a forest haul road. From Keller and Sherar (2003).

roads with broad-based dips may be more effective at reducing the occurrence of rill or gully formation than insloped, outsloped, or crowned roads, where wheel tracks may confine drainage for potentially long distances. However, there are no data that compare these road drainage techniques, so broad-based dips cannot be shown to be superior at controlling on-road erosion compared to other drainage techniques. Nor should this assumption be accepted widely without supporting data because much can happen to retard the effectiveness of dips. Ruts can continue through the entire dip so that the top of the dip (at least in the tracks) deteriorates. Water is not diverted across the road but instead remains trapped within the tracks, bypasses the dip, and continues running down the road. Hafterson (1973) showed that 3-inch ruts with 3-inch ridges on the sides of the wheel tracks were sufficient to prohibit lateral drainage and cause a 6-inch-deep dip to fail. An unobstructed downward outsloped angle in the base of the dip (Fig. 3) also must be maintained for dips to function properly. The accumulation of sediment can turn the dip into a mud hole and eventually fill the dip base enough to allow water to run down the road instead of drain off it (Swift 1985).

Drainage obstruction by grass at the outlet of a well-functioning dip can trap sufficient sediment to block the dip outlet (Swift 1985); the effectiveness of one BMP thereby can negate the effectiveness of another. A study by Bold et al. (2007) of 130 broad-based dips on haul roads of multiple ages on the Monongahela National Forest (MNF) in West Virginia reported that only 58 percent were outsloped to MNF specifications (2- to 5-percent outslope), and all dips had some obstruction to outward drainage by berms on each side of the wheel tracks. The dips were not fully dysfunctional in that the differences in elevation were not generally enough to result in overtopping the lower dip boundary. But they were not fully effective either, because most of the dips retained water or the base of the dip remained moist even between storm events. An earlier survey of dips on MNF roads by Eck and Morgan (1987) showed similar results with 27.5 percent of 255 dips categorized as drainage failures due to fillslope erosion, rutting, siltation, or ponding.

Road maintenance is required to restore dip function. However, restoration requires that road maintenance affect the source of the problem, which is the subsoil from which the roadbed was constructed. Swift (1985) found that small dozers or front-end loaders were better at maintaining road dips compared to motor-graders, which tended to fill in the dips.

Open-top culverts are alternatives to broad-based dips on steep road segments (Kochenderfer 1995). A variety of open-top culvert designs and materials have been developed and used (Copstead et al. 1998, Haussman and Pruett 1978, Kochenderfer 1995). If effective, they too provide some of the advantages of broad-based dips in that they can overcome some of the difficulties of water draining down wheel ruts by intercepting it at regular intervals. However, there are no studies showing the effectiveness of open-top culverts or illustrating the situations where they are best suited. But because open-top culverts require regular maintenance to keep them clean and operational (Hafterson 1973, Swift 1985) and erosion increases with increased traffic (Reid and Dunne 1984), the frequency of required maintenance rises substantially as traffic increases. Consequently, this type of drainage structure is appropriate only for very low volume roads.

The "proof" that cross drains are effective BMPs comes primarily from observations and limited measurements of physical road characteristics (e.g., road rutting, washouts) comparing roads with cross drains and those without cross drains. Long-term utility of drained roads also provides evidence of road drainage BMPs. Properly functioning cross-drain structures can maintain roads in conditions that are usable in the long term, though other protection on the road surface, such as surfacing, contributes substantially to reducing soil losses (see Chapter 3). Therefore, it is often difficult to separate the effectiveness of drainage BMPs from other road surface BMPs.

Additionally, there are no studies comparing the effectiveness of different types of cross drains to each other in situations where multiple types might be applicable. This also applies to less common water deflection devices, such as water bars (Copstead et al. 1998) or used tires or rubber belting (Wiest 1998), that are used on low standard roads or skid roads. Thus, no data-based prescriptions for specific types of drainage can be made for specific site conditions at this time. Instead, current recommendations are based on the

limitations or capabilities of the drainage features themselves relative to the physical site conditions (e.g., whether the road grade is suitable for a technique), the standard to which the road will be built (e.g., traffic levels, type and speed of traffic expected), and economic considerations. Even though the applications of techniques that will physically match the situation provide some degree of potential for erosion control, this is far from the desired outcome: the ability to choose the technique that provides the best degree of erosion control for the specific conditions.

Cross-Drain Spacing

Roads other than outsloped roads require features or structures, such as relief culverts, broad-based dips, and water bars, to ensure that drainage occurs. The retention of water on the road or the delivery of water from the road is determined by cross-drain spacing (Bracken and Croke 2007). The spacing and location of cross drains are critical as water concentrated on the road surface provides the energy for erosion and sediment transport. Road surfaces concentrate water because they are highly compacted with low infiltration rates (Reid and Dunne 1984), leading to rapid generation of overland flow. In terms of stream power, the erosion potential of overland flow routed to cross drains is proportional to the product of road surface slope and discharge (Croke and Hairsine 2006). For roads studied in the Oregon Coast Range, sediment production was correlated to the product of road segment length and the square of the slope, showing slope was most important (Luce and Black 1999). Thus, longer and steeper gradients result in surface runoff with greater velocity and energy (i.e., shear strength) and greater potential for erosion than low-gradient roads. Increased spacing between cross drains on low-gradient roads has much less effect on erosion than it does on high-gradient roads (Luce and Black 1999) because kinetic energy increases with the square of velocity, which is tied to gradient.

Road surfacing in the form of gravel or other coarse fragments can substantially decrease the potential for erosion by providing greater roughness and tortuosity than would otherwise occur without the surfacing (see Chapter 3). However, even when surfacing materials are present on unpaved roads, rill and gully formation can result if sufficient water concentrates on the

surface (Packer 1967). This tendency has led to the development of BMPs that focus on spacing drainage control features based on road gradient. Following these recommendations for the spacing of road drainage features is considered crucial to limiting overland flow and sediment delivery (Croke and Hairsine 2006).

The earliest study of and recommendations for cross-drain spacings in the United States were by Trimble and Weitzman (1953) on the Fernow Experimental Forest in the central Appalachian Mountains. Their recommendations were based on spacings that would maintain maximum allowable erosion of no more than 0.6 inch on skid roads after they had been closed (Table 2). These recommendations were calculated by using road gradient, road length (segment lengths between adjacent surface drainage features), and measured erosion data for skid roads located on benches overlaying limestone-derived soil following road closure. Forty-one profile stations were established on the skid roads, with 13 falling into slope gradients between 0 and 20 percent and road lengths from 0 to 132 ft. Twenty-three profile stations were between 21-and 40-percent grade with lengths from 0 to 132 ft. The remaining five were between 2- and 40-percent slope and 133 to 264 ft long. The authors used two approaches to develop recommendations; one was an "alignment table," where depth of erosion associated with pairs of slope gradients and road segment lengths

Table 2.—Recommendations for skid road water-bar spacing for the central Appalachian Mountains (from Trimble and Weitzman 1953)

Skid road grade	Distance between water bars	
percent	feet	meters
2	250	76
5	135	40
10	80	24
15	60	18
20	45	14
25	40	12
30	35	11
40	30	9

was identified and recommendations were based on those relationships. Because of limited data on the low and high ends of slope/distance pairs, they also used a modification of Manning's formula to calculate values and develop recommendations that included spacing recommendations for slope values beyond those used for the initial method. Although Trimble and Weitzman (1953) noted the importance of other factors (e.g., climate, soil organic matter, soil stoniness, and soil series-dependent characteristics) in affecting water bar spacing, the formula-derived spacings (Table 2) became the standard recommendation that these authors and others (e.g., Haussman and Pruett 1978, Weitzman 1952) presented in other general forest management publications.

Kidd (1963) also developed spacing recommendations for controlling erosion on skid roads (Table 3). His recommendations for western Idaho are based on amounts of erosion associated with cross drains derived from a combination of information in an unpublished 1954 report by Packer; spacings commonly used by the Boise National Forest at that time; and visual, qualitative scores of erosion from 569 skid trail segments on granitic and basaltic soils in Idaho surveyed for Kidd's (1963) study. Kidd found that erosion differed not only between the soils but also between ravine and hillside positions, so his recommendations were separated by those variables, as well as by skid road gradient.

Arnold (1957) developed maximum lateral drainage culvert spacing recommendations for Pacific Northwest truck roads based on soil erosion class, road grade, and rainfall intensities. Soils were assigned to 1 of 10 erosion classes based on the unified soil classification system used in engineering, and soil texture and parent material. Recommendations were made for road grades from 2 to 18 percent and rainfall intensities of 1 to 2 inches h^{-1}. Factors were included for the adjustment of the spacings for higher and lower rainfall intensities (e.g., spacings should be divided by 1.75 for rainfall intensities of 3 to 4 inches h^{-1}). However, no information was provided about how the spacing values were derived, and the recommended culvert spacings were much longer than those developed later. For a 10-percent road grade, spacings ranged from 180 to 845 ft, whereas spacings ranged from 120 to 565 ft on a road with a 15-percent grade.

Table 3.—Recommendations for skid trail control-structure spacing for soils and topographic locations found in west-central Idaho (from Kidd 1963)

Slope	SKID TRAIL SPACING			
	Granite-derived soil		Basalt-derived soil	
	Sidehill	Ravine	Sidehill	Ravine
percent	----------------------- *feet* -----------------------			
10	65	50	90	80
20	50	35	70	65
30	40	25	60	50
40	30	20	50	40
50	20	15	40	35
60	15	10	25	20
70	10	10	15	15

Packer and Christensen (1964) and Packer (1967) employed by far the largest quantitative dataset of those in the United States to develop cross-drain spacing guidelines for haul roads in the Rocky Mountain region. They gathered data from 720 study sites, with 120 sites in each of 6 major soil groups (Table 4). These were further stratified into 60 sites with southern aspects and 60 sites with northern aspects. Data from 20 sites in each of 3 slope positions (upper, middle, and lower one-third of slopes), and 5 study sites within each of those slope positions from each of 4 road gradient classes (0 to 3 percent, 4 to 7 percent, 8 to 11 percent, and 12 to 15 percent) on each aspect were used. They determined the distances that water could flow for various combinations of these variables between consecutive drainage structures before 1-inch-deep rills formed. The 1-inch-deep rill values were determined to be the depth beyond which the road surface would rapidly deteriorate (Packer 1967). From these strata of data, tables of cross-drain spacings were developed from regression equations for each topographic position, aspect, and upslope gradient of the hillside (Table 4). Roads on south-facing slopes are likely to erode more than on north-facing slopes due to earlier spring snowmelt, so they generally require closer cross-drain spacings (Packer 1967).

Table 4.—Cross-drain spacing recommendations for secondary logging roads in the upper topographic position[a] of north-facing slopes[b] having a gradient of 80 percent[c] (from Packer 1967)

Road grade	CROSS-DRAIN SPACING					
	Hard sediment	Basalt	Granite	Glacial silt	Andesite	Loess
percent	---------------------------------- *feet* ----------------------------------					
2	167	154	137	135	105	95
4	152	139	122	120	90	80
6	144	131	114	112	82	72
8	137	124	107	105	75	65
10	128	115	98	96	66	57
12	119	106	89	87	57	48
14	108	95	78	76	46	37

[a] On middle topographic position, reduce spacings 18 ft; on lower topographic position, reduce spacings 36 ft.

[b] On south aspects, reduce spacings 15 ft.

[c] For each 10-percent decrease in slope steepness below 80 percent, reduce spacings 5 ft.

Swift (1985) presented an equation for broad-based dip spacing on forest access roads:

Spacing in feet = 320 - (20 × road segment gradient in percent)

But this equation is based only on visual observations of functioning structures. Similarly, Rothwell (1978) stated that for Alberta, Canada, the distance in meters between water bars on skid roads should be calculated as:

350/ the road grade (presumably in percent)

There is no citation to identify what data were used to develop this method, however. In some instances spacings have been designed arbitrarily, and stated as such (e.g., Haupt and Kidd 1965).

As mentioned previously in this chapter, cross-drain spacings have been designed primarily to control erosion on the road surface (Croke and Mockler 2001, Edwards and Evans 2004). However, a few spacing studies have recognized the importance of considering the cross-drain spacing to control sediment delivery or erosion downslope of the cross-drain outfall. Croke and Mockler (2001) developed a table of cross-drain spacing recommendations specifically for Cuttagee Creek catchment, New South Wales, Australia, based on contributing road length and upslope contributing area. They surveyed road and road-to-stream linkage characteristics for 224 cross-drain structures. Discriminant function analyses were used to first determine the threshold value for contributing road length (distance between cross drains) that best predicted presence or absence of channels or gullies at drain outlets for a range of hillside gradients onto which runoff was cast. The threshold values for contributing length and upslope area were used to calculate recommended cross-drain spacings (for a range of road slopes and drain discharge hillslope gradients) which would minimize channel or gully initiation at drain outlets.

One of the most recent studies of cross-drain positioning was by Damian (2003). He focused on the location of cross drains that are nearest to stream crossings to reduce connectivity between roads and streams. Road segments that contain stream crossings have the greatest connectivity with streams, and thus, the greatest potential for sediment delivery, so their management is critical (Skaugset and Allen 1998). Conventionally, recommendations for those cross drains have been to position them close to crossings. This location was intended to minimize the amount of water and sediment delivered directly from the road and ditch line to the stream (i.e., the drainage and associated sediment

originating between the nearest cross drain and the stream crossing). In some states, placement within 50 to 100 ft of crossings is a recommended practice (Washington Forest Practices Board Manual 2000). Damian (2003) used a modeling approach to optimize cross-drain location and found that the last cross drain in most cases should be positioned between 100 and 200 ft from the stream. Closer positions did not allow effective filtration of sediment because the buffer strip was too short. Consequently, there was a much greater net delivery of sediment to streams when the nearest cross drains were positioned close to streams compared to when they were moved farther away. For two watersheds in Washington state with 28 and 39 stream crossings, the reduction in sediment delivery by repositioning cross drains through modeling was calculated to be about 75 percent in both watersheds. However, no cross drains were actually relocated in the field, so no data were collected to measure and verify any reduction in sediment inputs.

The lack of independent data to verify cross-drain spacing recommendations more broadly within a region or across regions is a limitation of all of these studies. Studies which were designed as more rigorous experiments (e.g., Packer and Christensen 1964) may provide more robust data that are likely to be applicable elsewhere in the region compared to studies with little experimental design or those that were based primarily on observations or measurements from only a few road segments. However, no studies are available to verify the applicability of these studies within or across regions, even though many of these recommendations, or slight variations, are used fairly widely. For example, Trimble and Weitzman's (1953) recommendations became the foundation for many eastern states' skid road BMPs (Elliot et al. 2014) and some western states' (e.g., Colorado State Forest Service 2010), even though the East and the West have very different physiographic, soil, and climate conditions. Additionally, cross-drain spacings defined in each study were developed for a specific type of road (e.g., skid roads or haul roads), but the recommendations are also commonly applied to other types of road systems (Copstead et al. 1998).

The more intensive studies of cross-drain spacing (e.g., Packer 1967, Packer and Christensen 1964) illustrate that cross-drain spacing is vital to controlling erosion and that cross-drain spacing should decrease as road gradients increase. But the lack of studies specifically comparing erosion resulting from cross drains installed at a variety of replicated spacings in similar conditions and the lack of validation of the recommended spacings within regions, across regions, or across road types make it impossible to quantify the effectiveness of current recommended spacings. Nor is it possible to determine if spacings closer than those currently used are warranted, and in what conditions they should be implemented. Modeled data by Damian (2003) suggest that improvements on cross-drain spacing on forest roads are possible, at least in some locations, but these results also have not been field verified.

Protecting the Driving Surface

This chapter includes information about the two types of BMPs most commonly applied to the roadbed: surfacing to control water-driven erosion and dust suppressants to control primarily wind- and vehicle-caused erosion.

The driving surface is inherently different from the rest of the road prism. It is purposely compacted during construction, and it is repeatedly disturbed by traffic. Consequently, it is highly susceptible to loss of soil and geologic materials due to vehicle use, especially during wet or extremely dry weather. So while surfacing and dust control techniques used to protect the road surface have value at all times, they are particularly aimed at these more extreme conditions.

Road Surfacing

Roads can be surfaced with a variety of materials, including asphalt or concrete pavement, quarried washed rock or stone, crushed rock, and gravel and sand materials (Beaty and Raymond 1995, Bolander and Yamada 1999, Dawson and Kolisoja 2006). Pavement is the most common type of road surfacing material (Succarieh 1992), but its use is typically restricted to moderate- and high-use roads due to its cost (Bolander and Yamada 1999, Sanders and Addo 1993). The primary reason that roads are paved is to provide a durable, smooth driving surface. Sediment control is obviously a benefit of paving because the surface is fully covered by a thick and relatively impermeable material, but few studies actually have quantified paving's effectiveness at controlling water-driven erosion. Reid and Dunne (1984) developed sediment rating curves and unit hydrographs for different types of surfaced road segments in Washington state and calculated that paved road segments yielded only 0.4 percent of the sediment that was generated from a heavily used gravel road. Clinton and Vose (2003) found much lower sediment

concentrations in runoff from a paved asphalt road than from the dirt or gravel road segments to which it was compared. However, because of differences in frequency of maintenance and maintenance procedures applied to the three road treatments, quantifying the reductions in sediment specifically due to paving could not be done cleanly. Even with the general lack of data showing reductions in sediment losses due to paving, it is commonly recommended as a technique for reducing erosion and sedimentation (e.g., MacDonald et al. 1997).

Runoff from asphalt-paved roads has the potential to affect water quality in other ways. Petroleum hydrocarbons can be washed or leached from pavement and move into terrestrial or aquatic ecosystems. Hydrocarbons also can result from tire abrasion, exhaust, and lubricating oils from vehicles on the roads (Ngabe et al. 2000). In the aforementioned study by Clinton and Vose (2003), measurable levels of total petroleum hydrocarbons (TPH) were found in the runoff from the 2-yr-old paved road (<0.5 ppm), but the concentrations were well below those permitted in sediment. No federal water quality standards exist for TPH because these hydrocarbons include complex aliphatic and aromatic hydrocarbons that are not well understood chemically (Todd et al. 1999). Clinton and Vose (2003) did not attempt to determine the concentrations of the individual compounds in the TPH in the runoff. Their study is the only one found in the literature review that examined runoff chemistry from paved roads in predominantly forested watersheds. Hydrocarbon data were found for urban areas but were measured in samples collected from water bodies (e.g., Hunter et al. 1979, Latimer et al. 1990, Whipple and Hunter 1979) rather than from roadway drainage. Thus, those data would not be applicable for assessing petroleum hydrocarbon levels on paved roads in most forested watersheds or even in surface waters in forested watersheds (Sanger et al. 1999).

Although paving may be the preferred method to surface roads for long-term protection, many miles of rural roads exist for which paving cannot be justified. Nearly all of the road miles managed by the U.S. Forest Service are unpaved roads (Foltz and Truebe 1995), and 53 percent of all roads in the United States are unpaved (Koch and Ksaibati 2010). In these types of situations, other surfacing materials, such as quarried washed rock or stone and crushed rock or alluvial gravel, may be applied to provide strength and protection against soil displacement from the driving surface. Raindrop impact and consequent soil displacement are eliminated if the surface is completely covered (Quinton et al. 1997, Stuart and Edwards 2006). Additionally, pores between large surfacing aggregate allow drainage and movement of water from the road. Road runoff is slowed, and its energy for detachment and entrainment of particles is reduced by the tortuosity and friction resulting from water moving among the coarse fragments (Wisconsin Transportation Information Center [WTIC] 1997). However, large aggregates that do not have sufficient fines to help bind them together are susceptible to being kicked off the road by traffic or washed off the road, depending upon the aggregate and overland flow conditions present (Sanders and Addo 1993).

Smaller aggregates create a smoother driving surface and help to hold larger particles together (Bennett 1994, Bolander and Yamada 1999), but their presence retards internal drainage. In graded materials, fines should be present in mixtures that minimize water infiltration (Foltz and Truebe 1995) so that water runs off the surface as dispersed overland flow. If the percentage of fines is too small, water will be retained in the existing fines during wet weather due to capillary forces. The road then will perform poorly due to the development of ruts and susceptibility to surface failure because of freeze/thaw processes (Dawson and Kolisoja 2006). Conversely, during dry periods, excessive levels of fines are susceptible to being detached from the road surface by wheel contact (Bolander and Yamada 1999). As fines are lost, larger aggregates loosen and begin to abrade the surface materials as the aggregates move under traffic. This then leads to displacement of particles and road raveling (Sanders and Addo 1993).

There is little published research concerning the effectiveness of specific aggregate types (e.g., clean gravel, various graded mixtures) on controlling erosion on unpaved, low-volume roads. The lack of data about relationships between road surfacing and erosion is somewhat unexpected given the relatively easy nature of designing and implementing such studies. Based on the review of literature, the most commonly cited papers concerning the effectiveness of road surfacing involve three studies: in the Idaho Batholith (Burroughs et al. 1984a, 1984b, 1984c); in the central Appalachian Mountains of West Virginia (Kochenderfer et al. 1997, Kochenderfer and Helvey 1987); and in the southern Appalachians of North Carolina (Swift 1984a). Each of these studies showed that adequate surfacing results in substantial reductions of soil losses from graveled roads (Tables 5 and 6).

Using four simulated rain events, Burroughs et al. (1984a, 1984b) provide a straightforward illustration of the effectiveness of a single type of gravel with a single application thickness. A fresh application of 10-cm-deep hard crusher run (38-mm diameter and smaller) gneissic rock reduced erosion by 77 percent compared to a segment with no surfacing material. Scheetz and Bloser (2008) and Bloser and Scheetz (2012) reported similar results during simulated rain events on Pennsylvania roads. They compared erosion before and after application of Driving Surface Aggregate (DSA), a specific gradation of crushed stone surfacing material designed to establish a well-packed driving surface (Penn State Center for Dirt and Gravel Roads 2014). The DSA surfacing treatment reduced sediment losses on four road segments by 67 to 95 percent compared to the original native surfacing (Scheetz and Bloser 2008). In a subsequent study, Bloser and Scheetz (2012) found that a year after applying pit run aggregate (locally obtained material from "borrow pits" that is variable in composition and quality) to two existing native-surface roads, sediment losses were reduced by an average of 39 and 64 percent during 30-min simulated rain events. These sediment losses were similar to average losses on other roads surfaced with pit run aggregate that they measured in the region. Analogous treatments of DSA on two road segments reduced soil losses by an average of 67 and 95 percent during identical simulated rain events. DSA produced one-tenth of the sediment that the pit run segments produced, but sediment losses from the road segments slated for pit-run treatment were about

three to four times as large as the DSA-treated segments prior to pit-run additions. In the southwestern Virginia Piedmont, Brown et al. (2013) monitored sediment delivery to streams through road approaches from newly reopened roads with bare soil surfaces and from legacy graveled roads, though no information was given about the gravel characteristics. During the year of study, sediment delivery from the five newly bladed bare-soil road segments averaged 98 Mg ha^{-1} yr^{-1} compared to 13 Mg ha^{-1} yr^{-1} from the four graveled road segments.

Kochenderfer et al. (1984) and Kochenderfer and Helvey (1987) compared the effectiveness of crusher run and clean gravel over a much longer timeframe with natural rain events and with vehicle traffic. Applications of 6-inch-deep layers of 3-inch-diameter crusher run and clean limestone gravel to replicated sections of a newly constructed haul road resulted in an average of 4.5 to 9 times less erosion than occurred on native soil, and the clean gravel was about twice as effective as the crusher run material in reducing soil losses (Table 5). Sediment yields from both aggregate surfaces were statistically less than from the dirt road sections. Because cutbank erosion contributed to the driving surface measurements in this study, the effectiveness of the road surfacing may be better than the data suggest, particularly for

the crusher run treatment, which had a small cutbank slump in one road section that contributed to soil losses (Kochenderfer and Helvey 1987).

One reason that crusher run surfacing can result in more erosion than clean gravel is that the fines within the aggregate matrix contribute to loss of mineral material. Fines in crusher run material are susceptible to displacement and kick-off from the road surface by traffic, and water can displace and transport them fairly easily, particularly during intense rain events if the surface can be infiltrated (Swift 1984a). Thus, the loosened fines contribute to the overall losses (Bilby et al. 1989, Kochenderfer and Helvey 1987, Swift 1984a, Toman and Skaugset 2011, Ziegler et al. 2001). Toman and Skaugset (2011) found that aggregate with the largest percentage of fines less than 0.6-mm diameter produced the highest amount of sediment of any of the surfacing treatments they examined. Sediment loss was higher than that from two other sites with the same treatments, but percentages of fines less than 0.6-mm diameter were lower.

The quality of surfacing material also can influence sediment production. Aggregate that is weak and friable under loads or that cannot resist breakdown in the presence of water makes poor-quality surfacing material

Table 5.—Sediment yield by surfacing treatment

Treatment	Average or total sediment yield	Reference
Native untreated soil	54.5 kg 100 m^{-2}	Burroughs et al. (1984a), Burroughs et al. (1984b)
Rolled native surface	67.1 kg 100 m^{-2}	
Rolled gravel surface with 10 cm of hard crushed gneissic rock	11.7 kg 100 m^{-2}	
Unsurfaced, bare soil	44 ton ac^{-1} [*] 47.2 ton ac^{-1} [**]	Kochenderfer et al. (1984), Kochenderfer and Helvey (1987)
3-inch crusher run on new road, 6-inch uncompacted depth	10.1 ton ac^{-1} [**]	
3-inch clean gravel on new road, 6-inch uncompacted depth	5 ton ac^{-1} [*] 5.7 ton ac^{-1} [**]	
1-inch crusher run on ≥50-yr-old road, depth not specified	5 ton ac^{-1} [*] 5.9 ton ac^{-1} [**]	Kochenderfer and Helvey (1987)

[*] Mean over first 2 yr of study.
[**] Mean over 4 yr of measurement.

(Rodgers et al. 2014). The percentage of fines increases and the percentage of coarser particles decreases as a result of breakdown, thereby creating an aggregate mixture that becomes more prone to road raveling, rutting, and overall failure. Foltz and Truebe (1995) compared a good-quality (resistant to breakdown) and marginal-quality (subject to breakdown) aggregate applied to existing roads and subjected to log truck traffic over 2 yr in Oregon. The marginal-quality aggregate broke down, and 3.7 and 17.3 times as much sediment came off that road section during years 1 and 2, respectively, compared to the road section with the good-quality aggregate. Most of the increase in sediment was due to breakdown of the smallest fines in the clay fraction.

Swift (1984a) further confirmed the reductions in soil loss resulting from using clean gravel compared to crusher run on unpaved roads, but his experimental design also provided insight into how other variables influence the effectiveness of road surfacing. His study was overlain on a commercial logging job, so the experimental design was somewhat complicated. It involved four surfacing thicknesses (5, 15, 20, and 0 cm/bare soil), two types of gravel with different maximum diameters (38-mm-diameter crusher run and 7.5-cm-diameter clean stone, both hard gneiss), two roadbed soil textures (sandy loam and sandy clay loam), and periods with a variety of road disturbance intensities (Table 6). Treatments involving sandy loam roadbeds were monitored during road construction; those on the sandy clay loam were added just after road construction was completed. The bare soil segment was planted to grass immediately after logging ended.

The presence of surfacing was critical during road construction (Swift 1984a). Total soil losses during road construction from both the 15- and 20-cm-thick treatments on sandy loam soil were about 78 percent less than from bare soil (Table 6). Soil loss during construction from the 5-cm-thick crusher run gravel on the sandy loam soil was about half that of the other two surfacing treatments, but the former included only the last month of the construction period compared to the entire construction period for the latter two treatments. However, erosion rates during the subsequent light traffic period suggest that 5 cm of the crusher run material would have been insufficient had it been in place during

Table 6.—Sediment yield from forest roads with different surfacing treatments and soil types (derived from Swift 1984a)

Treatment	Road construction May–June 1976	Light truck traffic July–December 1976	Active logging January–June 1977	Light truck traffic July 1977–June 1978	Light truck traffic July 1978–April 1979
			tonne ha^{-1}		
Bare soil control on sandy loam[a]	141[b]	61	198	---	---
Bare soil control planted to grass[a]	---	---	---	134	40
15-cm-deep crusher run on sandy loam	30[b]	3	18	20	Not measured
20-cm-deep clean stone on sandy loam	31[b]	0.5	12	3	Not measured
5-cm-deep crusher run on sandy loam	16[c]	58	146	258	52
15-cm-deep crusher run on sandy clay loam	---	20	146	187	75
5-cm-deep crusher run on sandy clay loam	---	33	212	161	97

[a] The road segment used as the control between May 1976 and June 1977 was planted to grass in July 1977.
[b] Loss during entire road construction period.
[c] Loss during last ~1 month of road construction.

the entire construction period. Five centimeters of crusher run gravel yielded more soil loss with only light traffic than thicker applications of crusher run or clean gravel, and rutting in both of the 5-cm-thick sections began under light traffic.

In contrast, there were substantial reductions in the amounts of sediment that originated from the control, the 15-cm-thick, and the 20-cm-thick surface treatments on the sandy loam during the first period of light truck traffic. Soil losses from the control dropped by almost 60 percent, whereas soil losses from the gravel treatments were only about 0.1 and 0.02 percent of what they had been during construction—even though the period with light truck traffic was three times as long (Table 6). The influence of higher percentages of clay on erosion is obvious from comparisons of the 15-cm crusher run treatments on the sandy clay loam and sandy loam roadbeds throughout the study. Similarly, the influence of a lower clay percentage on erosion control under heavy traffic with large loads is apparent by comparing the erosion losses of the two 15-cm crusher run treatments during logging; soil yields were an order of magnitude lower for the sandy loam than the sandy clay loam. Recovery to much lower erosion levels also was notably quicker for the sandy loam roadbed. Once grass became well established, it controlled erosion even better than the thinly graveled sandy loam section and both sandy clay loam sections.

Soil texture has been found to influence soil loss in other road studies. Sugden and Woods (2007) found relatively low road-erosion rates (5.4 Mg ha^{-1} yr^{-1}) from unpaved roadbeds composed of gravelly sandy loams and gravelly silt loams. Roadbeds with sandier soils in Colorado had 2 to 3.5 times less soil loss than roadbeds with higher silt content in Idaho, even though the sandier roadbeds had more loose soil (Foltz and Burroughs 1990). More energy is required to entrain and move coarser particles in overland flow compared to finer particles (Sugden and Woods 2007), so even if particle detachment occurs, soil loss from the road may be less than the detachment rate.

All of the studies cited in Tables 5 and 6 reported that rut formation increased erosion from the road tread, and this finding is common to many other studies as well. Sediment losses in the range of 100 to 500 percent greater have been reported from rutted road segments

compared to unrutted segments (Burroughs et al. 1984a, 1984b; Foltz 1995; Foltz and Burroughs 1990). The amount of increase depends upon specific road and site factors, but it is proportional to the severity of rutting (Burroughs and King 1989, Foltz 1995). The percentage increase also tends to be higher on rutted unsurfaced (i.e., dirt) roads than on rutted roads surfaced with aggregate (Kennedy 1997). Because rut formation increases erosion, it follows that actions taken to control ruts can result in concomitant reductions of sediment production. Reductions in the range of 50 to 75 percent were achieved when rut production was controlled, with the degree of reduction depending on the depth of the rut and site conditions (Foltz 1995, Kennedy 1997). If ruts form, simply filling the ruts with clean or crushed rock probably will not have a substantial effect on controlling soil losses, as Swift (1984a) found. Instead, regrading the road so that the road is reworked down to at least the bottom of the deepest ruts is needed to reduce aggregate losses and road breakdown (Bolander 1997, Bolander and Yamada 1999, Roads and Transportation Association of Canada [RTAC] 1987, Skorseth and Selim 2000).

Four factors lead to rut formation (Dawson and Kolisoja 2006): 1) compaction of unsaturated materials in the surfacing aggregate; 2) local shear on the aggregate road surface, which pushes aggregate located below the wheel downward and then upward to the outside of the wheel tracks; 3) shear deformation of the subgrade soil, in which the mechanisms described for factor 2 occur in the subgrade, and the surface materials sink; and 4) local shear on the aggregate road surface from contact with wheels, which damages and displaces particles. Toman and Skaugset (2011) found that ruts developed only within the surfacing aggregate on three newly built roads in California and Oregon. However, it is usually a combination of all four factors that causes ruts to form (Dawson and Kolisoja 2006), so rutting control requires that all of these causes be addressed in roadbed preparation and surfacing/resurfacing considerations.

In most cases, the greatest gains in erosion control from surfacing come from newly built or newly disturbed (e.g., widened) roads, such as those involved in the studies just described. However, applying aggregate to existing roads can provide some protection against road erosion (Kochenderfer and Helvey 1987). Kahklen and Hartsog (1999) found that resurfacing

existing roads generally reduced sediment yields by an order of magnitude at three sites in southeast Alaska. Improvements on existing roads tend to be less because, as most studies show, erosion rates decrease substantially as roads age (e.g., Beschta 1978, Megahan and Kidd 1972, Sullivan 1985). The exceptions to this generalization may be roads that are severely damaged and unmaintained, or roads that have been recently maintained. MacDonald et al. (2001) found no difference in erosion between older and newer roads on the island of St. John in the U.S. Virgin Islands, but the older roads were deeply rutted and had not been regraded for years. Appelboom et al. (2002) compared three freshly graded road sections with different surface treatments—preexisting gravel, 10 cm of new gravel over geotextile, and bare soil—in the lower Coastal Plain of North Carolina. Sediment production from the new and older graveled sections was not significantly different at 49.2 and 69.1 kg km^{-1}, respectively, whereas both graveled sections yielded less than half the sediment of the bare soil section (151.1 kg km^{-1}). For 109 native surface road segments monitored over 3 yr in the Sierra Nevada Mountains of California, Coe (2006) found that recently graded segments produced about twice as much sediment as ungraded segments.

Dust Palliatives

Dust is fine particulate matter (SynTech Products 2011), and it is an important issue for road managers. Fine particulates emanating from roads are more than a nuisance to drivers and those who live near roads; these particles also can affect human health, vegetative growth, water quality, and aquatic habitats (Forman and Alexander 1998, Sanders and Addo 1993, Succarieh 1992, WTIC 1997). Of particular concern are particulates that are less than 10-μm diameter. These are referred to as PM_{10} and are regulated by the U.S. Environmental Protection Agency (EPA) (Jones 2000a), primarily because of their influence on human health. Although both paved and unpaved roads contribute to particulates of this size (Claiborn et al. 1995, Jones 2000a, Norman and Johansson 2006, U.S. EPA 1996), unpaved roads are the largest sources of PM_{10}-sized particles in the United States (U.S. EPA 1996). Dust levels from unpaved roads are directly related to the percentage of fines (particles <75 μm) present in the

road surfaces (Sanders et al. 1997, U.S. EPA 1995). Consequently, application of dust control agents on unpaved roads is important in airsheds that do not meet the PM_{10} standards established by the U.S. EPA (Watson et al. 1989). Normally, paved roads receive dust abatement treatments only when an area is out of attainment of the PM_{10} standards (Claiborn et al. 1995, Norman and Johansson 2006).

Dusts generated in open areas are termed "fugitive dusts" (U.S. EPA 1995). Fugitive dusts from roads come from a variety of sources, including wear of vehicle parts (e.g., brakes, clutches, tires), vehicle exhaust, abrasion of the road surface and aggregate pullout due to traffic, and deposition from the atmosphere (U.S. EPA 1995, Watson 1996). But in general, most originate from fine particles in the bed of dirt roads or from the matrix of the surfacing materials (Jones 2000a, WTIC 1997). These become loosened primarily as the result of slippage of tires on the road surface (Succarieh 1992), and they then can be transported from the road surface by water or wind erosion (WTIC 1997). With the increasing loss of fines, the road surface becomes more dominated by larger particles that are susceptible to being kicked off the road by subsequent traffic or eroded by water. The loss of small and large particles leads to the formation of ruts, potholes, and corrugations (washboarding), which further contribute to erosion potential (Jones 2000a).

Aggregate applications, such as crushed rock or gravel, can be used to suppress dust on roads (Alaska Department of Environmental Conservation [DEC] 2010); however, proper composition of the aggregate is needed because some aggregate mixtures can contribute to dust generation. The proper amount of fines (including dust-sized fines) and the composition across all particle size classes in the aggregate matrix are important. A proper mixture ensures that voids are filled and held together by sufficient fines so the surfacing is strong enough to resist raveling, washboarding, and rutting by traffic (Bennett 1994, Bolander and Yamada 1999). Conversely, too many fines will create a surface mixture that cannot resist displacement by tires (American Society of Civil Engineers 1992), and too few fines will not effectively bind together particles in the road matrix (Bolander and Yamada 1999, Jones 2000a, WTIC 1997). However, it is often difficult to obtain desired mixtures or to ensure that aggregate mixtures meet

specifications before their application (Foltz and Truebe 1995, Lunsford and Mahoney 2001). In these situations another method may be needed to address dust control.

Other techniques include limiting road use and traffic speed, paving, applying dust control agents, or implementing some combination of these techniques (U.S. EPA 1995). Road use and traffic speed controls are discussed in Chapter 4. Paving with asphalt or concrete is the most common and most efficient dust control technique. Paving can suppress dust generation by as much as 90 percent (Succarieh 1992, Watson 1996). But paving is usually restricted to higher-volume roads because its high cost usually can be justified only where there is greater potential for excessive dust creation (Bolander and Yamada 1999). Dust palliatives typically are used on roads with moderately low to moderate traffic volume, such as 150 to 500 vehicle passes per day, and they are most beneficial and most cost effective on these types of roads. On low-volume roads, the cost of dust palliatives typically cannot be justified and dust generation may not be much of a concern due to infrequent traffic (Kirchner and Gall 1991, WTIC 1997).

Dust palliatives are chemicals that work in one of three ways: agglomerating fine particles (i.e., causing them to ball up), adhering or binding surface particles together, or increasing the density of the road surface (Bergeson and Brocka 1996, Bolander and Yamada 1999). Once a road is treated, particles resist being suspended in the air by traffic or the wind (Bolander and Yamada 1999).

Dust palliatives should not be confused with soil conditioners (see Chapter 6); they are designed to do two different things. Soil conditioners focus on controlling water-driven erosion by binding clay particles at the surface of soils that do not receive repeated disturbances. Soil conditioners are ineffective on surfaces that are mechanically disturbed after treatment (e.g., Orts et al. 2007); therefore, they do not abate dust on roads. Additionally, with respect to forest road prisms, soil conditioners are applied primarily only as a short-term stopgap measure until vegetation becomes established to control erosion. In contrast, dust generation is expected in the long term on unpaved roads unless road use is suspended or drastically reduced. As such, palliative retreatment is required through the long term.

Road surface characteristics influence the success of dust palliatives. In general, they are much less effective on roads that have more than 30-percent fines in the surface aggregate material or in the soil surface (in the case of dirt roads). Excessive amounts of fines (>30 percent) tend to overwhelm the ability of the dust palliative to control dust. Conversely, there is limited benefit in applying dust control to roads with less than 5-percent fines because these roads generate little dust (WTIC 1997). Dust suppression also is generally less effective for sandy soils that have little plasticity. These soils tend to lack sufficient fines (i.e., clays) to allow binding to occur, so the palliative may simply leach through the road materials (Kirchner and Gall 1991). However, these limitations are only generalizations, and some agents are more effective than others for either extreme of fines or low soil plasticity. Consequently, to maximize effectiveness and reduce the need for maintenance and retreatment, selection of a specific type of dust palliative should be based on the local road characteristics, weather, available equipment, and expected needs (Bolander and Yamada 1999, Jones 2000a, Langdon and Williamson 1983, Succarieh 1992). In addition, for dust palliatives to be effective, the road surface must be prepared properly before the dust control agent is applied. For unpaved roads this typically involves scarification and regrading the road surface, smoothing the road and ensuring proper crowning and surface drainage, and creating optimal compaction (Bolander 1997, Jacobson 1992, Sanders et al. 1997).

Dust palliatives have been in use since at least the 1940s (Gebhart et al. 1996). They exist in many forms and formulations and can be assigned to a variety of different classifications depending upon the user (e.g., Jones 2000a, Succarieh 1992, WTIC 1997). Bolander and Yamada (1999) suggested seven broad categories: water, water-absorbing (hygroscopic and deliquescent chemicals), organic petroleum, organic nonpetroleum, electrochemical, synthetic polymers, and clay additives (Table 7); they also provide tabular summaries of the attributes, limitations, application, origin, and environmental impacts of each type of road dust suppressant. An abbreviated summary of that information is given in Table 8.

Water is the simplest, but the most short-lived, dust control agent (Addo and Sanders 1995). It controls

Table 7.—Categories of dust suppressants with examples (after Bolander and Yamada 1999)

Dust suppressant category	Examples
Water	Water
Water-absorbing	Calcium chloride Magnesium chloride Sodium chloride
Organic petroleum	Asphalt emulsions Cutback asphalt Dust oils Bitumens
Organic nonpetroleum	Animal fats Lignosulfonates Molasses/sugar beet Tall oil emulsions Vegetable oils
Electrochemical	Enzymes Ionic products Sulfonated oils
Synthetic polymers	Polyvinyl acetate Vinyl acrylic
Clay additives	Bentonite

Table 8.—Common dust suppressants, treatment rates[a], limitations, application methods, and longevity of effectiveness (abbreviated summary, developed from information in Bolander and Yamada 1999)

Dust suppressant	Treatment rates	Limitations	Application methods	Longevity
Water	Frequent, low rates	Very short duration	Spray	≤1 day
Calcium chloride	Flakes: 0.9 kg m^{-2} Liquid: 1.6 L m^{-2}	Corrosive to vehicles, potential pollutant	Mix solids into surface, or spray brine on surface	6 months
Magnesium chloride	2.3 L m^{-2}	Corrosive to vehicles, potential pollutant	Mix solids into surface, or spray brine on surface	6 months
Organic petroleum products	0.5–4.5 L m^{-2}	Rutting in weak bases, could be toxic	Mix into or spray on surface	6 months
Lignosulfonates	2.3–4.5 L m^{-2}	Potential pollution from leaching	Mix into or spray on surface	6 months
Vegetable oils	1.1–2.3 L m^{-2}	Limited availability, becomes brittle	Mix into or spray on surface	1 yr
Tall oils	2.3 L m^{-2}	Highly soluble	Mix into or spray on surface	≥1 yr
Electrochemical derivatives	Diluted 1/100 or 1/600	Depends on clay mineralogy	Mix into surface with light compaction	Unknown
Synthetic polymers	2.3 L m^{-2}	Not studied well, difficult to maintain as hard surface	Mix into or spray on surface	≥1 yr
Clay additives	1–3% by weight	Rutting in wet conditions	Mix uniformly into surface	1–5 yr

[a] Treatment rates often depend upon characteristics of residual concentrate.

dust by flocculating particles through capillary cohesion (Hoover 1987). Repeated applications, sometimes as frequent as every few hours, are necessary for continued effectiveness (Bolander and Yamada 1999). Therefore, its use typically is limited to applications where dust suppression needs are very short term (Jones 2000a). Seawater is preferred to fresh water, if available, because the salts are water absorbing, and thus provide better and longer-duration dust control (Addo and Sanders 1995; also see the description of chloride salt palliatives that follows). Water should be applied in small amounts frequently to avoid overwetting the road surface, as overwetting can promote rutting (Bolander and Yamada 1999, Foley et al. 1996, Koch and Ksaibati 2010) and pullout and carryout of sediment on tires of vehicles traveling on the road (Watson 1996), especially on dirt roads with no surfacing.

Water-absorbing chemicals used for dust control are primarily calcium chloride and magnesium chloride (Bennett 1994). Calcium chloride is derived from the manufacture of soda ash, and magnesium chloride is obtained from seawater (Heffner 1997). Both of these salts are hygroscopic (sometimes erroneously referred to as hydroscopic, e.g., as described in RTAC 1987, Singer et al. 1982) and deliquescent, though calcium chloride is more so. Hygroscopic chemicals can absorb water from the surrounding environment, including the atmosphere, to help maintain a moist film around the soil particles and bind them together. Deliquescent chemicals can absorb so much moisture from the surrounding atmosphere that they dissolve and convert to a solution, so the generated moisture contributes to the soil binding properties and improves soil compaction (Bennett 1994, Kirchner and Gall 1991, Succarieh 1992, WTIC 1997). The ability to absorb and retain moisture also retards evaporation from the road surface, thereby prolonging the presence of moisture in the surface matrix (Kirchner and Gall 1991, Morgan et al. 2005, Sanders and Addo 1993, WTIC 1997). A crust is created on the road surface by the salts' absorption of water, which contributes to retaining fines on the road surface (WTIC 1997). Although sodium chloride can be used as a dust palliative, it is much less deliquescent and less hygroscopic than either calcium chloride or magnesium chloride (Addo and Sanders 1995).

The greater hygroscopic and deliquescent characteristics of calcium chloride allow it to be applied within a broader range of conditions than magnesium chloride. Calcium chloride can enter into solution at very low humidities (as low as 18 percent) in high temperatures (Addo and Sanders 1995, Kirchner 1988), so it works in dry conditions when dust formation is most likely (Sanders and Addo 1993). In contrast, magnesium chloride works as a dust suppressant only above 70 °F and greater than 32-percent relative humidity (Kirchner and Gall 1991, WTIC 1997). Outside those values it does not remain in solution, so its ability to control dust varies through time depending upon the ambient conditions (Kirchner and Gall 1991). When conditions are suitable for magnesium chloride, it is sometimes preferred because it creates a harder crust that is less prone to dust formation; however, it requires about 18 percent more salt to be used compared to calcium chloride (Kirchner and Gall 1991, WTIC 1997).

Both of these salts are hygroscopic under reasonably low humidities, but they are generally less effective at controlling dust than many organic petroleum and nonpetroleum products in those conditions. For example, in the Las Vegas Valley under desert conditions, disturbed soils treated with magnesium chloride as a dust suppressant resulted in more soil loss than no dust treatment (Loreto et al. 2002). Consequently, salts tend to be recommended for use in more humid climates (Langdon 1980). In addition, hygroscopic dust control agents should not be used on roads with more than about 25-percent clay in the surface because the water retained by the palliative will be passed to the clay and the road will remain wet, potentially compromising stability (Kirchner and Gall 1991). Chloride salts work best on roads of which 10 to 20 percent of the surface materials are composed of particles less than 75-μm diameter (Bolander 1997).

Salts can be sprayed onto the road surface as brine, or they can be mixed into the road surface during construction or maintenance as dry granules (Addo and Sanders 1995, Bennett 1994). Salts have little dust control effectiveness if applied during or immediately before rain events because they are water soluble and will leach or wash from the road (Federation of Canadian Municipalities and National Research Council 2005). They also are ineffective in wet climates because of

losses due to leaching (Addo and Sanders 1995, Bennett 1994, Federation of Canadian Municipalities and National Research Council 2005). On the other hand, some road moisture is needed for them to maximize their hygroscopic character, so wetting a dry road before application can improve effectiveness (Kirchner and Gall 1991). In dry conditions, salts that have penetrated into the road over time can be rejuvenated to some degree with light applications of water. The water allows salts to migrate back to the surface by capillary forces; however, at the surface, they again become susceptible to washoff (Slesser 1943, Succarieh 1992). Because effectiveness is lost due to washoff and leaching, reapplication of chloride salts two to three times per year typically is necessary to control dust continuously (Bennett 1994, Bolander and Yamada 1999, Monlux 1993). With no retreatment, salts provide no dust control within a year or less from the time of initial application, depending upon local conditions (Morgan et al. 2005).

Organic petroleum products are used commonly for dust suppression (Succarieh 1992). These chemicals include tars from coal distillation, bitumens from crude oil distillation, cutback asphalt (solvents such as gasoline, napthal, or kerosene combined with asphalt cement), and asphalt emulsions (asphalt dispersed in water + an emulsifier) (Addo and Sanders 1995). They act by binding or agglomerating road surface particles (Bolander and Yamada 1999). Petroleum products exist in a variety of viscosities, so they are suitable for a wide range of road surface characteristics. Higher viscosity petroleum agents are more effective on surfaces dominated by larger particles, and lower viscosity agents are more effective with higher amounts of fines (Giummarra et al. 1997). However, petroleum products are relatively ineffective when large percentages of clay exist in the road surface because the clay absorbs the petroleum rather than allowing it to act as a binding agent, so more binder must be added (Bennett 1994, Hoover et al. 1981). Asphalt recycled from roadways and roof shingles also is becoming a more common road surface treatment. It is typically used in highway resurfacing, but can be used as aggregate or as stabilizing material in the road base, sub-base, or embankment fills, or applied in thin coats, such as with chip seal (Koch and Ksaibati 2010).

Waste oils are organic petroleum products that once were used commonly for dust suppressants in the United States. However, because they were environmentally damaging and were contaminated with toxic materials (Addo and Sanders 1995, U.S. EPA 1990, Yanders et al. 1989), their use for dust control has been banned in this country (Foley et al. 1996, U.S. EPA 1991). This ban is not problematic because waste oils provide inadequate dust control due to poor aggregate binding capabilities (Addo and Sanders 1995), and other available organic petroleum dust suppressants provide better adhesive properties, are insoluble and resistant to washoff by water, and have fewer environmental concerns attached to their use (Addo and Sanders 1995).

Aside from pavement, asphalt emulsions are probably the most commonly applied petroleum-based dust control agents. They tend to remain effective longer than many products if applied under appropriate conditions, though they still require occasional retreatment to retain low dust emissions (Table 8). Repeated use of asphalt emulsion products can harden the road surface and create a surface similar to thicker recycled asphalt, making it particularly effective at dust control (Bennett 1994). However, recycled asphalt is prone to rutting in areas where turning, accelerating, or decelerating is concentrated (WTIC 1997), so asphalt emulsion treatments may have the same problem. Once ruts develop, erosion of subgrade materials can occur, but the emulsion-hardened surface makes regrading and the removal of ruts difficult (Monlux 1993, WTIC 1997). Tars and bitumens have been used for dust palliation (Addo and Sanders 1995, Jacobson 1992, Jones 2000a), but there is relatively little research on their effectiveness on aggregate surfaced roads (Jones 1999, 2000a). In general, bitumens require reapplication at least once or twice a year (Bennett 1994, Bolander and Yamada 1999), though the thickness and type of application affect their life span. Spray applications tend to be effective for only short periods (e.g., weeks to months), whereas thick applications mixed with sand and applied to the surface have been reported to be effective for up to 3 yr (Jones 1999, 2000a; WTIC 1997). Often tars and bitumens are used to temporarily control dust and stabilize roads until road upgrades can be made (Jones 1999).

Many types of organic nonpetroleum binders exist, but almost all of those that are used for dust suppression

are lignosulfonates (Succarieh 1992), which are alternatively termed "lignin sulfonates" (WTIC 1997). Lignosulfonates are residues resulting from the sulfite wood pulping digestion process (Heffner 1997, WTIC 1997). Consequently, their chemical composition depends upon the tree species from which they were derived and the chemicals added during the pulping process (Bolander 1999, Jones 2000a, Morgan et al. 2005, Succarieh 1992).

The lignin and sugars that are present naturally in lignosulfonates (Addo and Sanders 1995, Ledingham and Adams 1942, Pandila 1973) adhesively bind soil particles together, which prevents fines from forming and being released into the air by traffic (Jones 2000a). The sugar also makes them hygroscopic (Bolander and Yamada 1999), thereby giving them some of the dust control advantages of hygroscopic salts. Other advantages of treating unpaved roads with lignosulfonates are that they remain slightly plastic, which permits maintenance (e.g., regrading and reshaping) of the treated road, and the surface aggregate can become more compacted (Morgan et al. 2005).

Like many other palliatives that work by binding soil particles, lignosulfonates can be used effectively on roads with low levels of surface fines (e.g., 4 to 8 percent) (WTIC 1997), though they are most effective when between 8 and 20 percent of the road surface materials can pass through a 75-μm sieve (Bolander 1997). Lignosulfonates can be applied in liquid or solid form, but because of their physical composition, they do not penetrate well and are ineffective if not mixed into the road surface at the time of application (Kirchner and Gall 1991, WTIC 1997). When mixed into the top 2.5 to 5 cm of the road surface, they provide better penetration and dust control than at other depths (Bolander 1997, WTIC 1997). Lignosulfonates are biodegradable and water soluble over time (Adams 1988, Bolander and Yamada 1999, Lunsford and Mahoney 2001, Succarieh 1992), so at least annual applications are needed to retain effective dust suppression (Bennett 1994, Bolander and Yamada 1999) (Table 8). Lignosulfonates are particularly susceptible to being washed off during heavy rain events, so they are better suited to application in drier conditions (Giummarra et al. 1997; Jones 1999, 2000a). Although they remain a relatively common dust palliative, lignosulfonates are used less today than in the past due to changes in waste stream management by pulp producers (WTIC 1997).

The other types of nonpetroleum chemicals (Table 8) bind or agglomerate particles (Bolander and Yamada 1999), but they tend to be less effective at dust control and less available than lignosulfonates (Batista et al. 2002, Federation of Canadian Municipalities and National Research Council 2005). Animal fats and vegetable oils, of which soybean oil soapstock (or simply soapstock) is most common, agglomerate particles; molasses residues, sugar beet extract, and tall oils bind particles (Batista et al. 2002, Lohnes and Coree 2002). Soapstock is a fatty acid by-product from the refining of edible oils, so its availability is subject to soybean market conditions (Morgan et al. 2005). Some vegetable oils do not work well as palliatives, both during and following application, due to their physical characteristics at ambient temperatures (Morgan et al. 2005). After application they become brittle, which diminishes their effectiveness (Federation of Canadian Municipalities and National Research Council 2005). PM_{10}-sized dust losses are strongly associated with roads treated with dust suppressants that create brittle surfaces (Gillies et al. 1999). Because organic nonpetroleum compounds are derived from animals or plants, they also have associated unappealing odors for up to several weeks (Morgan et al. 2005). Molasses residues are water soluble, and substantial amounts will dissolve and wash off roads during heavy rains, meaning multiple applications may be needed annually (Addo and Sanders 1995). No specific recommendations on application intervals are available.

Electrochemical dust palliatives are prepared from sulfonated petroleum or highly ionic chemicals, such as enzymes or ammonium chloride. Climatic conditions have little influence on their effectiveness, and they are not easily lost by leaching (Federation of Canadian Municipalities and National Research Council 2005, Giummarra et al. 1997, Lunsford and Mahoney 2001). However, enzymes must be protected from freezing conditions during transport and application, and sufficient moisture must be present at the time of application (Lunsford and Mahoney 2001). Electrochemical materials interact with the clay fraction of soils (Batista et al. 2002, Lunsford and Mahoney 2001), so they are most effective when at least

moderate percentages of clay are present (Giummarra et al. 1997, Lunsford and Mahoney 2001) although there apparently is substantial variability in their effectiveness (Federation of Canadian Municipalities and National Research Council 2005). Many of the most common electrochemical enzymes are cultured bacteria; when exposed to air, they begin to reproduce and create large molecules that are absorbed into the soil clay lattice and form a tight compacted surface within days or hours. This process prohibits water absorption (Lunsford and Mahoney 2001) and increases compaction, thereby reducing dust generation (Jones 1999, Lunsford and Mahoney 2001). Electrochemical palliatives generally are mixed into the road surface during application (Bolander and Yamada 1999). There has been little widespread testing of electrochemicals, so almost no information is available on their duration as dust suppressants (Lohnes and Coree 2002) (Table 8).

Synthetic polymers are monomers that have been polymerized in an aqueous medium (Jones 2000a). They are usually by-products of paint and adhesive manufacturing (Bolander 1999, Lunsford and Mahoney 2001), so they suppress dust by binding particles together and forming a thin semi-rigid tackifier coating on the road surface (Alaska DEC 2010). They are currently some of the most expensive dust palliatives available (Lunsford and Mahoney 2001). When used for dust control, these polymers are applied in liquid form and require a drying or curing time at well above freezing temperatures for 12 to 24 h. During summer temperature and moisture conditions, they can increase the tensile strength of roads, which presumably would mean greater dust control. Tensile strength increases are as much as 10 times that of clay additives (described next), depending upon the product. Freeze-thaw cycles reduce the tensile strength of synthetic polymers, but it still remains about two to three times greater than that of clay additives (Bolander 1999).

Clay additives are made of bentonite, or impure montmorillonite clays (Bolander 1999). The most common bentonite clays are sodium and calcium montmorillonite. Sodium montmorillonite is a swelling clay in the presence of moisture, which allows it to seal and become waterproof (Murray 2000). Consequently, sodium montmorillonite is the clay used for dust suppression. Clays control dust through agglomeration (Bergeson and Brocka 1996). Because they have a net negative charge,

bentonite clays are best suited for use as dust suppressants on unpaved roads that are surfaced with limestone or other material that has a net positive charge. This allows the formation of agglomerates through electrostatic bonding (Wahbeh 1990). Bentonite also is most effective in conditions where low levels of fines are present in the surface materials because the added clay particles provide fines needed to bind surface aggregates (Bennett 1994, Lohnes and Coree 2002). Relatively small levels of clay are applied to avoid retaining too much moisture in the road surface (Bergeson and Brocka 1996, Wahbeh 1990). Recommendations include 1- to 3-percent clay by weight of aggregate (Bennett 1994, Bolander 1997), with the total materials passing through a 75-µm sieve at ≤15 percent (Bolander 1997). Because of their affinity for moisture, clays are best suited to drier climates (Lohnes and Coree 2002). If the treated road surface remains stable and unrutted, clay may have the longest effectiveness of all palliatives; Bolander and Yamada (1999) estimated that the longevity of clay additives is 1 to 5 yr.

Although dust suppressants have been used for decades, there are remarkably few quantitative studies of their effectiveness (Sanders and Addo 1993, Sanders et al. 1997). Far more studies involving dust suppressant chemicals focus on road strength and stability (e.g., Bolander 1999, Butzke 1974, Monlux 2003). Although the relationship between road strength/stability and dust control is acknowledged (e.g., see Bader 1997 and Foley et al. 1996), papers that did not specifically describe dust reduction results are not included in this synthesis because they did not focus on the control of nonpoint source pollution. Also, many unpublished reports of dust control effectiveness are based on interviews with state highway agency personnel or contracted grader operators rather than on measurements. These observations may have merit, but these reports also are excluded from this review of effectiveness due to the lack of supporting data.

A major limitation of dust suppressant research is the lack of standard ways to measure dust emissions (Addo and Sanders 1995). Many techniques have been used to measure dust, but the equipment and protocols usually have been developed for the local research purposes (e.g., Addo and Sanders 1995, Hoover et al. 1973, Irwin et al. 1986, Jones 1999, Koch and Ksaibati 2010, Morgan et al. 2005, Schultz 1993, Taylor et al. 1987, Wellman

and Barraclough 1972). Some methods measure dust at stationary points along the road with passive or active collection devices; others use a variety of devices that measure dust behind a moving vehicle traveling at one or several fixed speeds (Sanders and Addo 1993). Consequently, individual studies can show dust reduction from palliative use and relative effectiveness among agents, but interstudy quantitative comparisons typically cannot be made (Addo and Sanders 1995).

Another limitation of dust abatement studies is that they do not quantify the contribution of dust control to the reduction of soil losses from roads. Dust control agents commonly have been reported to reduce dust by 30 to 80 percent compared to no dust control (WTIC 1997), but a given reduction in dust does not correspond to an equivalent reduction in soil material losses from the road during the same period. This is because about two-thirds of fugitive dusts are estimated to return to the unpaved road surface after settling out of the air (Jones 2000a). Much of the remaining dust is believed to settle out within 20 m of the road unless wind carries it farther (Forman and Alexander 1998, WTIC 1997). But dust has been shown to affect corridors of more than 140 ft, which were up to six times the right-of-way width (Hoover et al. 1981). Therefore, the lack of specific information on the transport and fate of dust particulates (Forman and Alexander 1998) from various types of dust suppressants makes it virtually impossible to estimate the soil losses that accompany these reductions without field measurements.

Of all the studies reviewed for this synthesis, only one directly measured the effectiveness of dust palliatives on reducing erosion losses from roads (Burroughs et al.

1984a). They applied dust oil and a bitumen treatment to road segments in Idaho and applied artificial rain events to the untrafficked road segments. They compared soil losses from them to an unsurfaced road segment made of native granitic soil material. All road segments were newly reshaped and graded before treatment, and ranged in slope from 5.3- to 10.3-percent grade. Both the dust oil and bitumen treatments had substantially lower soil losses than the bare soil, but the bitumen was much more effective (Table 9). Compared to the unsurfaced road, sediment losses from the bitumen were 28.7 times lower on an area basis, whereas the losses from the dust oil were only 3.2 times less. The bituminous treatment also was superior to a 10-cm-thick application of 3.8-cm crusher run gravel in terms of controlling soil losses from the road (Table 9). However, this study involved only four simulated rain events closely spaced in time and the longevity of bitumen effectiveness is only about 6 months (Table 8), so in the longer term, erosion protection would diminish without repeated treatments.

In terms of dust reduction alone, petroleum-based products (excluding asphalt paving) sometimes have been found to be inferior to many other products, especially salts. Kirchner (1988) measured dust with air samplers for five road segments treated with different dust suppressants and one control. The suppressants were an asphalt emulsion, a natural brine, a semi-processed brine, liquid calcium chloride, and liquid magnesium chloride. A truck was driven on the road 50 times at 45 mi h^{-1} (mph). At the end of the first summer season, the section treated with asphalt emulsion performed almost as poorly as the control section even though it received two application treatments. A thin

Table 9.—Sediment yield from road surfacing treatments in the Silver Creek experimental watershed, Idaho (data from Burroughs et al. 1984a)

Treatment	Average sediment yield	Sediment loss compared to untreated soil	Sediment reduction from treatment
	kg 100 m^{-2}	*percent*	
Native untreated soil	54.5		
Native soil with dust oil	17.2	31.6	3.2 times less
Native soil with bituminous surface treatment	1.9	3.5	28.7 times less

crust had formed but became broken up, allowing the road surface to show through. The natural brine also did not work well because it did not retain moisture effectively. Consequently, it rutted and substantial dust was generated. The semi-processed brine exhibited slightly better dust control, but it also rutted and developed potholes. In contrast, the calcium chloride- and magnesium chloride-treated sections performed much better, though slightly more dust was generated in the sections treated with magnesium chloride than in those treated with the calcium salt. They generated 48 to 65 percent less dust than the control during the summer season. The road segments treated with these two salts also resisted rutting and pothole development. At the end of the summer, a second treatment of each road section except the asphalt emulsion did little to improve the effectiveness of the brines, but the magnesium and calcium chloride treatments retained high levels of dust control through the next 9 months (i.e., a full year from the time of first treatment). The effectiveness of both salts was within a few percentage points at the end of the year compared to the effectiveness observed soon after retreatment.

A year-long study in Colorado that compared asphalt emulsion to calcium chloride found similar results (Kirchner and Gall 1991). At the end of just 4 wk, calcium chloride resulted in average dust control of 72.6 percent compared to only 31.1 percent for the asphalt emulsion. The road segment treated with emulsion also developed many potholes, and a substantial amount of road surface aggregate was lost and accumulated along the side of the road. A common petroleum emulsion, Coherex® PM (Tricor Refining, LLC, Bakersfield, CA), was not considered effective at controlling PM_{10} dust emissions from unpaved roads in California for a 3-month period (Gillies et al. 1999), though its average efficiency over nine measurement periods was 67 percent. However, about 1 yr after the application, the average efficiency dropped to 44 percent.

In other studies, petroleum-based products performed well as dust suppressants. Hoover et al. (1975) found that two different asphalt emulsions performed well and had significantly lower dust emissions after a year compared to untreated controls. Conversely, at the end of that year, calcium chloride had become ineffective. In light of the inconsistent performance of petroleum-based dust

suppressants, Langdon (1980) suggested that petroleum products would be more effectively applied toward meeting the nation's energy needs than used for dust control.

In a visual rating (qualitative) study reported by Monlux (1993) on 3 mi of road in Montana, a concentrated emulsified oil, an emulsified asphalt, a polymer emulsion, an emulsion copolymer, a light mineral oil, a lignosulfonate, and magnesium chloride were examined for dust control and compared to a control section over 7 wk. Emulsified asphalt was outperformed by magnesium chloride, but both controlled dust better than all other treatments. Potholes and corrugations developed on all road segments due to insufficient crowning and inadequate drainage. Regrading was performed to improve the road surface, but the emulsified asphalt surface was the most difficult to reshape because of the crust that had formed. The magnesium chloride and emulsified asphalt continued to provide dust control benefits following maintenance even without further treatment. Magnesium chloride was an effective dust suppressant for 12 wk, the emulsified asphalt for 8 wk, and all other treatments for 5 wk or less.

Although lignosulfonates were not particularly effective in the study by Monlux (1993), they have been at least as effective as other types of treatments in many other situations. For example, Fox (1972) found that treatments of ammonium lignosulfonate, and ammonium lignosulfonate in combination with calcitic lime or aluminum sulfate as additives, each were effective and reduced dust by 80 percent on granular surfaced secondary roads. A 1 percent ammonium lignosulfonate treatment with no additives was as effective as a 1 percent ammonium lignosulfonate treatment + 0.5 percent of either of the additives. Measurements 1 yr after treatment in Iowa showed that lignosulfonate and lignosulfonate + herbicide each significantly lowered dust emissions compared to untreated roads (Hoover et al. 1975).

Lignosulfonate appears to be particularly effective for conditions with moderately high traffic levels and more effective than many treatments with poor-quality aggregate surfacing. In Colorado, 2-km-long graveled road segments that had been treated with lignosulfonate, magnesium chloride, calcium chloride, and a formulation

of calcium chloride containing no magnesium all had lower dust emissions than an untreated segment (Fig. 4), but lignosulfonate was most effective (Addo and Sanders 1995, Sanders and Addo 1993, Sanders et al. 1997). This occurred even though vehicle use on the treated sections was twice that of the untreated control section (400 versus 200 vehicle passes day[-1]). This study was continued a second year following regraveling and retreatment of the road sections (Fig. 4). The calcium chloride treatment with no magnesium was not used as a treatment the second year, but instead that road segment was used as the untreated section (Addo and Sanders 1995, Sanders et al. 1997). Dust levels were more similar among the three palliatives than they had been in the first test period, and again all three were more effective than

no treatment (Fig. 4). The lignosulfonate treatment usually had the lowest dust emissions, and aggregate losses from public road use calculated from cross-sectional measurements were least from the section treated with lignosulfonate (Fig. 4). Losses equated to depths of 5.8, 5.2, and 7.0 mm for the lignosulfonate, magnesium chloride, and calcium chloride treatments, respectively, and were about one-half to one-third the 15.6-mm depth of aggregate lost from the untreated graveled road segment. Unexpectedly, even though the temperatures were high and relative humidity was generally low throughout the study, magnesium chloride resulted in lower dust generation and aggregate pullout than the more deliquescent calcium chloride.

Morgan et al. (2005) measured dust generation in Iowa from road segments treated at the start of the study and again at 8 wk with lignosulfonate, calcium chloride, and a soybean oil soapstock. Their study also allowed investigation of the influence of road aggregate quality (crushed limestone rock and alluvial sand/gravel mixture), traffic volume (low = 45 to 60 vehicles day[-1] and high = 240 vehicles day[-1]) and time (16 wk and 52 wk). During the first 16 wk, average dust reduction was similar, about 50 percent, for both road surfaces compared to similarly surfaced roads with no palliation (Table 9). Traffic volume made the influence of road surface quality much more apparent over that short timeframe, with much poorer effectiveness on the gravel/sand surface compared to the crushed limestone. Only the lignosulfonate was effective on the alluvial surfacing, and it reduced dust by only one-fourth to one-third during the first 16 wk. Suppressant effectiveness declined through time, and by the end of 1 yr, average dust reductions of the palliatives that remained effective were between 10 and 30 percent (Table 10). In the long term, traffic volume was deemed to be a more important factor for controlling dust than surfacing, and lignosulfonate was the only palliative that consistently contained dust at levels below that of the untreated road segments.

Figure 4.—Mean dust weight by dust suppressant treatment and year (graphs developed from data in Addo and Sanders 1995, and Sanders and Addo 1993). Calcium chloride (Special) includes magnesium chloride.

Gebhart et al. (1996) also studied soybean oil soapstock effectiveness on unsurfaced roads and tank trails at the U.S. Army's Construction Engineering Research Laboratories in Fort Hood, TX, and Fort Sill, OK. It was compared to a 38 percent calcium chloride mixture, calcium lignosulfonate, and a polyvinyl acrylic polymer

Table 10.—Average dust reduction by surface, traffic volume, and treatment over two time periods for Story County, Iowa (data from Morgan et al. 2005)

Surface	Traffic volume	Dust suppressant	Dust reduction compared to no treatment[a]	
			Average over 16 wk	Average over 52 wk
			----------- *percent* -----------	
Alluvial sand/gravel	Low	Lignosulfonate	56	28.2
		Calcium chloride	40	17.9
		Soapstock	50	27.8
	High	Lignosulfonate	27	Not tested
		Calcium chloride	-1[b]	-26.0
		Soapstock	-2	-27.4
Crushed limestone rock	Low	Lignosulfonate	76	22.0
		Calcium chloride	51	11.6
		Soapstock	51	6.9
	High	Lignosulfonate	61	10.5
		Calcium chloride	46	-24.0
		Soapstock	24	14.6

[a] Percentage by weight of aggregate.
[b] Negative values indicate an increase in dust.

emulsion (PVA; the latter results are described in greater detail on page 37). At Fort Hood after 30 days, all four treatments resulted in at least 50-percent dust reduction compared to a control. The calcium chloride salt was most effective at abating dust, but it was not significantly better than the soapstock or other treatments. By day 60, the soapstock continued to have lower dust emissions than the control, and was not significantly different from the lignosulfonate or PVA. But the soapstock was significantly less effective than the chloride salt. At that time the calcium chloride reduced dust levels by at least 50 percent; the soapstock and lignosulfonate did not retain that level of protection.

Only a few studies have measured dust abatement from bentonite. Bergeson and Brocka (1996) used sodium montmorillonite as a dust palliative on limestone-surfaced secondary roads in Texas. Applications tested ranged from 0.5 to 9 percent by weight of aggregate. Dust generation was reduced by about 45 percent on sites where 3-percent bentonite was employed and 70 percent on sites with 9-percent bentonite. Wahbeh (1990) also examined the effectiveness of different application rates

of sodium montmorillonite using two application techniques on limestone-surfaced roads in two counties in Iowa. The treatments were a spray slurry application of bentonite + water + soda ash to loose-surface material, and a dry application of bentonite mechanically mixed with the crushed limestone surface aggregate and then saturated with water and soda ash. Bentonite application rates were 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 percent in Adair County; only the first three application rates were used on Dallas County roads. The bentonite treatments also were compared to spray applications of calcium chloride or magnesium chloride. Dallas County roads received 75 to 80 vehicle passes day^{-1} over the 2-yr study, though the dust measurements were determined only from 10 test passes by a ½-ton truck traveling at 40 to 45 mph in or out of the wheel tracks. Wheel track performance was tested on 21 days and out-of-the-wheel track performance was tested on 16 days throughout the 2 yr. In Dallas County, the maximum bentonite concentration (1.5 percent) and both chloride treatments resulted in similar dust control originating from the wheel track: about a 20-percent reduction compared to no palliative

treatment of the limestone aggregate (Table 11). Dust was best controlled out of the wheel tracks by the 1.5-percent bentonite treatment, where a 27-percent reduction in dust was obtained.

Bentonite effectiveness endured in Dallas County even with a reapplication of limestone aggregate to the road surfaces about halfway through the study. The short-term effectiveness of calcium chloride is apparent in the 3-month-long study on Adair County roads (Table 11). The best dust reduction both in and out of the wheel tracks occurred with the calcium chloride treatments and the highest percentage of bentonite clay (3.0 percent).

Little information could be found on the effectiveness of other dust control agents. Only a small discussion about the effectiveness of a sugar beet molasses, Molex, was available (U.S. Roads 1998). Even though its effectiveness was praised, only general, qualitative comments were given. There are few field applications with measures of dust control effectiveness from electrochemical palliatives or comparisons of their effectiveness to more traditional suppressants in the literature. This may be because many electrochemical palliatives are relatively new to the market (Jones 1999, 2000a; Lunsford and Mahoney 2001). A product called EMC SQUARED® (Soil Stabilization Products Co. Inc., Merced, CA) is the most commonly tested electrochemical palliative. Gillies et al. (1999) found that it was only marginally effective (33-percent dust reduction) during a period of 1 wk, and then its effectiveness declined quickly. McHattie (1994) reported that a single application of EMC SQUARED was as effective as montmorillonite clay and calcium chloride about 1 yr after application on a 2.5-mi length of a highway reconstruction project in Alaska, but an additional treatment was required after 20 months. The degrees of effectiveness of EMC SQUARED may vary because of the need for very specific moisture content during application; many papers also have noted that electrochemical dust suppressants may work only with certain types of soils (Bolander 1999, Piechota et al. 2002, Scholen 1992).

Synthetic polymers traditionally have been used primarily as soil conditioners, and there is little research on their ability to suppress dust on traveled roadways (Jones 2000a, Lunsford and Mahoney 2001). The information that does exist is mixed and typically provided as general statements with no data; for example, Jones (1999, 2000a) indicated that studies from South Africa showed little effectiveness for synthetic polymers due to poor penetration into the road surface. Scholen (1992) also reported poor dust control by an acrylic polymer in Florida. Bolander (1997) stated that polymers provide some promise from tests in the Pacific Northwest. Two studies at the U.S. Army's Construction Engineering Research Laboratories showed limited success of PVA (Gebhart et al. 1996). At Fort Sill, OK, PVA was tested over a 60-day period on unsurfaced roadways and tank trails. Thirty days after application, the PVA had three to four times lower dust emissions than untreated controls. At day 60, dust levels still were less than from the control road segment, but dust emissions had doubled from those present at day 30. The heavy track and wheel equipment traveling the roads broke up the PVA surface seal. Similar results were obtained from an identical study at Fort Hood, TX, though the levels of dust abatement at 60 days were even less than those measured at Fort Sill. Gillies et al. (1999)

Table 11.—Average percent dust reductions with bentonite clay and chloride salts for Dallas and Adair Counties, Iowa (data from Wahbeh 1990)

| Location | Treatment | Dust reduction | |
		In wheel track	Out of wheel track
		---------- percent ----------	
Dallas County[a] (21 test passes)	0.5% bentonite	2	6
	1.0% bentonite	6	15
	1.5% bentonite	20	27
	Calcium chloride	20	6
	Magnesium chloride	22	16
Adair County[b] (11 test passes)	0.5% bentonite	8	9
	1.0% bentonite	11	11
	1.5% bentonite	17	12
	2.0% bentonite	5	14
	2.5% bentonite	10	19
	3.0% bentonite	42	33
	Calcium chloride	30	48

[a] Data are from October 1987–October 1989.
[b] Data are from August 1989–November 1989.

found a polymer emulsion to be highly effective over 12 months, even with reasonably heavy use (6,400 vehicle passes) and wet winter conditions. They found the product, Soil-Sement® (Midwest Industrial Supply, Inc., Canton, OH), reduced PM_{10}-sized dust by an average of more than 80 percent throughout the entire study.

Environmental Effects of Dust Palliatives

The studies just summarized illustrate that most of these various chemicals have the ability to abate dust on unsurfaced roads, and thus, provide some control of soil and aggregate losses, at least temporarily. However, because of their chemical composition, some dust suppressant chemicals can themselves be nonpoint source pollutants.

There are two general types of studies that have been performed to examine the impacts of dust palliatives: 1) those that have worked toward establishing toxic thresholds for animals, humans, or plants, and 2) those that have quantified the chemistry of runoff and leachate or have examined the environmental effects of the chemicals or runoff/leachate on flora and fauna following field application or accidental spills. The first type of study dominates the literature, and despite the relatively common and widespread use of many types of dust suppressants, few studies have quantitatively examined their environmental impacts (Sanders et al. 1997). Toxicology studies and studies with extremely high loads or concentrations of palliatives indicate that most mammals and humans show little effect from most palliatives. Instead, the primary environmental concerns about their use at concentrations normally encountered tend to be their potential effects on groundwater quality, freshwater aquatic organisms, and to some degree plants (for some specific chemicals) (Bolander and Yamada 1999).

The effects of lignosulfonates have been studied far more than any other dust suppressant. In part, this may be because there are many studies showing the toxic effects of spent sulfite liquors on aquatic organisms, including trout (*Salvelinus* and *Oncorhynchus* spp.) (Fisher 1939, Griffin and West 1976, Walden 1976). Because spent sulfite liquors are precursors to lignosulfonates and a common waste product of the pulping industry, there also has been concern about potential effects of lignosulfonates. However, lignosulfonates are created by evaporating water from spent sulfite liquors, and during distillation, sulfur dioxide, and acetic and formic acids also are removed to yield about 50- to 60-percent solids. Thus, the resulting calcium, sodium, or ammonium lignosulfonates are less toxic than the original wastes (Adams 1988). Lignosulfonate toxicity also has undergone extensive study because the Food and Drug Administration allows the same formulations used for dust palliation (ammonium, calcium, magnesium, and sodium lignosulfonates) to be used as binders in pelletized animal feeds and in paper and paperboard products used to package liquid and fatty foods (Singer et al. 1982; Watt and Marcus 1974, 1976).

Overall, lignosulfonates seem to pose little toxicity to mammals and humans at concentrations or loads that normally would be encountered with dust suppressant use (Adams 1988, Bolander and Yamada 1999, Succarieh 1992). Studies of direct fluid ingestion of calcium, magnesium, or sodium lignosulfonates at concentrations of 40 g L^{-1} by guinea pigs (*Cavia porcellus*) over 8 wk found average lower weight gain by animals receiving sodium and calcium lignosulfonate (117 g and 144 g, respectively) compared to animals receiving no lignosulfonate (253 g). The guinea pigs treated with each of these chemicals also developed ulcerated colons. In contrast, the guinea pigs receiving magnesium lignosulfonate had much less difference in average weight (210 g) than the control animals and no development of ulcerated colons (Watt and Marcus 1976). These results confirmed earlier findings of lower weight gain and development of ulcerated colons when only sodium lignosulfonate was administered at several concentrations to guinea pigs (Watt and Marcus 1974). The data to support nontoxicity of lignosulfonates to humans primarily comes from workers handling lignosulfonates. No chronic health problems have been reported over the 40 yr they have been commonly used—including from people who have worked over the long term with these chemicals (Adams 1988).

Lignosulfonates are most harmful to aquatic species (Bolander and Yamada 1999, Schwendeman 1981). The sensitivity to lignosulfonates is attributed to the effects that these chemicals have on the biological oxygen demand (BOD) and through direct toxicity (Adams 1988, Poole et al. 1978). Lignosulfonates may contain

as much as 35 percent wood sugars, and these are fermented relatively easily by microorganisms, which increases BOD and reduces available oxygen in the short term (Adams 1988). The remaining fraction of the chemicals that are low molecular weight are degraded much more slowly, primarily by fungi (Engen et al. 1976, Pandila 1973, Singer et al. 1982, Stapanian and Shea 1986, Watkins 1970), allowing long-term elevations in BOD (Raabe 1968). Because microbial breakdown of lignin in lignosulfonates is incomplete (Ledingham and Adams 1942, Watkins 1970), the remaining compounds of higher molecular weight undergo decomposition via desulfonation, demethoxylation, and depolymerization, similar to the processes that occur for natural breakdown of lignin in wood (Engen et al. 1976).

Even in trout, which are considered to be the fish species most sensitive to lignosulfonates (Succarieh 1992), concentrations at which toxicity occurs are fairly high. In a study of sodium lignosulfonate effects on rainbow trout (*Oncorhynchus mykiss*), the 48-h LC50 was 7,300 ppm, and 50-percent survival occurred for 25 h even at a concentration of 2,500 ppm (Roald 1977a). The LC50 is the concentration of a chemical in water or air required to kill 50 percent of the test population during the observation period. Survival was 100 percent over 28 days for concentrations up to 1,875 ppm. In a follow-up study, rainbow trout were subjected to sublethal concentrations of 0 (control), 40, 80, 160, and 320 ppm for 60 days and concentrations of 0, 640, 1,280, and 1,920 ppm for 35 days (Roald 1977b). Fish exposed to concentrations of 160 ppm or greater had slower growth rates than those with no exposure. All rainbow trout subjected to the 1,920-ppm concentrations died during the 35-day exposure. The lignosulfonates did not affect the bacterial flora in the intestines, but the activities of some digestive enzymes were lower than the controls at concentrations as low as 320 ppm. It was not clear whether the lowered growth from reduced food consumption was due to decreases in enzyme activities, or if enzyme activities declined because of lower food consumption.

Lignosulfonates also are considered to be of little risk to plants, though this assumption is based on few studies. Stapanian and Shea (1986) applied calcium lignosulfonate with 50-percent solids at rates of 12, 42, and 63 ton of solids ac^{-1} (Adams 1988) directly to the ground of two clearcuts planted to Douglas-fir (*Pseudotsuga menziesii*) 1 or 3 yr before treatment. These rates were much higher than rates typically applied to roads for stabilization or for dust control (5 and 1.3 ton of solids ac^{-1}, respectively) (Adams 1988). Neither the growth of the Douglas-fir nor the aboveground woody biomass was affected through 12 wk of monitoring. Applications of 42 and 63 ton ac^{-1} significantly reduced herbaceous biomass, though the mechanism driving the decrease was unknown. Lignosulfonate migration through the soil occurred at approximately the same rates, regardless of the amount initially applied, but over the 12 wk it disappeared from the top 0.2 m of soil because of its high water solubility (Stapanian and Shea 1986). Yardley et al. (1980) found that lignosulfonate application to soil did not prevent seed germination.

The greatest risks related to use of lignosulfonates are associated with contamination of water. Lignosulfonates are water soluble, especially when associated with soil or road surface matrix pH values of 6 or greater. Consequently, lignosulfonates can leach through the soil, especially as rainfall increases (Singer et al. 1982). However, they also have low penetrability in soil because clays can adsorb lignosulfonates and retard leaching. Mobility can be retarded even in regions with high rainfall if the percent clay is sufficiently high, but even clay cannot stop transport of lignosulfonates by flowing water (e.g., concentrated overland flow) (Singer et al. 1982). Schwendeman (1981) suggested that 70 to 100 percent of road surface materials should pass through a ¾-inch sieve and 20 to 50 percent should be composed of silt or clay for optimal lignosulfonate retention and dust abatement.

Whether there are harmful or even measurable levels of lignosulfonates in soil leachate, streamwater, or groundwater will depend upon the concentrations applied (Stapanian and Shea 1986), road surface and soil texture, precipitation characteristics, and general road condition. At the levels applied as dust suppressants and when applied according to manufacturer's instructions, threats to these parts of the environment are believed to be minimal (Bennett 1994, Morgan et al. 2005, Singer et al. 1982, WTIC 1997). Any effects that do occur would be expected to be in the immediate area around the application site (Singer et al. 1982).

Only one study was found in which runoff from a lignosulfonate applied to abate dust on disturbed land (not a road) was measured and analyzed for concentrations of toxic materials, including volatile and semivolatile organic compounds, organic pesticides, metals, BOD, and a variety of other chemicals (Loreto et al. 2002). The lignosulfonate used, Dustac® (Quattro Solutions, Welshpool, Western Australia), had the fewest contaminants present in runoff of all the types of palliatives compared (Table 12). Volatile organic compound concentrations were less than 25 $\mu g\ L^{-1}$, and semivolatile organics and pesticides were not detected. Some of the highest concentrations of copper, chromium, and manganese were found in runoff from this plot, but none of these metal concentrations was more than 34 ppb. BOD was only about 1 $mg\ L^{-1}$, but chemical oxygen demand (COD) was approximately 350 $mg\ L^{-1}$. In this study, some of the chemicals measured may have been from the palliative itself, from chemical reactions (e.g., exchange) resulting from palliative chemicals, or from chemicals in the soil that would have been present in runoff regardless of whether the palliative was used.

Consequently, many of the statements describing the limited concern about lignosulfonates in the environment are based upon current understanding of their biogeochemical behavior rather than on data.

The environmental effects of petroleum-based dust suppressants are largely unknown. These may be the most difficult products about which to make generalizations because they exist in many different formulations, and new products are being developed regularly. To further complicate matters, very little field monitoring of contamination by these products using typical application rates has been accomplished. Therefore, much of the research applied to this subject extends from environmental emergencies (e.g., spills), or from toxicology studies that use concentrations exceeding the small amounts of petroleum in dust palliatives (Succarieh 1992).

Ettinger (1987) examined the effects of an accidental spill of commonly applied petroleum emulsion dust suppressant (Coherex) on aquatic organisms. An

Table 12.—Constituents with the highest concentrations, and other negative characteristics[a], observed in runoff from dust suppressant-treated plots (data from Loreto et al. 2002)

DUST SUPPRESSANT TYPE AND PRODUCT NAME						
Acrylic polymer EK35®	Lignosulfonate Dustac®	Petroleum-based ------------ Coherex® ------------		Nonpetroleum-based Road Oyl®	Mulch Plas-Bond[b]	Salt (MgCl₂) Dust Gard®
2-butanone	Nitrate	Acetone	Thallium	Acetone	Hardness	Chloride
Acetone	COD	Benzoic acid	Lead	Ammonia-nitrogen	Conductivity	pH >8
Nitrate	TOC	Ammonia-nitrogen	Arsenic	Sulfide	pH >8	Cyanide
Cyanide	Chromium	Sulfate	Selenium	pH >8	TDS	Turbidity
Turbidity	Barium	Sulfide	Copper	BOD	TSS	TS, TSS
TS, TDS, TSS	Silver	Conductivity	Manganese	COD	Sulfate	Thallium
Arsenic	Conductivity	Coliform	Nickel	TOC	Nickel	Lead
Benzoic acid	Copper	Alkalinity	Zinc	Aluminum		Arsenic
Pentachlorophenol		Cyanide	Cadmium	Iron		Boron
Hardness		BOD	Barium	Zinc		Zinc
BOD		Hardness	TVS	TSS		Silver
COD		TDS	Iron	Nickel		Sulfate
TOC		TSS		Cadmium		
TVS		COD				
Alkalinity						

[a] BOD = biological oxygen demand, COD = chemical oxygen demand, TOC = total organic carbon, TS = total solids, TDS = total dissolved solids, TSS = total suspended solids, TVS = total volatile solids.

[b] Manufactured by Soil Solutions Co.

unknown amount of the material was spilled into a ditch that led directly into a tributary of the Schuylkill River in southeastern Pennsylvania. The resin in the mixture adheres to soil and quickly attached to the stream bed. Concentrations of Coherex in tributary streambed sediments were as high as 3,550 mg kg^{-1} during the first 3 days. Within the first 8 hours of the spill, benthic macroinvertebrate density in the affected reach was significantly less than in unaffected reaches, and there were 6.5 times more dead benthic macroinvertebrates as live ones. By day 3, most macroinvertebrates and many of the fish, both adult and larval forms, in the area had died. The dead fish were primarily blacknose dace (*Rhinichthys atratulus*) and white suckers (*Catostomus commersonii*). Crayfish (*Cambarus* spp.) were not as severely affected, but they were very sluggish. Thirty two-lined salamander larvae (*Eurycea bislineata*) and one adult American toad (*Bufo americanus*) also were found dead. Coherex is biodegradable, and by day 10 the concentrations declined substantially and the affected reach had become repopulated with macroinvertebrates at numbers similar to unaffected reaches. There was little change in the streambed concentrations of the product from day 10 through day 59; the concentration at day 59 was 385 mg kg^{-1}.

Coherex was included in the runoff study of dust palliatives applied to disturbed soils in the Las Vegas Valley by Loreto et al. (2002). By a substantial amount, Coherex had the largest number of contaminants with the highest concentrations in the collected runoff (Table 12). Most notably, the concentration of acetone (a toxic volatile organic compound) was 66.2 μg L^{-1}, and the concentration of benzoic acid (a toxic semivolatile compound) was 225 μg L^{-1}. Coherex also had high concentrations of copper, chromium, and manganese.

Hoffman and Eastin (1981) examined the toxicity of a dust oil called RDCO on mallard duck (*Anas platyrhynchos*) embryos. Eggs exposed to 0.5 μl of oil on day 3 after being laid had 60-percent mortality by day 18. Exposure to the same concentration 8 days after being laid reduced mortality by about half (32 percent) by day 18. All of the ducks that survived this dose to be hatched had bill, brain, or eye defects, or incomplete ossification of the skeleton. A more dilute (2 percent) aqueous emulsion spray of RDCO applied at day 3 or day 8 resulted in lower mortalities by day 18: 13 percent

and 17 percent, respectively. Ducks exposed at day 3 showed no abnormalities; 12 percent of those exposed at day 8 had abnormalities.

Kimball (1997) evaluated the potential for pollution of groundwater by PennzSuppress® D (PennzSuppress Corp., Lago Vista, TX), a petroleum-based dust suppressant and road stabilizer. In place of a road study, he examined the chemistry of laboratory leachate obtained from limestone road-base material treated with the product. The leaching results were employed in a mathematical modeling exercise of fate and transport of those materials. He concluded that there was a low risk for this specific product to negatively affect groundwater quality, but warned against extrapolating these results to other geologic (soil and bedrock) situations or other products.

A cursory review of the literature suggests that chloride-based salt palliatives have undergone the most extensive studies related to their environmental effects. However, deeper examination of these studies indicates that these evaluations typically rely on information obtained from deicing studies using chloride salts (e.g., Ettinger 1987, Piechota et al. 2002, Singer et al. 1982). There have been very few studies in which off-road salt levels or environmental effects from dust control by chloride salts have been measured. Although the physics and chemistry related to environmental impacts for both types of applications are the same for like salts, the specific environmental effects that can be expected may be very different due to the different objectives, timing and frequency, and application techniques used for deicing versus dust abatement. For example, deicers may be applied to road surfaces repeatedly during and immediately after snow and ice events, resulting in high chloride concentrations in snowmelt runoff. In contrast, effective use of chloride salt dust suppressants requires application during dry periods with the compound either mixed into or sprayed on the road surface. Applications are made as needed, but generally occur one to two times per season (Bolander and Yamada 1999).

Chloride and magnesium salts are highly soluble, so they can move through the environment relatively easily with moisture (Addo and Sanders 1995, Federation of Canadian Municipalities and National Research Council 2005). Their deliquescent behavior and capillarity provide short-term retention (e.g., over

months), but eventually they will fully succumb to leaching or washoff (Singer et al. 1982, Slesser 1943, Succarieh 1992).

The potential environmental effects of calcium chloride and magnesium chloride come from the chloride anion and the base cation, calcium or magnesium. The chloride anions dissociate from the calcium or magnesium ions. Because soil has a net negative charge due to the presence of clay particles, the chloride ions are repelled by soil and largely will remain in solution. In contrast, the positive charges of calcium and magnesium ions allow them to be retained by soil clays via cation exchange (Bohn et al. 1985). Initially, they will be exchanged for other base cations held less tightly by the soil, such as sodium and potassium. Because anions pair with cations to retain electroneutrality during leaching, the cations that have been released from the soil during cation exchange will pair with the chloride ions (Christ et al. 1999, Reuss and Johnson 1986). Thus, sodium chloride and potassium chloride will be leached first. As inputs of calcium and magnesium increase, reserves of sodium and potassium become depleted so incoming calcium and magnesium ions must exchange for other cations held on exchange sites; these can include toxic metals such as mercury, copper, and lead (Feick et al. 1972). These metals have been found in runoff and soil leachate in association with the use of deicing salts (Bäckström et al. 2004, Feick et al. 1972, Granato et al. 1995). Increases of calcium and magnesium from dust palliatives applied properly and at rates normally associated with dust control generally would be expected to be small compared to background levels of those base cations, so damaging environmental effects from release of toxic metals would not be expected (Singer et al. 1982). However, no studies could be found in which toxic metal concentrations were monitored to confirm this expectation.

One of the largest concerns of salt mobilization is contamination of domestic wells, because humans tend to be much more sensitive to salt intake than most organisms (Hanes et al. 1970). Elevated salt consumption by humans is linked to a number of health effects, including hypertension, coronary heart disease, and cardiovascular disease (Asaria et al. 2007). Increased salt concentrations have been found in wells, groundwater, and surface water from deicing (Bäckström et al. 2004,

Granato et al. 1995, Kaushal et al. 2005), but similar studies could not be found for the use of dust control chloride salts. This does not mean that dust palliatives cannot pollute wells—only that studies of this type are rare or nonexistent, based on the available literature. It should be noted that because salinity levels in fresh waters are very low, small additions of salt can result in measurable increases; with sustained increases over time, elevated salinity can persist and result in ecosystem changes (Kaushal et al. 2005).

Fish, animals, and plants—unlike humans—can tolerate high concentrations of chlorides and salts before detrimental effects occur. Most freshwater fish species can withstand salt concentrations at least up to 400 ppm (Hanes et al. 1970), and many species can tolerate concentrations in thousands or tens of thousands of parts per million (Doudoroff and Katz 1953, Hanes et al. 1970). Salt tolerance or toxicity for fish depends not only on the concentrations and duration of exposure, but also the type of salt. Wiebe et al. (1934) found that golden shiners (*Notemigonus crysoleucas*) were much more sensitive to magnesium chloride and calcium chloride than sodium chloride, and fish that appear to be killed in high concentrations of sodium chloride could be revived if placed in fresh water; that was not the case for fish killed in magnesium or calcium chloride solutions.

Doudoroff and Katz (1953) reported that newly hatched rainbow trout could not tolerate concentrations of chloride (in sodium chloride) of about 3,256 ppm. However, older trout withstood chloride concentrations that were five to six times that level. One-day-old pickerel (*Stizostedion v. vitreum*) and whitefish (*Coregonus clupeaformis*) fry could withstand calcium chloride concentrations of 12,060 ppm and 22,080 ppm (i.e., 5,632 ppm and 10,326 ppm of chloride), respectively (Edmister and Gray 1948). Pike (*Esox* spp.), bass (*Micropterus* spp.), and perch (*Perca* spp.) were harmed when chloride concentrations reached 4,000 ppm (Hanes et al. 1970). Golden shiners exposed to 20,000 ppm sodium chloride survived an average of 1.33 h compared to 6.4 h and 0.5 h in the same concentrations of calcium chloride and magnesium chloride, respectively. At only 5,000 ppm chloride, survival times increased substantially, and were 148, 143, and 96.5 h for the three respective salts. There was little difference in survival times for calcium chloride salt at

20,000 ppm and 15,000 ppm for bream (*Abramis brama*). Survival times were 19.5 h and 17.7 h, respectively, but increased by more than double to about 49 h at 10,000 ppm (Wiebe et al. 1934).

Mortality of some small mammals and game birds, as well as pets, has been reported due to the consumption of deicing salts, but there is some debate as to whether the salt was responsible for the death. Deicing salts also contain chemicals, such as sodium ferrocyanide, to help prevent caking or reduce corrosion of vehicles, and these are highly toxic; thus, they may be responsible for or contribute to salt toxicity in birds, mammals, and fish (Hanes et al. 1970). However, controlled studies of salt intake by domestic animals have shown that toxicity and even death can occur at relatively high concentrations. Concentrations of 15,000 and 20,000 ppm resulted in reductions in food consumption and toxicity, respectively, to sheep (*Ovis aries*) (Peirce 1966). Dairy cows (*Bos* spp.) showed no health effects at sodium chloride levels of 9,000 to 10,000 ppm over 1 to 3 months, but they did show illness and reduced growth when drinking water contained 15,000 to 20,000 ppm sodium chloride (Weeth and Haverland 1961, Weeth et al. 1960). Conversely, nonlactating cattle could tolerate salt concentrations of 20,000 ppm (Heller 1933). Horses (*Equus caballus*) and sheep did not show any symptoms from drinking salt water with concentrations of 9,123 and 11,400 ppm, respectively (Ramsey 1924). In the laboratory, Heller (1932) and Heller and Larwood (1930) studied rats (*Rattus* spp.) supplied with drinking water containing 10,000, 15,000, 20,000, and 25,000 ppm of calcium chloride. These doses resulted in reproduction interferences, growth rate reductions, lactation problems, and mortality, respectively.

Chloride can be toxic to plants in low concentrations in the soil, but plants overall have a wide range of tolerance for salt that depends upon plant species, age, tissue type, overall nutrient conditions, and season (Hanes et al. 1976). Grasses are not easily injured by salts, but trees can be susceptible to damage (Hanes et al. 1970). Some of the tree and shrub species that are most intolerant to chloride concentrations are green ash (*Fraxinus pennsylvanica*), yellow-poplar (*Liriodendron tulipifera*), eastern white pine (*Pinus strobus*), Norway spruce (*Picea abies*), Canadian hemlock (*Tsuga canadensis*), spirea (*Spiraea* spp.), and rose bushes (*Rosa* spp.) (Hanes

et al. 1976). Vegetation damage reported from deicing salts includes reduction in leaf color, leaf browning, premature leaf fall, twig and branch dieback, and mortality of roadside trees (Sucoff 1975). If dust-control salts are properly applied, plant damage or toxicity should result only through elevated salt concentrations in the soil and not through spray, as often occurs with deicing. Even with spray applications, if the liquid is applied following appropriate techniques, salt in soil should be the dominant concern, as splash from cars and plowing would not occur with dust palliation. Additionally, chloride movement (without splash) is primarily vertical; the lack of horizontal movement tends to limit terrestrial effects to near the area of application (Singer et al. 1982).

Slesser (1943) confirmed that there was little movement of chloride dust control suppressants laterally from roads. He found that 23 percent of calcium chloride added to a road to improve its stability was present in the upper 15 inches of the road 55 months after treatment, and horizontal transport was limited. Only 4.1 percent of calcium chloride was found to a depth of 15 inches 2 ft from the road edge after 55 months. On a second road, 9.6 percent of the calcium chloride salt was found in the upper 15 inches of the road 46 months after treatment, and only 6.2 percent was measured to a depth of 14 inches 1 ft from the road edge 25 months after application.

The few studies specifically focused on dust palliative salts suggest they do have lower potential for environmental effects than deicing salts. This is probably largely due to the much lower application rates used for dust control (Singer et al. 1982). Capillarity also contributes to slowing losses vertically by pulling salt back up toward the road surface during dry periods. Consequently, if chloride-salt dust palliatives are applied during appropriate conditions (i.e., avoiding rain and wet conditions), large slugs of salts normally would not be leached in short time periods (Singer et al. 1982). Monlux and Mitchell (2006) compared the performance of magnesium chloride liquid, calcium chloride liquid, and two solid calcium chloride applications (77 percent and 94 percent) on unpaved roads in four western states. They measured chloride concentrations pre- and post-application in river water, in soil samples (48 samples each, before and after application, including controls),

and in 101 conifer trees adjacent to the road. After 2 yr there were no increases in chloride concentrations in river water samples. Chloride concentration increases were found in soil samples and tree tissue, but in both cases the concentrations were below levels that would be of concern for soils or that would threaten tree survival. Loreto et al. (2002) included magnesium chloride (DustGard®, Compass Minerals, Overland Park, KS) in the study of runoff quality in the Las Vegas Valley. The only notable chemicals in the runoff were chloride, boron, thallium, lead, and arsenic (though these soils have high naturally occurring arsenic concentrations). Thallium is very poisonous, but the concentrations found were only about 0.23 mg L^{-1}, and fish and aquatic invertebrate toxicity occurs at much higher concentrations: 10 to 60 mg L^{-1} and 2 to 4 mg L^{-1}, respectively (Zitko et al. 1975).

For all of the other types of dust suppressants, there is little specific information available about their environmental effects. Bennett (1994) stated that because clays are naturally occurring geologic materials, they are harmless to the environment. This probably is a reasonable assumption. Lunsford and Mahoney (2001) stated that enzymes are nontoxic and harmless to the environment, but they offered no studies or literature to substantiate that statement. Little is known about the environmental effects of synthetic polymers, but their cost and the high amount of quality control required during application may impede their widespread use

(Lunsford and Mahoney 2001). Loreto et al. (2002) found that an acrylic polymer (EK35®, Midwest Industrial Supply, Inc., Canton, OH) applied to disturbed soil was second only to a petroleum-based dust suppressant for the number of contaminants and the concentrations of those contaminants in runoff. This polymer had the highest concentrations of volatile organic compounds in runoff (slightly less than 200 µg L^{-1}) and the second highest concentrations of semivolatile organic compounds (~160 µg L^{-1}). BOD and COD also were high, about 42 mg L^{-1} and 900 mg L^{-1}, respectively. Runoff from a nonpetroleum-based road oil (Road Oyl®, BoVill Industries LLC, Redmond, WA) contained moderate numbers of contaminants, but most were at very low concentrations. Aluminum was the exception, with the highest concentrations in runoff of any suppressant tested, and exceeding 2,800 ppb.

Clearly, an important key to reducing the potential environmental impacts of every type of dust palliative is to follow the manufacturer's instructions for application after reviewing the safety data sheets (SDS). Further, local, state, or federal regulations should be understood and followed at all times. Particular attention should be paid to ensure that chemicals are not unintentionally applied to water bodies or ditches leading directly into water bodies (Bolander and Yamada 1999). Spray and mechanical applications should cease when crossing bridges (Piechota et al. 2002).

Gravel application on a new cut-and-fill forest road, and woody material from the right-of-way positioned as a windrow on the fillslope. (Photo by U.S. Forest Service, Northern Research Station.)

CHAPTER 4

Road Use

Road use results in soil losses through both water-driven erosion, and wind- and traffic-generated dust. The road use variables that are most influential in generating sediment losses and that can be manipulated with respect to BMP implementation are axle load and wheel configuration, vehicle weight, tire pressure, traffic intensity (number and timing of vehicle passes), and vehicle speed. This chapter is divided into sections by these major variables.

Axle Load, Vehicle Weight, and Tire Pressure

Large axle loads, vehicle weights, and tire pressures all contribute to increased soil compaction, which in turn can result in several negative soil-related effects. Among these effects are restricted root growth, poor root zone aeration and gas diffusion, poor drainage, and decreased vegetative growth (Abu-Hamdeh et al. 2000, Håkansson and Petelkau 1994, Helms and Hipkin 1986, Johnson et al. 1986, Stone and Elioff 1998). Much of the early research on these variables was in agricultural studies in an attempt to identify ways to avoid reductions in crop yields as a result of using farm equipment in fields. Other significant preliminary information came from studies in the early 20th century by the military in an attempt to alleviate problems with transporting and operating extremely heavy pieces of equipment. Not until relatively recently have research studies involving use of low-volume roads for forestry-related practices been initiated. Because soil loss on low-volume roads is tied strongly to rut formation (Foltz and Burroughs 1990, 1991), maintaining optimal compaction without rutting and avoiding pavement breakup have been the objectives for unpaved and paved roads, respectively.

Road surface damage is a function of three variables: surface materials and thickness, environmental conditions, and the traffic applied to the road (Kestler et al. 2007). However, damage to the road surface by traffic can occur as the result of changes to both surface layers and subsurface soil. Large axle loads and vehicle weights primarily contribute to elevated soil compaction in subsoil layers (Danfors 1994, Håkansson and Petelkau 1994, Janzen 1990), whereas high tire pressures primarily affect compaction near the soil surface (Danfors 1994, Janzen 1990).

The depth to which subsoil compaction occurs increases with the axle load (Danfors 1994). Axle loads of 4 Mg resulted in significant compaction at a depth of 30 cm, while 6-Mg and 10-Mg axle loads showed significant compaction extending down to 40- and 50-cm depths, respectively (Håkansson and Petelkau 1994). Subsoil compaction resulting from large axle loads or vehicle weights can be lessened by reducing the weight of the vehicle and its load, or alternatively by adding more axles and wheels (McLeod et al. 1966, Sebaaly 1992). However, the position of added wheels has a substantial influence on whether changes to subsurface compaction will ultimately result. For example, dual wheels mounted close together may reduce surface compaction but not subsurface compaction; therefore widely spaced extra wheels are preferable (Håkansson and Petelkau 1994). The use of tandem axles does not allow for doubling the load that can be carried because there is an interaction of the two axles that will increase compaction at some depth in the subsoil by more than the sum of each axle individually (Danfors 1994, Håkansson and Petelkau 1994).

Studies involving alterations of wheel or axle configurations sometimes entail reduced tire pressures because more wheels are used (e.g., Danfors 1994, McLeod et al. 1966, Shalaby and Reggin 2002). This makes it difficult to tease out the reductions in compaction that are attributable to changing wheel or axle configurations from those attributable to changing tire pressures. However, because tire pressure is primarily responsible for contact pressure at the soil

surface (Janzen 1990), changing tire pressures exerts little influence on subsoil compaction. Danfors (1990) reported only minimal differences in soil compaction at 30- and 50-cm depths among tire pressures of 21.75, 14.5, and 7.25 lb inch^{-2} (psi) with the same loads. Similarly, changes in subsoil porosity were very similar for 30- to 40-cm or 40- to 50-cm depths from passes made by single-axle vehicles with 7.25- and 21.75-psi tire pressures (Danfors 1994).

Of the three variables described in this section, tire pressure has been the most studied on low-volume forest roads, though forest applications still remain less studied compared to agricultural applications (Kestler et al. 2007). Ground contact pressure is primarily responsible for compaction at the soil surface (Håkansson and Petelkau 1994), and reduced tire pressure acts as a BMP by reducing the pressure of the tires transferred to the road surface as the tire flattens out and elongates to support the vehicle weight (Fig. 5). This increase in the tire footprint reduces the pressure exerted at any point where the tire is in contact with the road surface compared to a normally inflated tire. However, every tire has inflation design limits to ensure the tire can support its load and keep tire deflection at levels that will allow

Figure 5.—Example of tire surface area contacting the driving surface at different tire pressures (psi = lb inch^{-2}). From U.S. Forest Service (1993).

tires to remain sealed on the wheel and resist failure (Janzen 1990). These limits vary with the materials and techniques used to manufacture the tire (Yap 1989), so different types of tires can have markedly different low-end inflation pressures. Under reduced tire pressures, 20-percent sidewall deflection is optimal (Kestler et al. 2007). Reduced vehicle weight also can reduce pressure on the road surface, but if the tires are inflated within their design limits, the reduced vehicle weight translates to a much smaller difference in tire deflection and tire footprint than changes that result from reducing tire inflation (Douglas et al. 2000, Steward 1994).

Wide tires specifically designed to be driven under high loads with very low inflation pressures, known as "terra tires," have been developed for agricultural use to achieve the advantages of tire underinflation. Terra tires that ran under 4, 6, and 9 psi resulted in less soil compaction than single or dual tires at higher or even similar tire pressures when run off-road (McLeod et al. 1966). Under 100 ft of forward travel at 6 psi, the terra tires displaced 31.1 ft^3 of soil compared to 44.0 ft^3 for dual tires. At 6 psi and 9 psi, the terra tires displaced 24.6 ft^3 and 29.2 ft^3 of soil compared to 32.4 ft^3 and 38.0 ft^3 of soil for dual tires at those inflation rates.

There are two ways to reduce tire pressures. One is to manually reduce the pressure so that re-inflation can occur only at a garage or similar facility; this is called the constant reduced pressure method, or CRP (Foltz 1994). In this approach, the target pressure is determined by the vehicle gross weight, the type of tire employed, and the maximum speed of travel that will be used. Because the tire pressure stays low, it has a low ground contact pressure on all of the roads the vehicle travels. Therefore, tire pressures are near optimal for low-volume roads, but suboptimal for highway use where higher travel speeds are used (Kestler et al. 2007). Conversely, if normal highway tire pressures are used continually, these higher pressures result in higher contact pressures that are less than optimal for controlling soil losses on low-volume roads.

The second method to reduce tire pressures allows the driver to change tire pressures while the vehicle is moving (Foltz and Elliot 1997). This automatic pressure changing system is called the central tire inflation system (CTIS) and allows optimal tire pressures to be used for
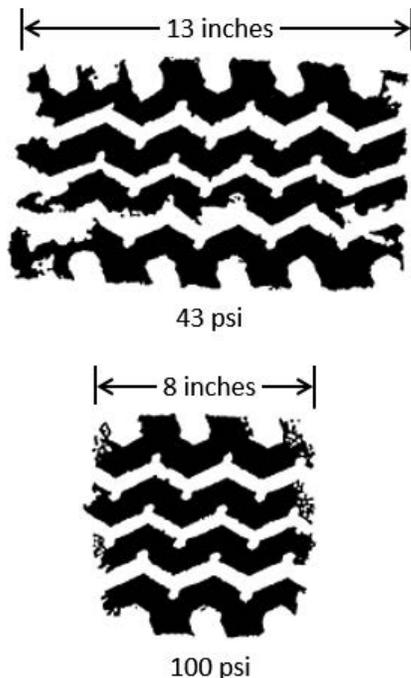
the conditions present. Because tire pressures can be adjusted to lower values on low-volume, unpaved roads, rut creation and erosion can be reduced and greater comfort and longer tire wear can be achieved by re-inflating the tires for paved surfaces.

CTIS has existed since before World War II to improve the mobility of large military vehicles (Foltz 1994, Foltz and Elliot 1997, Kestler et al. 2007). It is expensive to install ($15,000 to $20,000; reported in 2007), so in the United States its use and testing have been confined largely to within the military. The U.S. Forest Service has been the other primary user, with objectives of using CTIS to reduce road maintenance and aggregate thickness of low-volume roads, but the agency has far fewer vehicles equipped with CTIS than does the military (Kestler et al. 2007).

Studies of reduced tire pressures have shown fairly consistent and substantial reductions in rutting and sediment losses compared to higher tire pressures. Foltz (1995) measured sediment losses and rut formation attributable to highway tire pressures (90 psi in all tires), CRP (70 psi in all tires), and CTIS (70 psi on wheels on steering axles, 30.5 psi on other axles for unloaded trucks, or 50 psi on other axles on loaded trucks) on segments of a low-volume road with marginal-quality aggregate. Total sediment losses after three winter/early spring seasons of use in Oregon from the three respective tire pressure systems were 2,678 kg, 1,465 kg, and 530 kg. This equates to average reductions of 80 percent for the CTIS and 45 percent for CRP compared to highway pressures. The best improvements for both systems occurred during the wettest of the 3 yr, and the least during the driest year.

Tests using an individual simulated rain event showed a similar pattern of sediment loss and nearly identical percentage reductions compared to the highway pressure. Highway tire pressures resulted in 116 kg, CRP 54 kg (47-percent reduction), and CTIS 38 kg (83-percent reduction) (Foltz 1995). Foltz and Burroughs (1991) also found reduced tire pressure to be more effective at decreasing sediment losses under wet conditions than dry. Three replicate runs with loaded log trucks using normal tire pressures (95 psi) had only 7 percent greater sediment losses than reduced tire pressures (70 psi) during use with no simulated rain. Under wet conditions with simulated

rainfall, normal tire pressures yielded 120 percent more sediment than reduced tire pressures. Under very wet conditions, the normal tire pressures yielded 73 percent more sediment than reduced tire pressures.

Differences in sediment losses reported in most tire pressure studies have been attributed to the degree of rut development. Foltz (1995) and Foltz and Elliot (1997) reported 70- to 87-percent reductions in sediment losses from lower tire pressures because of less rutting. Ruts worsen under wet conditions because surface soil and subsoil are more susceptible to compaction, and as water concentrates in ruts, soil detachment accelerates. For the three tire pressures examined by Foltz (1995), rut depths were 133 mm for highway inflation rates, 32 mm for the CRP, and 8 mm for the CTIS after 3 yr (January–March only) of use. There was little change in the latter two depths from year 2 to year 3, but the highway rut depths continued to increase throughout the study and deepened from 38 mm to 127 mm from year 2 to year 3. Rutting also occurred more quickly with tire pressures of 100 psi than with 60 psi on a bituminous surface treatment applied over a 20-cm-thick aggregate layer (Kestler and Nam 1999). Tests with reduced tire pressures in Canada decreased rut development and even allowed ruts to be healed and smoothed out if truck drivers varied their wheel paths slightly (Kestler et al. 2007, Shalaby and Reggin 2002). Foltz and Burroughs (1991) found that ruts formed under wet conditions with normal tire pressures were 23 cm deep after 16 passes with a loaded log truck compared to 4 cm under reduced tire pressure; after 16 passes the subgrade also began to fail under normal tire pressures.

Research findings have supported the U.S. Forest Service's objectives for testing reduced tire pressures. The frequency of required road maintenance is reduced due to less rut development (Foltz 1995, Foltz and Elliot 1997, Steward 1994), and the amount of aggregate required for surfacing roads can be decreased by as much as 50 percent (Steward 1994). Both of these advantages can result in substantial savings in construction and maintenance (Smith 1993, Steward 1994). Because disproportionate amounts of sediment loss and road damage, including rutting, occur during wet periods, one of the additional major benefits of reduced tire pressures is earlier access to sites (e.g., 1 to 2 wk earlier) during spring thaw or wet periods (Kestler et al. 2007). This is

particularly applicable for poor-quality roads or roads surfaced with poor-quality aggregate because these are simultaneously most susceptible to damage during wet seasons and most helped by reductions in tire pressures (Foltz 1995). However, if the road's subgrade is extremely weak, tire pressure reductions will not be sufficient to overcome these problems and early reentry will not be possible (Taylor 1988).

Traffic Intensity

Traffic intensity (number of passes) on unpaved roads, particularly by heavy equipment, substantially influences sediment losses and the persistence of sediment availability (Kahklen and Hartsog 1999, Luce and Black 1999, Reid and Dunne 1984). Therefore, controlling traffic, including requiring periods of no use, is considered an important management tool for limiting sediment supply and sediment transport from unpaved roads (Croke and Hairsine 2006). Unused and abandoned roads have more-permeable road surfaces than actively used roads (Reid and Dunne 1984), in part because freeze/thaw and wet/dry cycles help break up road surfaces (Gatto 1998, Knapp 1992) and vegetation can become established (Jordán and Martínez-Zavala 2008, Knapp 1992), both of which improve infiltration. On lightly used roads, sediment control comes from the reduced production of available (loosened) sediment from tire friction, slippage, and other factors. Croke et al. (2006) measured available sediment levels that were half as great per unit area from infrequently used roads as those from well-used main access roads.

Reid and Dunne (1984) estimated sediment production on unpaved roads across a range of use levels using mathematical relationships between precipitation and culvert runoff characteristics for watersheds in the Pacific Northwest. Sediment losses were strongly related to the amount and type of traffic to which the road was subjected. Heavily used roads (more than four loaded log trucks per day) accounted for almost 71 percent of the average sediment yield, while moderate use (fewer than four log trucks per day) and temporary non-use (heavy use for 2 days, then no use) roads each accounted for slightly less than 10 percent of the annual sediment yield. Light use (light vehicle use but no log trucks) and abandoned roads accounted for 3.8 percent and 1.2 percent of sediment production, respectively. MacDonald

et al. (2001) found sediment production doubled in a road segment subjected to heavy traffic compared to one with only light vehicle use on the island of St. John in the U.S. Virgin Islands.

Annual yields of sediment from a heavily used existing graveled road were 13 times greater (44.2 ton mi^{-1} of road) than from an unused road (3.4 ton mi^{-1}) in western Washington state (Wald 1975). The average suspended sediment concentration from the heavily used road was 1,306 mg L^{-1}. Much higher suspended peak concentrations were measured from sediment generated by 30-min simulated rain events performed before, during, or after 20 passes of loaded trucks in New Zealand (Coker et al. 1993). Rainfall simulation during the truck passes resulted in the highest peak sediment concentration of 130,000 mg L^{-1}, which fell to 12,000 mg L^{-1} when use stopped. Road use generated peaks of 21,000 mg L^{-1} and 10,000 mg L^{-1}, respectively, when the rain was applied immediately after and before the 20 passes, and fell to 6,000 mg L^{-1} and 3,000 mg L^{-1}, respectively. Similar results were reported by van Meerveld et al. (2014) for rainfall simulation events with loaded log truck traffic in British Columbia. Peak sediment concentrations ranged from 5,200 to 15,000 mg L^{-1} during medium-intensity (~15 mm h^{-1}) rainfall simulations with three to six truck passes compared to peak concentrations of 900 to 3,800 mg L^{-1} with no truck traffic. Thirteen to 40 percent of the total sediment captured during simulated events was attributed to truck traffic. Wooldridge (1979) also observed increased suspended sediment as a result of heavy-truck traffic during periods of light and moderate rainfall in Washington.

Not surprisingly, traffic intensity also affects sediment generation at stream fords. Thompson and Kyker-Snowman (1989) evaluated the effects of individual and simulated multiple vehicle crossings (4 to 10 trips in rapid succession) by four-wheel all-terrain vehicles (ATVs), four-wheel-drive pickup trucks, and motorcycles on unimproved ford crossings on two small streams. Turbidity and total suspended solids increased from the off-road vehicles, but the average increases were significantly lower than values obtained from heavier logging equipment measured in an earlier phase of the study. Some individual passes by the pickup truck in spring and summer generated turbidities as high as that of some of the individual logging equipment passes 15 ft

downstream of the crossing. The impacts of ATVs and motorcycles traveling in groups were similar to that of logging equipment 15 ft downstream of the crossing, but 100 ft downstream the impact was much less than that of logging equipment. Individually, the four-wheel-drive pickup trucks generated more sediment than the ATVs and motorcycles. Less sediment was generated from streambanks with steeper approaches because vehicles had to slow down to enter and exit the fords.

Foltz and Truebe (1995) studied the simultaneous effects of traffic intensity and aggregate quality on sediment production. Log trucks with an inflation rate of 90 psi made 268 and 616 passes during the winters of 1992 and 1993, respectively, on road segments with good- and marginal-quality surface aggregate (Table 13). Sediment production (kg) was 30 times lower for the lower traffic intensity on marginal-quality aggregate in 1992 than it was for approximately double the traffic in 1993. By comparison, reduced traffic in 1992 resulted in six times lower sediment losses compared to higher traffic in 1993 on the good-quality aggregate. Some of the differences in sediment loss between years were due to greater precipitation during 1993; but when those differences are accounted for by expressing losses as kilograms of sediment per millimeter of precipitation, sediment production was 13 times higher in 1993 with the increased traffic loads for marginal aggregate and 3 times higher with good aggregate. Foltz (1999) extended this study by adding a year with another approximate doubling of the number of passes (1,205) in 1994 and then adding a fourth year when no traffic was allowed on the road. Even after 3 yr of heavy traffic use, as defined by Reid and Dunne

(1984), eliminating traffic in 1995 substantially reduced sediment losses (Table 14) where significant rut formation had occurred in the marginal-quality surface materials (Foltz 1999, Foltz and Truebe 1995).

Traffic Speed

Little research has been published in which the influence of changing travel speed has been studied in relation to changing water-driven sediment losses on unpaved low-volume roads. Travel speed probably has some effect for a given road surface in that speeds that result in tire slippage hasten rut development and washboarding (Shoop et al. 2006), and presumably result in elevated

Table 14.—Sediment production from forest road sections with different aggregate quality (data from Foltz 1999)

Year	Number of passes	Aggregate quality	Sediment loss		
			kg	kg ha^{-1}	g mm^{-1a}
1992	268	Marginal	47.3	1,850	334.7
		Good	12.7	500	82.0
1993	616	Marginal	1,400.0	54,800	2,643.0
		Good	81.0	3,170	157.8
1994	1,205	Marginal	1,231.3	48,180	3,875.1
		Good	262.1	10,260	823.7
1995	0	Marginal	149.0	5,830	188.7
		Good	32.2	1,260	41.6

[a] Mass of sediment in g per mm of precipitation.

Table 13.—Sediment production from forest road sections with different aggregate quality following natural precipitation events (data from Foltz and Truebe 1995)

Year	Aggregate quality	Sediment mass	Mass ratio	Sediment production		Average concentration
		kg	marginal:good	kg ha^{-1}	kg mm^{-1a}	g L^{-1}
1992	Marginal	47.3	3.7	1,850	0.57	2.1
	Good	12.7		500	0.15	1.2
1993	Marginal	1,400.0	17.3	54,800	7.58	27.6
	Good	81.0		3,170	0.44	7.7

[a] Mass of sediment in kg per mm of precipitation.

sediment production. However, because the surfaces of low-volume roads normally are not smooth or conducive to high speeds in terms of either comfort or safety, there are already de facto physical limitations in place that dictate lower speeds on these roads, which may explain the general lack of research in this area.

The published literature involving studies of traffic speed focuses primarily on dust suspension. Road dust can be generated from both paved and unpaved roads. It includes many different types of particles, including metals, organometals, rubber, and exhaust chemicals, as well as soil materials (Rogge et al. 1993). More than 100 types of chemicals are associated with nonsoil particulates, and these tend to be of most concern in urban environments, where humans are subjected to high concentrations of potentially toxic fine particles and aerosols through respiration (Nicholson et al. 1989). On unpaved roads where traffic intensity is much less than on paved roads, most fine particles originate from the bed of dirt roads or from the matrix of the surfacing materials (Jones 2000a, Wisconsin Transportation Information Center [WTIC] 1997). Consequently, these particulates are the focus of this section.

The premise that decreased traffic speeds reduce dust emissions from roads is well accepted—probably because this phenomenon is commonly and easily observed. Decreasing speed reduces turbulence, which lowers particle suspension (Nicholson et al. 1989); however, the specific reduction is dependent upon the road and traffic conditions. For example, increased moisture at the road surface reduces particle suspension (Nicholson et al. 1989). Taller and heavier vehicles also suspend greater amounts of dust at a given speed than shorter, lighter vehicles (Dyck and Stukel 1976, Gillies et al. 2005). The recency of past traffic can influence the amount of particles available for resuspension. Fewer particles, especially large particles, remain available at the road surface for resuspension if several vehicles have recently used the road at moderate speeds (Nicholson et al. 1989).

Even though these other variables have some influence on dust emissions by traffic, substantial reductions have been reported as the result of reducing travel speeds. A reduction from 45 mph to 35 mph resulted in a 22-percent reduction in dust (SynTech Products 2011). Reducing speeds from 40 mph to 35 mph and from 40

mph to 20 mph reduced dust emissions by 40 percent and 65 percent, respectively (Succarieh 1992, WTIC 1997). On paved roads, the minimum speed needed to suspend dust into the air is about 15 to 20 mph depending on particle size (Nicholson et al. 1989), but the threshold velocity on unpaved roads is probably much less (Watson 1996). Sanders and Addo (1993) determined that dust generation was linearly related to vehicle speed during tests on an unpaved road in Colorado. For speeds from 20 to 50 mph, the approximate equation was:

$$Y = 0.85 + 0.16X,$$

where Y was grams of dust generated and X was vehicle speed in mph ($r^2 = 0.98$; equation derived from Figure 10 in Sanders and Addo 1993).

On unpaved roads, dust particles suspended in the atmosphere by traffic are composed of aggregates of fine clays to sand-sized particles; thus, emitted particles can vary in size by several orders of magnitude (Pinnick et al. 1985). Small clay particles are particularly susceptible to loss (Succarieh 1992). In certain cases the linearity between vehicle speed and dust observed by Sanders and Addo (1993) extended across the entire suite of particle sizes within the PM_{10} class size (Etyemezian et al. 2003, Gillies et al. 2005); in another situation, linearity existed only for particle sizes less than or equal to $PM_{2.5}$ (Williams et al. 2008).

Conventional theory regarding PM_{10} dust emissions from roads has been that they redeposit near their sources (Countess 2001, Watson et al. 2000), particularly when wind speeds are low. Consequently, implications for water quality effects would be expected to be limited to water bodies that are next to or cross under roadways, or to water bodies that are connected to ditches adjacent to roadways. However, where moderate wind speeds (3 to 5 m s^{-1}) have been present in combination with little roadside vegetation, equivalent amounts of road dust have been measured at towers located 9 m and 50 m downwind of unpaved test-road sections (Etyemezian et al. 2003). More recent literature reflects a great deal of uncertainty about deposition velocity and dispersion of dusts, and the actual fate of road-dust emissions is not well understood (Gillies et al. 2005). Thus, it is not currently possible to make generalized statements about how well controlling vehicle speed protects water quality.

Stream Crossings, Stream Crossing Approaches, and Wet Soil Crossings

This chapter examines crossings in two fundamentally different types of environments: streams and wet soils (i.e., wet/weak soils, wet meadows, and wetlands). Studies of the effectiveness of stream crossing BMPs are focused directly on water quality or channel condition. In contrast, wetland studies focus primarily on BMPs to control rutting depth and damage to the surface because those effects can alter hydrology (especially subsurface flow). As noted in the Introduction (Chapter 1), BMP effectiveness of aquatic passage designs is not considered in this synthesis, but information about effects on fluvial geomorphology and substrate characteristics upstream and downstream of stream crossings is included.

Stream Crossings

An abundance of forest hydrology and watershed management literature states that stream crossings (or water body crossings in the broader sense) are the road areas with the greatest potential for contributing nonpoint source pollution to water (e.g., see Kruetzweiser and Capell 2001, Lane and Sheridan 2002, Rothwell 1983, Swift 1988, Weaver and Hagans 2004). This conclusion has been based largely on measurements of in-stream sedimentation or turbidity after stream-crossing construction and from comparisons of substrate, habitat, or channel condition above and below existing water body crossings. For example, Eaglin and Hubert (1993), Schnackenberg and MacDonald (1998), and Cornish (2001) reported increases in turbidity and sediment input to streams from stream crossings. Eaglin and Hubert (1993) found lower amounts of cobble substrate associated with stream crossings. Similarly, Schnackenberg and MacDonald (1998) found that the percentage of fine particles (<8-mm diameter) in the streambed was significantly and positively related to the number of road crossings, and explained 61 percent of the variability in the amount of those particles present. Because of the relatively large numbers of these types of studies and the inherent connectivity between crossings and water bodies (Weaver and Hagans 2004), crossings are well accepted as the primary conduit of sediment inputs to water in forested watersheds.

Given the broad acceptance of this tenet, one would expect that a substantial amount of research would have focused on identifying types of crossings, crossing features, or construction techniques that could reduce sediment inputs. Instead, there is surprisingly little research in these arenas, and this lack of information on crossings is noted commonly (Blinn et al. 1998; Bouska et al. 2010; Thompson et al. 1994, 1996; Tornatore 1995; Welch et al. 1998). Papers by Thompson et al. (1994, 1995, 1996) were the first that documented the effects of different types of stream crossings on water quality. Before their research, most studies focused on forest roads as a whole, rather than the stream crossings in particular (Welch et al. 1998).

Stream crossings include a wide variety of techniques and structures. Fords, culverts, and bridges are the most common types of stream crossings, and virtually every type of crossing used for streams and rivers (Clarkin et al. 2006) can be placed into one of these three categories. For lower order streams (e.g., ephemeral and intermittent channels), less complicated and less expensive crossings typically are employed (Clarkin et al. 2006). As stream width and discharge increase, the cost and complexity of crossing structures increase.

For the purpose of motorized vehicle use, a ford is a location in a stream or river that is shallow enough, and without large rocks or boulders, to allow traffic to pass

through. Fords can be classified as either unimproved (or natural) or improved (or mitigated or renovated) (Milauskas 1988, Welch et al. 1998). Unimproved fords have had no changes made to the water body or approaches[1] to help with vehicle passage or resource protection. Sediment levels in unimproved fords can originate from many causes. Waves produced by vehicles moving through the ford can erode soil from streambanks. Ruts can be created in wheel tracks in the approaches that allow overland runoff during storm events to become concentrated and directed to the channel. Sediment can be washed off vehicles as they contact streamwater in the ford. Sediment present in the channel that would not otherwise move under some flow conditions (e.g., baseflow) can become mobilized by the presence of the vehicle or the influence of the vehicle on the water in the stream (Clarkin et al. 2006). Additionally, streamwater can be polluted from vehicles traveling through fords. No studies could be located where pollutants from cars or trucks were measured, but U.S. Forest Service monitoring found measurable levels of naphthalene and hydrocarbons present in streamflow during an off-highway vehicle event that had 200 to 500 vehicle crossings day[-1] for 6 days (Clarkin et al. 2006).

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[1]Approaches are defined as the length of road or ditch line from which water would drain directly to the crossing. The outer boundaries of an approach are usually definable by road-surface drainage features or grade changes on the road surface and ditch line.

However, all of the compound concentrations were within limits established in water quality standards.

In contrast, at a minimum, improved crossings typically involve laying back streambanks to reduce the slope of the approaches to the channel, and installation of gravel, rock, or some type of synthetic pavement in the approaches and on the streambed to reduce the amount of rutting and detachment or suspension of sediment that occurs with travel through the ford. Improved fords also can employ other techniques to reduce contact and disturbance between vehicles and the streambed and banks (Looney 1981). A fairly common type of improved ford uses multiple small culverts encased in concrete (Fig. 6) which allow passage of low flows through the culverts, and the concrete pavement is overtopped during higher flows (Milauskas 1988); these structures are termed "vented fords."

Culvert crossings are composed of single or multiple pipes or box-shaped or arched structures placed into the channel, and positioned parallel to the flow of streamwater with the road surface located above the normal bankfull level. Culverts can be constructed of metal, plastic, or masonry products. Culvert installation normally involves excavating the streambed or banks, or both, within the area where the culvert will be placed and then refilling over and around the culvert after installation. These disturbances can result in short-term inputs of sediment to the stream, even if water is

Figure 6.—A vented ford. From Keller and Sherar (2003).

controlled (e.g., by diversion) during the installation. Redisturbance of the stream can result in another subsequent short-term pulse of sediment into the channel if the culvert is temporary and removed after its required use has ended. Such redisturbance often is considered acceptable because long-term, chronic sediment inputs associated with permanent culverts are avoided. Permanent culverts that remain in place for the long term may have chronic inputs of sediment because of road drainage (see Chapter 2), or even more-extreme inputs during high flows that cause washouts, especially if there is diversion potential. Temporary and permanent culverts are installed on small and moderate-sized streams, but as streams become very wide, bridge installation becomes economically competitive.

Bridges, like culverts, can be temporary or permanent installations. Temporary bridges are portable structures that typically are used on lower volume roads crossing smaller streams (Blinn et al. 1998, Taylor et al. 1996b), whereas permanent bridges are installed on wider streams and rivers where decadeslong use is planned (Taylor et al. 1996b). Temporary bridges almost never include pilings (i.e., supports extending into the channel bottom) and simply span from streambank to streambank. They may be hinged and foldable, or modular (disassembled) to allow easier transport and installation (Blinn et al. 1998, Keliher et al. 1995). Bridges with no pilings may result in little or no streambed disturbance, but bridges that require pilings necessarily involve channel disturbance during construction.

Crossing Effectiveness

Studies investigating the effectiveness of stream crossings fall into two categories: those that are relatively short-term, such as during crossing installation/ improvement or during discrete periods (e.g., logging use), and those that examine longer term influences. The former tend to involve monitoring of the receiving stream's water column for suspended solids/sediment or turbidity. The latter tend to focus on geomorphic and substrate conditions.

Improved fords consistently produce less erosion and sedimentation than unimproved fords. Sample et al. (1998) found that hardening a ford by replacing the original streambed materials with compacted rock and gravel resulted in substantially less measurable sediment downstream than the amount measured downstream of an unimproved ford with traffic. A pole ford (i.e., a ford filled with logs and two 16-inch-diameter iron pipes laid parallel to flow) and a ford filled with randomly oriented sawmill slabs in conjunction with hay bales anchored downstream from the ford to capture and filter sediment had significantly lower turbidity and suspended solids concentrations 15 ft and 100 ft downstream (resulting from passes by logging equipment) than unimproved fords (Thompson and Kyker-Snowman 1989). During some periods, elevated turbidity was measured as far as 1,000 ft and 2,640 ft downstream of the unimproved fords.

Tornatore (1995) and Tornatore et al. (1994) employed a similar crossing on a skid road in which a metal pipe culvert was placed in a stream with pole-sized logs filled in around it. Installation of the crossing occurred during extremely low flow, but median suspended solids concentrations were 412 mg L^{-1} and 28.5 mg L^{-1} 1 m and 61 m, respectively, downstream from the outlet during installation, compared to only 1 mg L^{-1} upstream. The peak suspended solids concentration was more than 1,000 mg L^{-1} 1 m downstream. Installation effects disappeared after about 96 hours, and high flows during snowmelt several months later did not result in increased suspended solids from the poled ford. About 6 months after installation, six simulated skidder passes during a period of baseflow yielded median suspended solids concentrations of 6.2 mg L^{-1} and turbidity of 7.2 NTU 1 m downstream, compared to 2,560 mg L^{-1} and 863 NTU 1 m downstream of an unimproved rocky-bottom ford.

Looney (1981) observed that unimproved fords had between 70 and 150 percent greater sediment losses during short periods of whole-tree skidding compared to improved fords in which rubber mats with side walls (constructed from conveyor belting) were installed. Although this design was referred to as a "dam bridge," it acted as an improved ford during use. The mat floated on the water surface when not in use, but was pressed to the stream bottom when a vehicle drove on it, thereby providing protection to the channel bed and banks. During 1.33 h of skidding, an unimproved ford yielded 52.7 kg of sediment, compared to 31.2 kg from the dam bridge. Two hours of skidding at another site yielded 208.4 kg of sediment from the ford, and 82.3 kg from the dam bridge.

Improvements to fords may help decrease total sediment inputs to streams compared with unimproved fords, but the process of installation or removal of ford mitigation measures can contribute to short-term sediment inputs. Thompson et al. (1996) examined the immediate effects of improving two existing fords in a third-order stream. The fords were cleared mechanically of logs that had been placed in the channel, ruts were removed, and 132 tonne of surge stone was placed in the bed and on the approaches of each ford. The mechanical in-channel work resulted in the highest peak sediment concentrations for ford 1 (2,815 mg L^{-1}), whereas the addition of gravel to ford 2 resulted in its peak sediment concentration (1,355 mg L^{-1}). By comparison, Blinn et al. (1998) reported that a ford containing a pipe mat constructed of bundled polyvinyl chloride (PVC) pipe laid parallel to flow and underlain with geotextile material was very effective at controlling sediment losses during use by logging equipment. They provided no data, but reported no visual increase in turbidity immediately below or farther downstream from the ford after 20 passes with a log forwarder. However, some sediment did enter the stream when the geotextile was removed as the ford was being dismantled. Such sediment losses are common when fabrics used to protect streambeds are extracted (Mason and Greenfield 1995).

Fords (including those that have been improved) tend to be less effective at controlling sediment inputs than other structural types of crossings—at least in the short term. A portable bridge with cribbing (logs laid parallel to streamflow against each bank and at the middle of the bridge to support the portable bridge) had much lower downstream turbidity measurements and suspended sediment concentrations than a pole ford and a ford filled with sawmill slabs and downstream hay bales (Thompson and Kyker-Snowman 1989). The pole ford was more effective than the ford filled with slabs, and the effectiveness of the slabs + hay bales was reduced further when the hay bales were less than 50 ft downstream from the ford because they backed water up into the ford. Looney (1981) found a culvert also to be more effective at controlling sediment than an improved ford (dam bridge) and unimproved ford. This is because the primary periods of sediment generation for the culvert occurred during installation and removal, whereas sediment continued to be generated by the dam bridge and unimproved crossings with each pass. Consequently,

within only a few hours of use, total sediment yields for both types of fords could easily exceed that associated with culvert installation and removal.

Thompson et al. (1994, 1995) compared sediment concentrations from the installation of one temporary corrugated metal culvert and two temporary glue-laminated (glulam) timber bridges. Mean net sediment concentration increases (downstream minus upstream) were 341 mg L^{-1} for the culvert, compared to 66 mg L^{-1} and 38 mg L^{-1} for the bridges. The mean sediment increase was higher for the culvert because its installation involved channel excavation, placement of crusher run gravel for a bed, and refilling around the culvert after placement of the pipe. Neither bridge installation disturbed the streambanks or channel other than preparing the top of the streambanks for bridge placement, making sediment inputs much lower. Sediment contributions remained negligible when one of the bridges was removed during the study, presumably due to the lack of in-channel disturbance and limited bank disturbances. In contrast, when even limited (one equipment pass) in-channel disturbance was required for installation of a portable steel bridge, Tornatore (1995) found that turbidity 1 m downstream was significantly greater than upstream (483 NTU 1 m downstream versus 1.8 NTU upstream, respectively), and exceeded that associated with a pole ford (238 NTU 1 m downstream). However, the effects from bridge installation were more localized, with turbidity of 14.6 NTU compared to 56 NTU 61 m downstream from the pole ford during installation. After installation, there was little difference in median turbidity among the portable bridge, the pole ford, or a culvert backfilled with shale on skid roads, but during use these all performed significantly better than an unimproved ford.

Witt et al. (2011) reported similar results when suspended solids and turbidity from unimproved fords were compared to PVC-pipe bundle crossings, culvert crossings, and portable bridges on ephemeral channels after logging equipment use. The improved crossings resulted in significant turbidity reductions ranging from 67 percent for the pipe bundles to 77 percent for culverts and 84 percent for the bridges versus the unimproved ford. A study by Aust et al. (2011) comparing temporary bridge, culvert, and pipe + pole crossings to improved fords found no significant

differences between crossing types though average sediment concentrations were 217 mg L^{-1} higher below the crossings compared to above the crossings. Mean sediment increases were highest at 253 mg L^{-1} for culvert crossings and 249 mg L^{-1} for improved fords, and lowest for the pipe + pole crossings at 145 mg L^{-1}. Sediment concentration increases of 221 mg L^{-1} for the temporary bridge crossings were similar to the overall mean increase of 217 mg L^{-1} for all crossings.

Thompson and colleagues' (1994, 1995, 1996) culvert installation and ford renovation studies illustrate how in-channel work can alter short-term streamwater sediment concentrations, and the bridge study by Thompson et al. (1994) illustrates the advantages of avoiding in-channel work. However, when in-channel work cannot be avoided, there are data, though extremely limited, that support the importance of controlling streamflow during the disturbance period. In a comparison of sediment generated from the installation of a culvert at two sites, where flow was diverted around construction, 0.2 lb of sediment was contributed to the stream. In contrast, where flow was not diverted or controlled in the construction area, 46 lb of sediment was contributed to the stream (U.S. Forest Service 1981).

In the longer term, culverts often result in the greatest changes to sediment inputs when compared with other types of crossing structures. For example, Tchir et al. (2004) found that 73 percent and 65 percent of crossings in two watersheds in Canada that were categorized as having at least moderate sediment inputs were culvert crossings. Sediment originated primarily from unstable soils where mass slumping occurred (e.g., in crossing fills) and from areas adjacent to crossings with exposed soil. Witmer et al. (2009) also identified poor crossing fill condition as a factor contributing to increased sedimentation risk at round culvert crossing structures compared to box culverts (i.e., rectangular reinforced concrete culverts) and bridges on unpaved roads in southeastern Alabama.

Norman (2006) reviewed seven 3-barrel pipe culverts, one 4-barrel pipe culvert, one box culvert, and two 3-barrel box culverts in Georgia for changes to channel geomorphology. Although there was substantial variation in the geomorphic conditions and changes present among sites, the only consistent changes observed across all types of culverts were shallower upstream thalweg depths and increased fining of streambed substrate downstream of culverts. Like Tchir et al. (2004), Norman (2006) attributed these changes to unstable banks around the crossings, as well as overwidening of the channel for culvert installation and undersized culvert diameters. Miller et al. (1997) evaluated 40 culverts, 21 bridges (temporary and permanent), and 9 fords that were between 2 and 28 yr old on first- and second-order streams. They examined geometric, sediment, habitat, and channel stability differences above and below the crossings, and found that most of the metrics were not affected by the crossings, but streambed fine sediment levels were elevated near the crossings due to the road and stream crossing fills. Wellman et al. (2000) measured the effects of construction or replacement for 18 culverts and 23 bridges on second- and third-order streams in Tennessee. Areas at and downstream of the culverts again had elevated percentages of fines (silt and clays) and greater depths of fines, whereas there was no evidence of elevated sediment accumulations at or downstream of bridges. Box culverts tended to be most susceptible to elevated sediment because their placement was not level with the streambeds, which resulted in scour pool formation and deposition of sediment near the culvert outflow. Perched pipe culverts that restricted high flows also resulted in scour pools downstream of their outlets (Merrill 2005).

Bouska (2008) and Bouska et al. (2010) found increasing entrenchment ratios, and hence, greater channel incision downstream of four of five vented fords, three of five box culverts, and one of two single, large corrugated pipe culverts in Kansas. The changes in entrenchment ratios were large enough to cause a shift in Rosgen stream classifications (Rosgen 1996). Spacing between riffles was increased by low-water crossings, but the influence was an upstream effect due to water backing up and causing inundation and submergence of upstream riffles. Mean riffle spacing was 8.6 bankfull widths upstream, compared to about 4.4 bankfull widths downstream (Bouska 2008, Bouska et al. 2010). Merrill (2005) also reported that channels downstream from all eight culvert and six bridge crossings in North Carolina had increased cross-sectional areas and they tended to have decreased hyporheic zone depths downstream of the crossings. The effects were greater for culverts than bridges. He

attributed the changes observed for all types of crossings to channel constriction and disconnection of the channel from the floodplain caused by the presence of the culverts. Channel morphology changes were least for box culverts, apparently because they tended to be oversized compared to other crossing structures, including bridges on small streams.

Similarly, Norman (2006) reported that large box culverts had less effect on cross-sectional areas downstream of crossings than pipe culverts. In contrast, Bill (2005) found no significant changes in channel width or depth characteristics in cross sections measured downstream from three large pipe culvert crossings 1 yr after construction. Although changes downstream from box culverts may be limited, Bouska (2008) and Bouska et al. (2010) found that the average cross-sectional area within box culverts at bankfull discharge was five times greater than regional curves and regional control streams (41.2 m^2 versus 8.29 m^2, respectively).

Bridges often are considered to result in the least effect to fluvial geomorphology because they are believed to modify and restrict channel geometry the least (Blinn et al. 1998, Norman 2006). However, even small bridges without in-channel pilings can constrict the channel and disconnect it from the floodplain, as Merrill (2005) found. Additionally, the driving surface of the bridge can influence water quality, even if channel geometry is unaffected. Gaps in bridge floors can allow excess organic material, sediment, and other pollutants to fall into the water from vehicles and transported materials (Blinn et al. 1998, Tchir et al. 2004). This is particularly a concern with temporary bridges, which tend not to be solid to simplify their transport and installation (Tornatore 1995).

Bridges with in-channel supports typically show evidence of bed scour around pilings. Wellman et al. (2000) found scour around pilings of all of the 18 bridges they evaluated. Downstream changes in channel morphology also can result from the presence of bridges if they constrict the channel, and the effects can be long lasting. Gregory and Brookes (1983) evaluated local channel adjustments for four types of 18th- and 19th-century bridges in England; three of the four types caused channel constriction (Table 15). Increases in width-to-depth ratios were evident from bridges that constricted the channel, but where channel constriction did not occur and the channel bed was not hardened, the downstream channel was not changed by the bridge (Table 15). Channel adjustments associated with the three former types of bridges persisted downstream for as much as 20 bridge widths. Further analyses using maps and aerial photographic techniques of 15 other 18th- and 19th-century multiple- or single-arched bridges showed channel widening 1.14 to 2.78 times more than observed upstream of the crossings. Resulting changes in capacity were evident 8 to 390 m downstream. In many cases, the effects of lateral and bed scour were evident to the first major meander in the river downstream of the bridges.

Table 15.—Changes to channel geometry downstream of 18th- and 19th-century bridges in England (data from Gregory and Brookes 1983)

Bridge type	Increase in downstream width–depth ratio		Distance change is observable downstream
	Average	Maximum	(Bridge or channel widths)[a]
Bridges with constricted channel width, paved bottom	1.6	2.35	4–20
Bridges with constricted channel width, unpaved bottom	2.0	4.5	Up to 12
Bridges with 1.25-m-diameter culverts conveying water beneath the road	Data not provided, but significant increases were noted		Less than 20 but the actual values were not specified
Bridges with no channel constriction, unpaved bottom	~0	~0	~0

[a] Channel and bridge widths were used interchangeably in the paper, so bridge width is assumed to approximate channel width.

Changes to channel morphology from crossing installation or reconstruction appear to occur relatively rapidly; however, the few studies that include older crossing structures suggest that changes reach equilibrium soon after their installation, and although they do not continue to worsen over time they do persist as long as the constricting features remain in place. Wellman et al. (2000) found that the depth of sediment downstream was not related to the age of the associated culvert. Similarly, the analysis of the geomorphology of 18th- and 19th-century bridges in England (Gregory and Brookes 1983) indicated relatively small increases in downstream width-to-depth ratios relative to the age of the respective bridges (Table 15).

Constricting structures can result in scour and increased channel capacity, width-to-depth ratios, and incision, but channel widening and the installation of oversized crossing structures also can result in changes to sediment routing and channel morphology. Merrill (2005) reported that in-channel bars were formed during low flows downstream of oversized culverts. Channel widening caused the cross-sectional area also to be oversized, so normal sediment transport could not occur and deposition resulted.

Geomorphic and substrate changes tend to be expressed most near crossing structures. Wellman et al. (2000) observed decreasing sediment deposition with distance from culvert outlets. For smaller and intermediate streams, measurable changes were typically confined to within 50 m of the structure (Bouska 2008, Miller et al. 1997, Norman 2006, Wellman et al. 2000). Although crossings can alter sediment erosion and transport at the reach scale (Wargo and Weisman 2006), such effects were reported only for some of the larger rivers (30 to 60 m wide) examined by Gregory and Brookes (1983). Even for those rivers, most of the channel adjustments remained more localized and within 20 channel widths downstream of the bridges.

Turbidity and sediment increases within the water column can extend much farther downstream, but they typically are short-lived, such as during installation activities, during fording with heavy equipment, or during isolated storm events. Only one study was found where elevated sediment inputs from crossing installation were reported as resulting in visually observable accumulations of silt

on the streambed surface downstream beyond the reach scale (Bill 2005). However, the sediment inputs were not sufficient to alter width-to-depth ratios locally or downstream of the installed culverts.

Stream Crossing Approaches

Virtually all of the sediment that is eroded at or delivered to a crossing from the road surface or ditch line enters the associated water body (Weaver and Hagans 2004). This type of sediment delivery occurs by movement through the crossing approaches, so their length and design can substantially influence sediment transport and delivery. For example, Thompson et al. (1994, 1995) found that better road drainage in the approaches to a bridge (broad-based dips at 20 m on one side and 50 m on the other side) resulted in about one-half the average sediment concentrations delivered to the receiving waters (38 mg L^{-1}) during construction compared to another bridge (66 mg L^{-1}) that had no drainage control in the approaches. Brown et al. (2015) used simulated rainfall events to compare mean sediment concentrations attributable to three surface treatments on six additional stream ford approaches in the southwestern Virginia Piedmont. The "low gravel" treatment (9.8 m of approach closest to the stream was graveled; 34 to 60 percent of the approach had gravel cover) resulted in a median total suspended sediment concentration of 1.1 g L^{-1}, which was not significantly different from the 0.82 g L^{-1} median concentration reported for the "high gravel" treatment (19.6 m of the approach length was graveled; 50 to 99 percent of the approach had gravel cover). Both gravel treatments resulted in significantly lower total suspended sediment concentrations than the ungraveled approaches, where the median concentration was 2.84 g L^{-1}.

Other sources of sediment delivery to the stream channel in approaches originate from crossing fills, and adjacent cutbanks and fillslopes (Lane and Sheridan 2002, Swift 1985). However, almost no data exist that quantify the importance or effectiveness of BMPs associated with these sources of inputs, either during crossing construction or in the longer term. The only applicable data found during this review are provided in Hamons (2007) and Stedman (2008), which both involve a single study in West Virginia. Sediment inputs from three crossings and their approaches were quantified during and for several years following the installation

Table 16.—Characteristics of three culvert crossings and their approaches on a newly constructed forest haul road in West Virginia (data from Stedman 2008)

Culvert crossing	Culvert diameter	Fill depth downstream	Road approach angle (left; right)	Sediment reaching the channel
	---------------- m ----------------		degrees	kg
1	1.52	7.4	15; 7.5	1,143.7
2	1.22	7.9	46; 42	25.8
3	0.91	4.5	39; 24	7.6

of culverts on a logging haul road. All of the crossings had deep fills (Table 16) and the approaches all had high, steep fillslopes. Most of the sediment that was delivered to the channel originated from the construction of the fillslopes in the approaches by mechanical additions (bulldozer pushing sediment into the streams) and from the approach fillslopes before they became vegetated.

However, the amount of sediment that reached the stream channels at each crossing during that time differed substantially (Table 16). This difference was attributed to the differences in the angle at which the road approached the stream channels. Sediment inputs attributable to 153 m of approaches to the stream crossing at angles of 8 to 15º (i.e., the road was nearly parallel and very close to the stream) exceeded the annual hillside contributions of sediment to that entire 33-ha watershed before road construction (Stedman 2008). The close proximity of the stream to the road made it virtually impossible to keep fillslope soil out of the channel during construction and

before revegetation. Based on the results from the three crossings, the author recommended that approach angles of ≥25º should be used if fillslopes are constructed, or alternatively, full bench construction (i.e., in which no fillslopes are created) should be used where small approach angles cannot be avoided. However, these suggestions were not tested at the West Virginia location or elsewhere to determine their degree of effectiveness in this type of situation (see Chapter 2 for additional discussion of full bench construction).

Although the Stedman (2008) study showed that sediment inputs from approaches can be relatively short-term with fillslope revegetation, flow diversion at culvert crossings also can contribute to elevated, long-term sediment inputs. Diversion potential (Fig. 7) exists where the road and ditch system (if present) of the approaches slope away from the crossing on one or both approaches (Hagans et al. 1986). During high flows when culverts are overtopped, streamflow can become diverted down
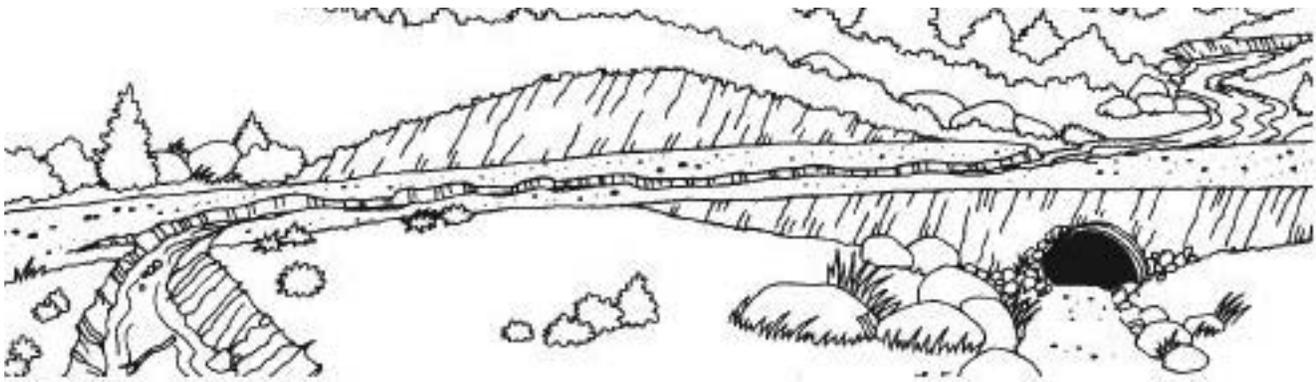
Figure 7.—Illustration of a stream crossing with diversion potential. If at least one of the approaches to the stream crossing slopes away from the crossing, overflowing water will flow down the road or ditch when the culvert is overtopped, creating erosion and damage to the road prism and surrounding hillside. From Keller and Sherar (2003).

the road or ditch line, forming new gullies on the road or hillside where constructed or natural drainage features turn water off the road. Hagans and Weaver (1987) estimated that gullies created by stream diversions were responsible for at least 40 percent of the total sediment production in the 419-km² Redwood Creek basin in California, and 89 percent of the gully erosion that followed harvesting in the lower portion of the watershed also resulted from streamflow diversions (Hagans et al. 1986). Hagans and colleagues recommended ensuring roads and trails are constructed without diversion potential, incorporating adequately sized culverts with debris filters, performing routine maintenance on roads and drainage features, and removing culverts and other crossings and their fills when the road or trail is no longer needed to reestablish an unobstructed channel. Again, however, there are no data to indicate how effective these suggestions are for long-term control of sediment inputs.

Wet Soil Crossings

Many road and crossing techniques are used to travel over wet soils (e.g., see Blinn et al. 1998, Mason 1990), yet there have been few tests of effectiveness for most techniques or few comparisons of alternative techniques. Rummer (1999) found that conventional crowned roads in bottomland hardwoods underwent sediment deposition during the flooding season, whereas those with a "zero profile" (i.e., trees were cut at the ground surface in the right of way, but root wads were not grubbed and no ditches were constructed) had net losses of sediment. However, the differences were explained in part by differences in flow direction but more by the speed of flood flows resulting from the variable water depths across the road prism due to its shape. The crowned road was oriented perpendicular to flow, so the ditches served as areas of deposition because there were slower velocities in the deeper waters present in the ditches. The zero-profile road was parallel to the direction of flood flows, and the velocities and water depths were about the same over the entire prism. As a result, erosion of the exposed soil occurred with no concomitant deposition within the prism.

One of the few studies comparing road surfacing effectiveness on sediment losses in wet soils in Georgia bottomland hardwoods showed no significant differences among native soil, 15 cm of gravel over geotextile, and seeded native soil during the flooding season (Rummer et al. 1997). However, a 6-cm thickness of gravel on native soil had significantly greater sediment yields than all the other treatments except native soil. The relatively high losses from the gravel were attributed to the lack of embeddedness into the roadbed because the gravel was applied to an exising road. As a result, the floodwaters transported some of the gravel, which contributed to the sediment load. For all of the surfacing treatments, sediment movement and deposition were confined to the area within the road right-of-way due to the low water velocities during flooding.

As these aforementioned studies suggest, sediment is not typically much of a concern for roads traversing wetlands and wet soils because slower flows and the greater roughness can keep sediment effectively contained near the area of displacement. Instead, the focus of roads in wetlands and on wet soils is on maintaining hydrologic function, as the integrity of wetlands and wet soils depends upon surface and subsurface hydrologic function (Blinn et al. 1998).

Hydrologic alteration associated with roads often occurs because of the development of ruts in wet soils, so most studies of wet soil crossing BMPs look at techniques to allow transportation while controlling the negative effects. Results of studies involving several types of surface BMPs to reduce rutting in wetlands are shown in Table 17. For those studies in which a control (no crossing mitigation) was employed, all of the techniques tested controlled rutting depth better than the control. Wooden mats and wooden pallets underlain by geotextiles resulted in similar reductions in rutting (Table 17), but wooden mats are generally considered a better alternative because they tend to cost less, are easier to assemble and install, and have less breakage and fewer repair needs than wooden pallets (Hislop 1996b).

Although none of the individual studies in Table 17 compared specific techniques (e.g., wooden mats or pallets, metal grating) with and without geotextile underlayment, comparisons of studies employing geotextiles (Hislop 1996a, Mason and Greenfield 1995) to the study by Blinn et al. (1998) where some of the same techniques were used without geotextiles suggest underlying geotextiles contribute substantially to

Table 17.—Rutting depths in wet soils using a variety of surfacing BMPs

Location/ Soil	Type and number of passes	Treatment	Rutting depth	Reference
			inches	
Florida silty sand	Loaded log truck, 300 passes	Geotextile beneath wooden pallets	0.5	Mason and Greenfield (1995)
		Control	6–10	
	Loaded log truck, 260 passes	Geotextile beneath deck span safety grating and expanded metal grating	0.5–1	Mason and Greenfield (1995)
		Control	12	
Florida silty sand	Loaded log truck, 240 passes	Geotextile beneath wooden pallets	1.5	Hislop (1996a)[a]
		Geotextile beneath wooden mats	1.5	
		Control	8	
	Loaded log truck, 75 passes	Geotextile beneath expanded metal grating	5	Hislop (1996a)[a]
		Control	15	
	Log truck, 30 loaded passes and 30 unloaded passes per day for 14 days	Geotextile beneath wooden pallets and wooden mats[b]	1–1.5	Hislop (1996b)
		Control	3.8–7.6	
Michigan deep black muck	Unloaded flatbed truck with a loader, 20 passes for mitigations, 1 pass for control	Wooden mat	12.5	Blinn et al. (1998)[a]
		Expanded metal grating	8	
		Tire mat	6.5	
		Wooden planks	4.5	
		Control	11.5	
Minnesota ponded histosol	Loaded forwarder, 20 passes	Geotextile beneath wooden mat	5.1	Blinn et al. (1998)[a]
		Geotextile beneath expanded metal grating	4.8	
		Geotextile beneath tire mat	21	
		Geotextile beneath wooden planks	6.8	
		Geotextile beneath PVC pipe mat	1.3	

[a] Reported as maximum rutting depth.

[b] Both techniques were used in series, but measurements were not separated between the two.

controlling rutting depth. The exception is for tire mats. The improvement observed with geotextiles may be because they help distribute loads more evenly and allow water to move through the fabric when under load while maintaining the soil below the fabric (Hislop 1996b, Mason and Greenfield 1995).

The effectiveness of tire mats has been inconsistent. In Michigan, Blinn et al. (1998) showed tire mats to be comparable to other methods when no geotextiles were used, but they were far inferior to other methods tested in Minnesota when used in combination with geotextile fabric (Table 17). Mason and Greenfield (1995) also reported problems with using tire mats made from recycled sidewalls (Terra Mat) on wet soils, but the soil disturbance came from equipment during placement of these heavy mats, rather than use of the mats.

After road use, removal of commonly used surfacing materials on wet or weak soils is generally relatively easy, but the removal of underlying geotextiles can be difficult. Because most are nonwoven materials (see the section on Effectiveness of Rolled Erosion Control Products in Chapter 6 for a description of nonwoven geotextiles), they tend to retain soil and water, which can make them too heavy to remove. To alleviate this problem, they can be installed in shorter lengths, rather than directly off a roll. This technique helps with removal, and still allows the material to be reused (Hislop 1996b).

Some wet soil crossing techniques involve application of wood chunks or wood fibers on the road surface or placed within the road subgrade. For these materials, there are concerns about water quality and aquatic health effects associated with the wood leachate and wood decomposition processes. The effects have not been examined in detail, and much of the information comes from sources not directly related to road investigations. Taylor et al. (1996a) reported that chemicals that are potentially toxic to aquatic organisms can be leached from trembling aspen (*Populus tremuloides*) wood, so care should be taken if these woods are used for road surfacing. They did not investigate the application on roads, however. Leachate from wood waste (mostly bark) disposed of in rock quarries near St. John Harbor on Zarembo Island, Alaska, was found to substantially reduce dissolved oxyen levels in nearby settling ponds

and receiving streams to below 7 mg L^{-1}, with some values below 1 mg L^{-1} (Reed and Wolanek 1994). However, after the water was aerated by running through about 1,000 linear ft of small cascades in the stream, oxygen increased to acceptable levels (>7 mg L^{-1}). Sphagnum (*Sphagnum* spp.) moss in contact with the leachate died, but filamentous bacteria and slime mold growth appeared to benefit from the leachate effects.

The influences of mill-generated wood fiber and bark used as the principal subgrade material on a road in the Tongass National Forest in Alaska generally were found to be small, and in some cases beneficial to water quality (Wolanek 1995). Total organic carbon (TOC) and chemical oxygen demand (COD) levels (indicators of the influence of wood materials on dissolved oxygen concentrations) in leachate collected within the road increased to levels that exceeded 800 mg L^{-1} several times during the first 50 days after construction. These concentrations then exponentially declined. The influence on stream chemistry was examined by using water samples collected from two streams crossed by the road. Downstream (below the crossings) chemistries were adjusted using upstream (above the crossings) chemistries to determine the effects of the leachate. Dissolved oxygen was not affected, but pH was increased by 0.5 to 1.5 pH units. The receiving streams were naturally acidic (mean pH 5.5 and 5.8 prior to road construction), so the pH increases slightly buffered the streamwater. All of the water quality data were within limits of the state's water quality standards.

A temporary bridge installed over a perennial stream to reach a timber harvest area. (Photo by U.S. Forest Service, Northern Research Station.)

Protecting Soil off the Driving Surface

During construction and sometimes during road maintenance activities, the width of disturbed soils can extend well beyond the width of the driving surface of the road. This is especially true on steeply sloping lands where road cutbanks are laid back to reduce their slopes to a more stable grade. Fillslope construction on the downhill side of roads also results in oversteepened areas with unconsolidated soil that is particularly susceptible to erosion (Edwards and Evans 2004, Megahan and King 2004, Rothwell 1978). Consequently, the need to provide soil cover on cutbanks, fillslopes, and drainage areas of forest roads has long been acknowledged (Hursh 1939). The focus of this chapter is restricted to protecting large areas of exposed soils, such as fillslopes and cutbanks; it excludes areas in which road drainage is or has become concentrated, as these are covered in Chapter 7. The following review considers two distinct types of practices to protect disturbed soils off the driving surface: soil conditioners applied to exposed soil and more conventional types of soil cover.

Soil conditioners traditionally have had more use in agriculture, especially tilled soils, but they have been used to some extent where soils have been disturbed at construction sites (including roads), open pit and strip mines, and landfills (Faucette et al. 2006; McLaughlin et al. 2009a, 2009b; Sojka et al. 2007; Soupir et al. 2004; Vacher et al. 2003). Soil conditioners also have been considered as a rehabilitation treatment to reduce erosion on burned forested sites (Davidson et al. 2009, MacDonald and Robichaud 2007, Wohlgemuth and Robichaud 2007).

The more conventional soil protection techniques described in this chapter are vegetation, mulches, rolled erosion control products (RECPs), and surficial slope stabilization techniques that primarily are aimed at controlling shallow mass failures from road construction and are particularly applied on fillslopes.

The effectiveness of mulches and RECPs is focused on controlling erosion only. Even though their application often includes the objective of restoring vegetation, the success of these materials at achieving that objective is not considered here. This is because vegetation establishment depends upon many other conditions that are extremely site-specific (e.g., seed selection and viability, soil nutrient levels, precipitation characteristics) and are independent of the soil cover treatment; often they are not described well enough to determine what factors contributed to or detracted from vegetative success.

Soil Conditioners

Soil conditioners are chemicals applied to soil to improve soil stability and aggregation, which in turn results in reductions in erosion and increases in infiltration (or reductions in surface runoff). Their use began in the 1940s and 1950s (Green and Stott 2001, Weeks and Colter 1952), when they were developed primarily for application on temporary roads and runways during wartime (Seybold 1994). It was not until the 1990s, however, that research began to suggest field use of soil conditioners could be effective and economical (Sojka et al. 2007).

The chemical composition of soil conditioners has evolved substantially since their initial development. Some of the first soil conditioners were water-soluble polymers of hydrolyzed polyacrylonitrile, vinyl acetate maleic acid, or calcium carboxylate (Trout et al. 1995, Weeks and Colter 1952). Today, soil conditioners primarily take the form of gypsum, less pure forms of other gypsiferous materials, and polyacrylamides (PAMs). Use of PAMs far exceeds that of other soil conditioners. A few other natural polymers, such as polysaccharides, also have been tested as erosion control agents (Agassi and Ben-Hur 1992, Lentz et al. 1992, Levy et al. 1992). They often do not perform as well as other conventional soil conditioners and they are more

expensive (Sojka et al. 2007). Research is continuing into development of organic biopolymers derived from by-products of crop production and shellfish processing because they are considered to have more environmental benefits and to be more sustainable (Sojka et al. 2007).

Contemporary gypsiferous materials are by-products of air pollution control technologies at coal-burning power plants. These include compounds resulting from flue gas desulfurization and fluidized bed combustion (Norton et al. 1993). Until 1989, a gypsiferous compound known as phosphogypsum also was used commonly as a soil conditioner in the United States. Phosphogypsum is a by-product of the phosphate fertilizer industry (Norton et al. 1993) and is composed of high percentages (~97 percent) of calcium sulfate (Shainberg et al. 1990, Zhang and Miller 1996a). However, it is commonly contaminated with radon gas (Norton et al. 1993), so phosphogypsum now can be used in the United States only if its average radium-226 levels are less than 10 pCi g^{-1} (Florida Industrial and Phospate Research Institute 2010).

PAMs are water-soluble, synthetic organic polymers (Seybold 1994). Like naturally occurring polymers, such as humic substances and polysaccharides, PAMs provide soil stability (Shainberg et al. 1990), but they provide better erosion control than their natural counterparts (Shainberg and Levy 1994). PAMs are manufactured in a broad range of molecular weights, charge types, and charge densities (Barvenik 1994, Lentz and Sojka 1994, Shainberg and Levy 1994), so their formulations can be tailored to a wide variety of soil conditions and mineralogies (Lentz and Sojka 1994, Shainberg and Levy 1994). In general, however, PAM formulations that have been the most successful for erosion control, prevention of seal formation, and duration of effect are anionic with moderate to high charge densities and high molecular weights (Lentz et al. 1993, Seybold 1994, Shainberg and Levy 1994, Sojka and Lentz 1997, Trout and Ajwa 2001). Low, medium, and high charge densities are defined as <10 mol %, 10 to 30 mol %, and >30 mol %, respectively. Low, medium, high, and very high molecular weights of PAMs are defined as <10^5 g mol^{-1}, 10^5 to 10^6 g mol^{-1}, 1 to 5 × 10^6 g mol^{-1}, and >5 × 10^6 g mol^{-1}, respectively (Barvenik 1994).

Crosslinked superabsorbent or gel-forming PAMs and cationic PAMs also are available commercially,

but neither is suitable for erosion control. Crosslinked superabsorbent PAMs do not prevent erosion because they are not water soluble (Sojka and Lentz 1997) and they have been shown to seal soil pores and actually increase surface runoff and erosion due to their viscosity (Ajwa and Trout 2006). Cationic PAMs are toxic to aquatic organisms such as fish and macroinvertebrates (Barvenik 1994, Sojka and Lentz 1997).

In contrast, anionic PAMs show essentially no toxicity to fish (LC_{50} >100 mg L^{-1}) (Barvenik 1994); Seybold (1994) presents ranges of toxicities for fish and invertebrates. PAMs in any form (anionic, cationic, and nonionic) have low toxicity to humans and typically result in only slight dermal or eye irritations in small mammals, even at high concentrations (Stephens 1991). PAMs are also nontoxic to plants, though at very high levels in the soil (i.e., ≥5 percent of soil dry weight, which is orders of magnitude higher than used for erosion control) PAMs can result in phosphorus deficiencies in plants (Wallace et al. 1986).

Anionic PAMs that are manufactured for and used at concentrations suitable for soil conditioning and erosion control are not considered to pose an environmental or human health threat (Barvenik 1994, Leib et al. 2005, Seybold 1994). The primary environmental or health threats related to PAMs involve the amount of residual acrylamide monomer that remains behind from product synthesis and potential contamination of groundwater (Abdelmagid and Tabatabai 1982, Seybold 1994).

The residual monomer is a human neurotoxin (Leib et al. 2005, Seybold 1994). However, all of the products available in the United States for erosion control are formulated to meet U.S. EPA and Food and Drug Administration standards for other common PAM applications, including wastewater treatment, potable water treatment, and food processing and packaging (Barvenik 1994, Sokja and Lentz 1997). Consequently, PAMs may contain no more than 0.05 percent monomer (Barvenik 1994), and actual residual monomer levels are usually less than 0.0002 percent (Seybold 1994). The free monomer that exists from the manufacturing process is metabolized in biologically active environments fairly quickly following application to the soil and does not accumulate in the soil; it has a half-life of hours (Barvenik 1994, Seybold 1994). During breakdown, there is no release of free acrylamide monomers from

the synthesized PAM itself (Barvenik 1994). Breakdown of PAM requires several weeks and occurs as a result of mechanical disturbances (e.g., rainfall impact, wetting/drying cycles, tilling), chemical and biological hydrolysis, and ultraviolet radiation from sunlight (Barvenik 1994, Seybold 1994, Sojka and Lentz 1997). Biological hydrolysis of PAMs by soil microorganisms produces ammonium that may then undergo further oxidation to nitrite and nitrate (Abdelmagid and Tabatabai 1982, Seybold 1994).

Anionic PAMs are a potential source of groundwater pollution because they are highly water soluble, and have low soil adsorption potentials (Seybold 1994) in the absence of cations in the soil or application solution. If PAM reaches water before breakdown and hydrolyzation, its degradation in water requires longer than in soil—typically 100 to 700 h (Seybold 1994). However, PAMs are generally applied at relatively low rates only to the soil surface, and they tend not to penetrate more than a few millimeters or centimeters below the surface (Lentz et al. 1995, Mitchell 1986, Seybold 1994). The exceptions to this are if they are applied to dry, cracked soil, in which case they may penetrate more deeply (Malik et al. 1991); this soil condition would be rare in forests.

Contemporary soil conditioners all work in similar ways, though the physical or chemical mechanisms involved may differ. They interact with the clay fraction of soil, and they depend upon cations to flocculate clays and to form cation bridges (Agassi and Ben-Hur 1991, 1992; Chaudhari and Flanagan 1998; Shainberg et al. 1990). That is, anionic conditioners can attach to multiple cations that have become attached to negatively charged clays, thereby forming bridges across clay particles. Cation bridging is most effective with multivalent, rather than monovalent, cations (Levy et al. 1992, Shainberg et al. 1990). Monovalent cations can participate in cation bridging, but these have weaker bonds than multivalent cations (Laird 1997). The conditioner itself may contain and release the bridging cation (e.g., Ca^{2+} in gypsum and gypsiferous materials). In the case of anionic polymers, an additional cation source must be applied with the polymer (e.g., combining the polymer with a gypsiferous material), or cations must be present in sufficiently high concentrations in the soil or in the water used to prepare the application solution (Green and Stott 2001, Orts et al. 2007, Shainberg et al. 1990, Warrington et al.

1989). Depending upon the chemistry of the local water source, tap water may have sufficient cations present to contribute to cation bridging (Shainberg et al. 1990, Smith et al. 1990). Applications should not depend upon subsequent rain events to provide the necessary amount of cations; Wohlgemuth and Robichaud (2007) found the cation loads in rainfall were insufficient to allow PAMs to be effective.

Cation bridges help strengthen aggregate bonding of clay particles by reducing repulsion of the net negative charges of clay particles (Ben-Hur 1994, Seybold 1994, Sojka and Lentz 1997). Bridging maintains large soil aggregates and pore integrity at the surface. In turn, bridging leads to other positive outcomes, including increases in soil wettability (Jańczuk et al. 1991), increased resistance to slaking during rapid wetting (Mitchell 1986), stabilization of shrinking and swelling in clays (Malik et al. 1991), increased resistance to aggregate breakdown and detachment by surface flows and rainfall impact (Bryan 1992, Helalia and Letey 1989, Shainberg et al. 1992, Terry and Nelson 1986, Trout and Ajwa 2001), increased soil infiltration, prevention of soil crusts, and reduction of soil sealing (Davidson et al. 2009, Kazman et al. 1983, Lentz and Sojka 1994, Seybold 1994, Sojka and Lentz 1996, Trout and Ajwa 2001). Thus, the physical conditions of soil, such as structure and permeability, are not improved by soil conditioners; instead they are stabilized against breakdown (Lentz and Sojka 1994, Trout and Ajwa 2001). In addition, conditioners and associated cations act as flocculants (Shaviv et al. 1988, Sojka and Lentz 1996), so fine dispersed clay particles flowing in runoff can clump together and settle out as the aggregate mass increases (Sojka and Lentz 1996, Warrington et al. 1989). Flocculation further helps combat soil sealing because the particles that settle out are larger and ineffective at filling fine voids among soil aggregates (Shainberg and Levy 1994).

Because soil conditioners depend upon flocculation and stabilization of clay particles, they are most effective in soils that have moderate to higher clay content. Indeed, most studies and applications of soil conditioners have focused on finer textured soils (Trout and Ajwa 2001), probably because these soils are most erodible and need stabilization. PAM effectiveness is most likely when the soil clay content is at least 30 percent (Davidson et al.

2009). PAM effectiveness in fine textured soils is further improved by using a formulation with an appropriate charge density (Green et al. 2000, Levy and Agassi 1995); effectiveness has been most commonly associated with charge densities in the mid-teens to mid-30 mol % range (Green et al. 2000, Malik et al. 1991, Michaels and Morelos 1955, Peterson et al. 2002, Sojka et al. 2007). The charge density is the percent hydrolysis of the polymer, which describes the percentage of hydroxyl groups that have been substituted for acrylamide groups in the polymer (Green et al. 2000). High charge densities (e.g., 40 mol %) can result in repulsion of the polymer and the clay particles, thereby reducing adsorption onto clays and effectiveness of PAMs (Ben-Hur et al. 1992, Green et al. 2000).

In a silty clay soil in Indiana, wet and dry applications of PAM both were found to be effective at controlling erosion and runoff (Peterson et al. 2002). Total runoff was reduced by 62 to 76 percent by using wet applications, and sediment yields were reduced 93 to 98 percent. Dry applications were slightly less effective at controlling both variables. Aase et al. (1998) examined PAM use at low concentrations (1, 2, 4, and 6 kg ha^{-1}) on a silt loam. For concentrations greater than 2 kg ha^{-1}, runoff and soil loss were each reduced 70 percent on average. PAM at high concentrations (10, 20, and 40 kg ha^{-1}) in a clay loam retained infiltration at rates substantially higher than clay loam with no soil conditioner (Shainberg et al. 1990). However, the addition of phosphogypsum with PAM resulted in the retention of even higher infiltration rates. The phosphogypsum dissolved over time, and provided a continued source of cations that allowed the soil clay to remain flocculated, thereby helping to retain soil bridging with the PAMs. Phosphogypsum also was found to be an effective soil conditioner in a clay loam in the Midwest (Norton et al. 1993). After 2 h of rainfall (74 mm), total soil yield on a 5-percent sloped plot was only one-third of the amount from an untreated control. Levy et al. (1991) recorded 50- to 70-percent reductions in runoff in a clay loam using PAM; this was the case for plots with and without a crop (cotton, *Gossypium hirsutum*) present. Reductions in erosion were more pronounced for bare soil (62 to 83 percent less than controls) than when the crop was present (22 to 52

percent less than controls), presumably because the crop contributed to soil stabilization.

Soupir et al. (2004) saw 82-percent reductions to sediment yields from a clay soil soon after the application of a dry form of PAM. A wet formulation applied at the manufacturer's recommended rate resulted in only a 40-percent reduction. Higher and lower application rates were not as effective, and resulted in only 28- and 33-percent sediment reductions compared to no treatment.

In coarser textured soils, the effectiveness of soil conditioners is not guaranteed due to the lower clay percentages present. This is especially the case for soils with high sand contents like sandy loams. Separate studies by Trout and Ajwa (2001) and Ajwa and Trout (2006) reported reductions in infiltration with the use of PAM compared to controls. Gypsiferous soil conditioners may result in more desirable effects with sandy loams. Final infiltration rates following phosphogypsum application were almost triple that of controls in a study by Warrington et al. (1989), and they were double that of controls in a study by Miller (1987) using two sandy loams in the Southeast. In the latter study, cumulative and average infiltration rates significantly increased compared to untreated soils. Erosion was reduced by 30 percent and 50 percent in the two soils, and there was essentially no loss of clay particles in runoff; however, silt losses were greater than in the controls. Zhang and Miller (1996a) found that a gypsum application allowed a sandy loam to have a 26-percent higher final infiltration rate after one rain event than with no soil conditioner. In an even coarser soil (loamy sand), erosion was not reduced with the use of PAM after a wildfire in southern California (Wohlgemuth and Robichaud 2007).

To improve the potential for PAM effectiveness in soils with high percentages of sand, the molecular weight of the PAM formulation is key (Green et al. 2000, Levy and Agassi 1995). It is important because it is directly related to the polymer length: the longer the polymer, the greater the molecular weight (Green et al. 2000). Polymers with lower molecular weights may not have chain lengths that are sufficiently long to bind together the relatively small number of clay particles present (Levy and Agassi 1995); polymers with very high molecular weights may be too

large to penetrate soil voids (Barraclough and Nye 1979). The molecular weight is not important in clayey soils because the clay particles are close enough together that even short polymer lengths can bind them (Green et al. 2000, Levy and Agassi 1995). However, using a PAM formulation of high molecular weight with a sandy loam still does not guarantee its effectiveness. Although Green et al. (2000) found that a high molecular weight PAM formulation (12×10^6 g mol^{-1}) was effective, molecular weights below (10^6 and 6×10^6 g mol^{-1}) and above (18×10^6 g mol^{-1}) that formulation were not effective. Likewise, similar molecular weights (15×10^6 g mol^{-1} and 12×10^6 g mol^{-1} to 15×10^6 g mol^{-1}) were not effective in studies by Trout and Ajwa (2001) and Ajwa and Trout (2006), respectively.

Medium-textured soils, such as silt loams and loams, tend to be responsive to soil conditioners and seem to be less sensitive to the molecular weight of the PAM formulation. Green et al. (2000) studied PAM formulations across a range of molecular weights (10^6, 6×10^6, 12×10^6, and 18×10^6 g mol^{-1}) and charge densities (0, 20, 30, and 40 mol %) in a silt loam, and all formulations except the one with the highest molecular weight and the highest charge density showed improvements in soil stabilization. Lentz et al. (1992) applied PAM with an even higher molecular weight (10^7 g mol^{-1}) to a silt loam and found that the mean sediment loss was reduced 97 percent compared to untreated soil, but the charge density of this formulation was in the more typical range of 20 mol %. Lentz and Sojka (1994) and Trout et al. (1995) both used PAMs with 15×10^6 g mol^{-1} molecular weights and 18-percent hydrolysis. Lentz and Sojka found soil losses were reduced by an average of 94 percent and infiltration was increased by an average of 15 percent. Trout et al. (1995) found similar reductions in erosion (ranging from 85 to 99 percent, average 70 percent) and 30-percent increases in average infiltration rates.

Gypsiferous compounds alone and in combination with PAM also are effective in medium-textured soils. Lepore et al. (2009) measured soil losses from silt loam soil using six soil conditioners (lime, gypsum, PAM-coated lime, PAM-coated gypsum, gypsum + PAM applied separately, and lime + PAM applied separately) and bare soil. All soil conditioners significantly reduced soil losses compared to untreated soil. Treatments involving lime resulted in less erosion than their gypsum counterparts, but the differences among the conditioners were not significant. Adding PAM to lime and gypsum also improved soil stability more than lime or gypsum alone, and coating the lime or gypsum with PAM was more effective than adding the PAM separately. Soil losses from PAM-coated lime and lime + PAM were 75 and 53 percent, respectively, less than lime alone, and 83 and 67 percent, respectively, less than soil with no conditioner treatments. PAM-coated gypsum and gypsum + PAM also had significantly lower soil erosion than gypsum alone (63 and 49 percent, respectively). The two treatments reduced erosion by 69 and 58 percent, respectively, compared to bare soil. The PAM coating on the lime and gypsum reduced the dissolution rates of both, and this may explain why PAM-coated treatments were more effective than applying lime or gypsum alone or separately with PAM.

In another study with a silt loam, Norton et al. (1993) measured lower soil losses using a nearly pure gypsum conditioner from fluidized bed combustion and using a gypsiferous material from flue gas desulfurization than with no treatment. A second gypsiferous material from flue gas desulfurization resulted in poorer erosion control than no treatment. Infiltration results paralleled those results. Phosphogypsum also improved erosion control and infiltration compared to the control. Miller (1987) found phosphogypsum applied to a silt loam increased infiltration rates and resulted in significant increases in cumulative and average infiltration rates compared to untreated soil. Soil losses also were half of those for the untreated soil. Shainberg et al. (1990) applied PAM to a loam soil and the final infiltration and cumulative infiltration rates were three and four times higher, respectively, than without treatment. Combining PAM with a phosphogypsum application increased the final infiltration rates to levels that were 10 times greater than the controls.

Many of the studies of soil conditioner effectiveness, including those just described, have been performed for agricultural uses. This raises the question of whether soil conditioners have application to nonagricultural soils, and for the purposes of this review, steep soils. These types of applications of soil conditioners have not been examined as extensively. But there are some studies that illustrate the potential for soil conditioner use on

disturbed soils of forest road prisms, including some studies directly from road construction, albeit generally highway construction. However, the results across all studies have been mixed. On a 30-percent gradient, Norton et al. (1993) found all of the four treatments tested (phosphogypsum, two gypsiferous materials from flue gas desulfurization, and almost pure gypsum conditioner from fluidized bed combustion) were ineffective at reducing erosion or increasing infiltration, even though three of them had been effective on a 5-percent slope. On the steeper gradient, sediment losses rose 3.5 to 4.8 times and were similar to the control. Warrington et al. (1989) found that phosphogypsum was less effective on steeper slopes than gentle slopes, but outperformed controls with no treatments. On 5-percent slopes, erosion from phosphogypsum treatments was 60 percent less than controls. At a 25-percent slope, the erosion rates doubled with the soil conditioner, but that same increase in slope resulted in a sevenfold increase in soil loss from untreated soil.

After a wildfire in Utah, Davidson et al. (2009) studied the effect of aerially applied granular PAM pellets (made with recycled paper) on soil losses over 3 yr. The slopes to which PAM was applied were 33-percent grade. They found that PAM resulted in significantly lower erosion rates than control soils. But because the controls were located on only 16-percent slopes, the impact of the improvement by the soil conditioner is probably underrepresented by the statistical comparison. MacDonald and Robichaud (2007) tested two PAM treatments in a burn area emergency rehabilitation treatment in the Colorado Front Range. They reported somewhat mediocre results because PAM became preferentially bound to the ash from the fire, rather than the soil. One treatment reduced erosion during two storm events and the other treatment was ineffective.

Flanagan et al. (2002b) examined PAM and PAM + gypsum applications on a 35-percent sloped highway cutbank in a clay loam and a 45-percent sloped reclaimed landfill in a silt loam in Indiana. The responses were compared to untreated controls following individual storm events over summer seasons. For individual storm events on the highway cutbank, erosion was reduced from 44 to 100 percent by PAM alone and from 26 to 100 percent for PAM + gypsum. Cumulative sediment reductions across the entire study period compared to no treatment

were 54 and 45 percent for PAM and PAM + gypsum, respectively; the results from these two treatments were not significantly different from one another.

Additionally, reductions in runoff from the two treatments compared to the controls were similar across storms and ranged from 25 to 91 percent for PAM and 36 to 90 percent for PAM + gypsum. Cumulative runoff for the entire study was reduced by an average of 33 percent for both treatments. At the landfill, soil yields were 39 to 100 percent less than the control for PAM and 44 to 100 percent less than the control for PAM + gypsum. Percent cumulative sediment reductions from the landfill were similar to the less steep cutbanks; they were 40 and 53 percent less than untreated soil for PAM and PAM + gypsum treatments, respectively, and again the results from the two were not significantly different from each other. However, PAM + gypsum was more effective at controlling erosion during very large events, even though runoff was similar. In the largest two storms, PAM + gypsum reduced sediment by 58 percent and 85 percent compared to the control, whereas soil losses from the PAM treatments during those events were not significantly different from using no soil conditioner. At the landfill, runoff for individual storms also was not significantly different between the two treatments, but PAM reduced runoff 30 to 55 percent and PAM + gypsum reduced runoff 27 to 74 percent compared to the controls. PAM + gypsum had significantly lower cumulative runoff (28 percent less) than the controls or PAM.

In another study by Flanagan et al. (2002a) in which a silt loam soil at 32-percent grade was subjected to repeated simulated rainfalls following PAM and PAM + gypsum treatments, total runoff over the entire experiment was reduced by 40 percent and 52 percent, respectively, by the two treatments compared to a control. After the first event, runoff and sediment losses were reduced by more than 90 percent by both treatments. Even when subjected to a 25-yr rain event, sediment yields were 60 percent and 77 percent less than the control for PAM and PAM + gypsum, respectively. Total sediment losses following a cumulative rainfall that equated to more than a 100-yr event were 83 percent and 91 percent less than the control for PAM and PAM + gypsum, respectively. On a sandy loam with a 48-percent slope, phosphogypsum significantly reduced runoff and erosion compared to untreated soils (Agassi and Ben-Hur 1991). Runoff

was reduced from 23 to 31 percent by the conditioner versus the control, and erosion was reduced two to three times that from the control. However, erosion increased substantially as the plot length increased on these steep slopes. As the length increased from 1.5 m to 10 m, soil loss increased by 6.4 times, but sediment yields still were less than from untreated soil.

In another study by Agassi and Ben-Hur (1992), PAM + phosphogypsum and phosphogypsum + polysaccharide conditioners were compared to a control on earthen dikes in Israel ranging in slope from 33 to 60 percent. Over a winter season, they observed that the soil losses from both treatments were 10 times less than with no treatments. Soil erosion from the two treatments was not significantly different from each other. On 58-percent slopes, a variety of application rates and approaches using both dry and wet applications of PAM were successful in reducing erosion from 75 to 100 percent in a sandy clay soil and a loam soil when subjected to simulated rainfall (Wallace and Wallace 1986). On a 50-percent fillslope at a highway construction site in the North Carolina Piedmont on sandy clay loam soil material, two PAM formulations each were applied at two different (albeit low compared to most literature) rates (0.8 and 1.5 kg ha^{-1} for formulation 1, and 5.2, and 10.5 kg ha^{-1} for formulation 2) (Hayes et al. 2005). Runoff, turbidity, and total sediment losses after seven storms were not significantly different from the control. However, average turbidity and total sediment yield did decrease with increasing polymer application rates. On a 20-percent cutslope of nearly the same soil material, the same PAM formulations and application rates resulted in no differences in runoff or sediment loss compared to the control, but turbidity was reduced.

Soil conditioners have been applied in several ways: furrow advance, overhead sprinkler/irrigation, spraying under high pressure, dry broadcasting or spreading over the surface, and dry or wet aerial application (e.g., Agassi and Ben-Hur 1991; Flanagan et al. 2002a, 2002b; Fox and Bryan 1992; Green and Stott 2001; MacDonald and Robichaud 2007; Mitchell 1986; Terry and Nelson 1986). Based on review of the literature, aerial applications have been undertaken only for wildfire restoration when a substantial area has been severely burned and the potential for catastrophic impact to watershed values is high, and for agricultural purposes when the

soil conditioner was spread over an entire field by crop dusting planes (e.g., MacDonald and Robichaud 2007, Wallace and Wallace 1986). Aerial application is not likely to be used to meet road BMP objectives, so it is not discussed further. The others are described further because the technique used to apply a soil conditioner influences its efficacy and the needed application rate.

Furrow advance is directed at reducing erosion from irrigation waters and improving infiltration in agricultural furrows. The actual treatment of the furrow, referred to as "furrow advance," typically is performed by mixing the soil conditioner with irrigation water or injecting it into irrigation water as the water is released into the dry furrow. If cation levels in the conditioner, irrigation water, or the soil are not believed to be sufficient to allow cation bridging, some form of cation is mixed in with the conditioner. This release continues until runoff through the entire furrow is achieved (Sojka and Lentz 1996). Once runoff occurs, irrigation is stopped. Effective erosion control via furrow irrigation illustrates the applicability of soil conditioners to controlling erosion in concentrated flow. Applications of PAM and other soil conditioners to concentrated flow associated with roads and construction (e.g., within swales and in combination with erosion barriers) are considered in Chapter 7. However, additional discussion of furrow irrigation is included in this chapter to keep the fundamental information about soil conditioners in one place.

All other soil conditioner application techniques are aimed at treating larger land areas, with the intent to protect soil from rainfall impact and surface runoff. As with furrow advance, cations also are applied, if needed, in dry or wet form; this can be done before or at the same time as application of the conditioner. Basic information about wet and dry applications is provided in subsequent paragraphs, but Lentz et al. (1995) provide detailed information about some of the pros and cons related to dry and wet applications of PAMs. Although these are directed at agricultural uses, many of the points also are applicable to any field use of PAM.

In general, wet applications of soil conditioners have been found to be more effective than dry applications (Cook and Nelson 1986, Peterson et al. 2002, Shaviv et al. 1987). Applications of solutions should be made to

dry soil. Studies in which soil conditioners have been applied to wet soil have shown inferior infiltration and erosion control benefits compared to applications to dry soil (Roa-Espinosa et al. 1999, Shainberg et al. 1990). Dry soil conditioners can be applied to slightly moist soil, or the soil can be lightly moistened before or after application; however, only enough water to moisten the first millimeter or two of soil should be used to dissolve the conditioner and enhance binding (Wallace and Wallace 1986). On dry soils, dry soil conditioners may not become adequately activated before the first precipitation event (Peterson et al. 2002). Following wet or dry application, a period that allows the soil to dry fully before it is contacted by rainfall (or irrigation water) is critical for maximizing conditioner effectiveness (El-Morsy et al. 1991, Shainberg et al. 1990). The drying or curing period allows the soil conditioner to fully adsorb onto soil clays, and allows PAM to become irreversibly adsorbed to the soil so desorption is negligible (Nadler et al. 1992, Shainberg et al. 1990).

Furrow advance treatments allow more dilute applications than sprinkler or spray treatments (Sojka et al. 2007). This is partly because furrow advance involves treatment of only a relatively small surface area (Lentz and Sojka 1994). Typical furrow advance loads for PAM have been in the range of 0.5 to 1.3 kg ha^{-1} (Lentz and Sojka 1994, Lentz et al. 1992, Sojka and Lentz 1997), though rates above 0.7 kg ha^{-1} had substantially smaller soil losses than rates below 0.7 kg ha^{-1} (Lentz and Sojka 1994). Overhead sprinkling systems have shown success with PAM with rates as low as 2 to 4 kg ha^{-1} (Aase et al. 1998, Bjorneberg et al. 2003), but overhead delivery is more commonly successful in the 20 to 70 kg ha^{-1} range (Agassi and Ben-Hur 1992, Flanagan et al. 1992, Fox and Bryan 1992, Levy et al. 1991, Norton 1992, Wallace and Wallace 1986). Spray application rates of PAM tend to be in this same range. Zhang and Miller (1996b) used rates of 15 kg ha^{-1} and 30 kg ha^{-1}, Green et al. (2000) used 20 kg ha^{-1}, and Flanagan et al. (2002a, 2002b) used a rate of 80 kg ha^{-1} for treating soils on steep slopes. However, Petersen et al. (2007) applied a specially designed PAM emulsion using a hand sprayer and found that only 5 kg ha^{-1} effectively curtailed erosion. Dry application rates of PAMs are less than what has been used for wet applications, 5.6 kg ha^{-1}, but the actual granular forms including the carriers result

in much larger total application rates (e.g., 224 kg ha^{-1} and 280 kg ha^{-1}) (Lepore et al. 2009). It should be noted that manufacturer-recommended rates for PAM are sometimes much lower than the typical rates that have been tested in the literature, or states have set maximum loads for application to construction sites; sometimes these low rates have resulted in poor erosion control or runoff control (Hayes et al. 2005, Soupir et al. 2004).

In contrast to PAM treatments, gypsiferous and cationic soil conditioners typically require much higher application rates. Zhang and Miller (1996a) used 5 tonne of phosphogypsum ha^{-1}, and Flanagan et al. (1997) applied fluidized bed combustion bottom ash at a rate of 5 tonne ha^{-1}. Miller (1987) also applied phosphogypsum at 5 tonne ha^{-1}. Lepore et al. (2009) applied gypsum and lime each at 280 kg ha^{-1}.

Except for furrow irrigation, where vegetation is undesirable in the furrows of agricultural fields, the purpose of soil conditioners in field applications typically is to provide soil aggregation and protection against soil sealing until vegetation becomes established (Vacher et al. 2003). Once vegetative cover reaches 50 to 60 percent, it is considered to be capable of taking over the role of soil stabilization (Carroll et al. 2000, Loch 2000). For disturbed soils on forest road prisms, this means that soil conditioners must remain effective long enough for revegetation to occur; otherwise retreatment with the soil conditioner will be necessary. Agricultural studies often recommend reapplication of conditioners repeatedly throughout the growing season (Sojka and Lentz 1997), but that is because repeated mechanical disturbances to the soil are expected during such activities as tilling and pesticide application.

Most soil conditioner studies have been performed for agricultural soils, so the available data on the expected life of soil conditioners are limited. There are, however, a few studies for PAM that show it has been effective over nearly season-long periods. Fox and Bryan (1992) found PAM was effective for 6 wk and Petersen et al. (2007) found it effective for at least 10 wk. Petersen et al. (2007) found runoff was reduced by an average of 100 percent after 2 days following application of PAM, by 59 percent after 3 wk, and by 55 percent after 10 wk. Erosion control was even better, with soil losses reduced by 100, 80, and 74 percent for those three respective time

periods. Shainberg et al. (1990) found PAM effective throughout at least 3 wk of study. A study by Soupir et al. (2004) showed relatively poor results for separate wet and dry applications of PAM after only about 4 wk for a construction site on clay soil in Virginia. At 1 month, the wet and dry treatments, respectively, had only 25 percent and 11 percent lower sediment yields than the control. However, they used an application rate of only 3.36 kg ha^{-1}, which was below typical spray application rates, though it was the manufacturer-recommended rates for this formulation.

Soil Cover Protection

Dozens, if not hundreds, of types of soil cover materials have been used for controlling erosion. Some of these are exclusive to specific land uses, such as stubble mulches in agricultural fields (Freebairn et al. 1986, Tibke 1988), that have little applicability to road-related soil disturbances. Consequently, the types of soil covers that are reviewed here emphasize techniques that have been used in forest road settings or have application to forested hillsides where roads may be constructed.

The major types of soil cover applicable to roads fall into four categories (Table 18). Vegetation and nonorganic mulches generally are meant to provide long-term soil cover. Organic mulches and rolled erosion control products are designed to have short-term (e.g., several months) to moderate-term (several seasons to a few years) lifetimes. Organic mulches and rolled erosion control products typically are used in conjunction with vegetative seeding, as these products are designed to allow vegetation to grow through them as they biodegrade or photodegrade. A few types of rolled erosion control products, such as plastic sheeting, are not biodegradable, but these rarely have utility in forest applications off the road surface. Inorganic mulches are nonbiodegradable, though some types may be photodegradable or thermo-degradable (e.g., plastics) over relatively long time periods. Inorganic mulches are designed to stabilize soil by physically keeping it in place, and revegetation typically is not an objective; it may even be an undesirable outcome with their use. However, inorganic mulches are not always incompatible with revegetation. Meyer et al. (1972) observed very good grass establishment with stone mulch, and it exceeded revegetation with wood chips, which seemed to have negatively affected the carbon/nitrogen ratio of the soil.

From the perspective of erosion control there is one primary objective common to all soil cover materials—preventing or reducing raindrop impact. Raindrop energy has been shown to be the most important process by which soil particle detachment occurs (Young and Wiersma 1973); it exceeds detachment even by concentrated flow. This is because of the great amount of energy that raindrops transfer to the soil (Berglund 1976). For example, a 30-minute thunderstorm in the Midwest is capable of resulting in an impact of cumulative dead weight of more than 100 ton ac^{-1} and expending >2,000,000 ft-lb ac^{-1} (Wischmeier and Smith 1958). Hudson (1957) demonstrated the importance of controlling raindrop impact by covering a plot of exposed soil with mosquito gauze. The gauze absorbed the raindrop energy, yet allowed most of the rain water to reach the soil surface. Soil loss from the gauze-protected plot was 127 times less and runoff was 13 times less than from a paired unprotected, bare soil plot. In laboratory studies, reducing raindrop energy by 89 percent resulted in nearly equivalent reductions (90 to 94 percent) in

Table 18.—Types of soil covers generally applicable to disturbed soils off the driving surface

Type of soil cover	Examples
Vegetation	Grasses and herbaceous plants primarily through seeding, tree seedlings less commonly
Organic mulches	Wheat straw, rice straw, barley straw, hay, other agricultural plant residues, wood chips, wood strips, sawdust, needles/leaves, fruit hulls, tree bark, shredded paper/cellulose
Inorganic mulches	Crushed or washed stone, geologic waste materials, shredded/recycled rubber or plastic materials
Rolled erosion control products	Excelsior blankets, jute netting, coir mats, and other types of erosion control mats or blankets; geocells; and various types of synthetic sheets, filaments, and meshes

total soil loss from three soils, whereas eliminating rills (and therefore rill erosion) resulted in only 17- to 37-percent reductions in erosion (Young and Wiersma 1973). Controlling raindrop impact reduces soil particle dislodgement, and associated compaction and sealing of the soil surface, which help reduce surface runoff and associated erosion (Bhatt and Khera 2006, Elwell and Stocking 1976, Lattanzi et al. 1974, Meyer and Mannering 1963, Moss 1991, Quinton et al. 1997, Young and Wiersma 1973).

An additional benefit common to many soil cover materials is that they provide roughness at the soil surface (Berglund 1976, Bhatt and Khera 2006) and sometimes tortuosity (Meyer et al. 1970). Surface roughness and tortuosity slow the movement of interrill and rill runoff and dissipate its energy, further contributing to erosion control (Lattanzi et al. 1974). With organic soil covers, decaying material also returns organic matter to the soil, which improves soil structure, forms stronger soil aggregates, and maintains high soil infiltration capacities—all of which decrease erosion (Baver 1956, Berglund 1976, Bhattacharyya et al. 2007, Loch 2000, Tengbeh 1993, Traoré et al. 2000). In 44 agricultural soils, organic matter content was the most important variable for explaining infiltration and controlling runoff (Wischmeier and Mannering 1965). A variety of soil cover materials improve growing conditions by providing shade that reduces soil surface temperatures, conserves moisture, and encourages fast vegetative growth (Berglund 1976, Bhatt and Khera 2006, McKee et al. 1964, Sheldon and Bradshaw 1977). However, some soil cover materials can increase the temperature at the soil surface (Anderson et al. 1996, Benoit et al. 1986), which can improve or degrade growing conditions, depending upon other variables, such as available moisture (Barkley et al. 1965, Dudeck et al. 1970) and time of year (Benoit et al. 1986, Kohnke and Werkhoven 1963).

The belowground biological processes that plants carry out provide additional benefits that are not available from other types of soil cover. Root growth improves soil structure and maintains high soil permeability, thereby reducing runoff and interrill and rill erosion (Baver 1956, Elwell and Stocking 1976). Plant roots also hold soil in place physically due to the presence of fibrous roots and chemically by binding soil particles with root exudates

(De Baets et al. 2006, Gyssels and Poesen 2003, Tengbeh 1993, Traoré et al. 2000). Tengbeh (1993) found soil shear strength (binding between roots and soil) in soil containing fibrous grass roots was at least 500 percent greater than that of bare soil. While aboveground vegetation provides protection against raindrop splash and interrill erosion, roots are at least equally important in controlling rill and gully erosion (Gyssels et al. 2005).

Effectiveness of Vegetation

Of all the types of soil cover used in rehabilitation and stabilization of disturbed soils that are associated with forest roads, the most common is revegetation through seeding of grasses and herbaceous species. Except when expensive native seed mixtures are used to revegetate, seeding is the most cost-effective measure to provide soil cover and erosion control (Miles et al. 1989, Robichaud 2005). Established vegetation (e.g., tree seedlings) can be planted (Megahan 1974a), but tree planting is usually inappropriate for road prism rehabilitation. It is preferable to keep tall vegetation away from the road to maximize visibility for safety and to provide light during the day to reduce moisture and control rutting on the road surface (see Chapter 3).

Unlike soil cover techniques that provide immediate protection, soil erosion control from seeding is ineffective until vegetation becomes sufficiently established. During the initial period of vegetation establishment, soil losses from seeded and untreated, bare soil can be comparable, both in amounts and patterns of loss. For example, Bethlahmy and Kidd (1966) measured nearly similar amounts of soil produced from untreated (no soil cover) and seed + fertilized plots (Table 19). Most of the soil losses occurred during the first 100 days, but they declined exponentially (Fig. 8). Similar exponential declines in sediment yields from seeded and bare soils have been reported by others through the first growing season (e.g., Burroughs and King 1989, Dyrness 1975, Harrison 2011, Megahan et al. 2001, Orr 1970, Wade 2010), and even over periods as short as a week (Burroughs et al. 1984c). This exponential pattern of sediment losses is common when no initial soil cover is available because large amounts of loosened soil from ground disturbance

Table 19.—Results from select erosion studies

Reference	Treatment	Soil loss, as specified	Duration	Field plot/ Simulation
		Average (*ton ac⁻¹*)		
Barnett et al. (1967)	Bare soil	96.57	2 simulated storm events: (1) 1.3 inches of rain in 30 min (2) 2.7 inches in 60 min	Field (highway construction site)
	Checkered dams (mulch punched into soil)	44.48		
	Surface mulch and asphalt	31.54		
	Mulch mixed in surface	27.14		
	Mulch mixed in surface + asphalt	27.59		
	Whisker dams (mulch pressed into soil)	9.88		
	Surface mulch	11.20		
		Average (of maximum and minimum sediment yields per event) (*kg ha⁻¹*)		
Benik et al. (2003)	Disc-anchored straw mulch	108	5 single storm events	Field (hillslope of a sedimentation basin at a highway construction site)
		99		
		54		
		2,125		
		732		
	Straw blanket	16		
		10		
		9		
		103		
		79		
	Straw/coconut blanket	18		
		17		
		7		
		228		
		179		
	Wood fiber blanket	29		
		15		
		19		
		258		
		157		
	Bare treatment	763		
		788		
		189		
		5,438		
		4,296		

(continued)

Table 19.—Results from select erosion studies

Reference	Treatment	Soil loss, as specified		Duration	Field plot/ Simulation
		Total (*1,000 lb ac⁻¹*)			
Bethlahmy and Kidd (1996)	Control	84.2		322 days, 20.40 inches of precipitation	Field (newly constructed road fillslope)
	Seed, fertilizer (2 plots)	104.7			
		89.4			
	Seed, fertilizer, straw mulch				
	Contour furrows, seed, straw mulch, fertilizer, holes	11.9			
	Seed, fertilizer, straw mulch with asphalt emulsion	36.0			
	Seed, fertilizer, straw mulch, netting				
	Paper netting	1.1			
	Jute netting	0			
	Chicken-wire netting	0.4			
		Average (of total sediment yield for two plots) (*g*)			
Bhattacharyya et al. (2008) (see also Bhattacharyya et al. 2007)	Bare	85.79		March 25, 2002– May 10, 2004	Field (hillslope)
	Grass	13.04			
	Buffer (of borassus mats)	37.16			
	Covered (completely by borassus mats)	31.22			
		Average eroded solids (3 plots) (*kg*)			
Buchanan et al. (2002)	Control (bare)	3.90		8 storm events over 130 days	Field (steep construction slope; 55%)
	Small wood chips (6.4–13 mm)	3.03			
	Mixture of wood chip sizes (13–25 mm)	0.53			
	Large wood chips (>25 mm)	0.86			
		Average (*lbs 1,000 ft⁻²*)			
Burroughs et al. (1984c)	Bare soil (2 plots)	116.72	(4 reps)	Simulated rainfall for 23–30 min, rate ~2 inches h⁻¹	Field (road fillslope)
		210.65	(1 rep)		
	Vegetated (2 plots)	0.52	(4 reps)		
		1.14	(3 reps)		
	Curlex mulch (1 plot)	10.50	(4 reps)		
	Filter windrow (1 plot)	15.33	(4 reps)		
		Cumulative averages (*cm*) (+ indicates soil accumulation)			
Carr and Ballard (1980)	Hydroseed + fertilizer + binder	+ 1.1		7 months	Field (forest roadside slopes)
	Hydroseed + fertilizer + binder + mulch	+ 1.3			
	Control	2.3			

(continued)

Table 19.—Results from select erosion studies

Reference	Treatment	Soil loss, as specified	Duration	Field plot/ Simulation
		Total ($g\ m^{-2}$)		
Döring et al. (2005)	Control (bare soil)	1,606	1 h simulated rainfall with total amount of 73 mm	Field (agricultural; 8% slope)
	Chopped winter wheat straw (mean length 58 mm)			
	1.25 tonne ha^{-1}	31		
	2.5 tonne ha^{-1}	42		
	5 tonne ha^{-1}	26		
	Unchopped winter wheat straw (avg. length 75 mm; 25% of pieces exceeding 100 mm length)			
	2.5 tonne ha^{-1}	133		
		Cumulative averages (*inches*) (+ indicates soil accumulation)		
Dyrness (1970) (see also Dyrness 1975)	Control	0.83	1 yr following construction	Field (forest road cutslopes)
		0.84		
	Mulch (wheat straw mulch, 2 ton ac^{-1})	+ 0.05	2 replicates	
		0.07		
	Blue River District mixture (25 lb ac^{-1}, no mulch)	0.77		
		0.31		
	Oregon highway mixture (40 lb ac^{-1} with straw mulch 2 ton ac^{-1})	0.20		
		0.23		
	Experimental mixture 1 (43 lb ac^{-1} with straw mulch 2 ton ac^{-1})	0.65		
		+ 0.17		
	Experimental mixture 2 (43 lb ac^{-1} with straw mulch 2 ton ac^{-1})	0.07		
		+ 0.11		
		Average (*kg*)		
Foltz and Dooley (2003)	Bare		3 simulated repetitions: (1) rainfall only (2) rainfall + 1st inflow (3) rainfall + 2nd inflow	Simulation (30% slope)
	Rainfall only	2.0		
	Rainfall + 1st inflow	4.2		
	Rainfall + 2nd inflow	29.4		
	Straw mulch ("agricultural straw")			
	Rainfall only	0		
	Rainfall + 1st inflow	0.03		
	Rainfall + 2nd inflow	0.53		
	Wide wood strand (16 mm wide)			
	Rainfall only	0		
	Rainfall + 1st inflow	0		
	Rainfall + 2nd inflow	0.39		
	Narrow wood strand (4 mm wide)			
	Rainfall only	0		
	Rainfall + 1st inflow	0.20		
	Rainfall + 2nd inflow	0.61		

(continued)

Table 19.—Results from select erosion studies

Reference	Treatment	Soil loss, as specified	Duration	Field plot/ Simulation
		Average (*kg*)		
Grace et al. (1996) (see also Grace et al. 1998)	Bare (control)		6-month study period	Field
	Cutslope	24,769	3 replications for each	(forest roads)
	Fillslope	20,204	treatment (i.e., 3 cutslope, 3 fillslope)	
	Erosion mat (wood excelsior)			
	Cutslope	345		
	Fillslope	2,358		
	Native grass (11.23 kg ha^{-1})			
	Cutslope	8,352		
	Fillslope	3,866		
	Exotic grass (11.23–28.07 kg ha^{-1})			
	Cutslope	1,742		
	Fillslope	2,669		
		Average (*g m^{-2}*)		
Grushecky et al. (2009)	Control		2 yr	Field
	Year 1	174.3		(downslope terminus of sections of newly constructed skid roads; average slope 18%)
	Year 2	615.5		
	Fiber mat			
	Year 1	34.8		
	Year 2	62.3		
		Terminal erosion rate (*kg ha^{-1} s^{-1}*)		
Jennings and Jarrett (1985)	Fallow soil	4.32	1 10-min simulated rainfall	Simulation
	Straw (2.24 Mg ha^{-1}, 35% coverage)	1.75		
	Straw (8.96 Mg ha^{-1}, 98% coverage)	0.27		
	Small bark (22.4 Mg ha^{-1}, 85% coverage)	0.78		
	Large bark (22.4 Mg ha^{-1}, 40% coverage)	1.89		
	Large bark (56 Mg ha^{-1}, 98% coverage)	0.54		
	Jute net (1 layer, 50% coverage)	0.42		
	Burlap (1 layer, 60% coverage)	0.83		
	5-mm-wide cellulose with netting (1 layer, 50% coverage)	1.61		
	Small rocks (10 mm thick, 30 mm diameter, 212 Mg ha^{-1}, 80% coverage)	2.10		
	Large rocks (25 mm thick, 100 mm diameter, 506 Mg ha^{-1}, 70% coverage)	1.38		

(continued)

Table 19.—Results from select erosion studies

Reference	Treatment	Soil loss, as specified	Duration	Field plot/ Simulation
		Average (*ton ac^{-1}*)		
Kill and Foote (1971)	Straw + an asphalt emulsion tack	19.3	About 1 month (3.7 inches of precipitation) 5 replicates	Field (highway roadside)
	Short-fibered wood pulp mulch (paper pulp)	59.3		
	Short-fibered wood pulp mulch (whole pulp bolt)	62.5		
	Short-fibered wood pulp mulch (using Douglas-fir)	40.4		
	Long-fiber green wood excelsior fiber	15.3		
		Average erosion rate (*kg min^{-1} m^{-1}*)		
Kramer and Meyer (1969)	Simulated straw mulch, 4% slope		30 min 2 replicates	Simulation (100 ft length)
	Control	0.35		
	0.125 ton ac^{-1}	0.32		
	0.5 ton ac^{-1}	0.16		
	Simulated straw mulch, 10% slope			
	Control	17.53		
	0.125 ton ac^{-1}	12.26		
	0.5 ton ac^{-1}	11.41		
		Average (*g m^{-2}*)		
Lattanzi et al. (1974)	Wheat straw mulch, 2% slope		60 min 2 replicates	Simulation (0.37 m²)
	Control	951		
	0.5 tonne ha^{-1}	602		
	2 tonne ha^{-1}	244		
	8 tonne ha^{-1}	7		
	Wheat straw mulch, 20% slope			
	Control	2,142		
	0.5 tonne ha^{-1}	1,246		
	2 tonne ha^{-1}	485		
	8 tonne ha^{-1}	2		
		Total (*tonne ha^{-1}*)		
Lekha (2004)	Control	151.1	1 yr	Field (hillslope)
	Coir net geotextile	7.75		
		Average at peak discharge (*mg L^{-1}*)		
Lemly (1982)	Low-intensity rainfall event (1.5 cm h^{-1})		60 min	Field (highway cutslopes; 30% slope)
	Control	118		
	Tacked straw	48		
	Jute netting	40		
	Mulch blanket	26		
	Wood chips	22		
	Excelsior blanket	21		

(continued)

Table 19.—Results from select erosion studies

Reference	Treatment	Soil loss, as specified	Duration	Field plot/ Simulation
	High-intensity rainfall event (4 cm h^{-1})		20 min	
	Control	720		
	Tacked straw	507		
	Jute netting	489		
	Mulch blanket	316		
	Wood chips	308		
	Excelsior blanket	300		
	Total (*ton ac^{-1}*)			
Mannering and Meyer (1963)	Wheat straw mulch		Simulated storm events over 3 days with a total of 6.25 inches of precipitation	Field (agricultural; 5% slope)
	0 (control) ton ac^{-1}	12.42		
	0.25 ton ac^{-1}	3.23		
	0.5 ton ac^{-1}	1.42		
	1 ton ac^{-1}	0.30		
	2 ton ac^{-1}	0		
	4 ton ac^{-1}	0		
	Average annual erosion (*ton mi^{-2} day^{-1}*)			
Megahan (1974a, estimated from Fig. 8 of that paper)	Control		3 yr	Field (road fillslopes)
	1970	11.6		
	1971	3.4		
	1972	14.5		
	Trees without mulch			
	1970	6.1		
	1971	2.4		
	1972	7.2		
	Straw mulch with netting			
	1970	0.3		
	1971	0.2		
	1972	1.1		
	Average (*tonne ha^{-1} yr^{-1}*)			
Megahan et al. (2001)	Control	16.4	4 yr	Field (road cutslopes)
	Dry seed alluvial soil	1.7		
	Hydroseed + mulch	7.1		
	Dry seed shallow soil + bedrock	7.8		
	Terrace + hydroseed + mulch	9.8		
	Total soil loss (*ton ac^{-1}*)			
Meyer et al. (1970)	Wheat straw mulch applied		3 simulated storm events over 2 days	Field (agricultural; 15% slope)
	0 (control) ton ac^{-1}	27.8		
	0.25 ton ac^{-1}	9.0		
	0.5 ton ac^{-1}	8.7		
	1 ton ac^{-1}	5.1		
	2 ton ac^{-1}	1.1		
	4 ton ac^{-1}	0.7		

(continued)

Table 19.—Results from select erosion studies

Reference	Treatment	Soil loss, as specified	Duration	Field plot/ Simulation
		Total (*ton ac⁻¹*)		
Meyer et al. (1972)	No mulch (control)	39.6	5 inches of simulated rain, at an intensity of 2.5 inches h⁻¹	Field (side slope of a borrow pit that had been dug during highway construction; 20% slope steepness; 35 ft slope length)
	Straw (wheat straw mulch, chopper-blower, 2.3 ton ac⁻¹)	12.1		
	Stone (crushed limestone ranging from 0.25 to 1.5 inches diameter)			
	15 ton ac⁻¹	25.6		
	60 ton ac⁻¹	11.4		
	135 ton ac⁻¹	3.5		
	240 ton ac⁻¹	<2		
	375 ton ac⁻¹	<2		
	Gravel (washed road gravel ranging from 0.25 to 1.5 inches diameter)			
	70 ton ac⁻¹	14.7		
	Wood chips			
	2 ton ac⁻¹	27.1		
	4 ton ac⁻¹	8.5		
	7 ton ac⁻¹	5.5		
	12 ton ac⁻¹	<2		
	25 ton ac⁻¹	<2		
	Portland cement	32.7		
		Average erosion rate (*tonne ha⁻¹*)		
Mitchell et al. (2003)	Geotextile net	0.08	April 10, 1995– April 15, 1996 (446 mm precipitation)	Field (hillslope)
	Geotextile mat	0.09		
	Grass	3.45		
	Bare soil	7.47		
		Average (*g*)		
Rickson (2006)	RECP 'Geojute'	29	10 min 3 replicates	Simulation
	RECP 'Geojute' fine	30		
	RECP 'Enviromat'	149		
	RECP 'Enkamat' surface laid	133		
	RECP 'Enkamat' buried	100		
	RECP 'Tensarmat'	167		
	RECP 'Bachbettgwebe'	68		
	Control	197		
Robichaud et al. (2010)	Various mulch treatment effectiveness results in Appendix C of cited paper			Field (hillslopes; primarily wildfire-burned areas)

(continued)

Table 19.—Results from select erosion studies

Reference	Treatment	Soil loss, as specified	Duration	Field plot/ Simulation
		Average ($kg\ ha^{-1}$)		
Robichaud et al. (2013)	Control		2 yr	Field (hillslope)
	Year 0 (postfire)	697		
	Year 1	104		
	Year 2	5.2		
	Straw mulch			
	Year 0 (postfire)	60		
	Year 1	22		
	Year 2	1.3		
	Wood shred mulch			
	Year 0 (postfire)	77		
	Year 1	29		
	Year 2	2.0		
		Average total (3 sites) ($kg\ day^{-1}\ ha^{-1}$)		
Rothwell (1983)	Unmulched (control)	6,033	4 months	Field (stream crossings)
	Mulched (brush mulch/logging debris)	1,033		
		Average erosion rate ($g\ m^{-2}\ h^{-1}\ mm\ precip^{-1}$)		
Sutherland and Ziegler (1997)	RECP 'Futerra'	0.93	Simulated rainfall events over 6 wk	Field (hillslope)
	RECP 'C125'	2.10		
	RECP 'Curlex I'	5.05		
	RECP 'P300'	5.12		
	RECP 'TerraJute'	7.86		
	RECP 'Geojute'	9.98		
	RECP 'SC150BN'	10.77		
	RECP 'BioD-Mat 70'	16.02		
	RECP 'BioD-Mat 40'	33.70		
	RECP 'PEC-MAT'	41.16		
	Control (bare)	134.90		
		Average ($Mg\ ha^{-1}\ yr^{-1}$)		
Wade (2010)	Control	137.7	May 2009–July 2010	Field (skid trails)
	Seed (grass seed, 300 kg ha⁻¹)	31.5		
	Hardwood slash	8.9		
	Pine slash	5.9		
	Straw mulch	3.0		

(continued)

Table 19.—Results from select erosion studies

Reference	Treatment	Soil loss, as specified	Duration	Field plot/ Simulation
		Average annual ($Mg\ ha^{-1}\ yr^{-1}$)		
Wagenbrenner et al. (2006)	Control		4 yr	Field (hillslope)
	2000 (8 plots)	>6.2		
	2001 (12 plots)	>9.5		
	2002 (12 plots)	1.2		
	2003 (12 plots)	0.7		
	Seeding (grass seeding, 34 kg ha^{-1})			
	2000 (1 plots)	>3.9		
	2001 (4 plots)	12.0		
	2002 (4 plots)	1.2		
	2003 (4 plots)	0.3		
	"Old"[a] mulch (weed-free wheat straw)			
	2000 (3 plots)	8.8		
	2001 (4 plots)	0.5		
	2002 (4 plots)	0.02		
	2003 (4 plots)	0.001		
	"New"[a] mulch (weed-free wheat straw)			
	2000 (0 plots)	---		
	2001 (3 plots)	0.02		
	2002 (3 plots)	0.006		
	2003 (3 plots)	0.000		
	"Old"[a] contour felling			
	2000 (4 plots)	>5.8		
	2001 (4 plots)	>5.7		
	2002 (4 plots)	0.03		
	2003 (4 plots)	0.02		
	"New"[a] contour felling			
	2000 (0 plots)	---		
	2001 (7 plots)	2.8		
	2002 (7 plots)	0.2		
	2003 (7 plots)	0.07		
		Annual accumulation ($ton\ ac^{-1}$)		
Wollum (1962)	Bare (control)		3 yr	Field (road cutbank)
	Year 1	12.7		
	Grassed			
	Year 2	4.2		
	Year 3	2.3		

[a]The terms "old" and "new" in this case refer to pre- and post-storm, which occurred Aug. 16, 2000. Plots installed before that date are referred to as "old" and after that date as "new."
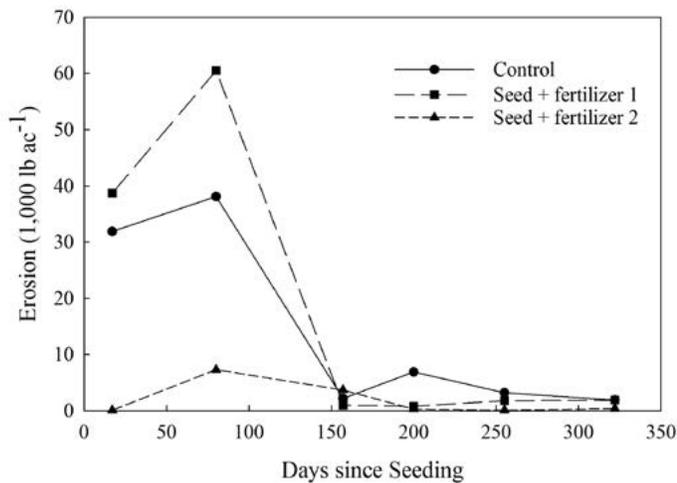
Figure 8.—Soil erosion loads measured from plots on a steep road fillslope in Idaho. The control plot (●) was untreated. One plot (■) was contour furrowed before grass seeding and fertilizing. One plot (▲) was treated with a soil emulsion before and after grass seeding and fertilizing. Data are from Bethlahmy and Kidd (1966).

Figure 9.—Erosion loads from the temporal data shown in Figure 8 expressed as cumulative erosion rates.

are easily displaced by gravity and water (and wind in some situations). Once fines are eroded away, coarser materials are left behind at the soil surface (Megahan 1974b, Ollesch and Vacca 2002) because these are more resistant to displacement and transport (Hairsine and Rose 1992). This is often referred to as "armoring" or creation of an erosion pavement (Megahan 1974b).

As vegetation begins to become established, differences in soil losses between unseeded (and otherwise unprotected) and seeded soil become apparent. Erosion from bare soil continues to increase for a longer time than from seeded soil, so sediment yields typically take longer to reach the "minimum" constant values shown in Figure 8. This difference is illustrated by using the same data graphed in Figure 8 but by plotting them as percent cumulative erosion over time (Fig. 9). About 95 percent of total erosion occurred within the first 100 days on the seeded plots, but cumulative erosion did not reach 95 percent for another ~150 days, approximately day 255, on the unseeded plots (Bethlahmy and Kidd 1966). Grace (2002a) reported substantial cumulative increases in erosion until about day 700 from unseeded/unprotected fillslopes and from 900 to 1,000 days on unseeded/unprotected cutbanks.

The greatest benefits from revegetation occur over the long term because erosion can be returned to approximately pre-disturbance levels (Burroughs et

al. 1984c). Four years after grass planting on roadside slopes, Grace (2002a) found erosion was at only 0.05 tonne ha^{-1} yr^{-1}, compared to an unseeded control, which continued to have erosion rates that were 80 times greater (4 tonne ha^{-1} yr^{-1}). Cycles of elevated erosion can continue, and may become more chronic for bare soil or soil that has had poor revegetation success. For example, following an exponential decline in erosion (similar to that found in Figure 8) during the first summer of soil disturbance on unseeded plots, Wade (2010) found high erosion rates (10 tonne ha^{-1}) were reinitiated in spring, whereas plots that had been seeded and revegetated that same summer had only small erosion increases during the subsequent winter and spring (2 tonne ha^{-1}). The reinitiation of soil erosion is attributable to freeze/thaw and wet/dry cycles in winter or spring (or other wet seasons), which loosen soil particles and make them available for erosion (Diseker and McGinnis 1967, Hipps et al. 1990, Putthacharoen et al. 1998, Römkens and Wang 1987, Shiel et al. 1988, Tisdall et al. 1978, Vandaele and Poesen 1995). In the presence of vegetation, the amount of soil that is loosened is less, and much of it is trapped by aboveground plant parts, so it is not lost to erosion (Berglund 1976). Carr and Ballard (1980) found net sediment accumulations resulting from vegetation on fillslopes and cutbanks in British Columbia.

A central question about the influence of vegetation is: "How much vegetative cover is necessary to protect soil?" This question has been examined from the perspective of both erosion and runoff, as sediment loss cannot occur without both detachment and transport. However, research on both variables has resulted in similar answers. Almost universally, vegetative cover in the range of about 50 to 75 percent is required to effectively control runoff or erosion, or both (Gifford 1985, Gutierrez and Hernandez 1996, Lang 1979, Loch 2000, Moreno-de las Heras et al. 2009, Orr 1970, Packer 1951, Quinton et al. 1997, Snelder and Bryan 1995), though erosion control often is achieved on the lower end of that range. If litter is present (i.e., on soil not newly disturbed), it also contributes to ground cover, so the 50- to 75-percent cover range may include vegetation plus litter, rather than just vegetation (e.g., Gifford 1985, Orr 1970, Pannkuk and Robichaud 2003, Robichaud et al. 2000). Generally the cover in these studies has been provided by low-growing plants, such as grasses, herbs, shrubs, or even agricultural plants, but from the perspective of erosion control the species present have been far less important than the total amount of ground cover (Gifford 1985, Grace 2002a, Packer 1951). Even on a landscape scale, restoration of ground cover or revegetation of forest trees to a level of about 75 percent has resulted in restoration of erosion rates to levels similar to those before large area disturbance or land conversion (Bailey and Copeland 1961, Vanacker et al. 2007).

Considering that different studies involved different types of soil (e.g., texture and structure, bulk density, antecedent moisture conditions), different experimental settings (e.g., field versus laboratory, slope, size of plot, vegetative species), and different precipitation characteristics (e.g., frequency, intensity, duration, quantity, simulated versus actual rain events), the cover percentages that have been found to keep erosion low are in good agreement. Even gully erosion has been shown to be stopped with a vegetative cover of just over 50 percent (Rey 2003). Heavy fern growth (near 100-percent cover) in a rill in South China also was successful at reducing erosion by an order of magnitude during a single monitored storm compared to a rill with no vegetation due to the greater roughness, higher infiltration, and greater shear strength of soil in the vegetated rill (Woo et al. 1997). However, the effectiveness of vegetation at controlling rill and gully erosion may depend upon the source of concentrated flow, the frequency of flow, and discharge levels. Grasses and herbaceous plants typically are not well suited for controlling erosion via concentrated flow from road drainage features that can carry large amounts of water on a frequent recurring basis (see Chapter 7 for further discussion).

Just as higher percentages of ground cover show good erosion control, ground cover below 30 to 40 percent shows consistently poor erosion control. Ground cover less than 30 percent (including litter) on grazed lands in Rhodesia was associated with much greater soil losses than denser ground cover (Elwell and Stocking 1974, 1976). After a wildfire, cover of 39 percent on forested hillsides with slopes averaging about 15 percent had erosion rates that were similar to hillsides with no remaining cover (Groen and Woods 2008). In northern Mexico, mean sediment concentrations were significantly higher where grass cover was less than 30 percent than where cover was greater than 60 percent during the growing season (Gutierrez and Hernandez 1996). Grass cover of only 35 percent in the Lake Tahoe Basin along the border of California and Nevada was not effective at controlling erosion (Grismer and Hogan 2005). The increases in erosion that are associated with less-dense vegetation apparently occur when individual bare areas begin to come in contact with one another and allow unimpeded runoff to occur (Lang 1979).

There is broad agreement in the literature from research studies across many land types and ecosystems showing that vegetation provides a high degree of protection against soil erosion when coverage is adequate (Descheemaeker et al. 2006, Elwell and Stocking 1976, Gutierrez and Hernandez 1996, Lang 1979, Loch 2000, Moreno-de las Heras et al. 2009, Quinton et al. 1997, Rey 2003). At almost any scale, the importance of vegetation to erosion control cannot be overstated (Tibke 1988). This is particularly true in the long term as vegetation is usually self-sustaining if not subjected to extreme disturbances, which makes it extremely cost-effective.

Ironically, despite vegetation's effectiveness as a long-term approach, additional techniques are needed to control erosion in the short term immediately after seeding; otherwise erosion will not be appreciably

different than from bare soil (e.g., Fig. 8). This is the period for which most mulches and rolled erosion control products are designed (Ingold and Thomson 1986, Rickson 2006, Smets et al. 2008).

Effectiveness of Mulch

A large variety of mulches have been tested for use, but in most applied field applications, the type of mulch that is used depends chiefly upon availability, cost, and the land use to which it is applied (Morgan and Rickson 1995). Grain and hay mulches are the most common mulches used where revegetation is the goal. Grain mulches can be derived from many plant species including oats (*Avena* spp.), rice (*Oryza* spp.), or barley (*Hordeum* spp.) (Jennings and Jarrett 1985, Robichaud 2005), but wheat (*Triticum* spp.) straw probably has been the dominant type for road applications (Foltz and Dooley 2003). Rice straw is being used increasingly because it is believed that its use will result in the spread of fewer invasive weed species. This is because rice straw is a wetland plant, so if the straw is used in areas away from water bodies and hydric soils, rice seeds and any associated weed seeds that also presumably require those wet conditions will not be able to survive (Beyers 2004). In contrast, hay is a mixture of all the plant species present in the field during cutting; consequently, it can contain much greater amounts of weed seeds than straw mulch (Cornell University Weed Ecology and Management Laboratory, n.d.). Old straw has been shown to be less effective at controlling erosion than new straw (Grismer and Hogan 2005), presumably because decay has already begun.

Other types of commonly tested mulches associated with forest roads include wood mulches (bark chips, wood strands, wood shreds, pulp wastes) and stone or rock. Because these are free of weed seeds, there has been some interest in shifting more toward some of these types of mulches (e.g., wood materials) and away from straws and hay (Yanosek et al. 2006). Many kinds of these mulches are available, but most of the available varieties are used for landscaping purposes. Therefore, large-scale erosion control with them has been fairly uncommon and limited to only a few major types. Asphalt emulsions alone or as tackifiers mixed with some types of mulches, and cement (Dudeck et al. 1967, 1970; King 1979, 1984; McKee et al. 1964; Meyer et

al. 1972) also have been used as mulches, though these are expensive, and result in inconsistent erosion control compared to many other types of mulches (Table 19). Asphalt also can have a negative effect on vegetation establishment (Dudeck et al. 1970), which can be long-lasting, so little current research involves asphalt tackifiers.

All types of mulches have been shown to provide better erosion control than leaving the soil bare (Table 19). Even small applications of mulch measurably reduce soil losses (Mannering and Meyer 1963, Meyer et al. 1970). Mulch provides soil cover, so it is not surprising that most types of mulch typically are most effective in the same soil coverage ranges as vegetation (50 to 75 percent) (Foltz and Copeland 2009, Foltz and Wagenbrenner 2010). Additional soil coverage results in diminishing rates of erosion control. Given the propensity for rill formation on poorly protected soils, mulch applied more evenly across the entire area of exposed soil provides more effective erosion control than mulch applied in strips along the contour or along the lower one-third of plots (Bhatt and Khera 2006). However, other variables also come into play in determining its effectiveness, especially beyond the short term. These variables include the type and character of mulch used, slope steepness and length, soil texture, and pattern of application to the soil (Bhatt and Khera 2006, Foltz and Copeland 2009).

The type and characteristics of a mulch determine its shape, size, weight, and ability to absorb moisture. These characteristics influence its coverage (per unit weight), its ability to remain in place, and its ability to deter runoff, particularly rill flow. Chopped and unchopped straw provide a good example of how the shape and size of straw affect its coverage. About twice as much unchopped (long) straw was needed to achieve 90-percent soil cover as chopped straw (4.43 tonne ha^{-1} versus 2.16 tonne ha^{-1}) (Döring et al. 2005). Straw loses its structural integrity and tends to split longitudinally when chopped into shorter-length pieces; consequently, chopped straw approximately doubles its effective coverage for a given weight of material compared to whole, long straw. Similarly, a much greater mass of large wood chips (16.54 tonne ha^{-1}) was needed to achieve 80-percent soil cover than mixed-sized chips (10.25 tonne ha^{-1}), whereas only a comparatively small

mass of small wood chips (3.31 tonne ha^{-1}) was needed for the same coverage (Buchanan et al. 2002).

Short-length or small-sized materials also can provide other benefits toward controlling erosion. Döring et al. (2005) found two classes of chopped straw (50 mm long and <35 mm long) reduced soil losses by 97.4 to 98.4 percent compared to untreated soil. Straw that was an average 75 mm long but included pieces >100 mm long reduced soil losses by 91.7 percent. Shorter pieces of mulch were more effective at filling the spaces between soil ridges and contacting the soil in the valleys. Chopped straw pieces also fitted more tightly into gaps between pieces of mulch, allowing a smoother, flat mat to be created that was not attainable with the longer pieces of straw (Döring et al. 2005). Long pieces of mulch tend to bridge across the ridges, leaving the soil underneath more susceptible to rill erosion (Döring et al. 2005, Foltz and Dooley 2003, Meyer et al. 1972). However, 6.5-inch-long ponderosa pine (*Pinus ponderosa*) needles were more able to weave together to form mini-dams and retard rill development than 1-inch-long Douglas-fir (*Pseudotsuga menziesii*) needles, though the latter had better overall soil contact and controlled interrill erosion (Pannkuk and Robichaud 2003). Similar mini-dams were formed by 60- and 120-mm-long wood strands, but not by 240-mm strands (Foltz and Dooley 2003). Thus, size, shape, flexibility, and strength all have a role in determining the effectiveness of a given type of mulch.

It should be noted that these studies were very short-term and performed in controlled conditions. Under ambient field conditions or in the long term, small-sized, lightweight mulch may exhibit erosion control rates that are much less than those in the studies cited earlier. This is because short-length lightweight mulch, such as straw or wood, is susceptible to movement by water and wind (Barnett et al. 1967, Buchanan et al. 2002, Meyer et al. 1972). Dudeck et al. (1970) found short strand lengths of chopped mulch (wood excelsior) became detached and transported off steep slopes, making it ineffective at controlling erosion. Even long straw has been shown to be susceptible to movement on slopes with high precipitation inputs (Harding 1988). The presence of relatively high percentages of lightweight fines in wood shreds was a dominant factor in undermining erosion control effectiveness on 40-percent burned slopes (Foltz and Wagenbrenner 2010). Wood shred blends containing

18 percent and 24 percent fines could not resist movement from concentrated flow and had poor erosion control. In contrast, when fines were limited to less than 2 percent, effective erosion control occurred with 50-percent cover. Likewise, mixed-sized (13- to 25-mm diameter) and large-sized (>25-mm diameter) wood chips provided superior erosion control on a 55-percent slope compared to small-sized chips (6.4- to 13-mm diameter) because the small-sized chips moved during natural rain events over 130 days (Buchanan et al. 2002; Table 19). After only three rain events, there was a reduction in soil cover from an original 80-percent cover to 37 percent for the small-sized chips, with only 10-percent and 5-percent reductions for the mixed-sized and large-sized chips, respectively. Most of the change in coverage for small-sized chips occurred in the bottom two-thirds of the 11.4-m-long slopes, whereas for the other two size classes, the average reduction in cover along the entire plot length never exceeded 10 percent. If mulch does not retain the level of soil cover that was intended due to mobilization, erosion control effectiveness can be reduced significantly over any timeframe.

Another potential problem with using small-sized or short mulch is that it can become partially or fully buried as soil is detached and redistributed over time. Foltz and Dooley (2003) observed rapid burial of short straw to 10 mm into the soil. In the short term, burial may help protect the soil against rill formation by providing organic matter to bind soil particles and contributing to roughness near the soil surface. But as burial progresses and deepens, mulch protection at the soil surface may be sacrificed. Loss of erosion protection has been observed when mulch was intentionally mixed into the soil compared to when it was applied at the soil surface (Barnett et al. 1967).

For wood mulch, fiber length or the degree of processing apparently influences its effectiveness. In general, short fibers (more processed) decrease effectiveness. Three short-fiber wood pulp products applied by using a hydroseeder provided significantly poorer erosion control than a long-fiber excelsior product (blown product, not rolled) (Kill and Foote 1971; Table 19). Soil losses from short-fiber products were more than twice as high per unit area as from the excelsior product. Most of the difference in sediment yields was from rill erosion on the short-fiber treatment plots; more grass became established on the long-fiber plots, which also

contributed to controlling soil losses. Zellmer et al. (1991) also observed much greater soil losses from a processed wood fiber mulch than from straw mulches on a 28-percent-gradient pipeline right-of-way in Pennsylvania.

Paper mulches manufactured from wood pulps have a mixed record of effectiveness. Zellmer et al. (1991) found paper strips in netting performed comparably to straw mulch (Table 19), yet Swanson et al. (1967) found poor erosion control from Kraft paper netting on 3:1 (horizontal:vertical) construction slopes. Stedman (2008) did not measure erosion directly from mulched cutbanks, but he reported that hydroseeded cellulose mulch (small-sized shredded paper) provided essentially no soil cover because rainfall washed it off within a few days of application.

Stone and gravel are unlike most mulches in that they are heavy mineral materials. They are used less commonly than other mulches on road prisms off the driving surface, and their typical application is confined to drainage areas where flow is intentionally concentrated (see Chapter 7). However, stone and gravel mulches occasionally have been used more broadly, especially where a high risk of erosion is anticipated. In some instances, the natural occurrence of stones at the surface of some soils also has been exploited as a type of mulch to protect against raindrop impact, increase soil roughness, and decrease rill and interrill erosion (Poesen and Ingelmo-Sanchez 1992).

Stone and gravel have shown somewhat inconsistent results in controlling erosion compared to other types of more traditional mulches. Although rock fragment cover of at least 10 percent at the soil surface almost always reduces sediment yields compared to no soil cover (Poesen et al. 1994), the degree of effectiveness varies substantially. In some studies, stone and gravel have provided reasonable erosion control (Meyer et al. 1972), yet in others erosion control has been relatively poor (Jennings and Jarrett 1985) (Table 19). Based on reported observations, the inconsistencies apparently are related to whether the protection they provided to the soil was sufficient to control rill erosion. Because of its weight, stone can resist movement by surface runoff and rill formation. When stone cover rates exceeded 88 percent, runoff could not create rills even on a 20-percent slope,

so stone provided more effective erosion control than lighter, mobile wood chips (Meyer et al. 1972; Table 19). At lower percentages of soil cover (60 to 70 percent), rills were able to form among the stones, so erosion rates exceeded that of wood chips (Meyer et al. 1972). Jennings and Jarrett (1985) similarly found that on relatively flat ground with soil cover between 70 and 80 percent, organic mulch (straw and bark) had better erosion control than stone; they attribute these results to organic mulch's capacity to absorb and retain moisture, which reduced runoff and erosion (Jennings and Jarrett 1985; Table 19).

The control of interrill and rill erosion resulting from stone cover is a function of the scale at which they are examined, and should be considered when interpreting erosion control effectiveness. At microscale (4×10^{-6} to 1 m^2) and macroscale (10 to 10,000 m^2) plot levels, coarse fragments will reduce erosion (relative to no soil cover); however, at the mesoscale (0.01 to 100 m^2), coarse fragment cover can result in increases or decreases in erosion, depending upon the porosity of the surface soil (Poesen et al. 1994). If the soil surface is dominated by what Childs (1969) called structural porosity (i.e., it contains voids and pores characteristic of newly excavated or tilled material), coarse fragments on or slightly embedded into the soil surface will reduce runoff and erosion (Poesen et al. 1994) due to the high infiltration capacity of macropores at the surface.

In contrast, a soil with textural porosity (essentially a sealed surface [Childs 1969]) will have lower infiltration rates. Coarse fragments on the surface of these soils may allow some infiltration, but it will be reduced compared to soils with structural porosity, and there will be little infiltration with embedded coarse fragments (Poesen et al. 1994). Consequently, overland flow can develop, and without 100-percent cover, erosion can increase with increasing cover (Poesen et al. 1999). Interrill and possibly rill erosion will result as flows are channeled into narrower pathways between more densely spaced fragments, thereby increasing the velocity, depth, and energy of the runoff (Poesen and Ingelmo-Sanchez 1992, Poesen et al. 1999). Although larger-scale processes ultimately overwhelm processes at smaller scales (Poesen and Ingelmo-Sanchez 1992), the processes at smaller scales contribute to the final efficacy of stone cover, and it is hypothesized that

erosion increases at the mesoscale may help explain poorer erosion control seen in some studies (Poesen et al. 1994). This further suggests the importance of applying stone cover soon after soil disturbance so that structural porosity is maximized and soil sealing is minimized.

It would seem logical that the porosity of the soil surface also would affect the performance of other types of mulches and perhaps rolled erosion control products, but there are no similar investigations of this phenomenon in the literature for other soil cover products. It is possible in the moderate-to-long term that other types of mulches may be less prone to the effects of initial soil sealing. Less heavy materials may allow rapid re-creation of macropores after sealing through freeze/thaw and wet/dry cycles and through biological processes, such as the growth and extension of roots and churning by soil fauna.

The actual influence that scale has on erosion under mulched conditions is largely dependent upon whether erosion is dominated by interrill or rill erosion or a combination of both. Long plots present greater opportunity for severe rill or gully erosion to develop because of their length, and thus for greater overall erosion if mulch is insufficient to protect the soil (Snelder and Bryan 1995). King (1979) and Meyer et al. (1972) observed these outcomes. In contrast, when present in sufficient amounts mulch can become more effective on long plots because of the greater potential to buffer runoff and sediment; that is, there is greater potential for runoff to infiltrate and for sediment to be deposited on the plot due to the greater length (Smets et al. 2008). This was apparently the situation in a study Smets et al. (2008) performed using a worldwide dataset for plots that exceeded a length of 11 m. Mulch became more effective from 11 m to 50 m (the maximum plot length). Of course, even with greater mulch effectiveness on longer plots, the absolute amount of erosion increases with length (Hudson 1957, King 1979, Meyer et al. 1972, Smets et al. 2008), simply because of the greater surface area and length from which soil loss can originate (Smets et al. 2008).

On short plots there is almost no chance for infiltration or deposition to occur, so effects of simulated or real rain or inflow events are almost immediately measured

(Smets et al. 2008). This explains the substantial variation in the effectiveness to control runoff or erosion by all of the mulches in the 65 plots that were less than 11 m long (Smets et al. 2008). Although rills can form on short plots, interrill erosion is typically more dominant, especially in the short term. But because both can exist and the buffering capacity of long plots is absent, it is much more difficult to make generalizations about whether mulch becomes increasingly effective with length on short plots.

Although slope length and scale are important site factors, slope gradient is sometimes the single most important factor in controlling erosion (Megahan et al. 2001). There are interactions between slope gradient and length, however, and the two together substantially affect the ability of mulch to remain in place and the likelihood of rill development (Foltz and Copeland 2009).

Flatter areas tend to be dominated by interrill erosion, and rill erosion dominates steeper gradients (Lattanzi et al. 1974, Meyer et al. 1972), but both interrill and rill erosion increase with increasing gradient (Lattanzi et al. 1974). The increase in both types of erosion occurs at least up to some point, after which soil armoring may form and thereby reduce erosion on some steep slopes (Descroix et al. 2001). Because soil detachment by raindrop impact—and not by runoff detachment—dominates interrill erosion, increasing slope increases the amount of soil detached (and therefore erosion) through the change in angle of impact. Gravity contributes to further downslope movement of detached particles (Lattanzi et al. 1974).

The generally direct relationship between slope and erosion, especially on newly disturbed soils, means that steeper slopes tend to require greater amounts of mulch than less steep slopes to provide the same level of protection (Kramer and Meyer 1969, Meyer et al. 1970). With a sufficient amount of mulch, interrill erosion is preventable on virtually any slope because raindrop impact can be nullified completely at 100-percent cover (Lattanzi et al. 1974). However, mulches that tend to be mobile (transported by water or wind) on steep slopes may require some type of anchoring, such as netting, to maintain their effectiveness (Megahan 1974a). Increasing the mass of a mobile mulch on increasing slopes without any anchoring may provide

little additional benefit because exposed soil would be susceptible to raindrop splash and rill erosion (Bethlahmy and Kidd 1966, Lattanzi et al. 1974, Meyer et al. 1972). Similarly, if the type of mulch applied cannot control rill erosion because of its physical characteristics (e.g., Foltz and Wagenbrenner 2010, Meyer et al. 1972), the mulch may be largely ineffective at controlling erosion on sloped land, especially steep slopes (Lattanzi et al. 1974).

Few studies specifically compare a variety of types of mulches at equivalent soil covers over a range of slopes, so it impossible to recommend types of mulch that are best suited for specific situations. However, Lemly (1982) and Meyer et al. (1970), respectively, reported tacked straw and straw provided poor protection on steep slopes. Erosion control by tacked straw declined by 10 percent from a slope of 10 percent to a slope of 20 percent, and erosion control on a 50-percent slope was about half of what it was on a 10-percent slope (Lemly 1982).

On probably any slope, but especially on steep slopes, soil texture is a large factor in the absolute amount of erosion control that any mulch will have. The ability to control erosion of the finest sized particles is key to erosion control. Small-sized particles are not necessarily the easiest to detach, as structure has a big influence on shear strength, but they are the easiest to transport once detached (Sharma 1996). Eroded particles smaller than 0.04 mm from a red clay soil were much more poorly controlled by mulches than particles that exceeded 0.04 mm (Lemly 1982). Yanosek et al. (2006) similarly found that wood strand mulch was much more effective at controlling erosion of coarse-grained gravelly sand than of a fine-grained sandy loam. Kramer and Meyer (1969) used glass spheres to simulate two fine soil particle sizes (33-μm and 121-μm diameters) to examine the effect of steepness, plot length, and mulch rates on controlling erosion of the different sized particles. They simulated straw mulch with $\frac{1}{8}$-inch-wide × 6-inch-long fiberglass strips. As slopes steepened for any given mulch rate and slope length, the erosion rate (kg min^{-1} m^{-1}) was greater for the smaller particles than larger particles (Table 19). The difference between the two particle sizes increased markedly with increasing slope gradient and length for all mulch rates.

Effectiveness of Rolled Erosion Control Products

Rolled erosion control products (RECPs), sometimes referred to as "geotextiles," have been used for more than 50 yr (Bhattacharyya et al. 2008). They come in many forms and may be all natural, all synthetic, or a combination of the two. They may be made from jute, coconut fibers (also called coir), sisal, paper, wood chips, cereal straw, nylon, polypropylene, polyester, polyethylene, or other materials (Rickson 2006). The composition of an RECP determines its longevity in the field. Natural products typically last about 2 to 5 yr and synthetic products may last more than 25 yr (Rickson 2006). Jute-containing products, which are common RECPs, can deteriorate measurably in less than a year (Mitchell et al. 2003). Some products are woven; others are blankets or mats (Fig. 10). Some have netting; others are net-free (Smith 2007). There has been a shift toward products composed of all or greater amounts of natural

Figure 10.—Examples of woven (top) and nonwoven (bottom) geotextiles.

fibers because of their biodegradability (Smith 2007). However, as long as netting remains intact, it can trap some smaller wildlife species (Barton and Kinkead 2005, Kapfer and Paloski 2011, Walley et al. 2005), so net-free products may be a better choice in areas that contain species of interest.

RECPs differ from traditional mulches in that the latter are not associated with specific manufacturers, whereas each RECP is trademarked and manufactured according to a standard set of specifications. New products are placed on the market regularly and existing products are removed or their specifications changed. This can make it difficult for RECP users to keep pace with the available information about effectiveness and be familiar with the specifications of available products.

However, most of the published papers and available reports on the erosion control effectiveness of RECPs have been reviewed in detail in four comprehensive publications. Sutherland (1998b) and Sutherland (1998c) provide thorough reviews and critiques of studies available before 1990 and from 1990 to about 1997, respectively. Sutherland (1998a) assesses the research on RECPs done at the Hydraulics and Erosion Control Laboratory at Texas A&M University. Smith (2007) reviews many of the same studies evaluated by Sutherland (1998a, 1998b, 1998c) and also includes studies that were completed after Sutherland's papers were published. Rather than providing a lengthy review of individual product comparisons here that would be redundant with and probably less detailed than the information in those papers, we direct the reader to those publications for a thorough evaluation of available studies. The focus of this portion of the chapter will instead be a broader discussion of product characteristics that appear to be important in controlling their effectiveness. We use the word "appear" intentionally in the preceding sentence because there are limited studies of the processes that contribute to RECP effectiveness, and this is an identified weakness when improving the manufacture of RECPs and selecting the appropriate RECP for specific field conditions (Smith 2007).

Comparative tests with other types of erosion control products indicate that in virtually all instances, RECPs can reduce erosion of bare soil substantially (Benik et al. 2003, Grace et al. 1996, Mitchell et al. 2003, Rickson

2006), and their performance is comparable to and usually better than mulches (Dudeck et al. 1970, Harding 1988, Kill and Foote 1971, Swanson et al. 1967, Urroz and Israelsen 1995) (Table 19). Neither of these statements is surprising because RECPs are subject to market demand, and if they perform poorly they are unlikely to make it to market or to outcompete better-performing products. However, erosion control varies substantially among products or in different situations, so selecting the best product for erosion control is not straightforward or necessarily easy. There are no standard ways in which the erosion control by individual products is evaluated or in which different products are compared in a given situation. Most studies are empirical or "black box" studies (e.g., Krenitsky and Carroll 1994, Sutherland and Ziegler 1996, Thompson et al. 2001, Urroz and Israelsen 1995) in which RECPs are applied in a specific setting and the results are monitored with little if any replication or consideration of other experimental design components (Ziegler and Sutherland 1998). Further, little effort is given in most studies to understanding the specific processes contributing to or controlling erosion (Morgan and Rickson 1995, Smith 2007, Thompson et al. 2001, Ziegler and Sutherland 1998).

Standardized or uniform testing procedures for evaluating and comparing erosion control effectiveness of RECPs have long been identified as a need for the industry (Harding 1988, Rickson 2006, Sutherland 1998c), though the need has generally been ignored in practice (Sutherland 1998c). Despite some movement in developing standard approaches, industry-wide standardization still does not exist (Sutherland 1998c). Instead, major users, such as members of the American Association of State Highway and Transportation Officials (AASHTO) in their National Transportation Product Evaluation Program (NTPEP), use results from a collection of standard American Society for Testing and Materials (ASTM) tests developed by the Erosion Control Technology Council to standardize comparison of RECPs (AASHTO 2012, Smith 2007). However, manufacturer participation is voluntary (AASHTO 2012) and ASTM tests evaluate physical components of materials, such as strength and flexibility, that do not equate to erosion control effectiveness (Harding 1988).

In addition to the lack of uniform testing across the industry, there is also no way to know how well results

can be extrapolated to other geographic situations or larger spatial scales (Sutherland and Ziegler 1997). Comparison of products across all types of field conditions would be an informative but extremely expensive, tedious, and lengthy process (Thompson et al. 2001) that might be unable to keep up with product development. Thompson et al. (2001) suggested an alternative approach to hastening those types of comparisons by focusing on understanding how each RECP or RECP attribute affects erosion, contributes to erosion control, or interacts with processes that influence erosion, such as shear stress. General processes and controls are understood somewhat. But a detailed understanding of processes would allow product selection on the basis of erosion control potential rather than other known, yet not useful, variables (from the perspective of erosion control effectiveness), even if a product has not been fully tested in a wide variety of situations. Understanding processes and interactions also would improve the development of more-effective erosion control products (Smith 2007). Without process-based studies, improvement of erosion control products will occur primarily through slow trial-and-error applications rather than through scientific study (Sutherland 1998c). Study duration would have to be considered in process studies to understand when, why, and how interrill erosion makes the transition to rill erosion and to understand when, why, and how erosion becomes self-healing through time (Sutherland et al. 1997).

Like other soil cover techniques discussed in this chapter, the effectiveness of an RECP depends on its ability 1) to control raindrop splash, runoff, and associated sediment transport; and 2) to allow, if not enhance the ability of, vegetation to become established (Benik et al. 2003, Lekha 2004). The second ability includes physically allowing developing vegetation to grow through the material and in some cases improving the microclimate for seed germination and plant growth, such as by providing moderating temperatures and improving soil moisture levels. And like mulches, the physical attributes of the RECP influence its effectiveness in preventing erosion and runoff processes and allowing vegetation establishment.

Few studies evaluate the effectiveness of RECPs in controlling raindrop splash (Bhattacharyya et al. 2010), but existing studies generally show that splash erosion

is substantially less or statistically less compared to splash from exposed soil (e.g., Bhattacharyya et al. 2010; Sutherland and Ziegler 1996, 2007; Ziegler et al. 1997). The limited number of studies that have analyzed or discussed results in the context of the product characteristics suggest that controlling raindrop impact is most dependent upon two attributes: a low amount of open area in the material (i.e., high surface coverage) and a complex, thick, three-dimensional design (Harding 1988, Ingold and Thomson 1986, Smith 2007, Sutherland et al. 1997). The first characteristic is somewhat analogous to the need to have mulch soil coverage of 50 to 70 percent to achieve substantial benefit. However, there has been little analysis to identify the surface area coverage required by different types of RECPs to provide effective protection against raindrop splash (Sutherland et al. 1997).

Sutherland and Ziegler (2007) compared raindrop splash erosion of two open-weave coir RECPs. They found that the one with the higher mass per area and 30- to 40-percent open space had significantly lower splash erosion than the product with lower mass per area and 50- to 80-percent open space. Sediment concentrations and yields were 6.5 and 6 times, respectively, greater for the material with more open space than for the more closed coir product. A randomly oriented coir fiber RECP with the least open space (less than 10 percent) had the smallest splash erosion concentrations and yields; both were about one-third that of the material with high mass and low open space. Bhattacharyya et al. (2010) found borassus mats (black rhun palm; *Borassus aethiopum*) with about 23-percent open area significantly reduced splash erosion and splash height compared to bare soil. Splash erosion was reduced by about 89 percent, and splash height by about 54 percent. In contrast, splash erosion from buriti mats (buriti palm; *Mauritia flexuosa*) with about 56-percent open area was not significantly different from bare soil.

Product thickness generally contributes to the material's ability to absorb raindrop energy instead of transferring it to the soil surface (Bhattacharyya et al. 2010, Ziegler and Sutherland 1998, Ziegler et al. 1997). RECPs that are thick also may do a better job of catching and retaining detached soil particles in their matrix than RECPs that are relatively thin (i.e., more sheet-like), especially on steep slopes (Sutherland and Ziegler 1996). However,

thickness alone does not guarantee energy absorption. Without a complex three-dimensional internal structure, raindrops can pass unimpeded to the soil, limiting energy dissipation by the product. Of 13 tested RECPs, Ziegler et al. (1997) found the only one that did not mitigate raindrop splash was the thickest one because it had the highest amount of open area, and thus, least soil cover. Because nonwoven blanket or mat products have thick, complex internal designs, they are often better at preventing raindrop impact than woven products, which tend to be thinner with holes extending through the entire product thickness (Smith 2007; Sutherland and Ziegler 1996, 1997).

If the RECP is effective at controlling raindrop splash, it necessarily absorbs much of the raindrop energy. As a result, soil sealing is prevented, infiltration is maintained, and the ability to transport sediment is reduced (Sutherland et al. 1997, Ziegler et al. 1997). However, the elimination of splash also can result in temporary ponding of water at the soil surface (Bhattacharyya et al. 2010) as water droplets make their way through the RECPs. With sufficient mass, these accumulations can be transformed into interrill and rill flow, especially on sloped land. Research suggests that in these situations, controlling runoff and sediment transport is dependent largely upon having good contact between the RECP and the soil surface, a characteristic termed "drapability" (Sutherland and Ziegler 1996, 1997).

Drapability is believed to be critical to reducing runoff velocity by impounding flow and increasing flow depth, and providing roughness for flowpaths even if the product has little effect on reducing overall runoff volume (Rickson 2006). Interrill and rill erosion and flow processes are poorly understood for RECPs, but there is a general belief that drapability creates conditions that favor interrill flow and discourage rill flow (Lekha 2004). RECPs that are most effective at controlling runoff and sediment loss apparently are those that prevent the transition from interrill flow to rill flow (Smith 2007, Sutherland and Ziegler 1997). Thus, even if sediment is available, little of it will be transported as long as the RECP remains highly drapable because runoff will occur primarily as interrill flow—which has lower velocity and energy than rill flow (Sutherland and Ziegler 1997).

Fiber flexibility is an important variable controlling drapability (Sutherland and Ziegler 1997), and flexibility can increase or decrease with moisture for some RECPs, particularly organic materials (Cazzuffi et al. 1994; Rustom 1993; Sutherland and Ziegler 1996, 1997). Consequently, declines in drapability can result in the initiation of rill erosion. Rustom (1993) observed these effects when stiff coconut fibers expanded and lost contact with the soil during wetting.

Although it may be possible to control rill erosion with RECPs, complete elimination of interrill erosion with a single RECP currently on the market is probably impossible on sloping hillsides because interrill runoff is extremely difficult to prevent. As with mulches, the soil particles detached by interrill erosion are dominated by small particles, and these can be transported with very little flow energy (Lemly 1982). Interrill erosion is related directly to runoff velocity and velocity increases with slope length, so on long slopes interrill erosion expands (Fox and Bryan 1999) and can be very challenging to control. Hence, stopping interrill erosion entirely probably is achievable only by immediate infiltration or by retaining water (through the formation of small dams by the product or absorption of surface water by the product) until complete infiltration can occur, or by treating the surface soil underlying the RECP with a soil conditioner to prevent detachment (see Soil Conditioners section in this chapter).

This bias for small-particle transport was illustrated by Lemly (1982), who examined erosion resulting from a variety of RECPs (and mulches) on clay soils at highway construction sites (Table 19). Consistently across five different slopes, the sediment in runoff at peak discharge was dominated by soil particles smaller than 0.038 mm (Table 20) for all types of erosion control products used. In most cases more than 90 percent of eroded soil was in this smallest size class and in all cases the majority was in this class. And while erosion control for size classes smaller than 0.038 mm improved with increasing slope for all RECP (and mulch) treatments, erosion control of particle sizes less than 0.04 mm was always much poorer than that of the larger particle sizes for slopes of 10 percent or greater (Table 21). For example, RECPs reduced sediment yields by 50 percent or more at 10-percent slopes, but silt- and clay-sized particles

Table 20.—Mean composition of sediment, as percentages, in runoff during peak discharge[a] (from Lemly 1982)

Treatment[b] and particle size (*mm*)[c]	Percent slope				
	10	20	30	40	50
No treatment					
0.50	99	96	93	90	85
0.25	98	91	88	83	79
0.10	97	89	86	80	73
0.038	96	87	83	77	67
Tacked straw					
0.50	99.5	99	97	95	94
0.25	99	98	96	93	90
0.10	98	97	94	91	88
0.038	97.5	96	93	88	85
Jute netting					
0.50	99.6	99	98	96	92
0.25	99	98.5	97	94	90
0.10	98.6	98	94	93	89
0.038	98	97	93	90	86
Mulch blanket					
0.50	99.7	99.2	98.8	97	95
0.25	99.2	99	98	96	94
0.10	99	98.5	97	95	93
0.038	98.8	98	96	93	91
Wood chips					
0.50	99.6	99	97	96	95
0.25	99.1	98.5	96	95	93
0.10	98.8	98	95	93	91
0.038	98	97	94	91	90
Excelsior blanket					
0.50	99.7	99.3	99	98	97
0.25	99.3	99	98.5	97	96
0.10	99	98.7	98	96	94
0.038	98	98	97	94	93
Multiple treatments					
0.50	99.9	99.8	99.5	99	99
0.25	99.8	99.6	99.2	98.7	98.5
0.10	99.6	99.4	99	98	98
0.038	99.3	99.1	98.7	97	97

[a] Data were pooled and averaged for 14 precipitation events.

[b] Rolled erosion control product treatments are jute netting, mulch blanket, and excelsior blanket; mulch treatments are tacked straw and wood chips; multiple treatments involve a chemical binder applied to the soil surface, a fiberglass erosion check dam at the base of the plot slope, and asphalt-tacked straw covered with secured jute netting.

[c] Values represent percent finer than the particle size indicated, based on dry weight.

Table 21.—Effect of treatment on sediment reductions[a] for different experimental construction plot slopes (from Lemly 1982)

Treatment[b] and sediment component	Percent slope				
	10	20	30	40	50
Tacked straw					
Total	42	39	36	29	23
>0.04 mm	98.5	91	90	89	82
<0.04 mm	1.5	9	10	11	18
Jute netting					
Total	55	43	32	31	30
>0.04 mm	98	90	90	87	81
<0.04 mm	2	10	10	13	19
Mulch blanket					
Total	76	70	61	55	52
>0.04 mm	96.2	89	87	84	76
<0.04 mm	3.8	11	13	16	24
Wood chips					
Total	78	74	63	58	51
>0.04 mm	98	90	89	86	77
<0.04 mm	2	10	11	14	23
Excelsior blanket					
Total	78	73	62	58	52
>0.04 mm	98	89	86	81	76
<0.04 mm	2	11	14	19	25

[a] "Total" values are percent reductions, dry weight, of average total sediment concentrations (mg L^{-1}) during peak discharge compared to untreated plots. Values for ">0.04 mm" and for "<0.04 mm" are the sediment concentration reductions as a percentage of the total for each particle-size class.

[b] Rolled erosion control product treatments are jute netting, mulch blanket, and excelsior blanket; mulch treatments are tacked straw and wood chips.

were the dominant particle size in runoff, which was primarily interrill flow.

Long-term effectiveness of an RECP also depends upon its ability to retain good drapability throughout its intended life. Wind, water, and, on steep slopes, gravity can cause the loss of contact of RECPs with the soil over time. Consequently, many products require the use of staples or pegs designed for the RECP to keep it attached to the ground properly (Ingold and Thomson 1986, Lekha 2004, Rimoldi and Zhao 1996). Thompson et al. (2001) found that the density of the placement of staples used to attach erosion control blankets was critical for retarding particle detachment because greater blanket contact reduced shear stress at the soil surface. Moisture absorbed by RECPs with high water-holding capacity can contribute to an RECP's drapability and help hold it in place due to the weight of the wet material (Rickson 2006).

Water absorption also reduces the amount of free water available for interrill or rill flow (Ziegler et al. 1997). Jute-containing RECPs particularly are known for their ability to retain moisture and increase their drapability (Cazzuffi et al. 1994, Sutherland and Ziegler 1996). Conversely, as some RECPs become wet, they expand and get heavier, which can result in their drifting down steep slopes. They will lose contact with the soil and lose their erosion control effectiveness if sufficient vegetation does not become established quickly to hold the product in place (Mitchell et al. 2003). If a product has high drapability because of high moisture absorbance but has low strength, it will be highly susceptible to tearing on slopes containing sharp rocks, debris, and perhaps even gravel (Sutherland and Ziegler 1997). This means that some RECPs are not suitable for all situations, particularly if large rocks, soil clods, root wads, and other debris are not removed or cannot be removed fully to achieve drapability and to avoid damaging or tearing the material (Rimoldi and Zhao 1996).

Even with good drapability, RECPs applied on a soil surface that is already sealed by fines (e.g., due to delayed application of the RECP) may not provide effective erosion control, and will be less effective than on a similar unsealed surface (Smets and Poesen 2009). Likewise, an RECP that has excellent drapability, moisture absorption characteristics, and other physical characteristics that encourage interrill flow can be

challenged if there is a soil layer beneath the surface that impedes percolation. Saturation excess overland flow can result, creating rill flow and erosion even if the product is functioning at its best (Rustom 1993).

In addition to drapability, surface area coverage, and thickness, fiber orientation is important for controlling sediment transport. Three-dimensional, randomly oriented fibers are most effective at reducing rill erosion (Sutherland and Ziegler 1996, 1997). Sutherland and Ziegler (2007) compared two open-weave coir products. Random fiber orientation in one RECP resulted in significantly lower sediment concentrations and loads, as well as less rill formation, compared to the second RECP, which had a more regular fiber orientation. Further, if the dominant fiber orientation is across the slope (i.e., along the contour) rather than vertical, interrill erosion of detached soil particles can be retarded (Sutherland and Ziegler 1997).

Fiber length also may play an important role in sediment transport, at least for natural fibers. Smith (2007) found that RECPs containing short fibers and low amounts of synthetic materials were most effective at controlling erosion and sediment transport. Essentially all of the 13 products she tested were effective at controlling raindrop splash, but only natural materials with short fibers were similarly successful at stopping or largely controlling sediment movement. These materials all had high percent ground coverage, high water absorption capacities, high drapability (in part due to the short fiber length) especially with wetting, and adherence to the soil from product tackiness. Long-fiber products were less effective and sometimes fairly ineffective at controlling runoff because the fibers were too long to conform to irregularities of the soil surface. Often they were thin so as not to absorb water well; thus, their flexibility remained poor in wet conditions. A fully synthetic product constructed from polypropylene was the least effective product. Its structure was the most regular, and it had poor water absorption, which led to the most rill formation.

Sutherland and Ziegler (1997) also reported that a PVC product provided poor erosion control because of its poor drapability, even though it had randomly oriented fibers and high mass density (an index of ground cover). Thin nylon monofilament materials provide poor erosion

control, in part due to their inability to trap and retain loose soil particles (Harding 1988). Even when they have good contact with the soil, structures can be so thin that water flows on top of the material (Smith 2007).

A few types of RECPs are designed to be laid on the soil surface and then covered or filled with topsoil (e.g., geoweb and geocells, respectively). The effectiveness of these types of products has been inconsistent, and in some cases erosion has been reported to be as high as or even exceeding that of bare soil (Cazzuffi et al. 1994, Ingold and Thomson 1986). Soil losses are elevated due to the combination of raindrop splash and increased runoff. The webbed nature of these products disrupts normal drainage patterns, causing soil saturation within the cells and greater surface flows.

The physical factors of RECPs that retard raindrop splash and sediment transport also often encourage the success of seed germination and vegetation establishment, and the converse is true as well. In open-weave or other products that permit substantial raindrop impact, seeds have become displaced from the soil surface or redistributed so that developing cover is not even (Rickson 2000). Redistribution or complete loss of seed also has resulted when RECP expansion during wetting has allowed rill flow and rill formation to occur. In some cases, the effects have resulted in seed germination that has been no better than bare soil with no protection (Krenitsky and Carroll 1994, Rickson 2000). In contrast, RECPs that provide good protection against raindrop impact, soil detachment, and sediment transport can result in very good seed germination. Dudeck et al. (1970) reported mulch and RECP effectiveness on fillslope plots, with the best grass seed establishment occurring on soil protected by excelsior or jute netting. However, there may be an antagonism between high surface area coverage and the complexity/thickness of products in that germinated seeds may not be able to penetrate the material easily (Krenitsky and Carroll 1994). Instead, germinating plants sometimes lift the product off the ground (Theisen 1992). Erosion

rates can increase due to the loss of RECP contact with the soil surface and the reductions in roughness (Rickson 2006) and water absorption (Ziegler et al. 1997) that result from loss of drapability.

Only recently has research begun to focus on identifying specific RECP characteristics that provide erosion control benefits, including controlling raindrop splash, absorbing and temporarily detaining water, controlling the transition from interrill to rill erosion, limiting interrill flow, and encouraging successful germination of vegetation. Some of this work has required a new approach to analyses, such as understanding how cellular structures of organic materials behave temporally through short-term wetting and drying cycles, and through extended periods of use in which product degradation may occur (Smith 2007). As the conditions and interactions that affect RECP performance become better understood, new products are expected to be developed that exploit that information and improve their erosion control effectiveness; also anticipated is guidance that better defines situations and sites best suited for specific product application (Smith 2007).

Riprap applied to a forest road cutbank for stabilization after initial erosion control measures following road construction were not adequate during winter storms. (Photo by U.S. Forest Service, Umpqua National Forest.)

Barriers and Biofilters

The focus in this chapter is on drainage, and hence, sediment control once water is diverted off the road surface or from a relief ditch. On forest roads, most road drainage typically is discharged onto roadside fillslopes or onto the original hillside adjacent to the area disturbed by road construction. The water's energy, erosive potential, and sediment delivery/deposition then are expected to be controlled by infiltration and sediment deposition, via the natural landscape attributes and features or humanmade structures, or a combination thereof. There are varying degrees of sophistication in the design of BMPs that rely on infiltration and deposition, but those that require substantial engineering, such as concrete energy dispersion ditches and settling ponds with designed outflow devices, are not included in this chapter or elsewhere in this document because they are rarely used in most forest road applications.

The barriers that are described in this chapter are non-engineered barriers—in other words, barriers that are installed with little or no design requirements other than standard installation guidelines (e.g., standard techniques given in BMP manuals for anchoring to the ground). Non-engineered barriers include such techniques as silt fence, straw bales, and fiber rolls or logs. In most cases, barriers are applied in two types of situations. One is when discharge is concentrated, including where concentrated discharge is cast onto adjacent land. This application typically is associated with roads, such as for water turnouts, ditches, and other similar features. The second is along the perimeter of, or as slope interrupters within, disturbed areas of construction sites (Faucette et al. 2009b). Barriers in both types of applications tend to be meant only for short-term use because the reestablishment of vegetation is the primary long-term erosion control technique.

The second section of this chapter is devoted to the class of BMPs known as "biofilters," which depend upon vegetation to reduce pollutant levels. These include buffer strips, such as vegetated filter strips and conventional forest buffers, and vegetated waterways and swales.

Non-engineered Barriers

Many types of non-engineered barriers are used to control erosion, but they fall into two general categories. One type will be called nonreactive barriers, which include the more commonly applied and more conventional types of barriers such as silt fence, straw bales, rock/stone berms, and fiber rolls or logs (also called wattles). These are in contrast to reactive barriers, the term given by Shipitalo et al. (2010) to the more recently developed techniques of filter berms and filter socks (Faucette et al. 2009b).

Nonreactive Barriers

Except for rare situations where barriers are used only to trap gravity-transported material (i.e., dry ravel), most nonreactive barriers involve water transport of pollutants and depend upon ponding and particle settling as the mechanisms for pollutant removal. The emphasis in this section is on this latter type of nonreactive barriers. The specific processes that lead to ponding and settling have been identified and described in detail only for silt fence, but all nonreactive barriers probably depend upon those same processes to one degree or another.

The initial key step for effective pollutant control is blinding and clogging of the openings in the barrier by large particles in runoff (Barrett et al. 1996, Kouwen 1990, Theisen 1992). Multiple small particles also can clog barriers if they reach an opening simultaneously and form bridges that clog barrier openings (Barrett et al. 1996). Blinding is a surface phenomenon where a crust forms across pores along the outer surface of the

receiving side of the barrier, whereas clogging occurs when the interior pores become filled with solids and obstruct water flow (Holtz et al. 1998, Ossege 1993). Because it is impossible to distinguish between the two processes during testing or field use, the terms may be used interchangeably or no distinction may be made between the two in the literature (e.g., see Crebbin 1988, Kouwen 1990). Many people erroneously believe nonreactive barriers remove sediment by filtering (especially silt fence, which is often referred to as "filter fabric"), but particle filtering by nonreactive barriers happens only over the short time during which blinding and clogging occur (Barrett et al. 1996). Ponding and settling follow as a result of clogging and blinding.

Clogging and blinding reduce the permeability of the barrier material, which encourages temporary ponding, thereby allowing sediment to settle out during the much longer periods of inflow detention (Barrett et al. 1996, Kouwen 1990, Theisen 1992). Thus, barrier characteristics that contribute to ponding and increasing the time of detention are the ones that are most effective at retaining sediment (Barrett et al. 1998a). Such materials tend to be thick (three-dimensional) and have small pore sizes, as these characteristics reduce permeability and create slower, more tortuous flow paths that are conducive to greater particle interception and clogging, as well as longer ponding times (Barrett et al. 1996, Crebbin 1988).

Larger particles, particularly sands, dominate the settling process because settling velocities of smaller particles (silts and clays) are too low for deposition to occur during the time that water is ponded (Barrett et al. 1998a, Keener et al. 2007). Clays also are affected by Brownian forces that can keep them in suspension almost indefinitely (Smith 1920); thus, particles less than 0.02-mm diameter (i.e., medium-sized silt and smaller particles) are not removed effectively by ponding or by filtering/clogging with nonreactive barriers (Kouwen 1990). To illustrate, silt fence materials tend to remove 80 to 99 percent of sands compared to 50 to 80 percent of silt loams, and only up to 20 percent of silty clay loams (U.S. Environmental Protection Agency [EPA] 1993). Consequently, as the percentage of smaller particles in runoff increases, the trapping efficiency of nonreactive barriers decreases (Wishowski et al. 1998).

Silt fence is the industry standard for sediment control barriers during construction (Barrett et al. 1996, Faucette et al. 2008), so it is commonly used at road construction sites. Silt fence (and most nonreactive barriers) is meant to be used with sheet flow or small quantities of overland flow; it is not intended for use with concentrated flow or large amounts of overland flow, even if that flow occurs as sheet flow (Crebbin 1988, Island County Public Works 2003, Wyant 1980). Large volumes of inflow can overwhelm the ponding capacity and potentially compromise silt fence strength (Farias et al. 2006), which can result in overtopping, undercutting, circumventing, or tearing the fence material (Keener et al. 2007). Therefore, silt fence fabrics are not designed to control erosion at the outlet of most road drainage features (e.g., culverts, broad-based dips) even though they commonly are placed in those locations. Instead, silt fences are designed for use around the perimeters of disturbed areas, downslope of areas that contribute sheet flow, in small swales or ditches that carry very limited runoff, or upslope of points of concentrated flow to keep sediment from entering that flow (Barrett et al. 1996).

Silt fence is manufactured as either woven or nonwoven fabrics, using the same techniques described for woven and nonwoven rolled erosion control products in Chapter 6. Both woven and nonwoven materials are permeable to flow because the purpose of the fabric is to slow and temporarily pond water but not detain it indefinitely or until infiltration is complete. Consequently, fabric permittivity, as determined by the American Society for Testing and Materials (ASTM), is important for controlling flow-through rates and ponding (Barrett et al. 1998a, Farias et al. 2006).

Permittivity is a measure of the quantity of water that can pass through the fabric with a head of 50 mm of water (Chopra et al. 2010). The rate of ponding is inversely related to the permittivity of a fabric (Farias et al. 2006). However, ASTM-determined permittivity values for a given geotextile material are not equivalent to permittivity that would occur in field conditions (Denkler et al. 2000). This is because ASTM permittivity evaluates the quantity of clean water that can pass vertically through a specified cross-sectional area of a given fabric (subjected to 50-mm head of water; ASTM 2009), which is very different from field runoff that contains sediment and other contaminants,

passes through the fence laterally, and has a variable and sometimes large head of water behind the fence.

Silt fence permittivity declines during use within and across storms as successive sediment-laden inflows increasingly clog the fabric (Wishowski et al. 1998). During flume studies, Barrett et al. (1998a) measured flow-through rates that were two orders of magnitude less than ASTM permittivity specifications. Farias et al. (2006) found permittivity was reduced to 62 percent and 85 percent of that for clean silt fence after two simulated rain events. For the four types of nonwoven geotextiles they tested, reductions in permittivity were greatest for thicker, less open geotextiles. Using woven silt fence fabrics, Denkler et al. (2000) measured initial flow-through rates that were four orders of magnitude less than the permittivity values specified for the material, and after long-term measurements of continuous flow-through (up to 2,000 h), they determined that flow-through decreased by as much as 50 percent compared to flow-through rates 1 h into the experiment.

Although permittivity affects water flow-through, sediment retention is not dependent upon flow-through rates (Wishowski et al. 1998). Instead, sediment retention has been found to be a function of the fabric's apparent opening size (AOS) (Theisen 1992) because the AOS provides an estimate of the size of the largest opening in a fabric through which soil particles can pass (ASTM 2004, Barrett et al. 1996, Chopra et al. 2010). The AOS is based on standard U.S. sieve sizes, and the AOS number and size of the opening are inversely related (Robichaud and Brown 2002). Some of the evidence linking AOS with sediment retention comes from findings that large particles are trapped more effectively than small ones; that is, fewer larger particles pass through material because the AOS estimates the largest size opening, but not all openings are that size and many are smaller. Wishowski et al. (1998) recorded trapping efficiencies of 99, 91, 74, 60, 54, and 45 percent, for the respective particle size classes >50 µm, >20 to 50 µm, >12.5 to 20 µm, >5 to 12.5 µm, ≥2 to 5 µm, and <2 µm. Similarly, retention of sand by four nonwoven silt fence fabrics over four replicate runs ranged from 84 to 99 percent (all but three runs for one fabric were 99 percent), whereas three nonwoven fabrics over four replicate runs all retained less than 7 percent of the fine silt/clay fractions (Fisher

and Jarrett 1984). Coarse silt retention was between these two, ranging from 43 to 81 percent.

However, the relationship between retention and AOS is fairly weak and comparisons of fabrics with different AOS values have shown inconsistent results with respect to sediment retention. Britton et al. (2001) did find that the largest AOS corresponded to the fabric with the greatest particle transport (simulated with glass beads) through the material, but all three of the fabrics tested had similar particle retention (55, 65, and 66 percent) even though their AOS values spanned a fairly wide range relative to soil particle sizes (AOS=10, 30, and 40, which correspond to diameter openings of 0.80, 0.59, and 0.42 mm, respectively). Crebbin (1988) also reported that a fabric with a high AOS had markedly greater sediment retention than a fabric from the same manufacturer with a lower AOS.

Several factors contribute to the weak relationship between AOS and sediment retention. One is that AOS corresponds to the largest size opening, but not the frequency of those openings, which may be inconsistent across the fabric (Barrett et al. 1996, Ossege 1993). The frequency at which the manufactured AOS-sized opening occurs affects the probability that a given sized particle in inflow will encounter an opening of sufficient size to allow the particle to pass through the material. Second, the AOS is not uniform through the thickness of three-dimensional (i.e., nonwoven) fabrics, so particles transferred through larger openings on the surface may be captured in smaller openings within the interior of the material (Ossege 1993). Third, the AOS also decreases as clogging and blinding progress (Farias et al. 2006). Consequently, while permittivity and AOS have some control on flow-through and particle retention/loss, neither specification as determined through ASTM testing gives an accurate prediction of silt fence effectiveness in the field (Barrett et al. 1996, Martin 1985).

The temporal decreases in permittivity and AOS make geotextile materials increasingly susceptible to excessive ponding, and failure (Farias et al. 2006); therefore, although it is not discussed directly in the literature, it is probably important to anticipate and plan for changes in flow-through rates when selecting silt fence fabric. Selection of poorly suited materials for the

soil texture, inflow rates, and erosion rates can result in structural failures that can substantially reduce silt fence effectiveness and yield large amounts of scour downslope from the fence when great volumes of ponded water are released suddenly (Storey et al. 2006, U.S. EPA 2002, Yeri et al. 2005). Broad guidance exists for selecting silt fence fabrics (e.g., California Stormwater Quality Association 2003, Wisconsin Department of Natural Resources 2006), but specific recommendations for material selection in different field conditions (e.g., soil, inflows, slopes, contributing areas) are not present in the literature. Denkler et al. (2000) described the appropriate silt fence for a given soil and situation as one that eventually reaches a steady rate of flow through the fence. Under steady state flow, clogging is no longer occurring and piping of fines through the fence is not increasing. However, steady state flow can take an excessively long time to achieve (for example, 360 to 2,000 h of inflow was required for loess soils in Denkler et al. [2000]), so this recommendation is probably not particularly valuable as a selection criterion.

Because the performance of silt fence cannot be accurately predicted from its simple physical characteristics, much of the effectiveness testing has defaulted to laboratory and flume studies that use controlled inflow and sediment (or simulated-sediment) composition. These studies have been useful in providing insight into the processes of clogging and deposition by which silt fence and other nonreactive barriers control pollutant transport (described previously). They suggest that some silt fence fabrics are capable of good to excellent sediment retention in controlled, short-term situations, whereas other fabrics result in very poor control (Table 22).

The variability in effectiveness is attributable to differences in the physical silt fence characteristics just described, as well as inflow rates, soil characteristics, and sediment slurry concentrations. Increasing inflow rates tend to result in lower sediment retention when all other variables are held constant (see Keener et al. [2007] in Table 22) because high inflow rates can cause overtopping or other failure of the fence (Keener et al. 2007). To avoid overtopping and failure, fabrics designed for high inflows have larger pore sizes and higher flow-through rates, which also contribute to poorer erosion control (Carroll et al. 1992). Retention increases when

the soil suspended in inflow is dominated by larger particles (e.g., sands), as these can be trapped by the fabric or settled by ponding; in contrast, clays are more likely to stay suspended in water as it passes through the fence fabric (U.S. EPA 1993).

Elevated sediment concentrations tend to clog and blind silt fence fabric more quickly than inflow with low sediment concentrations (Henry et al. 1999), so fabrics with large pores can improve sediment trapping as long as the inflow rates are not so great that ponding results in overtopping or other silt fence failures. High-density silt fence fabrics, which tend to be nonwoven, typically trap more sediment than low-density fabric (Wishowski et al. 1998). This is because nonwoven silt fence materials have longer and more tortuous pores, so the probability of clogging, ponding, and sediment trapping are increased (Bell and Hicks 1980), and they are stronger so they can support greater volumes of ponded water (Wyant 1980). However, most geotextiles used for silt fence are woven (Crebbin 1988) so they often do not have optimal sediment retention or water detention characteristics (Wyant 1980).

Expectations of silt fence performance in the field should not be based on flume and laboratory experiments (Barrett et al. 1998a, U.S. EPA 2002). Flume and laboratory studies provide exaggerated estimates of silt fence performance compared to field conditions because the former often employ disproportionately large percentages of sand particles in inflows (Barrett et al. 1998a). In contrast, because fines are displaced by runoff and suspended easily, the percentages of clay and silt present in runoff in the field generally will exceed the percentages of clay and silt particles in the parent soil from which the eroded particles originated (Schueler and Lugbill 1990). Fines tend to pass through silt fence (Barrett et al. 1996, Yeri et al. 2005), so field performance can be poor under certain soil, fence, and inflow combinations. For example, when the median value of silt + clay in inflow was 96 percent in field studies, Barrett et al. (1998a) recorded a median retention efficiency of 0 percent with a standard deviation of just 26 percent.

Other field tests of silt fence performance show a wide range of effectiveness (Table 23), with some field effectiveness values being very low or even negative (i.e., sediment losses are increased with the presence of the silt

Table 22.—Trapping efficiencies of various types of silt fence fabric measured from flume or laboratory experiments

Reference	Trapping efficiencies	Description of study charactersistics
	percent	
Barrett et al. (1998a)	70, 90, 68	3 woven fabrics
	90	1 nonwoven fabric
Britton et al. (2001)	55, 65, 66	3 different woven fabrics; used glass beads to simulate soil particles
Crebbin (1988)	79, 87, 91, 91	4 woven silt fence fabrics
Farias et al. (2006)	62–85	4 types of needle-punched nonwoven fabric
Fisher and Jarrett (1984)	12–31	5 nonwoven fabrics using a sand slurry
	1–19	5 nonwoven fabrics using a coarse silt slurry
	0.7–2.6	5 nonwoven fabrics using a silt–clay slurry
	1.8	1 woven fabric using a sand slurry
	0.8	1 woven fabric using a coarse silt slurry
	0.1	1 woven fabric using a silt–clay slurry
Keener et al. (2007)	56	Average for 0.126 L s^{-1} inflow
	42	Average for 0.252 L s^{-1} inflow
	33	Average for 0.315 L s^{-1} inflow
		All with a silt loam slurry
Kouwen (1990)	>99	3 woven geotextiles using a 0.22-mm-diameter sand
Wishowski et al. (1998)	81	High density clean fabric
	69	Low density clean fabric
Wyant (1980)	97–99	9 nonwoven fabrics using a sandy soil slurry
	90–100	9 nonwoven fabrics using a silty soil slurry
	93–99	9 nonwoven fabrics using a clayey soil slurry
	92–98	6 woven fabrics using a sandy soil slurry
	49–99; only one was <84	6 woven fabrics using a silty soil slurry
	85–98	6 woven fabrics using a clayey soil slurry

Table 23.—Trapping efficiencies of various types of silt fence fabric measured from field experiments or field applications

Reference	Sediment retention	Comments
	percent	
Barrett et al. (1996)	-61 to 54[a]	One silt fence sample removed more than 26% TSS; 54% removal was a nonwoven fabric; measurements after 8 h following 1 storm; inflow contained mostly silt- and clay-sized particles
Ettlin and Stewart (1993)	16	From 5 storms on 34% slopes; as TSS
Grace (2003)	85	Silt fence installed in road turnout ditches; 3 replicates; 90 flow events; over 42 months; as TSS concentration
Horner et al. (1990)	85.7	Average from 2 plots with silt fence compared to 2 bare plots over 7 storms; as TSS
Yeri et al. (2005)	91	Sandy loam slurry at 10% slope
	51	Sandy loam slurry at 13% slope
	94	Loam slurry at 10% slope
	88	Loam slurry at 13% slope
	97	Silt loam slurry at 10% slope
	95	Silt loam slurry at 13% slope
		All 6 tests included new design of silt fence to improve effectiveness; as total sediment mass

[a]Negative values indicate that sediment in outflows exceeded that in inflows.

fence). In addition to the limitations of silt fence materials even under laboratory conditions, poor performance in field tests and field use often is associated with silt fence structural failures (e.g., Barrett et al. 1996, 1998a). Common reasons for silt fence failure include: improper installation, which can result in undercutting of the toe, erosion of poorly compacted fill in the toe trench, or flow around one or both ends of the fence; excessive stretching and tearing; and overtopping the fence at low points (Barrett et al. 1996, Harbor 1999, U.S. EPA 2002, Yeri et al. 2005). Supplemental support, such as the additional stakes (Robichaud and Brown 2002) or wire woven into the silt fence fabric during manufacturing (Wyant 1980), can help provide greater strength to silt fence, but even these extra precautions may not be sufficient to keep silt fence operational with high volumes of inflow or when installed improperly or in the wrong location. Lack of

maintenance, even for short-term use, also is often cited as a reason for silt fence failure (Landphair et al. 1997, Stevens et al. 2007). Because the need for maintenance increases with duration of use, the effectiveness of silt fence for erosion control during field applications may be poorer than "effective" short-term field tests suggest (e.g., Horner et al. 1990, Yeri et al. 2005) (Table 23). However, if fences are maintained, Grace (2003) (Table 23) has shown them to provide reasonable levels of sediment retention over periods typical of field use.

Given the general inability of silt fence fabrics to retain fines (Yeri et al. 2005), it is not surprising that silt fence typically is ineffective at controlling turbidity (Barrett et al. 1996, 1998a). Turbidity is influenced primarily by fine particles with low settling velocities (Barrett et al. 1998a, Horner et al. 1990, Leytem and Bjorneberg 2005), which correspond to the particles most apt to be carried by flow through the fence fabric. Horner et al. (1990) reported only 3-percent reduction in turbidity. Barrett et al. (1998a) measured a median turbidity reduction of 2 percent, though removal during individual experimental tests ranged from -32 percent (i.e., an increase in turbidity) to 49 percent. Results from a study by Faucette et al. (2008) were unusual compared to other published literature. From four experiments of individual simulated rainfall-runoff events, silt fence consistently resulted in relatively high turbidity reductions of 45, 50, 54, and 76 percent.

The tendency of silt fence to allow fine particles to pass through the fabric also can influence other pollutant losses. Metals on roadways and in roadway runoff exist across the spectrum of sizes ranging from settleable particulates to dissolved colloidal forms; the size/form is related to the type of metal involved (Butler et al. 1992, Pitt 1979). Many metals attach to particles, of which the great majority are small diameter (Pitt 1979, Pitt and Amy 1973, Revitt and Ellis 1980, Sartor and Boyd 1972, Wilber and Hunter 1979), so it is likely that silt fence will have poor retention of metals. However, there is scant research about the effectiveness of silt fence on metal or other road-associated pollutant removal, perhaps because silt fence is designed primarily to remove settleable sediment. A single study by Büyüksönmez et al. (2012) examined "first flush" loss of metals from a single simulated runoff event. Silt fence removed 82 percent of total zinc and more

than 50 percent of total cadmium, total lead, and total copper compared to a control. In contrast, for soluble forms of those metals only copper levels were reduced significantly. Loads of soluble forms of the other three metals increased compared to the control due to leaching from the silt fence material.

Far fewer studies have considered effectiveness for other types of nonreactive barriers (Table 24). Most available information about nonreactive barriers aside from silt fence involves straw or hay bales. But even these barriers have had very limited investigations of effectiveness (U.S. EPA 2002) despite their common use (Brown and Caraco 1997).

The effectiveness of straw and hay bales as barriers is greatest when they are positioned at the base of a slope to capture loose sediment (transported by gravity or small amounts of water), rather than erosion associated with overland or concentrated flow (U.S. EPA 2002). Collins and Johnston (1995) found straw bales positioned in rows downslope of urban road cuts were very effective at capturing the ubiquitous but manageable levels of sediment inputs. Results also suggested that straw bales

installed to collect dispersed sources of sediment stay in place and function for longer periods than bales regularly affected by inflows of water.

In the presence of overland flow (even as sheet flow), straw and hay bale effectiveness depends largely on securely anchoring the bales to the ground (with stakes or rebar) and on keeping them wedged tightly together (U.S. EPA 2002) to resist failure and encourage sedimentation behind them. Models indicate that straw bales can be effective at sediment reduction in field use, but the results assume ideal conditions for installation and proper installation techniques (U.S. EPA 2002). Proper installation apparently is rare, however. In a visual review of field applications, Collins and Johnston (1995) found that straw bales regularly were not installed or maintained properly. As a result they were undercut or water flowed between bales, making them ineffective at controlling sediment losses. In a survey of experts on erosion and sediment control, Brown and Caraco (1997) reported inconsistencies between perceptions of straw bale effectiveness and use in the field. Only 27 percent of the surveyed

Table 24.—Sediment retention by nonreactive barriers other than silt fence

Reference	Type of erosion control barrier	Sediment retention	Comments
		percent	
Faucette et al. (2009b)	Straw bales	65.1	Total solids concentration
		71.3	Total solids load
		53.8	Total suspended solids concentration
		61.5	Total suspended solids load
			All replications: to simulate construction site perimeter erosion control
Kelsey et al. (2006)	6-inch excelsior fiber logs	55.2	All replications: 12.5% slope; to simulate slope interrupter and perimeter barriers; as sediment concentrations
	12-inch excelsior fiber logs	71.2	
	9-inch straw wattles	34.3	
	12-inch straw wattles	19.5	
Kouwen (1990)	Weighted or clamped-in-place straw bales	>95	Laboratory study to simulate check dams; sediment slurry composed of medium-sized sand
	Loose straw bales	70–80	
Line and White (2001)	Washed stone and rock check dam	69	Average for 34 storms; as TSS mass
McLaughlin (2003)	Large rock dam	77	Retention decreased through time
	Gravel check dam	90	
Wright (2010)	Riprap check dam	~80	As mass of sediment

experts considered straw bale barriers installed around the perimeter of construction sites to be an effective erosion control technique, yet straw bales were still allowed in more than half of the communities that were surveyed. The tradition of using straw bales for erosion control is linked to their affordability compared to other techniques (U.S. EPA 2002) rather than to proven effectiveness, as there are more data that show straw to be a far more effective BMP when applied as mulch (see Chapter 6) than when used as nonreactive barriers.

A controlled short-term study using test plots with flumes did suggest perimeter application of straw bales could remove relatively large amounts of solids when overland flows are limited if the bales were installed properly. From a single simulated storm, reductions in pollutants by straw bales around the perimeter of construction sites were 65.1 percent for total solids concentrations, 71.3 percent for total solids loads, 53.8 percent for total suspended solids (TSS) concentrations, 61.5 percent for TSS loads, and 11.8 percent for turbidity (Faucette et al. 2009b). However, performance typically is much poorer with increasing inflows. During the 1991–1992 wet season in southern California, Collins and Johnston (1995) examined straw bales installed as erosion barriers on alluvial fans (outside of channels) and at drop inlets following wildfires. Straw bales at drop inlets on roads increased erosion levels because the bales restricted water entry into the drains; water instead flowed downhill and eroded fillslopes. Decaying straw bales also clogged the inlets, resulting in the same type of consequences from overflow. On alluvial fans, straw bales were ineffective because they were displaced by overland flows that quickly overwhelmed the barriers. The bales were also susceptible to rapid decay in this situation.

Kelsey et al. (2006) studied straw-containing wattles and showed their effectiveness also was dependent upon good contact with the ground rather than the diameters of the barriers. Denser (72.62 kg m^{-3}), smaller diameter (22.9 cm) straw wattles were more effective at capturing sediment than less dense (61.2 kg m^{-3}), larger diameter (30.5 cm) wattles during 30-min applications of 10.2-cm h^{-1} simulated rain events. The greater density resulted in better contact of the barriers with the ground, making them less susceptible to rill formation and sediment transport than their larger diameter, but lighter weight,

counterparts. Increased diameter of excelsior (wood fibers) logs became important only for barriers that had similar densities (Kelsey et al. 2006). Their more complex structure (curled and barbed) expanded and pieces linked to each other when wetted, such that even though the excelsior density (dry) was less than half of that of straw wattles it trapped substantially more sediment than the straw wattles (Table 24), as long as the excelsior logs were secured to the soil surface. In this test, stakes holding the excelsior logs in place were half as far apart (0.6 m) as for the straw wattles (1.2 m).

Effectiveness of barriers may be most challenged when they are employed as check dams (i.e., barriers applied to channels, gullies, ditches, or convergent topography where concentrated flow is present at least ephemerally). However, check dams generally are considered poor choices for overall erosion control because the primary role of check dams is to prevent or reduce erosion of the channel itself, and sediment capture is only a secondary objective (Collins and Johnston 1995).

Studies suggest that materials which are dislodged or displaced easily are most at risk for poor performance as check dams. In two watersheds in which 440 straw bale check dams were installed in ephemeral channels and gullies for postfire erosion control, 67 percent and 54 percent failed due to undercutting, side cutting, filling, or displacement, or a combination thereof, about 3.5 months after installation (Collins and Johnston 1995). In short-term experiments by Storey et al. (2006), bales were not displaced, but water moved under instead of through them. On sandy soils, this created substantial scouring immediately downstream of the bales, whereas on clay soils underflow remained dispersed and did not cause scouring. Kouwen (1990) found properly installed straw bales could provide high retention of sand in short-term flume studies with concentrated flows (Table 24), but the composition of the slurry mixture and duration of study do not represent realistic conditions of field applications of straw bale barriers.

Check dams constructed from rock materials, such as riprap, are more resistant to displacement and failure if the materials are the proper size. The limited data available suggest that rock check dams can perform surprisingly well, though the effectiveness probably depends primarily upon the type and grading of the

coarse fragments. Over about 19 months of monitoring, a sediment trap with rock check dams in a drainage ditch of a construction site in the Coastal Plain of North Carolina had an average trapping efficiency of 69 percent, and a similarly constructed sediment trap installed in an intermittent channel draining a construction site in the Piedmont trapped an average of 59 percent of total suspended sediment (Line and White 2001). A third rock check dam installed at the outlet of a storm drain in the Piedmont was sampled for just over 2 months and had an overall efficiency of 58 percent. As with silt fence, all three sediment traps were more effective at retaining sand-sized particles compared to smaller silt- and clay-sized particles, as sands settle more easily. Silt- and clay-sized particles that were trapped tended to be associated with larger aggregates.

Wright (2010) examined 0.3-m-high trapezoidal rock (riprap) in 24:1 (horizontal:vertical) or 2.4-degree sloped field plots with natural rain events, as well as in the laboratory with simulated slopes of 6:1, 9:1, and 12:1 (horizontal:vertical) using artificial rain events. In the field study, about 80 percent of sediment was retained across three replicate rock check dams compared to losses from bare soil. The performance of the rock check dams in the laboratory was similar across all slopes and similar to the field results; they removed about 70 to 85 percent of sediment in inflow, with the best performance from the 9:1 slope (horizontal:vertical).

Standard state BMPs in North Carolina involving 1.5-ft-deep sediment traps in combination with rock check dams in road ditches were much less effective at sediment capture than combinations of stiff coir logs and malleable straw wattles (King and McLaughlin 2007, McLaughlin et al. 2009b). Average per storm sediment losses were 428 kg for the standard BMPs compared to 2.1 kg for the fiber check dams; respective average turbidity levels in outflow were 3,813 NTU and 202 NTU. When polyacrylamide (PAM) (see Soil Conditioners section in Chapter 6) was added to the coir log and straw wattle check dams, sediment retention increased even more: average per storm sediment and turbidity in outflow were 0.9 kg and 34 NTU, respectively. Similar results occurred at another site, where fiber check dams with PAM and standard state BMPs were used in road ditches, though the differences between the standard rock check dams

and the fiber check dams were not nearly as great as at the other site (McLaughlin et al. 2009b). Average per storm sediment loss with the standard BMPs was 3.3 kg compared to 0.8 kg for the fiber check dam + PAM. Average per storm turbidity with the standard BMPs was 867 NTU compared to 115 NTU for the fiber check dams + PAM. Because the cost of the fiber check dams was comparable to the standard BMPs and water quality discharges were close to or below regulatory requirements, the authors recommended fiber check dams as an alternative to the sediment traps and rock check dams (McLaughlin et al. 2009b).

Check dams also are used in vegetated swales and grassed waterways to improve sediment deposition. Application in vegetated swales and waterways is described in subsequent sections of this chapter, where those biofilters are covered in greater detail.

Reactive Barriers

Filter berms and filter socks are the two types of reactive barriers currently on the market. Filter berms and filter socks physically differ from one another only in that the former are non-encased, and the latter are encased, accumulations of compost or mulch material. Thus, filter berms are simply piles or dikes of compost or mulch material used to control erosion (U.S. EPA 2010a). Filter socks are 8-, 12-, 18-, or 24-inch-diameter (Faucette et al. 2006) tubes made from mesh netting (e.g., polypropylene) that are filled with an organic compost or mulch, or both, and sealed on both ends (Faucette et al. 2009a, Shipitalo et al. 2010). During installation, filter berms and socks are laid on the ground along the perimeter of disturbed areas and along the contour at intervals (i.e., as slope interrupters) on the slope to detain sheet flow (Miller and Joaquin 2011). Filter berms are incompatible with concentrated flow (Alexander 2006, Storey et al. 2006, U.S. EPA 2012) because they are prone to washouts and failure in concentrated flow. Filter socks also may be used in vegetated waterways, swales, ditches, and similar (nonperennial) channels to control limited amounts of concentrated runoff (Alexander 2006, Shipitalo et al. 2012). Filter socks and berms are recommended for relatively steeply sloping surfaces, ranging from >4:1 to 2:1 grade (horizontal:vertical), where the likelihood for erosion is high and other types of surface erosion control may be less suited (Alexander

2006, Risse and Faucette 2001, Storey et al. 2006). Their ability to absorb substantial amounts of water allows them to remain effective on steep slopes (Risse and Faucette 2001), as long as inflows do not become concentrated.

The material in filter berms and socks may be nonmineralized (e.g., mulch), mineralized commercial or municipal organic wastes, or both (Alexander 2006). In most cases at least some portion is mineralized (i.e., humus), in which case these barriers are referred to as "compost filter berms" or "compost filter socks." However, the composts in filter berms and socks have substantially larger particle size distributions than that of composts used for planting and growing purposes (Faucette et al. 2006). The U.S. EPA provides recommendations for particle-size mixtures in its menu of BMPs for construction (U.S. EPA 2012). These recommendations essentially follow the specifications developed by the American Association of State Highway and Transportation Officials (AASHTO) (Alexander 2003).

Both filter berms and filter socks can be seeded to provide vegetative growth on the structure to help enhance stability (Storey et al. 2006). Seeding is usually done when at least part of the structure is made of compost rather than simply nondecomposed mulch, as the former provides a more suitable growing medium. Seeds can be mixed into the organic material as it is fed into the netting or before it is positioned on the ground, or they can be applied to the structure's surface after the material is positioned on the ground (Miller and Joaquin 2011; U.S. EPA 2010a, 2010b). In the case of filter socks, the mesh netting does not interfere with seed establishment because it has relatively large openings through which the seed can come into contact with the compost (Faucette et al. 2009a).

If filter socks are not seeded, they generally are used as temporary structures. When no longer needed, they are cut open, the mulch is spread around the area, and the synthetic netting is removed (U.S. EPA 2010b). When filter socks are left onsite, the netting should be biodegradable so it mineralizes in place (Miller and Joaquin 2011). Filter berms also may be left intact onsite following use, or the organic material may be dispersed around the area as a soil amendment (Storey et al. 2006).

In contrast to nonreactive barriers, reactive barriers depend only partially on ponding for sediment retention (Shipitalo et al. 2010; U.S. EPA 2010a, 2010b). As water passes through reactive barriers, chemical sorption onto the organic mulch or compost materials also is critical for sediment retention (Faucette et al. 2008)—it is this chemical adsorption that has led to characterizing these barriers as "reactive" (Shipitalo et al. 2010). The initial demonstration of the importance of filtration and sorption in compost barriers is largely credited to Keener et al. (2007). They documented slower and shallower ponding behind compost filter socks than behind silt fence even though the filter socks retained approximately the same amounts of sediment as silt fence (Faucette et al. 2008). It is believed that some small particles are filtered out when water passes by the sorption sites of larger sediment particles that previously have been adsorbed onto the filter media in the barrier (Demars and Long 2001). Faster flow-through rates with comparable or greater retention by reactive barriers means that they do not have to be as tall as silt fence to accommodate a given nonconcentrated inflow rate (Faucette et al. 2006, Keener et al. 2007).

Filtering and sorption occur by the combination of physical retention of solids among organic particles (i.e., blinding and clogging) and by chemical adsorption of charged particles onto the organic material in berms and socks (Faucette et al. 2009a). The humus fraction of compost provides both positively and negatively charged exchange sites (Faucette et al. 2006), both of which adsorb oppositely charged particles contained in runoff (Faucette et al. 2006). This ability is very important for retaining small particles that are not well retained by traditional nonreactive barriers. Clay- and silt-sized particles are difficult to retain without adsorption because they have very low settling velocities and can pass through porous barriers. Clay particles have net negative charges (Brady 1984), so they can be adsorbed by positive sites in filter media (Faucette and Tyler 2006). Silt particles do not possess a charge per se, but organic matter bound to them can provide positive or negative charges (Schafer 2008) for adsorption onto oppositely charged sites in filter berm or filter sock media. Faucette et al. (2009a) found filter socks removed 65 percent of both clay- and silt-sized particles (< 2-μm and 2- to 50-μm diameter,

respectively); 60 percent of 0.01- to 5.75-μm-diameter particles, and 80 percent of 5.75- to 19.95-μm-diameter particles, were removed.

For both filter berms and filter socks, the three-dimensionality of the organic media and the mixture of organic particle sizes play important roles in filtration (Faucette et al. 2006, 2009b; U.S. EPA 2012). The open design of the sock mesh itself does not impede water entry into the organic material (Faucette et al. 2009a, 2009b). But too many small particles in a berm or filter sock hinder flow through the structure, reducing the sediment control effectiveness; conversely, too many large particles will not effectively trap sediment particles (Storey et al. 2006). Optimally, the three-dimensionality and the particle-size mixture allow runoff to flow through the media along tortuous pathways, thereby increasing the surface area and spatial area of compost contacted by inflow to encourage filtration and sorption (Faucette and Tyler 2006).

Ion exchange and filtration are a function of time of contact (Shipitalo et al. 2010), so it is not surprising that the amount of suspended solids retained by filter socks has been shown to be inversely related to flow-through rates (Faucette et al. 2006). Based on a review of particle sizes used in compost mixtures for sediment control, Faucette et al. (2006) concluded that smaller particle size distributions (i.e., <0.25 inch) of compost filter media remove more fines from runoff than larger filter-media particles. Thus, if pollutant removal by a given mixture is found to be inadequate, a greater portion of smaller particles can be added to improve retention; these particles can be added to the surface of the barrier (Demars and Long 2001). However, smaller particle sizes result in slower flow-through rates, which can lead to overtopping of filter socks and berms if inflow contains high concentrations of sediment that clog large amounts of voids and reduce flow-through rates (Faucette et al. 2006). Clogging and reductions in flow-through rates also can occur as increasingly more small particles from runoff are retained (Demars and Long 2001). Taller berms or larger diameter socks may compensate for the reduced hydraulic flow rate, so these factors should be considered in the design of the barriers (Faucette et al. 2006).

Most filter berm studies have been flume or laboratory studies, or short-term field studies on small plots.

Reported removal rates of solids from these studies have been variable. About 92 percent of total settleable solids and 96 percent of TSS were removed by using filter berms constructed of mixed-material residential yard wastes on 32-ft-long slopes of 34-percent grade during five rain events (Ettlin and Stewart 1993). From a single simulated storm event, Faucette et al. (2009b) observed that a compost filter berm reduced total solids concentrations and loads by 54.8 percent and 63.5 percent, respectively, and reduced TSS concentrations and loads by 51.3 percent and 60.4 percent, respectively. With an inflow sediment concentration of 340 g L^{-1}, Demars et al. (2000) found that 99 percent of the total solids were removed with a compost medium having a particle size distribution adhering to U.S. EPA specifications. With higher inflow concentrations of sediment (500 g L^{-1}) two compost particle size distributions not meeting EPA specifications also removed 99 percent of total solids. In a separate study by Faucette et al. (2005), more than doubling the sediment concentration (to 1,200 g L^{-1}) did not reduce the removal efficiency (98-percent efficiency) of a filter berm containing compost medium with a particle size distribution not meeting EPA specifications. In contrast, another compost medium that did not meet EPA specifications subjected to an inflow sediment concentration of 500 g L^{-1} removed only 20 percent of total solids (Demars and Long 2001). The latter compost mixture had the lowest percentage (6 percent) of compost particles capable of passing through a 0.25-inch mesh compared to 18 to 93 percent of particles in the other studies; therefore, it could not effectively trap/sorb sediment particles (Storey et al. 2006).

Physical failure of filter berms results in runoff bypassing much of the organic medium, making them ineffective at removing pollutants. Storey et al. (2006) found 14 of 15 unseeded filter berms failed within 16 min of exposure to 0.25 ft^3 s^{-1} inflow rates on a 3-percent slope (i.e., simulating a shallow concentrated runoff). Each berm was constructed to Texas Department of Transportation specifications by using one of three different materials: dairy manure compost, yard waste compost, or biosolid compost. Longitudinal displacement of berm materials and berm breakthroughs were common on clay soil, whereas berms on sandy soil were susceptible to undercutting of the soil on which

the berm was constructed after runoff infiltrated into the soil behind the berm. Seeding appeared to have increased stability and decreased failures; the filter berms had been seeded 45 days before the introduction of runoff although there was little evidence of vegetative growth on the composted yard waste berms at the time of experimentation. All of the berms were capable of structurally withstanding three runs with inflows of 0.35 ft^3 s^{-1} (Storey et al. 2006), even though these inflow rates resulted in overtopping the berm and were higher than inflow rates that caused failures of the unseeded berms. There are, however, few other data to suggest that seeding provides more stable berms or more effective pollutant removal.

The quality of compost and mulch in filter berms and socks also has consequences for the quality of the water flowing from these barriers. Leaching from the organic material composing the berm or sock can result in increased levels of TSS and total dissolved solids in water flowing from the barriers compared to inflow waters. This was the case during "first flush" effects for berms constructed of composted yard wastes, composted dairy manure, and composted biosolids (Raut Desai 2004, Storey et al. 2006). The yard waste compost resulted in the highest TSS in flow-through water, but leached the least amount of nutrients. The authors noted that the leachate concentrations were insufficient to have caused a problem in receiving waters, but in practice the outcome may be different with actual storm inputs. Consequently, the quality of compost materials is an important consideration and the reason that media for filter berms and socks should meet physical and chemical specifications (Alexander 2006). Criteria for compost quality are changing as research becomes available (Alexander 2006).

Filter socks provide a significant design improvement over filter berms because the encasement of organic materials makes the barriers less susceptible to failure (Raut Desai 2004). Almost all reports of sediment capture by filter socks originate from laboratory studies, but they consistently show good to excellent performance. Tests of 10 compost products from commercial and municipal composting operations in the United States, Canada, Japan, and New Zealand showed that 4 of the products removed 100 percent of total solids and the remaining 6 products each removed more than 95 percent of total solids in single test runs (Faucette and Tyler 2006). Through three consecutive runs, the average removal of TSS was 71 percent. The rate increased from 58 percent to 69 percent to 84 percent with each successive run, showing that the ability to retain particles was not diminished through the short term by repeated sediment-laden inflows.

A comparison of 12- and 18-inch-diameter filter socks containing identical mixtures of compost materials found that both removed an average of 70 percent of total suspended sediment (Faucette et al. 2006). Another comparison of 8- and 12-inch-diameter compost filter socks showed average TSS concentration removal efficiencies of 75.9 percent and 71.4 percent, respectively, for a single simulated runoff event (Faucette et al. 2009b). When expressed as loads, effectiveness was higher by about 10 percent, at 83.9 percent and 84.9 percent for the 8- and 12-inch socks, respectively. The percentages of total solids removed were similar to these values. Removal efficiencies for total solids concentrations were 76.3 percent and 72.7 percent and for loads, 84.3 percent and 85.0 percent, respectively, for 8- and 12-inch-diameter filter socks. In a bench study by Faucette et al. (2008) that used several different runs with different compost media (not all particle-size mixtures met AASHTO specifications), compost filter socks removed 62 to 87 percent of TSS. Sadeghi et al. (2006) found almost identical removal efficiencies during tests of six types of filter socks. Total suspended solid loads were reduced by 68.3 to 89.7 percent.

The ability of filter berms and filter socks to filter and sorb clay and silt particles can contribute to controlling turbidity, but the actual effectiveness is largely dependent upon the chemical constituency of the organic materials used in the barrier. Faucette et al. (2009b) observed turbidity reductions of 8.1, 28.6, and 19.1 percent, using a mulch filter berm, an 8-inch-diameter filter sock, and a 12-inch-diameter filter sock, respectively, after a single storm. Using bench studies, Sadeghi et al. (2006) reported turbidity reductions by compost filter socks of 52.5 to 77.8 percent. Turbidity was reduced an average of 24 percent across 45 different compost media in filter socks, and even with high inflow, a filter sock reduced turbidity by 21 percent (Faucette et al. 2006).

The addition of flocculating coagulants and polymers (including PAM; see the Soil Conditioners section in Chapter 6 for more information on these chemicals) can enhance retention of sediment by filter socks and berms. Flocculants and polymers can be added internally or externally to filter berms and socks. In a comparison of compost filter socks with and without flocculating and coagulating agents, Faucette et al. (2008) reported TSS removals in the range of 91 to 97 percent compared to 62 to 87 percent without the chemical agents. When identical particle-size mixtures were used in all tests, TSS removal remained at 91 to 97 percent with sediment-targeting flocculating agents but was 78 percent without polymers. Sadeghi et al. (2006) reported similar high levels of removals of TSS loads by compost filter socks with polymers, ranging from 94 to 98 percent.

However, the benefit provided by polymers is more apparent for turbidity. Sadeghi et al. (2006) reported turbidity reductions of 79 to 98 percent by compost filter socks with polymers. Faucette et al. (2006) found that 12- and 18-inch-diameter filter socks with PAM or polysaccharide polymers reduced turbidity by averages of 74 percent and 84 percent, respectively. The larger reductions with the larger diameter socks were attributable to the greater distance that runoff had to travel within the barrier, which resulted in greater contact with the compost medium within the sock.

Polymer additions may be most useful when the barrier is designed to handle large inflows for which some degree of sediment retention otherwise may be sacrificed (Faucette et al. 2006). Under high flow situations, turbidity was reduced by up to 90 percent with PAM and up to 77 percent when the polysaccharide polymer was applied to the media in an 18-inch-diameter filter sock, compared to 58 percent with no polymers (Faucette et al. 2006). Thus, compost filter socks, especially in combination with polymer flocculants or coagulants, may provide an effective alternative BMP in situations where turbidity-based water-quality standards are not attainable with barriers unable to retain suspended fines. The longevity of polymer effectiveness has not been studied with filter socks or berms (Faucette et al. 2006), and it is unknown whether the duration of efficacy is similar to that found when polymers are applied to the soil surface for erosion control (see Chapter 6).

The charged nature of compost also provides opportunities for sorption of other ions and chemicals by filter berms or filter socks. These constituents include nutrients (e.g., phosphorus), bacteria, herbicides, metals, and petroleum products, though removal only of petroleum compounds and metals is discussed here as these materials are the most often associated with road construction and use. Papers by Faucette and Tyler (2006), Faucette et al. (2006, 2008, 2009a), Shipitalo et al. (2010), and Storey et al. (2006) provide information on the efficacies associated with nonmetal and nonpetroleum types of chemicals and organisms.

Only a couple of studies have examined the efficacy of filter berms or filter socks in removing petroleum compounds or metals. The existing data suggest that both types of materials can be removed from runoff with berms and socks, but petroleum products are captured more effectively. In individual test runs, six of seven compost mixtures in filter socks removed at least 96 percent of motor oil and the seventh removed 85 percent (Faucette and Tyler 2006). With three consecutive runs, seven filter socks removed nearly 100 percent of the motor oil. Tests of 45 organic media in filter socks had a similar high average removal rate (89 percent) for motor oil (Faucette et al. 2006), and an average of 84 percent in another study using U.S. EPA-approved compost medium in 3 replicate filter socks (Faucette et al. 2009a). Average diesel fuel removal was 99 percent, whereas gasoline capture averaged only 43 percent (Faucette et al. 2009a). Additions of a petroleum flocculating agent had a negligible effect on the amounts of petroleum chemicals removed (Faucette et al. 2009a). The flocculating agent increased removal of the motor oil to 99 percent and removal of gasoline to 54 percent, but neither was significantly higher than without the flocculating agent. Diesel fuel capture with the flocculating agent stayed at 99 percent.

Faucette et al. (2009a) reported moderately effective capture of metals with filter socks, though there was little increase in effectiveness when a metal flocculating agent was added externally to the socks (Table 25). Additionally, specific forms of some metals were poorly retained; only 17 percent and 29 percent of soluble chromium was retained with and without the flocculating agent, respectively, and less than 50 percent of sediment-bound copper was captured regardless of use of the flocculating agent.

Table 25.—Percentage of metals in inflow removed by compost filter socks alone and compost filter socks in combination with a metal flocculating agent applied externally to the socks (data from Faucette et al. 2009a)

Erosion control	Constituent form[a]	Cadmium	Chromium	Copper	Nickel	Lead	Zinc
		-- percent --					
Filter sock only	Soluble	64	17	68	61	72	53
	Sediment-bound	73	75	42	60	70	64
	Total	64	37	67	61	71	54
Filter sock + metal flocculant	Soluble	72	29	70	69	79	57
	Sediment-bound	77	78	45	63	61	47
	Total	73	47	70	69	73	53

[a] Inflow inputs included 500 ml of 15 ppm concentrations of each metal.

Comparative Studies of Nonreactive and Reactive Barriers

It is difficult to compare the effectiveness of nonreactive and reactive barriers as determined in different studies, even qualitatively, because of the myriad differences in conditions that could influence overall performance. However, a few papers have compared different types of reactive and nonreactive barriers, so the opportunity is taken here to review these studies. They tend to have little, if any replication, but they do provide insight into performance with identical inflows, sediment concentrations, slopes, and other variables.

Results from Demars et al. (2000) may be the most applicable to field use as the tests were longer term and involved natural rain events. They compared silt fence, a hay bale berm, and a compost (wood waste) filter berm during 11 events of varying intensity and magnitude over about 5 months. Compared to controls of bare ground plots with no erosion control, all three erosion control techniques performed well on 2:1 (horizontal:vertical) slopes; the compost filter berm performed best, followed by the silt fence and hay bale berm (Table 26).

Keener et al. (2007) reported nearly the same level of performance for both compost filter socks and silt fence (Table 26), but compost filter sock effectiveness was mediocre compared to most other filter sock studies (e.g., those described previously). Keener and colleagues

found compost filter sock effectiveness to be consistently less than 50 percent, even for low inflows.

Faucette et al. (2009b) compared two different diameter filter socks with and without polymer additives, a mulch filter berm, and a straw bale barrier. All barriers significantly reduced both concentrations and loads of total solids and TSS (Table 26). The compost sock treatments retained significantly more total solids and TSS (concentration and load) than either the mulch filter berm or straw bale barrier. The filter berm and straw bale also were less effective than all other treatments at reducing turbidity (Table 26); the addition of the polymer to the filter socks significantly improved their ability to reduce turbidity (Faucette et al. 2009b). The TSS removal effectiveness reported by Faucette et al. (2005) for mulch filter berms was much better than the aforementioned study, and silt fence performance in the 2005 study also was much better than many other studies (Tables 26 and 23).

Ettlin and Stewart (1993) compared the effectiveness of filter barriers against silt fence placed at the base of 32-ft-long plots on 34-percent slopes on a closed landfill in Oregon. The filter barriers were composed of mixed types of yard debris compost. They removed substantially more settleable solids and TSS for five events (1.6 inches of rainfall) than the silt fence. Final results for settleable solids and TSS were 2.9 mg L^{-1} and 1,300 mg L^{-1}, respectively, for the filter barriers

Table 26.—Comparisons of different types of nonreactive and reactive barriers within individual studies

| Reference/Comments | Type of erosion control barrier | Removal efficiency | | | | |
		Total solids concentration	Total solids load	TSS[a] concentration	TSS load	Turbidity reduction
		-- *percent* --				
Demars et al. (2000)	Geosynthetic silt fence				98.4	
11 natural rain events of varying intensity and duration	Hay bale				98.0	
	Wood compost filter berm				99.8	
Faucette et al. (2009b)	8-inch-diameter compost filter sock	76.3	84.3	75.9	83.9	28.6
	12-inch-diameter compost filter sock	72.7	85.0	71.4	84.9	19.1
	8-inch-diameter compost filter sock + polymer	77.1	86.3	75.8	84.7	49.1
	12-inch-diameter compost filter sock + polymer	80.7	88.2	83.1	89.5	41.8
	Mulch filter berm	54.8	63.5	51.3	60.4	8.1
	Straw bale	65.1	71.3	53.8	61.5	11.8
Faucette et al. (2008)	8-inch-diameter compost filter socks with various particle size distributions			62–87		53–78
	8-inch-diameter compost filter sock + polyacrylamide			91		79
	8-inch-diameter compost filter sock + polymer			97		94
	8-inch-diameter compost filter sock + copolymer			97		98
	Silt fence			63–87		

(continued)

Table 26.—Comparisons of different types of nonreactive and reactive barriers within individual studies

| Reference/Comments | Type of erosion control barrier | Removal efficiency | | | | |
		Total solids concentration	Total solids load	TSS[a] concentration	TSS load	Turbidity reduction
		-- *percent* --				
Faucette et al. (2005)	Mulch filter berms		96			
	Silt fence		95			
Keener et al. (2007) Flume study with 30-min flows for each structure	8-inch-diameter compost filter sock with 0.126 L s^{-1} inflow	42.8[b]				
	8-inch-diameter compost filter sock with 0.252 L s^{-1} inflow	20.4[b]				
	8-inch-diameter compost filter sock with 0.315 L s^{-1} inflow	30.0[b]				
	12-inch-diameter compost filter sock with 0.126 L s^{-1} inflow	50.0[b]				
	12-inch-diameter compost filter sock with 0.252 L s^{-1} inflow	43.1[b]				
	12-inch-diameter compost filter sock with 0.315 L s^{-1} inflow	26.1[b]				
	24-inch-width silt fence with 0.126 L s^{-1} inflow	56.0[b]				
	24-inch-width silt fence with 0.252 L s^{-1} inflow	41.9[b]				
	24-inch-width silt fence with 0.315 L s^{-1} inflow	32.7[b]				
Sadeghi et al. (2006) Bench study	Compost filter socks				68.3–89.7	52.5–77.8
	Compost filter socks + polymer				94.0–98.2	79.2–98.0
	Silt fence				71.5–89.1	44.8–76.0

[a] TSS = total suspended solids.
[b] Estimated from Figure 10 in Keener et al. (2007).
Empty cells indicate variable was not measured.

compared to 32 mg L^{-1} and 26,000 mg L^{-1}, respectively, for silt fence. These silt fence values were similar to controls, where no erosion control devices were installed (34 mg L^{-1} and 31,000 mg L^{-1}, respectively).

Biofilters

Biofilters take many different forms, but are always composed of vegetation. While the vegetation itself contributes to erosion control through soil stabilization and soil cover (see Chapter 6), the primary role of biofilters is to stop sediment transported by water from reaching downslope water bodies. This is achieved through sediment deposition, by slowing water, encouraging water infiltration, or both. For some types of biofilters, such as forest buffer strips, other features that provide roughness at the soil surface are critical for limiting sediment transport.

There tends to be inconsistency in the terms "length" and "width" in biofilter literature. Consequently, to avoid confusion, the terms used in most of the literature are used here; that is, in this chapter the direction along the contour is referred to as the "width" and the downslope direction of flow is referred to as the "length." Note that this is opposite of the terminology typically used for buffer strips in forestry literature, where "width" denotes the downslope distance.

Buffer Strips

Buffer strips are a major category of vegetation-based pollution controls. They are designed to remove primarily sediment (Correll 1996, Dillaha et al. 1989, Hayes et al. 1984, Magette et al. 1989), though they also have some ability to remove nutrients and other chemical constituents (Dillaha et al. 1989, Magette et al. 1989). They differ from vegetated swales and waterways (described later) in two distinct ways. First, buffer strips are not channels, so they are not designed to be submerged; and second, their largest dimension (i.e., width) runs approximately along the contour, perpendicular to the direction of runoff that is cast onto them (Deletic and Fletcher 2006).

The two types of buffers described in this chapter are vegetated filter strips (VFS), and forested buffer strips. VFS have most commonly been associated with agricultural applications, but their use in urban areas and along or in the medians of roadways has been increasing. However, their effectiveness for these latter areas has not been studied as intensively as for agriculture (Deletic 2005). They typically are composed of herbaceous cover, primarily grasses, although in agricultural fields they may consist of agricultural crops (Hayes et al. 1984).

Forest buffers are used in forests for a variety of reasons in addition to sediment trapping, including aquatic habitat protection such as shade and water body bank stabilization. For sediment control, forest buffers differ from VFS in several ways. They predominantly depend upon overstory vegetation and resultant litter to provide infiltration and filtration mechanisms, and they tend to be longer than VFS. Typical VFS might be 5 to 15 m long (e.g., Abu-Zreig et al. 2003, Daniels and Gilliam 1996, Dillaha et al. 1987, Schmitt et al. 1999), whereas typical forest buffer length in the United States and Canada ranges from 15 to 30 m (Lee et al. 2004). Additionally, VFS are positioned immediately adjacent to or are interspersed within the potential pollutant source (e.g., a roadway or an agricultural field, respectively); a forest buffer is located adjacent to the water body it is intended to protect. Forest buffers and VFS positioned along water bodies commonly are called riparian buffers. However, when a forest road is located sufficiently close to a water body, the forest buffer also may be adjacent to the road and span the entire distance between it and the water body.

VFS and forest buffers very frequently are collocated along forest roads: the area immediately adjacent to the road (typically the fillslope) has grass or herbaceous vegetation that serves as a VFS, which leads into a forest buffer farther downslope. However, most forest buffer literature makes little distinction between the VFS and the forest buffer, and both features are collectively referred to as the "forest buffer." Only a few papers have examined the importance of the VFS separately from the adjoining forest buffer, so to ensure that these papers are described, they are discussed at the end of the VFS subsection. The Forest Buffers and Windrows subsection includes the more conventional review of forest buffers, and discusses them only in relation to water quality (primarily sediment). Even though forest buffers provide a myriad of other benefits (e.g., for wildlife), the attributes that make them effective for protecting water quality do not necessarily make them effective for other

purposes (Richardson 2004). Readers interested in other facets of forest buffers are directed to papers by Barling and Moore (1994) and Belt et al. (1992).

Forest buffers used in an agricultural setting are a specialized, third type of buffer. They are composed of trees, sometimes in association with other herbaceous, grass, or shrub vegetation, positioned along waterways. Their purpose is to protect waterways from sediment, nutrients, pesticides, and other chemicals in runoff originating from upslope agricultural areas. Because the high nutrient and chemical loads present in agricultural runoff are not associated with forest road construction or use, these buffers are considered only from the context of sediment reduction. Readers who are interested primarily in forest buffers from the perspective of other nutrients and chemicals may review papers by Peterjohn and Correll (1984), Corley et al. (1999), Schmitt et al. (1999), Lee et al. (2003), and Schoonover et al. (2005) as a starting point for coverage of these topics.

Vegetated Filter Strips

There are two primary types of VFS used for erosion control: conventional strips that are composed of relatively common types of flexible vegetation, such as fescue (*Festuca* spp.), ryegrass (*Lolium* spp.), bluegrass (*Poa* spp.), and orchardgrass (*Dactylis glomerata*) (Abu-Zreig et al. 2004), and those composed of stiff, erect (and usually tall) vegetation (Blanco-Canqui et al. 2004). The term "VFS" often is used for both, but the stiff grasses are distinct from conventional VFS (Dabney et al. 1993) and are often specifically referred to as "grass hedges" or "grass barriers" (Blanco-Canqui et al. 2004, Meyer et al. 1995). Switchgrass (*Panicum virgatum*), which is native or has become naturalized in much of the United States, along with nonnative tropical grasses, especially vetiver (*Chrysopogon zizanioides*, formerly known as *Vetiveria zizanioides*), are commonly employed in stiff grass hedges (e.g., see Dabney et al. 1995, Dalton et al. 1996, Desbonnet et al. 1994, Owino and Gretzmacher 2002, Shariff 2000, Truong 2000).

Conventional VFS and grass hedges have some important differences but also share many similarities. The most important similarity is that they both depend upon the vegetation in the strip as the key for providing sediment control. The vegetation provides roughness, which reduces

energy and transport capacity (Deletic and Fletcher 2006, Gumiere et al. 2011, Hösl et al. 2012) by decreasing the speed of flow to encourage sediment deposition, filtering, and infiltration (Prosser et al. 1995). The abatement of water's shear stress by vegetation also reduces soil scour within the filter strip (Prosser et al. 1995).

The ability to provide these benefits across a variety of inflows depends in large part upon the flexibility or stiffness of the plants in the filter strip. That is, energy control is derived primarily from the roughness of the vegetation, which is directly related to the flexibility or stiffness of the plant and stem density. Flexible grasses, even when dense, have less strength and lower moduli of elasticity (i.e., less ability to return to their original shape when deformed by a force) than stiff grasses. As a result they will bend and fail in the presence of high velocities, submergence, or sediment inundation (Dillaha et al. 1982, Kouwen et al. 1981) more easily than stiff grasses, which can withstand much greater inflow rates, water depths, and sediment weights (Dillaha et al. 1982, Dunn and Dabney 1996, Kouwen et al. 1981). In a prone position, grass blades provide substantially less roughness and energy dissipation than when upright (Fiener and Auerswald 2006, Kouwen and Unny 1973) and hence little ability to retain sediment. For example, Meyer et al. (1995) found that fescue grass failed under a range of tested inflow rates and was only marginally effective at trapping sediment. In contrast, stiff grasses can become fully inundated and overtopped with water and still withstand bending or breakage (Boubakari and Morgan 1999). Consequently, even though the water column above the top of the plants may have high velocity and shear stress, the shear velocities within the plant's (upright) height are much lower, allowing sedimentation to occur (Pethick et al. 1990, Prosser and Dietrich 1995).

Because flexible plants have limited strength and moduli of elasticity, conventional VFS are effective only when inflow occurs as sheet flow (Barfield et al. 1979; Blanco-Canqui et al. 2004; Dillaha et al. 1986, 1989; Hösl et al. 2012). Sediment removal rates exceeding 70 percent have been reported with conventional VFS for sheet flow (Dillaha et al. 1986, 1988, 1989; Neibling and Alberts 1979), but as inflow rates increase they tend to become less effective (Dabney et al. 1995, Gharabaghi et al. 2006, Meyer et al. 1995).

The strength and density of most grasses used for hedges (i.e., typically stiff, erect grasses) allow them to be employed in concentrated flow in rills, and even ephemeral gullies (Blanco-Canqui et al. 2004, Dabney et al. 1993, Van Dijk et al. 1996). However, even though grass hedges can retain sediment in concentrated flow, they still perform best when subjected only to sheet flow (Xiao et al. 2010) as deposition, filtering, and infiltration depend upon the ability to spread water out (Prosser et al. 1995).

Even though the means for energy dissipation and particle settling depend upon vegetation's roughness, a substantial portion of sediment deposition ironically occurs before (i.e., upslope of) the leading edge of the vegetated strip. In most applications, conventional VFS and grass hedges receive inflows from areas with little roughness (e.g., agricultural fields, feed lots, roads, urban areas), so when inflow reaches a strip, water spreads out along the contour and builds up in response to hitting the "plant wall" (Blanco-Canqui et al. 2004, Dillaha et al. 1987, Neibling and Alberts 1979). The wall slows the water and promotes sedimentation behind the leading edge of the strip (Boubakari and Morgan 1999, Spaan et al. 2005). For grass hedges this is typically referred to as "ponding" because the water may become deep. For conventional VFS the term "ponding" may be used, but the more subtle term "back water" is sometimes favored (e.g., Loch et al. 1999) to denote the generally lower amount and depth of water because incoming water should be as sheet flow.

Ponding and back water development are critical to sedimentation because settling is inversely related to flow velocity (Spaan et al. 2005), and slowed water results in greater sediment deposition than would occur from the presence of the vegetation alone, even if all inflow occurs as sheet flow. Detention of water behind the vegetative wall also helps encourage infiltration (Blanco-Canqui et al. 2004, Deletic 2001), which contributes to sediment settling.

Ponded water and back water are concentrated water, but they differ from concentrated flow in that ponded water or back water moves into the VFS as sheet flow (Loch et al. 1999) and not in discrete pathways or rills. Flow delivered as concentrated flow can become ponded and transformed to sheet flow if the density and stiffness of stems or grass blades are sufficient to back water up and disperse it laterally without plants failing (Blanco-Canqui et al. 2004).

Ponding, infiltration, and sediment trapping efficiencies of VFS are directly related to the density of vegetation (Boubakari and Morgan 1999, Polyakov et al. 2005, Spaan et al. 2005). Sparse or open vegetation may have little influence on slowing velocities, backing up water, and promoting sediment settling. Depending upon the characteristics of the plants involved, sparse vegetation can sometimes increase the velocity of water moving through the vegetated strip by concentrating water into the spaces between plant stems or bunched plants (Spaan et al. 2005). As the water is compressed through smaller openings that have little roughness, velocities increase, thereby negating the potential for settling while increasing the tendency for rill erosion (Boubakari and Morgan 1999, De Ploey et al. 1976).

Ponding or back water can be enhanced by positioning the VFS (including grass hedges) at or slightly above the elevation of the upslope contribution lands and installing the strip on a gentler slope or with an inverse slope compared to the contributing area. Slope control techniques allow water to slow and pile up more than if the strip simply was positioned adjacent to and on the same slope gradient as the contributing area (Deletic 2001), thereby encouraging sheet flow, settling, and infiltration to occur. Sediment capture typically is strongly related to the slope of a VFS (conventional or grass hedge). Dillaha et al. (1989) reported that sediment retention was inversely related to slope for VFS gradients ranging from 5 to 16 percent. Sediment concentrations in runoff from the outflow of a VFS on a 12-percent slope were twice as high as those from a 7-percent slope (Robinson et al. 1996). Xiao et al. (2010) found a slope of 20 percent resulted in a 54-percent reduction in runoff compared to a 77-percent reduction with a 5-percent slope. Even under concentrated flow, greater sediment retention has been documented on gentle slopes (5 percent) compared to sheet flow on steeper slopes (11 percent and 16 percent) (Dillaha et al. 1989).

However, care must be used when ponding is enhanced to encourage sediment deposition. Even if inflow occurs as sheet flow, there is a maximum degree of inundation that can occur before the vegetation becomes ineffective

at controlling the factors that contribute to pollution reduction, especially when the VFS is dominated by flexible vegetation. When water becomes too fast or deep, hydrostatic, hydrodynamic, and sediment weight forces can cause herbaceous plants to bend and fail (Dunn and Dabney 1996). The modulus of elasticity and the strength of switchgrass are four and three times, respectively, that of fescue, which explains why switchgrass has greater resistance to bending or breaking than fescue (Dunn and Dabney 1996). But even stiff-bladed plants will reach a point of failure at some level of water velocity or depth (Dillaha et al. 1989, Kouwen et al. 1981). Failure of vegetation in a VFS not only substantially reduces sediment deposition, but can also lead to scour within the VFS because preferential flow paths and rills can develop where vegetation has failed (Blanco-Canqui et al. 2004).

Ponding and settling also have the potential to create sediment berms at the front edge of the vegetated strip. Berms can retard movement of sheet flow into conventional VFS and grass hedges and can cause breakthroughs at weak points by the water stored behind them. Concentrated flow paths develop at the breakthroughs (Barrett et al. 1998b, Parsons et al. 1994), which can create cascading problems of preferential flow and scour pathways (Barrett et al. 1998b). Routine removal of these berms (Pankau et al. 2012) or installation of longer berms to encourage dispersion of concentrated flow to sheet flow over the long term (Parsons et al. 1994) may be necessary. This may be difficult to do effectively, however, because berm breakthroughs with measurable erosion have been observed even where only very small berms exist (including those less than a few centimeters in height) (Pankau 2010, Pankau et al. 2012).

Studies suggest that sediment deposition within a conventional VFS or grass hedge does not cause the same problems as berm formation at the leading edge. Sediment deposited in either type of VFS does not simply lie on the soil surface, but instead tends to become incorporated with the soil surface (Barrett et al. 1998b, Dillaha et al. 1989). Vegetation grows through it, and the roots and stems help bind captured soil and reduce its potential for resuspension.

Sedimentation is a function of the velocity of surface flow, so it is not surprising that large particles are removed most effectively by vegetated strips, as these settle out most easily (Neibling and Alberts 1979, Zanders 2005). In a flume study performed by Meyer et al. (1995), vetiver and switchgrass hedges trapped more than 90 percent of sediment greater than 125-µm diameter. The percentages that were retained declined as sediment size decreased, with only about 20-percent capture of particles smaller than 32-µm diameter. Pan et al. (2010) found that grass strips removed 30 percent more 10- to 25-µm-diameter particles than smaller fines. Gharabaghi et al. (2006) observed more than 95-percent retention of sediment particles larger than 40-µm diameter in runoff compared to about 65 percent for particles smaller than 12-µm diameter. Deletic and Fletcher (2006) found that VFS removed almost all particles from 57- to 180-µm diameter, but there was almost no reduction in particles less than 5.8-µm diameter. It should be noted that the percentage of fine clay and silt particles captured can be significant if soils are well aggregated and may contribute to the high retention rates just reported for larger diameter classes.

The slope of a VFS also influences the retention of large particles; as the slope increases, a smaller percentage of large particles is captured. VFS retained about 92 percent of particles greater than 50-µm diameter on 3-percent slopes compared to 75 percent on 15-percent slopes (Pan et al. 2010). For particles less than 10-µm diameter, about 46 percent was retained on 3-percent slopes and about 25 percent was retained on 15-percent slopes. Although the difference between retention on the gentle and steep slopes was only slightly greater for the small particles, the influence of steepness is of particular concern for small particles because they have an overall lower potential to be retained at all gradients.

Increasing the grade of the VFS decreases the effective length of the VFS; that is, a greater flow length is required to achieve the same sediment trapping efficiency (Pan et al. 2010), especially for small particles (Barfield et al. 1979, Line 1991). Increasing sediment concentrations and inflow rates similarly decreases the effective flow length. In some situations, flow rates and sediment concentrations or loads can be controlled by reducing the overall size of the contributing area relative to the area of the VFS (Magette et al. 1989, Van Dijk et

al. 1996). If variables that control the effective length cannot be altered or adjusted sufficiently, the length of the VFS may have to be increased (Deletic and Fletcher 2006), or additional BMPs, such as adding a mulch soil cover to all or part of the contributing area (Xiao et al. 2010), may be warranted. In all situations, techniques that encourage complete or nearly complete infiltration of inflow are required to retain very fine particles (Gharabaghi et al. 2006).

Although increasing the length of the VFS encourages greater sediment retention, a maximum length apparently exists for each field condition beyond which there is little advantage, in terms of sediment capture, to further increasing the length (Gharabaghi et al. 2006). The optimal flow length required to meet sediment retention goals may be fairly short for both conventional VFS and grass hedges because: 1) most sediment retention occurs in the back water area and first few meters of a VFS (Gharabaghi et al. 2006, Line 1991, Meyer et al. 1995, Neibling and Alberts 1979, Van Dijk et al. 1996), and 2) grass hedges are much shorter than conventional VFS (Dabney et al. 1993), yet they are reported to be more effective than VFS (Blanco-Canqui et al. 2004).

No rigorous, replicated experiments have been performed to identify VFS flow length guidelines for specific sets of environmental conditions, but 10 m may be sufficiently long to capture the majority of retainable sediment (Liu et al. 2008). Increasing the length from about 5 m to 10 m generally results in some improvement, though it can vary widely from almost no change in sediment retention to increases up to 30 to 40 percent (Dillaha et al. 1987, 1989; Magette et al. 1989; Van Dijk et al. 1996) (also see Table 27). Van Dijk et al. (1996) found that 90 to 99 percent of incoming sediment was removed within 10 m. Schmitt et al. (1999) found little improvement in sedimentation between 7.5 m and 15 m in three types of VFS composed of mixed grass, mixed grass and trees/shrubs, and sorghum (*Sorghum bicolor*), suggesting that extending VFS lengths up to 15 m provides little benefit to sediment retention.

The greatest advantage to using VFS lengths of a full 10 m may come in situations where sediment in runoff is dominated by fines (Gharabaghi et al. 2006), as capture of these particles (<0.45-µm diameter) is by infiltration

into soil pores (Gumiere et al. 2011). Doubling VFS length from about 5 m to 10 m approximately doubled infiltration rates (Dillaha et al. 1987). Neibling and Alberts (1979) also showed that clay concentrations in outflow from bluegrass VFS were directly related to strip length. More than 90 percent of the particles larger than 20-µm diameter were captured by strips as short as 0.6 m long compared to only 37 percent of the clay fraction. Increasing the VFS length to 1.2, 2.5, and 4.8 m substantially increased the clay fraction retention rates to 78, 82, and 83 percent, respectively.

Most studies show conventional VFS and grass hedges are reasonably effective at reducing sediment in runoff (Table 27). However, almost all of these studies have been nonreplicated or poorly replicated, or the data are observations from simple monitoring efforts (Gumiere et al. 2011, Hayes and Hairston 1983) done in small-scale settings, such as plots and flume experiments (Gumiere et al. 2011). In most of these situations, contributing areas, inflow rates, sediment levels, study duration, and overall conditions do not mimic field situations; consequently, their reported effectiveness may bear little resemblance to effectiveness measured in actual field conditions (Daniels and Gilliam 1996, Dillaha et al. 1989, Dosskey et al. 2008). A case-in-point comes from Dillaha et al.'s (1989) examination of 24 km of conventional VFS on 18 working farms in Virginia. They found most VFS (they did not specify how many or the length) were not functioning effectively because runoff was collecting in natural drainages due to the hilly terrain, causing the runoff to reach the VFS as concentrated flow rather than sheet flow. In fewer situations with flat terrain, sediment accumulations in older VFS (1 to 3 yr old) became so great that they caused runoff to flow parallel to the VFS until a low point. At those low points, runoff was directed through the VFS as concentrated flow, rendering the VFS less effective.

Variables contributing to or detracting from VFS effectiveness have been identified primarily from observations or small-scale, short-term empirical studies, and these have yielded only a general understanding about the sediment retention processes occurring under VFS installation as a working BMP. Little effort has been put into rigorous and quantitative examinations of physical processes or interactions that would allow prediction of expected runoff responses in different

Reference/ Type of runoff	Type of VFS[a]	Slope	VFS length or distance through VFS	Sediment reduction Concentration	Sediment reduction Mass	Comments
				----- percent -----		
Ahearn and Tveten (2008)/Highway	Mixed grasses	~4%	2 m	59–82		As TSS[b]
			4 m	93–96		
Barrett et al. (2004)/ Highway	Nonnative flexible grasses	5–33%	4.2–13 m		77–97	Range represents results from 8 locations; as TSS
Chaubey et al. (1995)/Agriculture	Fescue	3%	3.1–21.4 m	35		Sediment reduction not significantly different at 3-, 6-, 9-, 15-, and 21-m sampling points within VFS; as TSS
Dabney et al. (1995)/Flume experiment	Fescue hedge	5%	280 mm		15–46	Multiple flow rates; Dubbs I soil; flexible grass VFS identified as a hedge; as sediment
	Vetiver hedge		200 mm		34–60	
	Wild switchgrass hedge		200 mm		35–61	
Dillaha et al. (1988)/ Agriculture	Orchardgrass	3 replicates each of 5, 11, and 16%	4.6 m		81	VFS received inflow from simulated feedlot plots; average from 3 simulated rainfall events; as TSS
			9.1 m		91	
Dillaha et al. (1989)/ Agriculture	Orchardgrass	3 replicates each of 5, 11, and 16%	4.6 m		74	VFS received inflow from cropland plots; average from 6 simulated rainfall events; as TSS
			9.1 m		87	
Gharabaghi et al. (2006)/Agriculture	A variety of flexible grasses	~5%	First 2.5 m	50		Sediment reduction in second 2.5 m dependent upon inflow rate; most >40-µm-diameter particles removed in 5 m
			Next 2.5 m	25–45		
Ghate et al. (1997)/ Aquaculture effluent	Bermuda grass and bahaigrass	3%	24 m	18–90		High effluent application rate
				14–82		Low effluent application rate
		1.5%	24 m	45–73		High effluent application rate
				27–84		Low effluent application rate
						As suspended sediment for all 4 tests
Hayes and Hairston (1983)/Agriculture	Kentucky-31 fescue	~2.4%	25.7 m	23–89		Average percentage of sediment trapped during individual storms over 16 months; 2 replicates
				38–87		
Lee et al. (1999)/ Agriculture	Switchgrass	3%	3 m		69	As sediment
			6 m		78	
	Cool season grasses		3 m		62	Cool season grasses were bromegrass, timothy, and fescue; as sediment
			6 m		75	
Lee et al. (2000)/ Agriculture	Switchgrass	5%	7.1 m		70	As sediment
	Switchgrass + woody		7.1 m + 9.2 m		92	VFS order: switchgrass upslope, mixed shrubs and trees downslope; as sediment
Lee et al. (2003)/ Agriculture	Switchgrass	5%	7.1 m		95	As sediment
	Switchgrass + shrubs + trees		7.1 m + 4.6 m + 4.6 m		97	VFS order: switchgrass upslope, shrubs in middle, and trees downslope; as sediment
Line (1991)/ Agriculture	Ryegrass + fescue	5–5.5%	1.5 m		40–80	Contributing area was tilled soil; VFS had ~100% ground cover; both 3 and 6.1 m VFS had approximately the same efficiency; as sediment
			3.0 m		72–95	
			6.1 m		72–95	

(continued)

Table 27.—Studies documenting the effectiveness of vegetated filter strips (VFS) in reducing sediment

Reference/ Type of runoff	Type of VFS[a]	Slope	VFS length or distance through VFS	Sediment reduction		Comments
				Concen- tration	Mass	
				----- percent -----		
Magette et al. (1989)/Agriculture	Kentucky-31 fescue	Not stated	4.6 m		66	As TSS mass
			9.2 m		82	
Meyer et al. (1995)/Flume study	Vetiver	5%	200 mm		34–60	Sediment removal efficiency generally decreased with increasing flow rates
	Tall fescue		280 mm		15–46	---
	Wild switchgrass		200 mm		35–61	
	Fescue + wild switchgrass		350 mm		44–62	Fescue in front of wild switchgrass
	Kanlow switchgrass		760 mm		36–62	
Neibling and Alberts (1979)/Agriculture	Commercially available bluegrass sod	7%	0.6 m		37	Retention for sediment particle sizes <0.002 mm; all tests with shallow sheet flow
			1.2 m		78	
			2.4 m		82	
			4.9 m		83	
			0.6 m		56	Retention for sediment particle sizes 0.002–0.01 mm; all tests with shallow sheet flow
			1.2 m		70	
			2.4 m		94	
			4.9 m		95	
Paterson et al. (1980)/Agriculture	Fescue	3.4%	35 m	71		Dairy waste used for inflow; as suspended solids
Robinson et al. (1996)/Agriculture	Bromegrass	7%	3 m	70		As sediment concentrations
			9.1 m	85		
		12%	3 m	80		
			9.1 m	85		
Schmitt et al. (1999)/Agriculture	Sorghum	6–7%	7.5 m	63	79	As TSS
			15 m	65	93	
	2-yr-old grass		7.5 m	76	84	Predominantly switchgrass and fescue: as TSS
			15 m	87	96	
	2-yr-old grass + shrubs + trees		7.5 m	79	89	Grass upslope, shrubs in middle, trees downslope; as TSS
			15 m	88	94	
	25-yr-old grass		7.5 m	89	95	Mixed-grass hay field; as TSS
			15 m	93	99	
Van Dijk et al. (1996)/Agriculture	Grass strips	2–9%	1 m	50–60		Species not given; results from 2 sites with differing soil porosity; as sediment concentrations
			4–5 m	60–90		
			10 m	90–99		
Yonge (2000)/Highway	Native grass mix	Not stated	4.6 m	72		Period 1: 18 months; as sediment concentration
				95		Period 2: 3 months; as sediment concentrations; as sediment concentration

[a] Scientific names of VFS species may be provided in reference.
[b] TSS = total suspended solids.
Empty cells indicate variable was not measured.

types of field conditions with a reasonable degree of confidence (Deletic 2001). Consequently, even though a variety of design recommendations and suitability checklists for VFS installation have been developed (e.g., Dillaha and Hayes 1992), they are not well supported by a breadth of scientific or process-based studies (Dabney et al. 1993, Deletic 2001). Mathematical models, such as the Vegetative Filter Strip Model (Muñoz-Carpena and Parsons 2012), are available to assist with or evaluate VFS design (Dosskey et al. 2008, 2011), but most were developed for agricultural fields.

Applying results from VFS for mostly agricultural land uses to forests has even more unknowns because there have been so few studies of VFS in forests, particularly in association with roads. Roadside vegetation is different from traditional VFS vegetation. Most notably, roadside vegetated strips are not designed to intentionally back up and pond runoff due to the steepness of most forest roadside areas (e.g., fillslopes), the majority of flow received by the roadside vegetation is concentrated flow from road cross-drain features, and the attributes of areas that contribute to VFS from roads are very different from the attributes in agricultural applications. These differences could have a major influence on the specific processes at play in road-applied VFS performance and the consequent effectiveness of roadside vegetated strips.

Barrett et al. (2004) studied the effectiveness of grass strips adjacent to eight freeways in northern and southern California. Using VFS lengths ranging from 4.2 m to 13 m at 31 sites, they measured TSS reductions ranging from 77 to 97 percent. Ahearn and Tveten (2008) observed moderate to high TSS removals, with the effectiveness improving substantially with short distances. At 2 m from the edge of a road pavement, 59 to 89 percent of TSS was removed compared to 93 to 96 percent at 4 m from the edge. Yonge (2000) found that VFS along highways removed an average of 72 percent of TSS. The favorable BMP effectiveness of VFS in many agricultural settings and along highways suggests that VFS should be at least moderately effective in the application to both paved and unpaved forest roads.

As noted earlier, there are few studies associated with forest roads that have examined VFS effectiveness separately from the total vegetated strip/forest buffer

combination. Those that exist frequently show the VFS provides a greater contribution to sediment reduction than does the forest buffer. This is the case for sediment transport associated with nonconcentrated as well as concentrated runoff, though effectiveness is greater with nonconcentrated flow (e.g., with outsloped roads rather than cross-drain discharge).

Swift (1986) found that grass on the fillslope of newly constructed roads was capable of reducing sediment transport more than bare soils and more than mulched, ungrassed fillslopes. Maximum and minimum sediment transport distances (based on visual evidence) from roads were twice as long through bare soils and ungrassed fills compared to grassed fillslopes; these included measurements associated with concentrated culvert discharge and nonconcentrated drainage. Even on 60-percent slopes, sediment deposits did not extend more than 45 m on grassed fillslopes.

Hairsine (1997) found VFS to be more effective at retaining sediment than forest buffers of the same length, especially as runoff velocities increased. The combination of VFS and forest buffer within a riparian forest did little to increase sediment trapping compared to the VFS alone. Grass filter strips positioned downslope of the fillslopes and in forest plantations also had greater sediment retention and were more resistant to erosion than the forest floor (i.e., forest litter) on both steep and gentle slopes (29.1-percent and 6.3-percent grade, respectively) (Loch et al. 1999). Some litter scour was visible on the steep slope even when litter was thick, but where litter was thin all litter was scoured from the area. The grass filter strips captured sediment on both types of slopes, but effectiveness was much greater in the strips on the gentle slopes, especially with increasing grass strip length. Because these grass filters were positioned downhill from the fillslope on a gentler grade, they were capable of ponding water at the leading edge, which improved sediment retention. In the North Carolina Piedmont, most of the sediment reduction originating from two agricultural plots occurred as the result of the grass strip portion of a grass/riparian forest buffer because there was not enough roughness to slow flow and settle particles in the forest buffer (Daniels and Gilliam 1996).

Not surprisingly, in the studies by Swift (1986), Daniels and Gilliam (1996) and Hairsine (1997), larger sediment particles were more easily retained than small ones. Hairsine (1997) and Loch et al. (1999) reported that fines tended to move through the entire buffer. Hairsine (1997) did not clarify the diameters of fines, but Loch et al. (1999) defined fines for that study as < 0.125- to 0.05-mm diameter. Daniels and Gilliam (1996) found greater removal of sand-sized particles than silt + clay-sized particles, and the finer particles moved farther through the buffers. Where roadside mowing may take place, the height of the residual grass may be an important consideration during management for influencing both the overall effectiveness and the ability to retain finer particles, though this subject has been only minimally investigated. Overall sediment capture by montane riparian grasses was not significantly different for unclipped grass and grass clipped to 10-cm height; however, much greater sediment transport resulted when the grasses were clipped to the soil surface (Pearce et al. 1998). In contrast, significantly more sediment was captured more quickly by uncut sedges (*Carex* spp.) than by sedges cut to 10 cm. Sedges cut to the ground trapped significantly less sediment than natural or 10-cm-tall vegetation. The differences in all of these comparisons were most pronounced for a fine soil compared to a coarse soil. Overall, larger particles did not move as far as fine particles.

The retention or lack of retention of fines by deposition, filtration, and infiltration in a VFS can have a direct influence on the capture of or transport of metals to receiving waters as metal sorption tends to be dominated by small clay particles (Zanders 2005). Barrett et al. (2004) measured substantial reductions in copper (77 to 97 percent), lead (84 to 99 percent), and zinc (87 to 99 percent) from freeway VFS that were 4.2 to 13 m in length. Metal capture is probably a more important issue for filter strips applied to roads or in urban areas than for agricultural land, where VFS use is more traditional, because metal concentrations in runoff from the former two can greatly exceed those from agricultural land. Even if clays are retained in a VFS it is possible that metals and other clay-bound pollutants eventually may leach into receiving surface water or groundwater. But there has been little research into the fate of these constituents (Barrett et al. 1998b).

There have been no substantive efforts to identify effective flow lengths for forest road VFS. Based on Swift's (1986) findings, the 10-m flow length that generally serves as an effective guideline for agricultural applications may not be sufficient to control erosion associated with roads, where cutslopes and fillslopes usually are steeper. Sediment in runoff that moved through paired upslope VFS and riparian forest buffers could be traced visually (during nonstorm periods) a maximum of 148 ft. This maximum was applicable to situations with and without brush barriers, as well as dispersed runoff and runoff that originated from cross-drain culverts. The lack of visually traceable sediment suggested little or no sediment movement farther downslope. Given the extremely limited data from VFS applications in forests, it is impossible to provide recommendations for VFS lengths appropriate for forest roads.

Forest Buffers and Windrows

Forest buffers are subjected to both diffuse discharge from along the overall road length and to highly concentrated discharge from road drainage features (Swift 1986). Diffuse discharge may be composed of sheet flow or small amounts of concentrated flow, but for the latter the volume of water is usually small enough that concentrated flow paths do not develop or their development is limited in extent and severity. Points of planned discharge from drainage features make up only a small percentage of the road length, but the volumes and velocities of water flowing from those outlets are much greater. Such concentrated flows are the greatest challenge to a buffer's effectiveness in controlling associated erosion and sediment transport (Megahan and Ketcheson 1996, Polyakov et al. 2005, Swift 1986) because infiltration and sediment deposition are difficult to induce with concentrated flow.

The inherent differences in the delivery mechanisms for diffuse and concentrated discharge result in considerable variation in sediment transport distances. Sediment transport by concentrated discharge from road drainage structures typically results in much longer travel distances than by diffuse flow alone (Belt et al. 1992, Burroughs and King 1989), and thus, would require substantially greater buffer lengths for infiltration and sediment retention. Ketcheson and Megahan (1996)

measured the length of visibly identifiable sediment deposits originating from roads in Idaho. From 4 yr of monitoring during and after road construction, they found that downslope sediment movement from road cross-drains averaged 49.6 m, which was 3.5 times and 5.7 times the average distance associated with berm drains and rock drains, respectively. The maximum transport distance from cross drains was 275 m, whereas maximum distances for the other sources barely exceeded 100 m. They concluded there was a 15-percent probability that sediment associated with concentrated flow could travel more than 100 m, and for some large cross-drain discharges it could travel as far as 450 m downslope. Eighty-five percent of the individual observations of sediment movement were associated with fillslope erosion and not cross drains, and had an average travel distance of only 3.8 m. A similar result was observed in northern Idaho (Burroughs and King 1989, Croke and Hairsine 2006), where about 90 percent of sediment movement was attributable to fillslopes not influenced by road drains. Sediment associated with fillslopes moved less than 88 ft, whereas sediment transport associated with cross-drain discharge was up to 200 ft.

High levels of erosion and the consequent formation of gullies below drainage features often contribute to the longer sediment transport distances (Mockler and Croke 1999, Takken et al. 2008, Wemple et al. 1996). Gullies or other convergent topographic features that keep flow concentrated substantially increase transport distances (Rivenbark and Jackson 2004), thereby increasing the probability that road-to-stream connections will develop (Croke and Hairsine 2006). Once gullies form, they are difficult to rehabilitate (Barfield et al. 1979), making it challenging to reduce sediment transport distances. On the other hand, divergent topographic features disperse runoff, promote infiltration, and result in short transport distances (Swift 1986). In North Carolina, soil movement never exceeded 20 ft below roads on the hillsides on the outside of curves despite substantial disturbance from road construction on the noses of ridges (Swift 1986).

Because sediment can be transported far downslope from forest roads, recommended forest buffer strip lengths are fairly long (Table 28) compared to recommended VFS lengths (Table 27). Commonly used forest buffer lengths are 30 m, or 60 to 100 m (Barling

and Moore 1994, Belt et al. 1992, Clinnick 1985, Davies and Nelson 1994). Different criteria are used to estimate sediment trapping efficiencies for VFS and forest buffers. Sediment trapping efficiencies for VFS are determined from comparisons of incoming sediment and sediment at some point within or at the downslope end of the strip. Studies from which forest buffer lengths are derived usually involve visual observations (Clinnick 1985) of whether sediment is transported through the full length of one or a few buffers (Wenger 1999). There is no comparison between sediment inputs and outputs, so efficiency calculations (percent removal) cannot be made. Consequently, the resulting recommendations from forest buffer studies tend to be by-products of the sampling design rather than experimentally determined (Fennessy and Cronk 1997).

Many of the most basic questions about buffer effectiveness remain unanswered, in part due to the limitations of this type of study design and lack of information about basic site factors that may substantially influence sediment transport distances (Clinnick 1985). These questions include what effective buffer lengths are and how acceptable forest buffer lengths should be established given the widely varying conditions within and among forested watersheds (Correll 1996, Croke and Hairsine 2006, Norris 1993). Despite the lack of this basic knowledge, there is popular acceptance about the effectiveness of forest buffers for protecting water quality (Norris 1993). This acceptance may be attributable to anecdotal observations or monitoring results following forest operations (primarily harvesting or harvesting combined with road construction) with buffers that have shown no or only small turbidity or sediment increases in streamwater during or soon after ground disturbance (e.g., Kochenderfer et al. 1997, Lynch and Corbett 1990). Although these studies typically do not measure or provide visual observations of hillside sediment movement through or retention within the buffer, the lack of evidence in the water column at some point downstream (usually the watershed outlet) is interpreted as evidence of buffer effectiveness. The danger in this indirect approach of determining buffer effectiveness is that sediment may be transported through the buffer at some locations upstream, but storage within the channel

Table 28.—Forest buffer strip lengths recommended for use or stated as being effective within the associated study conditions or review paper

Reference	Geographic location	Hillside gradient	Buffer length	Comments
Aubertin and Patric (1974)	West Virginia	10–65%	10–20 m	Clearcut
Balmer et al. (1976)	Georgia	Level ground and stable soils	9 m	Minimum length required
		Up to 60% and erodible soils	Up to 97 m	
Belt et al. (1992)	Literature review	Not stated	200–300 ft	Lengths that are "generally effective at controlling sediment that is not channelized" (p. 16)
Bren and Turner (1980)	Northeastern Victoria, Australia	Not stated	20 m	Length of undisturbed forest buffer on either side of the channel
Broadmeadow and Nisbet (2004)	Literature review	Not stated	20–30 m	---
Burroughs and King (1989)	Idaho	Various	88 ft	Length needed to capture 90% of sediment flows below road fillslopes
			200 ft	Length needed to capture 90% of sediment flows below road fillslopes where road drains influence runoff
Castelle and Johnson (2000)	Literature review	Various	5–30 m	Lengths were at least 50% and often greater than 75% effective at protecting streams
Castelle et al. (1994)	Literature review	Not stated	15–30 m	Minimum buffer length to protect streams and wetlands in most circumstances
Chalmers (1979)	New South Wales, Australia	Various	30 m	Length is maximum sediment travel distance
Clinnick (1985)	Literature review	Various	30 m	Length is the most commonly recommended, but length should increase with site limitations (e.g., slope, impermeable soil)
Corbett et al. (1978)	Literature review for eastern United States	Not stated	11–22 m	Length needed to prevent water quality deterioration
			20–40 m	Length required to maintain stream ecosystem
Cornish (1975)	Literature review	Not stated	20 m	---
Curry et al. (2002)	Newfoundland	Not stated	20 m	Length "successful in reducing the magnitude of sedimentation following a major storm event (in a stream) subject to clear felling"
Erman et al. (1977)	California	17–22°	≥30 m	---
Graynoth (1979)	New Zealand	17–22°	30 m	---

(continued)

Table 28.—Forest buffer strip lengths recommended for use or stated as being effective within the associated study conditions or review paper

Reference	Geographic location	Hillside gradient	Buffer length	Comments
Haupt (1959a, 1959b)	Idaho	>56%	185 ft	Length needed to trap 83.5% of sediment flows
			230 ft	Length needed to trap 97.5% of sediment flows
Haupt and Kidd (1965)	Idaho	35–55%	3–10 m	Proximity of streams to roads was directly related to frequency of sediment delivery
Haussman and Pruett (1978)	Technical guide		8–50 m	8 m needed for 0% slope; 0.6-m increase in buffer length needed for each additional 1% slope, with a maximum of 50 m for slopes of 70%
Ketcheson and Megahan (1996)	Idaho	15–40°	450 m	Length is maximum sediment travel distance originating at cross drains with large water supply; only a 15% probability that it will exceed 100 m
			60 m	Length needed to capture sediment from all other road sources (e.g., fillslopes, berm drains, and rock drains)
Lynch et al. (1985)	Pennsylvania	Not stated	30 m	Length needed to remove about 75 to 80% of suspended sediment
Packer (1967)	Northern Rocky Mountain Region	Various	35–127 ft	Length depends on types and spacing of obstruction; length needed to capture 83.5% of sediment flows
			95–187 ft	Length depends on types and spacing of obstruction; length needed to capture 97.5% of sediment flows
Plamondon (1982)	Canada	5–30%	10–15 m	---
Rashin et al. (2006)	Washington state	Average near-stream hillslope gradient ranges from 4 to 75%	10 m	Length needed for ground disturbances; can be expected to reduce sediment delivery to streams from harvest-related erosion features
Swift (1986)	North Carolina	47%	65 ft	Lengths represent average sediment travel; maximum travel lengths were 314 ft and 198 ft, respectively
		42% (also burned)	96 ft	
Trimble and Sartz (1957)	New Hampshire	0%	25 ft	Lengths needed to trap 90% of sediment flows
		70%	165 ft	For 100% efficiency, they recommend doubling the distance
van Groenewoud (1977)	Canada	Relatively flat	15 m	---
		Moderately sloping	65 m	
Wong and McCuen (1982)	Maryland	2°	30 m	Length needed for 90% sediment removal
			60 m	Length needed for 95% sediment removal

is sufficient to mask that delivery downslope where the water column is monitored or sampled (Edwards 2003).

Only a small number of published papers have used large datasets or rigorous approaches to define recommended buffer lengths in specific physiographic areas. The most notable are Haupt (1959a, 1959b) and Packer (1967). Haupt (1959a, 1959b) mathematically related sediment movement to site and road drainage factors for 75 sections of haul road in southwestern Idaho; variables included aspect, cross-drain spacing, road gradient, fillslope length, and number and types of obstructions on the hillside. Packer (1967) performed a similar analysis on 720 study sites in the northern Rocky Mountains. He examined sediment travel distances as a function of soil type, road age, cross-drain spacing, distance to first obstruction on the hillside, and fillslope cover density.

Haupt's (1959b) analysis showed that numbers, kinds, and spacings of obstructions on the hillside were the most important variables in determining sediment transport distances. The cross-drain interval was the next most important variable: transport distance increased with the square of cross-drain spacing. Packer (1967) used variables that were statistically significant in explaining sediment movement to develop recommended buffer lengths suitable for 5-yr-old logging roads built in basalt geology with 9-m cross-drain spacings and various obstruction spacings. He also provided adjustments for a variety of conditions, such as different geologic materials, increasing cross-drain spacings, and decreasing fillslope cover. From these analyses, he determined that to retain about 85 percent of sediment flows from cross drains installed on 9-m spacings, the required buffer lengths ranged from 11 to 46 m, with the distance depending upon obstructions, soil characteristics, road width, and vegetative cover associated with the area from which and onto which the structure drained.

It is not surprising that these studies reported the presence of hillside obstructions, or roughness features, as critical to controlling sediment movement in forest buffers. Obstructions, including vegetation, forest floor litter, downed wood, and rocks, along with hillside depressions, provide means to slow or temporarily trap water and allow sediment to settle and be stored (Barling and Moore 1994, Belt et al. 1992, Croke and

Hairsine 2006, Ohlander 1976). Obstructions restrict travel distances, as shown in two locations in Idaho where sediment transport lengths were strongly inversely related to the density of hillside obstructions (Burroughs and King 1989, Megahan and Ketcheson 1996). Beasley et al. (1984) found hillside depressions allowed water to accumulate or infiltrate, and dense vegetation and other debris on the soil surface slowed runoff and allowed sediment to settle out during events in which there were small to moderate amounts of water discharged onto the forest floor.

In forests, trees play a much more limited role in controlling sediment delivery through the presence of their stems compared to grasses and herbaceous vegetation along the roadside (i.e., VFS) at the upslope edge of forest buffers (Dorman et al. 1996). This is because overstory stems are not dense enough to sufficiently slow water and promote sedimentation. But tree root growth creates high soil infiltration rates that can substantially contribute to controlling sediment transport through deposition (Lyons et al. 2000). Litter also provides limited roughness because it is not anchored to the soil surface. Even thick litter layers have been shown to be susceptible to scour by concentrated flow (Loch et al. 1999).

The presence of obstructions and depressions varies by site and within sites, making dependence on natural features for energy dissipation, infiltration, and sediment deposition unpredictable and inconsistent. Consequently, filter windrows (or brush barriers) are commonly created during road construction. Windrows are composed of woody slash from right-of-way clearing placed along the contour at or near the base of the fillslope (Burroughs and King 1989). The debris provides a barrier, albeit a porous one, to slow and spread concentrated flow, thereby encouraging water infiltration and sediment deposition (Burroughs and King 1989, Cook and King 1983). Slash presumably is most useful when it is in contact with the ground, so road contracts often include provisions requiring slash to be cut into short lengths to improve contact with the ground and contact with other pieces of debris. However, no studies could be found to compare the effectiveness of simply placing the slash on the hillside to this practice, so the degree of improvement is unknown.

Experiments with filter windrows involve a variety of data collection techniques, so the results are not entirely comparable, but they do tend to show that these barriers are generally effective at reducing sediment delivery. The first year after road construction in Idaho, filter windrows retained all but an average of 0.22 ft³ of eroded material per 100 ft of road length. Fillslope slumping did result in some larger amounts of soil passing through or over the windrows during spring snowmelt (King 1979). Machine-constructed filter windrows resulted in 75 to 85 percent lower sediment losses from fillslopes than hydromulched fillslopes (Cook and King 1983). Hand-constructed windrows resulted in 88-percent reductions in fillslope sediment losses in the Intermountain Region compared to 99 percent for Curlex® (American Excelsior Co., Arlington, TX) mulch, but the creation of filter windrows is much less expensive than is procuring and applying Curlex mulch (Burroughs and King 1989). Rill formation also was less common on fillslopes that had windrows, and even when rills formed, the average and maximum sediment transport distances (3.8 ft and 33 ft, respectively) were much less than in a variety of permutations of conditions without windrows (average = 25.8 to 80.4 ft and maximum = 85 to 125 ft) (Burroughs and King 1989). In North Carolina, sediment movement on vegetated fillslopes with brush barriers at the toe of fillslopes never exceeded 75 ft (Swift 1985).

Log barriers or log + brush barriers have been used as an alternative to conventional windrows in a variety of situations. Rothwell (1983) experimented with close placement of logging debris barriers on roads. He placed log/brush barriers along the contour 60 and 120 cm apart on road shoulders, ditches, and cutslopes at three stream crossings. These resulted in an average reduction of 75 percent of total suspended sediment production during a summer season. Log erosion barriers installed on two hillsides in California after a wildfire reduced sediment yields by 66 percent compared to a hillside with no log barriers (Wohlgemuth and Robichaud 2007). As with the windrows on fillslopes, site characteristics, including differences in runoff and sediment loads, influenced the effectiveness of log barriers (Wohlgemuth and Robichaud 2007). In some cases the areas behind the logs were completely filled with sediment within only a few years.

These findings by Wohlgemuth and Robichaud (2007) show that vegetative roughness features have a finite

capacity for sediment accumulation. They also have a limited life expectancy due to decay and mineralization (Ohlander 1976), but longevity will vary depending upon the size and species of the material. No information was found in the literature concerning how long windrows remain effective in different climates, nor was information found about whether road-to-water body connectivity increases as windrows lose functionality or whether previously deposited sediment becomes remobilized. Other barrier techniques also exist that can be applied in buffers, including silt fence. But because these tools have application other than just within buffers, they are covered elsewhere in this chapter (see the subsection on Vegetated Waterways and Swales, and the section on Non-engineered Barriers).

In addition to roughness, buffer gradient is the other landscape variable that most influences forest buffer effectiveness. Slope is important primarily with respect to sediment in concentrated runoff because velocity and hence energy are directly related to slope. From a review of the effective buffer lengths in the literature, Clinnick (1985) concluded that buffer lengths should increase with increasing slope, and increases in length become most critical on slopes over 30-percent gradient where the topography is concave. In these situations, spreading flows out, and encouraging infiltration on the hillside is very difficult. Trimble and Sartz (1957) recommended increasing forest buffer flow lengths as the hillside slope between roads and streams increased because they observed substantial differences in sediment transport across the range of slopes present in the White Mountains of New Hampshire. Only 8 m of buffer length was needed to retain 90 percent of incoming sediment from roads on fairly level ground, but 51 m of length was necessary to trap that amount on 70-percent slopes.

There is relatively little discussion in the literature to indicate at what gradient a forest buffer becomes too steep to be effective and should be replaced with other types of BMPs for erosion control or sediment retention. That so many other important factors, such as roughness, road discharge rates, sediment concentrations, and soil permeability, vary among sites and through time may make simple generalizations impossible.

Buffers can be fixed or variable lengths (Polyakov et al. 2005). Fixed-length buffers have a pre-determined

minimum length that is applied to all or part of the area adjacent to a water body (Lee et al. 2004). Fixed lengths are most commonly used in forest buffer application because they typically are specified in governmental regulations or guidelines, and they are simple to apply. All of the field-based studies on VFS and forest buffer effectiveness reported previously in this chapter were derived from fixed-length buffers.

Variable-length buffers are used less commonly. As their name indicates, their length along a water body varies, depending upon physical characteristics present in the catchment near that location. These characteristics include contributing area, hillside slope, soil characteristics, and pollution sources (Polyakov et al. 2005). Little field-based research has been devoted to developing techniques to define variable-length forest buffers or to validate their effectiveness. Most research in this area has taken the form of heuristic or optimization models (e.g., Dosskey et al. 2002, 2011; Polyakov et al. 2005; Weller et al. 1998).

Based on heuristic modeling, Weller et al. (1998) found limitations to using variable-length buffers because they may capture lower pollutant loads than fixed-length buffers (i.e., when the average buffer lengths of the two types are equal). This is because pollutant transport through the buffer occurs primarily where the buffer length is narrow. Therefore, the average length of a variable-length buffer must be greater than the average length of a fixed-length buffer to attain a specified level of pollutant removal. The Weller modeling used uniform sheet flow from the uphill source areas whereas Dosskey et al. (2002) modeled filter strip pollutant trapping efficiencies using nonuniform runoff and the buffer area ratio (i.e., the ratio of filter strip area to upslope contributing area) from agricultural fields with variable-length buffers. Sediment trapping efficiency was predicted to be 7 to 56 percent less across four sites for nonuniform flow conditions compared to model results for uniform flow, which agreed with the Weller et al. (1998) results.

Establishing variable-length buffer boundaries on the ground can be difficult because buffer lengths that have been defined spatially from models can result in complex patterns that are impractical for field staff to implement (Polyakov et al. 2005). The theoretical advantage of variable buffers is that if properly designed and

implemented, they should result in less land within the buffer. This situation can have economic benefits as most buffers have defined limits on disturbance, which can take some land or material out of production.

In highly dissected landscapes with a high density of nonperennial channels, there is a constant tension between protection and production with respect to buffer application. A type of compromise between fixed- and variable-length buffers has been the application of different (usually fixed-length) buffer designations to different types of water bodies (e.g., perennial versus intermittent versus ephemeral streams) (Norris 1993) or to specially designated water bodies. This arrangement recognizes the need to protect water quality and the connectedness of water bodies, while trying to alleviate some of the economic impacts associated with applying buffer protection. However, often the assignment of the specific buffer lengths to a given type of water body is arbitrary (Phillips 1989). At best, research-based lengths are applied to perennial channels, while nonperennial channels, particularly ephemeral channels, typically receive less protection. Nonperennial channels typically have buffers based on lengths that are palatable to users but not defined or supported by scientific data.

The economic impacts of applying buffers to headwater channels are probably the main reason that headwater channel reaches are not consistently buffered, but inconsistent application of buffers to these channels leads to the question posed by Cornish (1975: 10): "Which watercourses require filter strips?" He argued that neither permanence nor frequency of flow should be used to identify water body segments that should receive buffer protection, and instead suggested that any length of stream that has high peakflows and is susceptible to receiving pollutants should be accorded protection from a forest buffer. Norris (1993) went further and stated that ensuring water quality protection requires that buffers extend along all tributaries to the end of the headwaters where flow initiation begins.

The modeling results by Weller et al. (1998) support the need for providing buffers along the entire channel. They showed that eliminating gaps in buffer widths would yield greater protection than providing longer buffers along only parts of a channel. Their work provides further support for avoiding stream crossings

and keeping roads far from streams if possible, because stream crossings necessarily create gaps in buffers and provide direct conduits for sediment delivery (along the road). Road impingement in streamside areas (including in the approaches to crossings) necessarily creates short buffer lengths and high potential for sediment delivery in those areas, even if the rest of the buffer has long fixed lengths (i.e., akin to the problems with narrow buffers in variable-length buffers).

Qiu and Prato (1998) noted that riparian buffers in agriculture have a positive economic value, but the prices of agricultural products do not include the value of maintaining water quality, so there is little incentive for buffer installation. Similar challenges exist in forests because of the low profit margins associated with most forest products (Blinn et al. 2000, Timberharvesting. com 2011). To improve the acceptability of applying forest buffers to the entire channel length, nonmarket incentives need to be considered (Polyakov et al. 2005), particularly because headwater forests already have more buffer length and width than downstream lands dominated by multiple-use (Norris 1993). Acceptance of implementing buffers along the full channel length in forested watersheds might increase if the improvement to water quality attained by buffering headwater forests could be shown to influence water quality downstream in lands that do not include buffers. Currently there is a lack of data demonstrating that local forest buffer implementation provides any measurable improvements to water quality at the landscape scale (Norris 1993, Polyakov et al. 2005).

Vegetated Waterways and Swales

Vegetated waterways and vegetated swales are open channels that are lined with low-growing, flood-tolerant vegetation (usually grass) (Dorman et al. 1996). They are oriented in the direction of the slope, and stormwater runoff (both sheet flow and concentrated flow) from upslope contributing areas is collected and transmitted through them (Deletic and Fletcher 2006) with the objective of reducing pollutants in the runoff (Mazer et al. 2001). A properly designed vegetated waterway or swale transmits runoff slowly to allow complete or nearly complete pollutant retention, if not also complete water infiltration (Burkhard et al. 2000, Mazer et al. 2001). Runoff that does not infiltrate fully within the

swale or waterway's length is transported with outflow and discharged into additional drainage or treatment systems, or receiving waters (Daniels and Gilliam 1996, Deletic and Fletcher 2006). Some vegetated channels are used only to convey drainage water to another pollution control structure (usually some type of detention pond) and there is no pollution-reduction objective for the waterway itself (Novotny and Olem 1994). However, in this chapter, only the pollution control aspects of vegetated waterways are considered.

Although the terms "vegetated waterways" and "vegetated swales" often are used interchangeably, for some practitioners the appropriate term depends upon the shape of the feature, with the shape being a function of available space (especially width). When a distinction is made, vegetated waterways usually are narrower and V-shaped (e.g., see Resource Conservation District of Monterey County 2005), or trapezoidal (e.g., see Natural Resources Conservation Service 2003). Swales tend to be wider and shallower (Iowa State University 2009). Typical locations for vegetated waterways and swales are in medians of divided highways, along roadways or parking areas, or adjacent to or within commercial or residential developments (Burkhard et al. 2000, Donaldson 2009, Iowa State University 2009, Yu et al. 2001, Zanders 2005). Their application in urban areas also is increasing substantially (Deletic 2005).

Pollution reduction in vegetated waterways and swales occurs by biochemical and physical processes (Deletic and Fletcher 2006) that are influenced by standing vegetation, organic matter, and soil (Mazer et al. 2001). Biochemical processes control retention of dissolved forms of pollutants; these processes involve uptake by vegetation, adsorption onto soil and organic matter (Deletic 2005, Iowa State University 2009, Yu et al. 2001), and transformation into less harmful substances by microbial decomposition (Mazer et al. 2001). Physical processes dominate pollutant removal in vegetated waterways and swales; these include particulate deposition, vegetative filtration, and infiltration of chemicals into the soil with infiltrating water (Deletic 2005, Deletic and Fletcher 2006, Iowa State University 2009, Yu et al. 2001). Particulate deposition, or settling, is the most important means of pollution retention (Bäckström 2002, Claytor and Schueler 1996, Deletic and Fletcher 2006, Dorman et al. 1996). Aboveground plant

parts induce sedimentation of particulates by providing roughness and slowing velocity of inflow, while plant roots stabilize sediment deposits and discourage sediment resuspension (Claytor and Schueler 1996, Kadlec and Knight 1996). Filtration of particulates by grass blades or other vegetative parts is much less important for sediment capture (Claytor and Schueler 1996, Deletic and Fletcher 2006, Kadlec and Knight 1996).

The interrelationships between vegetative characteristics and inflow are important to the effectiveness of vegetated waterways and swales. Because vegetated waterways and swales are channels (Barling and Moore 1994, Dorman et al. 1996, U.S. EPA 1999), the depth of water in them changes through time with the size of storm and runoff events (Dorman et al. 1996). Vegetation can be fully submerged (submerged flow) or only partially submerged (nonsubmerged flow) (Tollner et al. 1976). The length of time that plants in a vegetated waterway or swale are subjected to submergence can affect their condition. Greenhouse experiments showed biomass and leaf blade density of grasses were affected by growing them in inundated pots. Biomass and the number of leaf blades were least for pots with 2 to 4 cm of water inundation above the soil surface for two 14-day cycles (Mazer et al. 2001). In contrast, plants grown without inundation had the greatest number of leaf blade and biomass accumulations, regardless of species tested. Biomass averaged across the four inundated turf grass species studied was only about 11 percent of biomass for the same species kept moist but not inundated.

Even establishment of plants well adapted to limited inundation can be reduced by extended inundation (Crawford 1992, 1996; Ernst 1990; Ewing 1996; Kozlowski 1984). In field experiments, swales that were inundated with water for more than 35 percent of the time during summer had significantly less vegetative growth and biomass accumulations in litter (Mazer et al. 2001). Water stagnation also should be avoided as it has similar effects (Burkhard et al. 2000), though standing water in the short term (1 to 14 days) may have slightly less effect on vegetative growth than flowing water over the same duration (Temple 1991).

To be effective, vegetation must have characteristics that allow it to accommodate the range of expected flows without failing, or inflow must be controlled in a way to ensure vegetation can be effective. Substantial reduction in settling potential results during submergence if vegetation becomes prone, breaks (i.e., is shortened) (see Vegetated Filter Strips subsection in this chapter for details on how roughness is affected when vegetation is prone or broken), or is scoured from the feature. Scouring of vegetation from swales is predominantly a problem when flows or inundation persists for long periods (Mazer et al. 2001) or when the feature is too narrow and water becomes too concentrated (Barrett et al. 1998b).

Research by Bäckström (2002) illustrated the importance of vegetative condition in controlling roughness and influencing sedimentation for swales. Using nine grassed swales with a standardized runoff event simulation process, he found short, thin grass had the lowest removal of TSS, at 80 percent. In contrast, swales with well-developed thick turf had the greatest TSS removal (90 to 100 percent). Colwell et al. (2000) examined roadside ditches in Washington state and found that those that were well vegetated and lacked rocks or other coarse roughness features appeared to perform like vegetated swales based upon indirect estimates of vegetative cover, siltation, scour, and energy profiles. Though pollutant removal was not measured directly, their survey data suggested that these ditches resulted in a net removal of pollutants compared to those that had less vegetation or rocky bottoms, or were created in rocky soils. The latter ditches appeared to serve as sources of pollutants, especially sediment.

The removal of particulates by vegetated swales or waterways ultimately depends upon achieving some balance between flow rate and particle settling velocity (Deletic and Fletcher 2006). Although vegetation abundance contributes to controlling velocity and particle retention, it is not the only controlling feature, because even nonsubmerged flows can have high flow rates that are not conducive to particle settling (Mazer et al. 2001). Altering the longitudinal slope, length, and overall shape of vegetated waterways and swales can change the inflow rate and depth of water; these in turn influence the degree of infiltration and deposition (Deletic and Fletcher 2006). Reducing the longitudinal slope and increasing the length of the vegetated waterway or swale both help to increase retention times

and potential sediment deposition (Deletic and Fletcher 2006, Yu et al. 2001).

Mazer et al. (2001) observed that vegetated swale performance was most effective when inflow was controlled in such a way that it was always shallow (<37 mm) and hydrologic retention time within the feature was long (>9 min). They did not recommend specific slopes because they found that a slope of even 1.5 percent was too much for some swales to handle the high flow rates that developed for even small storms. Yu et al. (2001) tested swale performance in Virginia, comparing a swale with a 1-percent grade to one with a 3-percent grade. Based on sediment reductions that they measured and results of eight other studies from the literature, they concluded that a 3-percent longitudinal slope performed better and was optimal for swale construction. Similarly, Colwell et al. (2000) examined roadside ditches in Washington state; those that behaved like vegetated swales had slopes of 2 to 3 percent in combination with gentle side slopes of no more than 3:1 (horizontal:vertical). Those that were flatter longitudinally would retain too much water, whereas those that were steeper had high energy and vegetative and soil scouring. These studies suggest that the maximum longitudinal slope for swales and waterways is probably no more than 3 percent. However, slopes of swales generally range from 0.5 to 6.0 percent (Mazer et al. 2001), so many existing swales may be challenged by their associated inflow velocities.

The actual effect that any change in vegetated swale or waterway shape has on sediment capture depends in some part on the particle size distribution of incoming sediment. Most pollutant reduction by vegetation follows exponential decay (Deletic and Fletcher 2006); that is, most occurs in the first few meters of length (Bäckström 2002, Kaighn and Yu 1996) and then retention falls off exponentially. This is because the largest/heaviest particles settle out most easily throughout the entire range of flow velocities, and these particles compose most of what is captured (Deletic and Fletcher 2006, Yu et al. 2001). For this reason Bäckström (2002) found no relationship between pollutant removal and swale length; the heaviest particles settled out in the first few meters of the feature, so extending the flow length contributed little to sedimentation.

Increasing swale length is important for retaining fine particles (e.g., clays) and dissolved constituents (Bäckström 2002, Wang et al. 1981), but only as long as infiltration rates remain high (Bäckström 2002). This is because fines and dissolved constituents are not captured easily through sedimentation, but instead depend upon having sufficient flow-through or residence time in the swale or waterway to allow infiltration to occur (Kaighn and Yu 1996, Yousef et al. 1985). Bäckström (2002) found the advantage of increasing swale length was associated primarily with particles less than 25-μm diameter. In Washington state, about 90 percent of lead levels were removed by a 60-m-long swale compared to 60-percent removal by a 20-m-long swale (Wang et al. 1981). However, even when infiltration capacity is high, infiltration may become inadequate to allow for retention of small particles (<50 μm diameter) when velocities become too great or flow too deep (Mazer et al. 2001). For this reason, swales work best when they are exposed to frequent light rainfalls—even those of extended duration—rather than large intense events (Yu et al. 2001).

Some studies have shown that the presence of a strip of vegetation located between the edge of the pavement and the beginning of the swale or waterway is an important physical attribute in their design (Barrett et al. 1998b, Wu et al. 1998). This strip acts as a vegetated filter strip (VFS; described previously in this chapter), which "pretreats" runoff (Stagge et al. 2012) before it enters the swale or waterway. However, other studies have shown the swale or waterway to be more important than the VFS (Bäckström 2003, Schueler 1994).

Low concentrations of incoming pollutants to vegetated waterways or swales, whether due to initial removal by VFS or by naturally low inflow pollutant levels, generally result in poor performance (Welborn and Veenhuis 1987). When influent TSS concentrations were less than 30 mg L^{-1}, no sediment reduction occurred in Maryland swales (Dorman et al. 1996). Similarly, Bäckström (2003) found no significant reduction in TSS when inflow concentrations were less than 40 mg L^{-1}. In contrast, when TSS concentrations have been in ranges normally associated with highway runoff (i.e., where swales and vegetated waterways normally are installed), substantially improved TSS removal usually results. For example, 93 and 94

percent of TSS was removed during two storms when influent concentrations were between 100 and 200 mg L^{-1} in Florida (Dorman et al. 1996). Bäckström (2003) summarized three studies and showed that 79 to 89 percent of TSS was removed during simulated storm events and the parameter that best explained TSS removal was TSS concentrations in inflow.

Because so many factors influence pollutant retention in swales and vegetated waterways, it is not surprising that a wide range of pollutant removal efficiencies is reported in the literature (Table 29). Total suspended solids (i.e., primarily sediment) tend to be removed more efficiently than other constituents (Horner et al. 1994, Municipality of Metropolitan Seattle 1992), but even suspended solids removals have ranged from being ineffective to completely effective (Weiss et al. 2010). Metals (Table 29) tend to be removed more effectively than dissolved nutrients because metals commonly adsorb to sediment (Dorman et al. 1996, Schueler et al. 1992).

The inconsistency in retention efficiencies among studies has resulted in a general lack of confidence in the effectiveness of vegetated waterways and swales (Bäckström 2002, Barrett et al. 1998b). Many stormwater handbooks recommend these techniques primarily as pretreatment techniques (Barrett et al. 1998b) before releasing water into other filtration or stormwater controls.

Structural barriers, known as check dams, can be installed in vegetated waterways and swales (Fig. 11) to increase detention times, thereby helping to compensate for poor infiltration or poor vegetative cover (Mazer et al. 2001) by temporarily ponding and storing water (Yu et al. 2001). Ponding water slows its velocity, and storing water increases the time of detention; both of these factors increase the opportunity for deposition and infiltration (Kaighn and Yu 1996, Yu et al. 2001). During low runoff events, check dams in swales have been found to double the detention times of water compared to where there was no check dam in place (Yu et al. 2001). Check dams can be constructed from a variety of materials, including stone berms, railroad ties, riprap, gabions (large wire cages usually containing rocks or broken concrete), pressure-treated wood, and natural wood that is resistant to decay (U.S. EPA 2004). Specific details about pollutant retention processes associated with barriers are provided in the previous section of this chapter (Non-engineered Barriers). The effectiveness of using barriers aside from those in vegetated swales and waterways also is covered in the previous section.

A few studies have demonstrated that swales and waterways containing check dams tend to be more effective than those without check dams. Not surprisingly, the greatest improvement in pollutant retention by check dams typically results for fine particles and dissolved chemicals (Kaighn and Yu 1996)

Figure 11.—A series of rock check dams in a grassed swale to create storage potential within the swale. Photo by Virginia Department of Conservation and Recreation (1999), used with permission.

Table 29.—Sediment, metal, and other chemical removal efficiencies reported for vegetated waterways and swales

Reference	Type of feature	Sediment removed (as TSS[a])	Metals and other constituents removed		Comments
		-------------------- *percent* --------------------			
Bäckström (2003)	Grassed swale	79–98			Simulated runoff events
Barrett (2008)	Grassed swales	Mean = 60 Range 6–70			Data extracted from 14 swales in international BMP database
Goldberg et al. (1993)	Grassed swale	67.8			8 storm events
Kercher et al. (1983)	Grassed swale	97.9			Residential area
Mazer et al. (2001)	Grassed swales	60–99			Non-roadside swales
Municipality of Metropolitan Seattle (1992)	Grassed swale	83	72	Total iron	All values from 200-ft-long swale; THP = total petroleum hydrocarbons
			67	Total lead	
			46	Total copper	
			63	Total zinc + total aluminum	
			30	Dissolved zinc	
			75	Oil + grease/THP	
Oakland (1983)	Grassed waterway	33			11 storm events
Walsh et al. (1998)	Grassed swale	35–59			At 10 m through swale
		54–77			At 20 m through swale
		50–76			At 30 m through swale
		51–75			At 40 m through swale
Wang et al. (1981)	Grassed swale	90.4			At 21 m length
		93.2			At 43 m length
		94.5			At 67 m length
Yousef et al. (1985)	Grassed swale		90	Total zinc	Reductions of metal concentrations in highway runoff through swales over 8 months
			82	Dissolved zinc	
			91	Total lead	
			50	Dissolved lead	
			41	Total copper	
			19	Dissolved copper	
			71	Total iron	
			44	Dissolved iron	
			44	Total chromium	
			13	Dissolved chromium	
			29	Total cadmium	
			18	Dissolved cadmium	
			86	Total nickel	
			47	Dissolved nickel	

[a] TSS = total suspended solids.
Empty cells indicate variable was not measured.

as fines and dissolved species have low settling velocities (which require lengthy detention times) or depend upon infiltration, or both (see Non-engineered Barriers section). Kaighn and Yu (1996) compared pollutant retention from highway runoff by a swale without a check dam to one with a weir-type check dam during eight rain events. Removal of TSS ranged from 73 to 100 percent with a single check dam compared to a range from -4.1 percent (i.e., there was a net increase in TSS through the swale) to 57.4 percent for a swale of the same slope and length with no check dam (Table 30). Likewise, reductions in zinc, chemical oxygen demand, and total phosphorus were much greater with the check dam (Table 30). The 100-percent pollutant reductions observed in this study correspond to storms in which 100 percent of inflow was infiltrated into the soil, which occurred due to the check dams. Yu et al. (2001) examined the effects of length, longitudinal slope, and the presence of check dams in swales and also found the most important feature for improving retention of TSS and total phosphorus was a check dam.

Shipitalo et al. (2010) examined the efficacy of check dams constructed from compost filter socks (see Non-engineered Barriers section in this chapter for more description of compost filter socks) placed in grassed waterways that received drainage from tilled or no-till corn (*Zea mays*) fields. Sediment concentrations from the no-till fields were not reduced significantly by filter socks, presumably because sediment concentrations in

inflow were very low. However, from tilled fields, which had much higher inflow sediment concentrations, the filter socks decreased the sediment concentrations by an average of 49 percent. The filter socks worked well even with high runoff volumes in the waterway, where many other types of BMPs may have been challenged. The composition of compost media (e.g., particle-size mixture) may be designed specifically to handle large inflow volumes, but these designs usually require higher flow-through rates to avoid overtopping, which translates to less-effective control of suspended sediment and turbidity (Faucette et al. 2006).

Straw or hay bales are sometimes used as check dams in swales and waterways, but there is no information in the literature on their application to these types of biofilters. However, the U.S. EPA (2002) recommends against their use as check dams with flowing water because they are easily undercut or overtopped due to their impermeability and proclivity to dislodge and collapse when flow concentrates in channels (Indiana Department of Natural Resources 1992, Robichaud 2010, U.S. EPA 2002). In addition, hay and straw bales decay easily, so even if they are installed properly and are effective in the short term (<3 months) (Harbor 1999, U.S. Department of Transportation 1995), failure in the long term is likely despite intensive maintenance. Additional information about straw bales as check dams in ditches or as general erosion control barriers to overland flow is provided in the section on Non-engineered Barriers.

Additives show promise for increasing the effectiveness of vegetated waterways and swales. A wide variety of chemical and organic material additives have been tested, primarily in laboratory studies, for their potential use for increasing pollutant retention in vegetated waterways or swales. These include activated charcoal, compost, metal compounds, clay compounds, and other chemical additives. However, because many of these materials have undergone little if any field testing—and they probably would not be used much in swales or waterways associated with forest roads—they are not described here. Interested readers are directed to Weiss et al. (2010), who have synthesized this literature.

Table 30.—Percent reductions in various constituents without and with a weir-type check dam in a swale during eight storm events in Virginia (data from Kaighn and Yu 1996)

| Constituent[a] | Range removed | | Average removed | |
	Without check dam	With check dam	Without check dam	With check dam
	------------------------ percent ------------------------			
TSS	-4.1–57.4	73–100	23.3	87
Total zinc	5.1–35.4	58–100	17.8	83.8
COD	-27.8–54.9	67–100	29.8	84
TP	-14.9–55.6	80–100	11	91.5

[a] TSS = total suspended solids; COD = chemical oxygen demand; TP = total phosphorus.

There has been little research on the moderate- to long-term fate of particulates or dissolved chemicals that have been removed by vegetated waterways and swales (Davis et al. 2003, Yu et al. 1993). Intense storms create the potential for resuspension of settled particles in the short term (Yu et al. 2001), but little information is available about whether particles become part of the general soil substrate through time, as they can with VFS (Barrett et al. 1998b, Dillaha et al. 1989). Chemicals that were retained through plant uptake or adsorption onto plant or organic surfaces have the potential for remobilization during mineralization (Bäckström 2003). Consequently, clippings from mowed waterways and swales should be removed to reduce the potential for transport of metals and other pollutants released by decomposition (Colwell et al. 2000, Dorman et al. 1996, Schultz 1998).

Straw bales installed in a ditch line to slow drainage and capture sediment, and straw mulch and silt fence on a cutbank used to control erosion after construction of an access road to a natural gas well pad. (Photo by U.S. Forest Service, Northern Research Station.)

CHAPTER 8

Research Needs, Potential Direction, and Concluding Thoughts

Research Gaps and Potential Future Direction

There is a common perception that the effectiveness of forestry BMPs, including forest road BMPs, is well supported by scientific research (e.g., see Hornbeck and Kochenderfer 2001 or Ice, n.d.). Many road BMP effectiveness studies do exist; however, the effectiveness of most forest road BMPs has not been investigated rigorously (including replicated and quantitative studies) under a wide variety of geologic, topographic, physiographic, and climatic conditions since their development decades ago. Much more quantification of effectiveness is needed (Anderson and Lockaby 2011a, Moore and Wondzell 2005, Stafford et al. 1996) to understand the site characteristics for which each BMP is most suitable and for proper selection of the most effective BMP techniques (Carroll et al. 1992, Weggel and Rustom 1992).

The divergence between the general belief of well-supported science and lack of critical analysis may result from several factors:

1 Many of the most commonly cited studies that provide the basis for illustrating forestry BMP effectiveness are paired watershed tests in which a treated watershed (e.g., harvesting with road construction) is compared to a control or reference watershed in which no land-disturbing activities were undertaken (Hewlett 1971). Some of these studies were designed and analyzed following classic paired watershed regression techniques (e.g., Arthur et al. 1998, Brown and Krygier 1971, Lynch and Corbett 1990, Rice et al. 1979); others simply compared water quality results between watersheds (e.g., Reinhart et al. 1963). These studies interpreted

small changes in water quality (usually sediment loads or turbidity) at the mouth of a treated watershed compared to a control as "proof of effectiveness."

Although paired watershed studies are common, they are limited in their ability to demonstrate and quantify BMP effectiveness for water quality protection. Most paired watershed studies have less than 5 yr of pretreatment measurements, which limits the amount of variation that can be captured for the comparisons. Therefore, it is difficult to accurately interpret post-treatment data that fall outside pretreatment ranges (Lewis et al. 2001). Sediment measurements at the mouth of a watershed do not account for in-channel storage of delivered sediment and the associated lag times in sediment delivery to the mouth of the watershed (Edwards 2003, Rice et al. 1979). Finally, in paired watershed studies BMPs are considered en masse, making it impossible to quantify the effectiveness of individual BMPs or to identify the individual BMPs that were most or least effective.

2 Studies have investigated the effectiveness of individual road BMPs, but the lack of replication and broad-scale testing across different physiographies, climates, soil types, and other factors for most BMPs weakens the argument that their effectiveness is scientifically well proven. As a result, a single study or just a few studies typically are cited in the literature to support a BMP's effectiveness or the overall general effectiveness of BMPs.

3 The similarity of forest road BMPs used in many different states' forestry BMP manuals and handbooks suggests a degree of confidence in their

validation that may not be justified. For example, many eastern state BMPs employ recommendations for waterbar spacings on skid roads developed from a single study (Elliot et al. 2014) performed in West Virginia (Trimble and Weitzman 1953, Weitzman 1952).

However, the lack of replicated testing of individual BMPs under different conditions should not dismiss them from consideration as tools for protecting water quality. Because most BMPs are based on the laws of physics and chemistry, they typically contribute some degree of nonpoint source pollution control if installed and maintained properly (Anderson and Lockaby 2011b, Stuart and Edwards 2006). For example, it is well understood that controlling the mass or velocity of water reduces its energy available to do work, so it is logical that incorporating that principle into BMPs will reduce erosion. But the dearth of information about most individual BMPs leaves many important questions unanswered, such as: How effective (i.e., quantified) is the BMP in different situations or conditions? and Does its level of effectiveness warrant its implementation or would another technique be more effective and possibly more cost-effective? These questions are particularly applicable to skid road BMPs, as skid roads are included in only a small minority of road BMP research, and those that do involve skid roads focus on BMPs applied once they are "put to bed" (i.e., removed from service). There is scant information on the effectiveness of BMPs applied during skid road use when the potential for water quality impact is high.

As indicated in the previous chapters of this document, most BMP effectiveness studies have focused on the initiation of erosion and quantifying erosion rates. Historically, this information was critical for promoting the acceptance of BMPs and their implementation. But in the future it will no longer be sufficient for BMP effectiveness studies to measure only erosion rates, as these do not provide the necessary information to quantify sediment delivery to water bodies (Anderson and Lockaby 2011b, Dickinson and Wall 1977, Grace 2005, Walling 1983). In conjunction with sediment delivery measurements, there is a pressing need to identify the locations or sources where sediment originates, understand why/how sediment delivery is controlled and explain the mechanisms by which BMPs

protect water quality (Anderson and Lockaby 2011b, Dickinson and Wall 1977, Sutherland 1998c). These questions generally have been ignored in forest road research (Anderson and Lockaby 2011b, Rivenbark and Jackson 2004). Most BMP studies report only outcomes, such as erosion rates or captured volumes of sediment, and they were not designed to provide information about the processes or environmental variables that contributed to or resulted in those outcomes. Being able to predict sources of sediment and understand the mechanisms and processes that control or contribute to sediment losses and mobility are critical for improving BMP effectiveness (Anderson and Lockaby 2011b, Rivenbark and Jackson 2004).

Understanding the sources, mechanisms, and processes also will improve models used to predict sediment delivery (Anderson and Lockaby 2011b). Commonly used contemporary road erosion models (e.g., the Water Erosion Prediction Project; U.S. Forest Service, n.d.) typically are driven by physical parameters, including road geometry or contributing area. These models exclude important hillslope hydrology mechanisms and processes, including subsurface flow interception by the road prism and infiltration of water discharged off the road. They also exclude the conditions that influence those processes, which may be the most critical factors controlling sediment delivery (Thompson et al. 2010). Improving prediction models by incorporating source and mechanism/process information should help validate BMP effectiveness and illustrate BMP robustness across many different conditions when replicated rigorous field testing has not been performed in a specific region or condition.

BMP studies tend to extend over only one or a few years, which is much shorter than the life of most forest roads. Due to the potential lag in sediment delivery that can occur, long-term studies of road BMP effectiveness are warranted (Anderson and Lockaby 2011b, Daigle 2010). The conditions to which a road is subjected over the long term also are likely to include more interannual extremes than would occur during an individual study.

Many of the initial studies of the effectiveness of individual road BMPs (e.g., surfacing material, cross-drain spacing) were conducted at U.S. Forest Service experimental forests or similar institutional research

locations. Thus, for some studies it may be possible to return to the location of the initial study and resume data collection after reinstrumentation of the site. Current (i.e., long-term) results can be compared to data collected when the road was newer. If current circumstances do not allow studies to be resumed or would confound interpretation, or if it is impossible to pinpoint past research locations, space-for-time (SFT) studies of long-term effectiveness may produce useful findings. For example, studies of the effectiveness of road BMPs that were implemented several years or decades ago provide the opportunity to evaluate responses to years of wetting and drying cycles, extreme storm and runoff events, and long-term use and maintenance (e.g., Bold et al. 2007).

SFT studies also allow comparison of effectiveness for BMPs that have undergone refinement through time (e.g., cross-drain spacings may have changed with revisions to state BMPs over time) (e.g., Henderson 2001). The effectiveness from road segments containing a range of the prescription for that BMP can be compared. Of course, SFT studies must account for differences in road and landscape conditions (e.g., soil erodibility, road design) when comparisons are made across sites. Whenever possible, long-term studies should be coupled with validated models or used to improve models so the spatial and temporal variability of sediment delivery can be better understood and predicted (Anderson and Lockaby 2011b).

Understanding the mechanisms and processes that affect whether sediment delivery to water bodies will occur and the differences between short- and long-term effectiveness will move the science toward the ability to develop the most effective site-specific BMP prescriptions, a need identified for many years (Aust and Blinn 2004). Site-specific BMP prescriptions involve selecting the most effective BMPs for the site conditions and locating them where they provide the greatest benefit. This approach requires acknowledgment that some BMPs do not perform as well as others in a given situation (Sutherland 1998a).

Site-specific BMPs would result in much different BMP implementation strategies than current approaches, in which blanket applications of state recommendations are employed. Blanket application typically allows the user to identify the BMPs that will be applied. Without the advantage of scientifically based studies to guide the decision, however, the individual BMPs may not be the most effective. Furthermore, blanket application typically allows little flexibility in where BMPs are applied. Blanket application of BMPs within a watershed or managed area presupposes that all areas have more or less equal potential for being the source of delivered sediment. For forest roads, where sediment tends to originate from discrete segments or features on only a small percentage of the corridor length (Cafferata et al. 2007, Mills 2006, Rice and Lewis 1991, Skaugset et al. 2007), this assumption is false. Consequently, although blanket application is probably the easiest and most efficient way to ensure BMP implementation, it can be economically inefficient and suboptimally effective (Thompson et al. 2010). Blanket BMP implementation also can create disincentive to apply extra dollars where they are most needed to protect water quality; available funds, which typically are limited, are expended across the entire project area/road length, including where they provide little benefit to water protection. The lack of flexibility in BMP application may cause some to question the environmental benefits they provide (Brynn and Clausen 1991), thereby reducing the likelihood of their implementation.

As suggested above, BMP flexibility inherently includes an economic component— that is, being able to define and apply funds where they are most needed to address current or potential impacts. As such, application of BMP treatments is increasingly being viewed as inefficient if it does not include an analysis of the overall cost-effectiveness of the outcome (Thompson et al. 2010). This approach requires an analysis of environmental performance measures (e.g., what, if any, BMPs can provide the desired environmental outcome, including consideration of their location) for forest roads (Mills 2006) and a technique to simultaneously achieve economic and environmental goals. The latter includes determining the point at which increasing benefits end.

Optimization modeling is one approach to meeting these outcomes (Veith et al. 2003), but field measurements of the effectiveness of specific BMPs are necessary to validate optimization models. Optimization modeling requires that incommensurate objectives (e.g., cost of road construction and mass of sediment delivered, or cost of BMPs and cost of environmental impacts)

be developed and compared to determine the optimal outcomes (Rackley and Chung 2008, Thompson et al. 2010). However, research into the valuation of many environmental factors, such as maintenance of water quality or soil loss, is in its infancy.

Different people value environmental consequences differently, so there is no unique answer within optimization modeling (Thompson et al. 2010). This factor impedes the broad use of optimization, particularly as an alternative to current blanket applications of BMPs. If optimization modeling becomes widely used for helping to more efficiently prescribe BMPs, states (to whom the U.S. EPA has delegated BMP authority) could set sediment reduction objectives (e.g., on a watershed scale) to achieve environmental outcomes and water quality protection.

All the previous issues and needs presented in this chapter will be complicated in the future by potentially significant changes to climate. Although the specific changes and their magnitude will vary by region, more-extreme weather conditions are expected to increase the frequency of flooding, soil surface and in-channel erosion, and annual variability in streamflow (e.g., greater peakflows and lower baseflows) (Furniss et al. 2010, Marshall and Randhir 2008). Maintaining forest road integrity and protecting water quality may become more difficult during more-extreme events (i.e., changing precipitation timing, intensity, and volume) as these may create conditions that challenge BMP performance. Even under the conditions in which BMPs were developed, intense events have been observed to severely test road BMPs, sometimes resulting in failure or suboptimal performance. More-intense events, more frequent events, and longer duration events that accompany climate change may demonstrate that BMPs perform even more poorly in those situations. Research is urgently needed to identify BMP weaknesses under extreme events so that refinements, modifications, and development of BMPs do not lag behind the need.

The focus of road BMPs is controlling erosion and sediment transport on the road prism and on hillsides where road runoff is influential; in other words, the ultimate objective of BMPs is to control nonpoint source pollutant delivery to water bodies (Blinn and Kilgore 2001). Under climate change, hydrologic changes are predicted to increase on-the-ground erosion/sediment transport as well as to increase in-stream erosion and alter channel characteristics (Furniss et al. 2010). Although some road BMPs do include aspects of hydrology (e.g., turning water off roads in small parcels), they are not designed to control in-stream erosion or channel modifications (with the exceptions of controlling substrate changes from sedimentation and channel morphology alterations from road crossings). However, because roads have such a significant effect on watershed hydrology, under climate change the onus of controlling in-stream hydrologic changes attributable to roads (e.g., increased discharge attributable to cross drains connected to the stream) may fall to BMPs. Tempering road-induced hydrologic changes may become necessary for maintaining healthy and resilient aquatic habitats as climate-induced changes in streamflow regimes and resultant changes to habitat conditions are expected to stress some aquatic systems (Marshall and Randhir 2008). If controlling road-induced hydrologic changes becomes a BMP objective, substantive changes to existing BMP prescriptions and development of entirely new BMP techniques may be necessary.

Concluding Thoughts

At the opening of this chapter, we indicated that the effectiveness of most BMPs has not been well quantified from the perspective of statistical rigor and replicated studies across many different types of conditions. But the sheer number of papers included in this document shows there are many studies of road BMP effectiveness as well as studies with results that may be applicable to roads. Based on the results of most of these studies, the case can be made that most BMPs result in some level of effectiveness in terms of reduced sediment generation or transport. Until more extensive and rigorous comparisons of effectiveness become available for specific types or categories of BMPs, the information and tabulated data herein provide the reader a starting place for selecting BMPs for local use.

During the compilation of this document we decided to include some techniques that are rarely used for forest roads, but that we believe have application to them. For some BMPs this was somewhat of a controversial position, even during the manuscript review period. In the end, we retained all the sections we originally

included so as to provide a breadth of BMP possibilities for individuals wanting to extend their options beyond those that they have traditionally used. Considering and perhaps trying new techniques when those typically employed do not perform to expectations is key to adaptive management. Especially as new stressors are placed on the ecosystem, adaptive management is essential for continued watershed protection and improvement.

Wide ranges of BMP effectiveness were reported in many studies in which different techniques were tested under identical conditions. Comparisons of specific types of BMPs across studies also show variability. This variability is evidence that use of the phrases "BMPs minimize erosion" or "BMPs minimize nonpoint source pollution," which are often found in BMP literature, should be discontinued. If one BMP performs more poorly than another in the same or similar situations, both cannot be minimizing pollution. Furthermore, if the intention is to minimize pollution, the actions taken are likely to be much more intensive and involve much greater costs than simply implementing BMPs. In many cases the only action that would truly minimize pollution

would arguably be the decision not to implement any management or cause any disturbance. The Society of American Foresters' dictionary of forestry (Society of American Foresters 2008) defines best management practices as "a practice or usually a combination of practices that are determined by a state or a designated planning agency to be the most effective and practicable means (including technological, economical, and institutional considerations) of controlling point and nonpoint source pollutants at levels compatible with environmental quality goals." The ideas of "practicable means" and "compatible with environmental goals" describe the essence of BMPs: Neither the most complex/costly techniques nor the total elimination of pollutants is required or expected with BMP use. Using statements such as "BMPs minimize pollution" can create a false impression about the degree of pollutant generation and transport to be expected with BMP implementation. This false impression in turn provides fodder for individuals and groups who argue for a shift to regulatory means of pollution control for roads. It is best to portray BMPs for what they are because they play such an important role in protecting watersheds and water quality.

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APPENDIX
English, Metric, and Gradient Conversions Applicable to Text, Tables, and Figures

Converting metric units to English units

If you know	Multiply by	To convert to
cm	0.394	inch
g	0.0022	lb
g L^{-1}	0.0624	lb ft^{-3}
g L^{-1}	0.00835	lb gal^{-1}
g m^{-2}	0.000205	lb ft^{-2}
g mm^{-1}	0.056	lb inch^{-1}
g m^{-2} h^{-1} (mm precip)$^{-1}$	3.613 x 10^{-5}	lb inch^{-2} h^{-1} (inch precip)$^{-1}$
ha	2.471	ac
kg	2.205	lb
kg ha^{-1}	0.892	lb ac^{-1}
kg 100 m^{-2}	0.205	lb 100 ft^{-2}
kg km^{-1}	3.548	lb mi^{-1}
kg m^{-2}	0.205	lb ft^{-2}
kg m^{-3}	0.0624	lb ft^{-3}
kg min^{-1} m^{-1}	0.672	lb min^{-1} ft^{-1}
kg mm^{-1}	55.99	lb inch^{-1}
km	0.621	mi
km^2	0.386	mi^2
kPa	0.145	psi (lb inch^{-2})
L m^{-2}	0.0245	gal ft^{-2}
L s^{-1}	0.0353	ft^3 s^{-1}
m	3.281	ft
m^2	10.76	ft^2
m^3	35.31	ft^3
Mg	1.102	ton
ml	0.0338	oz
mm	0.0394	inch
m^3 ha^{-1}	14.29	ft^3 ac^{-1}
Mg ha^{-1} yr^{-1}	0.446	ton ac^{-1} yr^{-1}
µg L^{-1}	1	ppb
µm	3.937 × 10^{-5}	inch
mg kg^{-1}	1	ppm
mg L^{-1}	1,000	ppb
mg L^{-1}	1	ppm
N·m ha^{-1}	0.298	ft-lb ac^{-1}
tonne	1.102	ton
tonne ha^{-1}	0.446	ton ac^{-1}
tonne km^{-1}	1.774	ton mi^{-1}
tonne km^{-2} day^{-1}	2.855	ton mi^{-2} day^{-1}

Converting English units to metric units

If you know	Multiply by	To convert to
ac	0.405	ha
ft	0.305	m
ft^2	0.0929	m^2
ft^3	0.0283	m^3
ft-lb ac^{-1}	3.350	N·m ha^{-1}
ft^3 ac^{-1}	0.07	m^3 ha^{-1}
ft^3 s^{-1}	28.32	L s^{-1}
gal ft^{-2}	40.75	L m^{-2}
inch	2.54	cm
inch	25.4	mm
inch	25,400	µm
lb	453.6	g
lb	0.454	kg
lb ac^{-1}	1.121	kg ha^{-1}
lb ft^{-2}	4,882.43	g m^{-2}
lb ft^{-2}	4.882	kg m^{-2}
lb 100 ft^{-2}	4.882	kg 100 m^{-2}
lb ft^{-3}	16.019	kg m^{-3}
lb ft^{-3}	16.019	g L^{-1}
lb gal^{-1}	119.83	g L^{-1}
lb inch^{-1}	17.86	g mm^{-1}
lb inch^{-1}	0.0179	kg mm^{-1}
lb inch^{-2} h^{-1} (inch precip)$^{-1}$	27,680.37	g m^{-2} h^{-1} (mm precip)$^{-1}$
lb mi^{-1}	0.282	kg km^{-1}
lb min^{-1} ft^{-1}	1.488	kg min^{-1} m^{-1}
mi	1.609	km
mi^2	2.59	km^2
oz	29.57	ml
ppb	0.001	mg L^{-1}
ppb	1	µg L^{-1}
ppm	1	mg L^{-1}
ppm	1	mg kg^{-1}
psi (lb inch^{-2})	6.895	kPa
ton	0.907	tonne
ton	0.907	Mg
ton ac^{-1}	2.242	tonne ha^{-1}
ton ac^{-1}	2.242	Mg ha^{-1}
ton mi^{-1}	0.564	tonne km^{-1}
ton mi^{-2} day^{-1}	0.350	tonne km^{-2} day^{-1}

APPENDIX

English, Metric, and Gradient Conversions Applicable to Text, Tables, and Figures

Factors for gradient conversions

If you know	Multiply by	To convert to
degrees[a] (°)	tan (degrees) × 100	percent slope (%)
percent slope (%)	$\tan^{-1}$ (percent slope/100)	degrees (°)

[a] The conversion from degrees to percent slope holds only for gradients that are <90°.

Literature describing the effectiveness of best management practices (BMPs) applicable to forest roads is reviewed and synthesized. Effectiveness is considered from the perspective of protecting water quality and water resources. Both paved and unpaved forest roads are considered, but BMPs that involve substantial engineering are not considered. Some of the BMPs included are commonly used on roads; others are used less often. The synthesis focuses on quantitative BMP effectiveness and descriptions of processes or characteristics that influenced the effectiveness. Qualitative results and observations not supported by data are excluded. Most of the effectiveness results describe sediment losses and sediment delivery, but there is also some coverage of chemicals used as BMPs, such as dust palliatives and soil conditioners. Chapters and subheadings are based on how or where protection is provided, or type of BMP. The final chapter provides information on research needs and potential direction of BMP implementation in the future. Although there remains a great need to quantify BMP effectiveness more rigorously across more physiographic, topographic, climate, and soil conditions, the data provided in this synthesis give road and watershed managers and landowners a starting place for evaluating and selecting BMPs.

KEY WORDS: erosion, sediment delivery, road location, drainage control, soil protection, road characteristics, research needs

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June 15, 2017

<u>MEMORANDUM</u>

SUBJECT: Drinking Water Assessment for the Registration Review of Glyphosate.
                 PC Code: 417300, 103601, 103604, 103607, 103608, 103613, 103603,
                 103605, 128501; DP Barcode: 440486

TO: Neil Anderson, Branch Chief
                 Risk Management and Implementation Branch I
                 Pesticide Re-Evaluation Division

FROM: James A. Hetrick Ph.D., Senior Science Advisor
                 Environmental Risk Branch 3
                 Environmental Fate and Effects Division

THROUGH: Dana Spatz, Branch Chief
                 Environmental Risk Branch 3
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PEER REVIEW: Rosanna Louie-Juzwiak, Risk Assessment Process Leader
                 Environmental Risk Branch 3
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Executive Summary

This updated drinking water assessment for glyphosate includes new environmental fate data, current surface and ground water models, and a comprehensive evaluation of surface and ground water monitoring data. Parent glyphosate, expressed on an acid equivalence basis, is considered the residue of concern for drinking water.

Maximum observed and predicted glyphosate concentrations in surface water are shown in Table 1. The maximum glyphosate concentrations in surface source drinking water are associated with the glyphosate use as a direct water application to control aquatic weeds in potable source waters. The maximum estimated drinking water concentration (EDWC) of glyphosate in surface source water are not expected to exceed 700 µg/L for the 1 in 10 year daily peak, 104 µg/L for the 1 in 10 year 90-day average, 75 µg/L for the 1 in 10 year annual average, and 75 µg/L for the 30 year annual average. These concentrations were derived from label language that defines the maximum allowable glyphosate concentration at the intake of a treated drinking water system, as well as model predicted concentrations for the long term average glyphosate concentrations. Estimated glyphosate concentrations from monitoring sites with comparable watershed areas to

community water systems are substantially lower than the glyphosate concentration from direct water applications. The maximum EDWC's for glyphosate from monitoring data are 35.1 µg/L or the 1 in 10 year daily peak, 13.5 µg/L for the 1 in 10 year 90-day average, and 2.8 µg/L for the 1 in 10 year annual average. Although the glyphosate concentrations from monitoring data have not been corrected for the inherent underestimation due to less than daily sampling, a preliminary analysis of bias factors for glyphosate suggests that bias factor corrected EDWC from monitoring data are comparable to the recommended EDWCs from direct water application of glyphosate to potable water sources.

Table 1. Maximum EDWCS for Glyphosate in Surface Water

Use Sites	1 in 10 year				30-year Annual Average
	Daily	Average Daily	90-day Average	Annual Average	
	µg ae[1]/L				
Terrestrial Food and Non-Agricultural Uses-PWC		199	99	65	50
Direct Water Application-using label restriction for MCL and 50% treatment area	700[2]	700[2]	104	75	70
Rice and Cranberry-PFAM	162	162	13.8	5.2	3.6
All SW Monitoring Data[3]	257	257	106	59.7	NC
All SW Monitoring Data 1 in 10 year at 90th percentile site	61	61	13	3	NC
SW Monitoring Data for Potential Watersheds Supporting CWSs[4] 1 in 10 year at 90th percentile site	35.09	35.09	13.47	2.82	NC

1-Concentrations of glyphosate have been normalized to acid equivalence because glyphosate is formulated as amine salts in end use products. The acid equivalence is the ratio of the molecular weight of the acid (grams/mole) to the molecular weight of the amine salt of glyphosate (grams/mole). This ratio was used to adjust the application rates in modeling. Additionally, monitoring data occurrence analyzed for glyphosate acid.

2- Represent the maximum label restricted concentration in glyphosate treated potable water. This concentration is equal to the OW Maximum Contaminate Level (MCL).

3-Data represent maximum concentrations of glyphosate in surface water monitoring data without a distributional assumption of the 1 in 10 year exposure concentration at a 90th percentile site. These are the observed glyphosate exposure concentration from all surface water monitoring data.

4-Concentrations represent 1 in 10 year concentration at a 90th percentile site for monitoring sites with watersheds ≥ 0.04 km[2].

Maximum observed and predicted glyphosate concentrations in ground water are shown in Table 2. Although the PWC modeling indicate no glyphosate breakthrough in groundwater during a 100-year simulation, ground water monitoring data indicate a very high peak (285 µg/L) and annual average concentration (20.6 µg/L) for glyphosate. The groundwater monitoring data with high glyphosate concentrations are associated with subsurface drains and, therefore, they are not representative of groundwater source drinking water. Typically, tile drain fields form preferential flow pathways into tile drains, which allows for a less torturous flow pathway when compared to advection-dispersion flow, as assumed in PWC modeling.

Table 2. Maximum EDWCS for Glyphosate in Groundwater

Assessment Process	Peak	Annual Average
	μg/L	
PRZM-GW Modeling	No breakthrough in GW	
Ground Water Monitoring	285	20.6

EFED recommends that the Health Effects Division (HED) use 700 µg/L for the 1 in 10 year daily peak, 104 µg/L for the 1 in 10 year 90-day average, 75 µg/L for the 1 in 10 year annual average, and 75 µg/L for the 30 year annual average in the dietary health risk assessment. These concentrations were derived from label restrictions for direct water applications of glyphosate on the maximum allowable glyphosate concentration (700 µg/L) at the intake of a drinking water system, as well as model estimated concentrations for the long-term average glyphosate concentrations.

Commercial Formulations and Residues of Concern

Several salts of glyphosate are currently marketed, as well as the acid, and are considered as the active ingredient in end-use products. The parent acid is the chemical species that exhibits herbicidal activity and is the actual chemical stressor considered in this risk assessment, unless otherwise specified.

In order to have comparable results, each salt is considered in terms of its glyphosate equivalent, (acid equivalent; a.e.), determined by multiplying the application rate by the acid equivalence ratio, defined as the ratio of the molecular weight of *N*-(phosphonomethyl)glycine to the molecular weight of the salt. Table 3 shows the salts of glyphosate that may be used as the source of the actual herbicide-active chemical species. For the purpose of this assessment, the acid and all salt species are referred to collectively as "glyphosate" throughout this document.

Table 3. Identification of Glyphosate and its Salts

Counter Cation	PC Code	CAS No.	Acid Equivalence Ratio
Glyphosate acid (no counter cation)	417300	1071-83-6	1
Isopropyl amine	103601	38641-94-0	0.74
Monoammonium	103604	114370-14-8	0.94
Diammonium	103607	69254-40-6	0.83
N-methylmethanamine	103608	34494-07-7	0.79
Potassium	103613	70901-12-1	0.81

The Health Effects Division determined that glyphosate([*N*-(phosphonomethyl)glycine) is the only residue of concern in the human health dietary exposure assessments.

Regulatory Criteria

The National Primary Drinking Water Regulations (NPDWR) have defined a Maximum Contaminate Level (MCL) for glyphosate (**https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations**)**.** The MCL is 700 µg/L. This concentration represents a rolling average concentration for 4 consecutive 90-day sampling (quarterly) intervals.

Previous Drinking Water Assessments

Drinking water assessments have been conducted for a number of different terrestrial crop, terrestrial non-crop, and aquatic use patterns (D376484, D372055, D364549). The highest EDWCs were derived from the direct aquatic applications (D364549).

Use Statistics

Glyphosate is used as a non-selective foliar systemic herbicide in both aquatic and terrestrial environments on a wide variety of food and feed crops, non-food and non-feed crops and for other uses including forestry, greenhouse, non-crop, and residential. Based on agricultural usage data provided by the Biological and Economic Analysis Division (BEAD), on average, roughly 196,355,300 pounds of glyphosate are applied annually to agricultural crops (Table 4). Glyphosate usage is highest on soybeans, with annual average applications of 100,000,000 lbs a.i. applied (representing nearly 51% of the total use on agricultural crops). The crop with the highest average percent crop treated with glyphosate is soybeans (95%), followed by oranges (90%), and then almonds, cotton, grapefruit, and pistachios (85%).

Table 4. Screening Level Estimates of Agricultural Uses of Glyphosate

| Crop | Pounds A.I. | Percent Crop Treated | |
		Average	Maximum
Alfalfa	400,000	<2.5	5
Almonds	2,100,000	85	95
Apples	400,000	55	70
Apricots	10,000	60	80
Artichokes	1,000	10	15
Asparagus	30,000	55	70
Avocados	80,000	45	65
Barley	600,000	25	40
Beans, Green	70,000	15	25
Blueberries	10,000	20	25
Broccoli	3,000	<2.5	<2.5
Brussels Sprouts *	<500	N/C	N/C
Cabbage	20,000	10	25
Caneberries	3,000	10	25
Canola	500,000	65	80
Cantaloupes	20,000	10	25
Carrots	3,000	5	10
Cauliflower	1,000	<2.5	5
Celery	1,000	5	10
Cherries	200,000	65	85
Chicory*	<500	N/C	N/C
Corn	59,300,000	60	85
Cotton	18,300.000	85	95
Cucumbers	30,000	20	35
Dates	3,000	20	25
Dry Beans/Peas	600,000	25	45
Fallow	8,400,000	55	65
Figs	5,000	40	70
Garlic	4,000	10	25
Grapefruit	400,000	85	95
Grapes	1,400,000	70	80
Hazelnuts	30,000	65	90
Kiwifruit	2,000	30	40
Lemons	200,000	75	90
Lettuce	10,000	<2.5	10
Nectarines	20,000	45	70
Oats	100,000	5	10
Olives	20,000	45	50

Crop	Pounds A.I.	Percent Crop Treated	
		Average	Maximum
Onions	40,000	30	40
Oranges	3,200,000	90	95
Pasture	700,000	<1	<2.5
Peaches	100,000	55	70
Peanuts	300,000	20	35
Pears	100,000	65	90
Peas, Green	20,000	10	20
Pecans	400,000	35	45
Peppers	30,000	20	35
Pistachios	500,000	85	95
Plums/Prunes	200,000	65	80
Pluots*	1,000	N/C	N/C
Pomegranates*	40,000	N/C	N/C
Potatoes	80,000	10	15
Pumpkins	20,000	20	25
Rice	800,000	30	50
Sorghum	2,800,000	40	60
Soybeans	100,000,000	95	100
Spinach	2,000	<2.5	10
Squash	10,000	20	40
Strawberries	10,000	10	20
Sugar Beets	1,200,000	55	100
Sugarcane	300,000	45	50
Sunflowers	1,100,000	55	75
Sweet Corn	100,000	15	25
Tangelos	9,000	55	80
Tangerines	60,000	65	80
Tobacco	9,000	5	10
Tomatoes	100,000	35	45
Walnuts	600,000	75	85
Watermelons	30,000	15	25
Wheat	8,500,000	25	70

All numbers rounded.
<500 indicates less than 500 pounds of active ingredient.
<2.5 indicates less than 2.5 percent of crop is treated.
<1   indicates less than 1 percent of crop is treated.
* Based on CA DPR data only; N/C = not calculated, only lb a.i. available

The survey data included in the SLUA report does not differentiate between which exact chemical code(s) are included from the Case. Data years 2004-2012

SLUA data sources include:
USDA-NASS (United States Department of Agriculture's National Agricultural Statistics Service),
Private Pesticide Market Research, and California Department of Pesticide Regulation data.
These results reflect amalgamated data developed by the Agency and are releasable to the public.

As shown in Figure 1, based on U.S. Geological Survey (USGS) National Water Quality Assessment Program (NAWQA) data from 2011, glyphosate is used on agricultural crops across

most of the U.S., but predominantly in California, Midwestern states, Arkansas, Tennessee, Mississippi, Louisiana, and Southeastern states from Maryland to Florida.

Estimated Agricultural Use for Glyphosate , 2011
EPest-High

Estimated use on agricultural land, in pounds per square mile

	< 2.58
	2.58 - 9.64
	9.65 - 29.14
	29.15 - 92.77
	> 92.78
	No estimated use

Figure 1. Map of Estimated Annual Agricultural Use of Glyphosate in 2011
(Source: http://water.usgs.gov/nawqa/pnsp/usage/maps/show_map.php?year=2011&map=GLYPHOSATE&hilo=L)

Application Methods and Rates

Target pests include a broad spectrum of emerged grass and broadleaf weeds, both annual and perennial. Glyphosate is formulated as water-dispersible granules (WG) (80% active ingredient), emulsifiable concentrate (EC) (13.4% - 36.5% active ingredient), water-dispersible liquids (L) (5% - 14.6% active ingredient), ready to use (RTU) (0.81% active ingredient), and soluble concentrate/solid (SC/S) (95.2% - 96.7% active ingredient). Application equipment includes aircraft and various ground equipment (boom sprayer, hand held hydraulic sprayer, hand held sprayer, high volume ground sprayer, hooded sprayer, hose-end sprayer, low volume ground sprayer, low volume sprayer, motor driven sprayer, product container, ready-to-use spray container, shielded applicator, sprayer, tank-type sprayer, wick applicator, and wiper applicator).

Application is via band treatment, broadcast, crack and crevice treatment, directed spray, edging treatment, ground spray, high volume spray (dilute), low volume spray (concentrate), perimeter treatment, soil broadcast treatment, spot treatment, spray, strip treatment, stump treatment, and wipe-on/wiper treatment. Single application rates are up to 8 pounds active ingredient (as acid equivalents)/acre (lb a.e./A), but are generally 1.55 lb a.e./A for aerial applications and 3.75 lb a.e./A for ground application. Maximum combined annual application rates are up to generally 6 to 8 lbs a.e./A. For some uses, the single application rates were calculated as up to 40 lbs a.e./A, however, these applications are intended for spot treatment or treatment over areas much smaller than an acre. In these cases, the application rate is also expressed in terms of the smaller coverage area.

The label data used in this assessment were derived label and use information compiled by the Joint Glyphosate Task Force (JGTF). The Agency requested that the JGTF submit label information to clarify non-specified information in the LUIS report (Memorandum attachments from Ms. Katie Miller, Administrator for the Joint Glyphosate Task Force, LLC. to Ms. Carissa Cyran, Chemical Review Manager in the Office of Pesticides Program. February 15, 2013, Regarding JGTF Submission of Data Matrix Sheet). The non-specified information clarified included maximum number of applications in a crop cycle, maximum number of applications per year, maximum application rate per year, and the minimum retreatment intervals. Table 5 and Table 6 show the maximum single application rates for glyphosate from the JGTF.

Table 5. Maximum Single Application Rates for Ground Applications of Glyphosate from the JGTF Use Matrix

Crop Group	Max Single App Rate (lb a.e./A)	Max Apps	Min Interval (days)	Max Annual App Rate Crop Cycle (lb a.e./A)	Max Combined Annual App Rate (lb a.e./A)
Round Ready 2 Yield Soybeans	3.75	3	10	3.75	6
Root Tuber Vegetables	3.75	3	7	6	6
Rangelands	0.38	6	7	2.25	2.25
Pome Fruits	3.75	10	7	8	8
Pastures	8	4	7	8	8
Oilseed Crops	3.75	3	7	6	6
Non-Food Tree Crops	8	30	7	8	8
Miscellaneous Tree Crops	3.75	10	7	8	8
Miscellaneous Crops	3.75	3	7	6	6
Legume Vegetables	3.75	6	7	6	6
Leafy Vegetables	3.75	6	7	6	6
Herbs and Spices	3.75	6	7	6	6
Grass/Turfgrass/Sod Production	3.75	3	7	6	6
Grain Sorghum	3.75	3	7	6	6
Fruiting Vegetables	3.75	6	7	6	6
Forestry	8	5	7	8	8

Crop Group	Max Single App Rate (lb a.e./A)	Max Apps	Min Interval (days)	Max Annual App Rate Crop Cycle (lb a.e./A)	Max Combined Annual App Rate (lb a.e./A)
Fallow	3.75	3	7	6	6
Cucurbits Vegetables/Fruit	3.75	6	7	6	6
Cotton	3.75	5	7	6	6
Corn (Field, Seed, Silage, Popcorn)	3.75	3	7	6	6
Conservation Reserve Program	3.75	3	7	6	6
Citrus Fruit Crop	3.75	10	7	8	8
Cereal and Grain Crop	3.75	3	7	6	6
Bulb Vegetables	3.75	6	7	6	6
Brassica Vegetable	3.75	6	7	6	6
Round-up Ready Flex Cotton	3.75	3	10	3.75	6
Round-up Ready Cotton	3.75	3	10	3.75	6
Round-up Ready Corn (GA-21)	3.75	3	10	3.75	6
Round-up Ready Corn 2 (NK603)	3.75	3	10	3.75	6
Round-up Ready Alfalfa	1.55	3	10	4.61	6
Round-up Ready Sugarbeets	3.75	3	10	3.75	6
Tropical/Subtropical Trees/Fruits	3.75	3	10	8	8
Tree Nut Crops	3.75	3	10	8	8
Sweet Corn	3.75	3	7	6	6
Sugar Cane	3.75	3	7	6	6
Stone Fruit	3.75	3	7	8	8
Round-Up Ready Canola(Winter Varieties)	1.55	3	10	1.55	6
Soybeans	3.75	3	7	6	6
Sweet Corn with Round-Up Ready 2 Technology	3.75	3	10	3.75	6
Round-Up Ready Canola (Spring Varieties)	1.55	3	10	1.55	6
Vine Crops	3.75	3	7	8	8
Non Crop	8	10	7	8	8
Aquatic	8	4	1	8	8
Alfalfa, Clover, and Other Forage Legume	3.75	3	7	6	6
Berry and Small Fruit Crops	3.75	3	7	8	8
Residential	40	12	7	40	40

Table 6. Maximum Single Application Rates for Aerial Applications of Glyphosate from the JGTF Use Matrix

Crop Group	Max Single App Rate (lb a.e./A)	Max Apps	Min Interval (days)	Max Annual App Rate Crop Cycle (lb a.e./A)	Max Combined Annual App Rate (lb a.e./A)
Round Ready 2 Yield Soybeans	1.55	3	10	3.75	6
Root Tuber Vegetables	1.55	3	7	4.65	6
Rangelands	0.38	6	7	2.25	2.25
Pome Fruits	1.55	3	7	4.65	8
Pastures	8	4	7	8	8
Oilseed Crops	1.55	3	7	4.65	6
Non-Food Tree Crops	8	3	7	4.65	8
Miscellaneous Tree Crops	1.55	3	7	4.65	8
Miscellaneous Crops	1.55	3	7	4.65	6
Legume Vegetables	1.55	6	7	4.65	6
Leafy Vegetables	1.55	6	7	4.65	6
Herbs and Spices	1.55	6	7	6	6
Grass/Turfgrass/Sod Production	1.55	3	7	4.65	6
Grain Sorghum	1.55	3	7	4.65	6
Fruiting Vegetables	1.55	6	7	4.65	6
Forestry	8	2	7	8	8
Fallow	1.55	3	7	4.65	6
Cucurbits Vegetables/Fruit	1.55	6	7	4.65	6
Cotton	1.55	3	7	4.65	6
Corn (Field, Seed, Silage, Popcorn)	1.55	3	7	4.65	6
Conservation Reserve Program	1.55	3	7	4.65	6
Citrus Fruit Crop	1.55	3	7	4.65	6
Cereal and Grain Crop	1.55	3	7	4.65	6
Bulb Vegetables	1.55	6	7	4.65	6
Brassica Vegetable	1.55	6	7	4.65	6
Round-up Ready Flex Cotton	1.55	3	10	3.75	6
Round-up Ready Flex Cotton	1.125	6	10	4.5	6
Round-up Ready Cotton	1.55	3	10	3.75	6
Round-up Ready Corn (GA-21)	1.55	3	10	3.75	6
Round-up Ready Corn 2 (NK603)	1.55	3	10	3.75	6
Round-up Ready Alfalfa	1.55	3	10	4.61	6
Round-up Ready Sugarbeets	1.55	3	10	3.75	6
Tropical/Subtropical Trees/Fruits	1.55	3	10	4.65	8
Tree Nut Crops	1.55	3	10	4.65	8
Sweet Corn	1.55	3	7	4.65	6

Crop Group	Max Single App Rate (lb a.e./A)	Max Apps	Min Interval (days)	Max Annual App Rate Crop Cycle (lb a.e./A)	Max Combined Annual App Rate (lb a.e./A)
Sugar Cane	2.25	3	7	6	6
Stone Fruit	1.55	3	7	4.65	8
Round-Up Ready Canola (Winter Varieties)	1.55	3	10	1.55	6
Soybeans	1.55	3	7	4.65	6
Sweet Corn with Round-Up Ready 2 Technology	1.55	3	10	3.75	6
Round-Up Ready Canola (Spring Varieties)	1.55	3	10	1.55	6
Vine Crops	1.55	3	7	4.65	8
Non Crop	8	10	7	8	8
Aquatic	8	4	1	8	8
Alfalfa, Clover, and Other Forage Legume	1.55	3	7	4.65	6
Berry and Small Fruit Crops	1.55	3	7	4.65	8

Environmental Fate Assessment

The glyphosate salts dissociate rapidly to form glyphosate acid and the counter ion. Because glyphosate acid will be a zwitterion (presence of both negative (anionic) and positive (cationic) electrostatic charges) in the environment, it is expected to speciate into dissociated species of glyphosate acid as well as glyphosate-metal complexes in soil, sediment, and aquatic environments. The environmental fate data for glyphosate, with the exception of a photodegradation study (MRID 44320643), did not address the impact of environmental fate processes on different species of glyphosate acid.

The major route of transformation of glyphosate identified in laboratory studies is microbial degradation (Table 7). In soils incubated under aerobic conditions, the half-life of glyphosate ranges from 1.8 to 109 days and in aerobic water-sediment systems is 14 - 518 days. However, anaerobic conditions limit the metabolism of glyphosate (half-life 199 - 208 days in anaerobic water-sediment systems).

In laboratory studies, glyphosate was not observed to break down by abiotic processes, such as hydrolysis, direct photolysis on soil, or photolysis in water at pH 7. In the field, soil dissipation half-lives for glyphosate were measured to be 1.4 to 142 days. The majority of terrestrial field dissipation studies showed glyphosate half-lives less than 25 days. Although the variability in glyphosate dissipation rates cannot be statistically correlated to any specific test site properties, dissipation half-lives tend to be higher at test sites in the central to northern United States. Along with significant mineralization to carbon dioxide, the major metabolite of glyphosate is aminomethylphosphonic acid (AMPA).

AMPA is a major degradation product from glyphosate. It was detected in all laboratory studies except for the abiotic hydrolysis studies. This degradation product is ionic because it retains the

phosphonate and amine functional groups. Because of these functional groups, AMPA will form metal complexes with Ca^{2+}, Mg^{2+}, Mn^{2+}, Cu^{2+}, and Zn^{2+} (Popov, et al., 2001). Batch equilibrium data for AMPA indicate high sorption to soils. Freundlich sorption coefficients range from 10 to 509 with exponents (1/n) of .78 to 0.98. The laboratory and field dissipation data indicate that AMPA is substantially more persistent than glyphosate.

Table 7. Environmental Fate Data for Glyphosate

Study	Value	Major Degradates[1], Comments	MRID #
Abiotic Hydrolysis Half-life	Stable	None	00108192 44320642
Direct Aqueous Photolysis	Stable ($t_{1/2}$ = 216 days)	AMPA (6.6% of AR)	41689101 44320643
Soil Photolysis Half-life	Stable (for at least 30 days)	Degradation in dark control was equal to that in irradiated samples	44320645
Aerobic Soil Metabolism Half-life	1.8 days (sandy loam; 25°C) 2.6 days (silt loam; 25°C) 7.5 days (sandy loam; 25°C) 2.04 days (sandy loam; 25°C) 19.3 days (sandy loam;20°C) 27.4 days (scl loam; 20°C) 7.78 days (clay loam;20°C) 109 days (silt loam;20°C)	AMPA (24-32% of AR) CO_2 (53 to >70% of AR)	42372501 44320645 44125718 PMRA1161813 Al-Rajab and Schiavon, 2010
Anaerobic Aquatic Metabolism Half-life	208 days 203 days 199 days	AMPA (21.9-31.6% of AR) CO_2 (23-35% of AR) AMPA and glyphosate were detected in sediment at 1 year posttreatment	41723701 42372502 44125718
Aerobic Aquatic Metabolism Half-life	14.1 days (25°C) 267 days (20°C) 518 days (20°C)	AMPA (25% of applied AR) CO_2 (≥ 23% of applied AR)	41723601; 42372503 PMRA 161822

Study	Value				MRID #
Batch Equilibrium	*Soil*	K_F	*1/n*	K_{Foc}	44320646
	sand	64	0.75	22,000	
	sandy loam	9.4	0.72	1,600	
	sandy loam	90	0.76	5,000	
	silty clay loam	470	0.93	21,000	
	silty clay loam	700	0.94	33,000	
	Silty clay loam	62	0.90	3,172	00108192
	Silt	90	0.94	13,050	
	Sandy loam	70	0.95	5,075	
	Sandy loam	22	0.78	5,468	
	Sediment	175	1.0	20115	

Study	Value			MRID #
Terrestrial Field Dissipation Half-life	Glyph. AMPA 1.7 d 131 d (TX) 7.3 d 119 d (OH) 8.3 d 958 d (GA) 13 d 896 d (CA) 17 d 142 d (AZ) 25 d 302 d (MN) 114 d 240 d (NY) 142 d no data (IA)	Bare ground studies. Glyphosate and AMPA were found predominantly in the 0 to 6 inch layers		42607501 42765001
	Glyph. AMPA 2.79 d 48d (CA) 31 d ND (NC)	Bareground Studies Glyphosate and AMPA were found predominantly in the surface soil layers		44125719 44422201
	Glyph AMPA 3.9 d ND Bareground 1.4 d ND Turf	Bareground and turf plots in MS Glyphosate and AMPA were found predominantly in the surface soil layers		44320648
	Glyph AMPA 19 d ND Bareground 12 d ND Turf	Bareground and turf plots in CA Glyphosate and AMPA were found predominantly in the surface soil layers		44320649 44320650
Aquatic Field Dissipation Half-life	7.5 d – water 120 d- sediment	In a farm pond in Missouri. At 3 sites (OR, GA, MI), half-lives could not be calculated due to recharging events.		40881601
	Water: Dissipated rapidly immediately after treatment. Sediment: Glyphosate remained in pond sediments at ≥ 1 ppm at 1 year post treatment.	In ponds in Michigan and Oregon and a stream in Georgia Accumulation was higher in the pond than in the stream sediments		41552801

Forestry Dissipation	Foliage: < 1 day
	Ecosystem:
	    Glyphosate: 100 d
	    AMPA: 118 d
		3.75 lb a.e./A, aerial application		41552801

[1] Major degradates are defined as those which reach >10% of the applied.

The available laboratory data indicate that both glyphosate and AMPA sorb strongly to soil. The formation of glyphosate-metal complexes promotes a high sorption affinity of glyphosate to Fe and Al oxide surfaces on soils and sediments (McBride, 1994; Popov, *et al*. 2001). AMPA is also expected to form similar metal-ligand complexes (Popov, *et al*. 2001). Freundlich partitioning coefficients (K_f) for glyphosate ranged from 9.4 to 479 with exponents of 0.72 to 1, which corresponding organic carbon partitioning coefficients (Kf_{oc}) of 1,600 to 33,000 mL/g_{oc}. Freundlich sorption coefficients for AMPA range from 10 to 509 with exponents (1/n) of 0.78 to 0.98. Because the Freundlich exponents for glyphosate and AMPA are not equal to 1, the sorption process is non-linear and, therefore, sorption coefficients are dependent on the

concentration in soil solution or aquatic environments. Although this non-linearity in sorption is not captured in the exposure modeling, it is expected to reduce the exposure concentrations in aquatic exposure modeling.

Although the coefficient of variation for K_{foc} is less than the coefficient of variation for K_f, indicating that pesticide binding to the organic matter fraction of the soil may explain some of the variability among the adsorption coefficients, the physicochemical properties of glyphosate (ionic) and the propensity for glyphosate and AMPA to form metal-ligand complexes on surfaces of iron and aluminum oxides would suggest the Freundlich model is the most appropriate partitioning model. This model would account for sorption on both mineral and organic constituents in soils and sediments. Based on measured K_{oc} values, glyphosate is classified as slightly mobile to hardly mobile according to the FAO classification scheme and would not be expected to leach to groundwater or to move to surface water at high levels through dissolved runoff. However, glyphosate does have the potential to contaminate surface water from spray drift or transport of residues adsorbed to soil particles suspended in runoff. It is expected to be persistent in anaerobic sediments.

The potential for volatilization of glyphosate from soil and water is expected to be low due to the low vapor pressure and low Henry's Law constant. Several studies have shown both glyphosate and AMPA detections in rainwater near use locations. In most cases, these detections were found during the spraying season in the vicinity of local use areas and can be attributed to spray drift rather than to volatilization or long range transport (Baker *et al.*, 2006; Quaghebeur *et al.*, 2004). The highest concentrations were found in urban locations. At one site in Belgium that was 5 m from a spraying location in an urban parking lot, glyphosate was detected in rainwater for several months following a single application (Quaghebeur *et al.*, 2004). Deposition was measured to be 205 µg a.i./m^2 at one week after spraying and 0.829 µg/m^2 two months after spraying. These data suggest that volatilization of glyphosate from hard surfaces is possible despite its low vapor pressure.

Surface Water Exposure Modeling

Drinking water assessments were conducted to assess EDWCs for terrestrial crop use sites, non-agricultural use sites, rice use sites, and direct application to water use sites. Each of these use sites require a different environmental fate modeling strategy for estimation of glyphosate concentrations in drinking water.

Environmental fate data parameters used in the modeling were selected from the available studies in general accordance with *Guidance for Selecting Input Parameters in Modeling the Environmental Fate and Transport of Pesticides*, Version 2.1, October 22, 2009. Environmental fate data used in glyphosate modeling are shown in Table 8.

Table 8. PWC Modeling Inputs for Glyphosate

PARAMETER	Measured VALUES	VALUE	COMMENT	SOURCE
Spray Drift Fraction	NA	No buffer-0.13 500 feet buffer-0.018 (AR and CA only)	Default fraction for no buffers simulations Calculated	AgDrift
Aerobic Soil Metabolism Half-life (days)	1.8days 2.6 days 7.5 days 2.0 days 13.6 days[b] 19.4 days[b] 5.5 days[b] 77.1 days[b]	29 days	Upper 90th percentile confidence bound of the mean half-life= $16.19+(1.415*25.37)/SQR(8)$ Average=16.19 SD=25.37 $T_{n-1,90}$ =1.415 n=8	MRID 44320645 MRID 44125718 MRID 42372501 PMRA 1161813 Al-Rajab and Schiavon, 2010
Organic Carbon Partition Coefficient (Koc) (mL/ goc)		157	Mean K_F[a]	MRID 44320646 MRID 00108192
Aerobic Aquatic Half-Life (days)	14 days 188 days[b] 366 days[b]	381 days	Upper 90th percentile confidence bound of the mean half-life= $189.7+(1.886*175.8)/SQR(3)$ Average=189.7 SD=175.8 $T_{n-1,90}$ =1.886 n=3	MRID 41723601 PMRA 1161822
Anaerobic Aquatic Half-Life (days)	208 days 203 days 199 days	208	Upper 90th percentile confidence bound of the mean half-life= $203.33+(1.886*4.509)/SQR(3)$ Average=203.33 SD=4.509 $T_{n-1,90}$ =1.886 n=3	MRID 41723701 MRID 42372502
Aqueous Photolysis half-life (days)		Stable	Represents photo-degradation rate at pH 7	MRID 41689101 MRID 44320643
Hydrolysis half-life (days)		Stable		MRID 00108192 MRID 44320642
Vapor Pressure (torr)	9.750E-10	9.750E-10	Vapor Pressure @ 25^{0}C	
Molecular Weight (g/mole)		169.08		Calculated
Water Solubility @ 25°C (mg/L)		12,000		Product Chemistry

a=Data derived according to Guidance of Selecting Input Parameters in Modeling Environmental Fate and Transport of Pesticides Version 2.1 (10/22/2009)
b=Half-lives corrected from 20°C to 25°C using Q10 temperature correction equation.

Terrestrial Crop and Non-Agricultural Terrestrial Use Sites

EDWCs in surface water from terrestrial and non-agricultural uses were estimated with PRZM5 and Variable Volume Water Model (VVWM) models in the operating platform of Pesticide Water Calculator (Version 1.52). PRZM5 simulates pesticide fate and transport as a result of leaching, direct spray drift, runoff and erosion from an agricultural field. The VVWM model simulates pesticide loading via runoff, erosion, and spray drift assuming a standard watershed of 172.8 ha that drains into an adjacent standard drinking water index reservoir of 5.26 ha, an average depth of 2.74 m. A more detailed description of the index reservoir (IR) watershed can be found at https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/development-and-use-index-reservoir-drinking-water. Simulations for drinking water used the index reservoir scenario in the VVWM, which is a surrogate for a drinking water source drawn from a surface water source (nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100JIT6.TXT). Weather and agricultural practices are simulated for 30 years so that the 1 in 10-year exceedance probability at the site can be estimated. The simulation was generated using the 30 years of meteorological data, encompassing the years from 1961 to 1990.

The EDWCs for surface water were multiplied by a percent crop area factor (PCA) of 1. Because glyphosate is used on multiple crops and non-agricultural areas, an all agricultural PCA of 1.0 was used to adjust EDWCs for the percentage of agricultural crops in a watershed (https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/development-community-water-system-drinking-water).

The modeling strategy used to estimate EDWCs for glyphosate included all crop and non-crop scenarios. This modeling approach was used because glyphosate can be used on most crops and non-agricultural use sites. Application rates of glyphosate used in modeling include 1) two applications at 3.75 lbs ae/A, 2) a single application at 8 lbs ae/A, and 3) a single application of 40 lbs ae/A. The application rate of 40 lbs ae/A is a calculated rate based on a residential spot treatment application rate and is expected to be highly conservative.

Pre-emergent applications were assessed assuming an application at 37 and 30 days before emergence at 3.75 lbs ae/A/application or 30 days before emergence at 8 lbs ae/A/application. Post-emergent applications were assessed assuming applications at 20 and 27 day after emergence at 3.75 lbs ae/A/application or 20 days after emergence at 8 lbs ae/A/application. The application date for the residential spot treatment of glyphosate was set to be May 1st because there is no clear emergence date for turf and residential areas. Aerial and ground applications were modeled. Default drift fractions were used to assess drift except for aerial glyphosate applications in CA scenarios (Brady, 2013[1]). Glyphosate labels in AR and CA require a 500 feet spray drift buffer for aerial applications of glyphosate. Drift fractions for the 500 feet spray drift buffer was estimated to be 0.018[2].

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1 Brady, December 13, 2013. Guidance on Modeling Offsite Deposition of Pesticides via Spray Drift for Ecological and Drinking Water Assessments. Environmental Fate and Effects Division, Office of Pesticide Programs.
2 Drift fraction calculation : ((area streams/area reservoir)*drift fraction for 500 feet buffer on a 4 meter wide stream) + drift fraction for 500 ft on an 82 meter wide reservoir. The equation used in calculation of drift fraction is as follows: ((6,000 m2/52,480 m2)*0.0183)+0.0156=0.0181.

The maximum EDWCs for Tier 1 simulations are shown in Table 9. The PWC output is shown in Appendix A. As expected, the highest EDWCs for terrestrial crop and non-agricultural uses is from the residential spot use expressed on an area calculated application rate of 40 lbs a.e./A in the Barton Springs Residential scenario. These EDWCs are expected to be very conservative due to scaling the spot treatment rate to a field application rate on lb a.e./A basis. More realistic EDWCs are expected from post and pre-emergent applications on terrestrial crops because of the defined use rates on field crops and the widespread use of glyphosate on terrestrial crops. The highest EDWCs (peak=206 µg/L) among the terrestrial crop scenarios is associated with an aerial application at an application rate of 8 lbs a.e./A in the MS cotton standard scenario.

EDWCs for glyphosate use on terrestrial crop and non-agricultural use sites are not expected to exceed 199 µg/L for the 1 in 10 year daily average peak concentration, 99 µg/L for the 1 in 10 year 90 day average concentration, 65 µg/L for the 1 in 10 year annual average concentration, and 50 µg/L for the 30 year annual average concentration.

Table 9. Tier I PWC Estimated Environmental Concentrations of Glyphosate in Surface Water from Terrestrial Crop and Non-Agriculture Use Sites

Application Method	Spray Drift Buffer (feet)	Single Application Rate (lb a.e./A)	EDWC				30 Year Annual Average
			1 in 10 year				
			Peak	Daily Average Peak	90 day Average	Annual Average	
			µg/L				
Pre-emergent Application							
Aerial Spray	0	3.75[1]	176	171	89	58	45
	0	8	**206**	**199**	**99**	**65**	**50**
	500[3]	3.75[1]	123	121	74	52	29
	500[3]	8	125	123	80	57	32
Ground Spray	0	8	202	196	94	60	45
Post-emergent Application							
Aerial Spray	0	3.75[1]	170	167	103	74	55
	0	8	179	175	104	76	56
	500[3]	3.75[1]	53	52	31	25	17
	500[3]	8	79	77.2	44	33	20
Ground Spray	0	8	175	196	98	71	51
Residential Spot Treatment							
Ground Spray	0	40[2]	418	406	157	91	57

1-2 applications @ 7 day interval
2-Residential Spot Treatment- Application rates are expressed as lbs ae/A.
3-Spray Drift Buffer for CA and AR

Direct Applications to Aquatic Environments

Direct water applications of glyphosate are allowed to control of aquatic weeds. The EDWCs for direct water applications were calculated using the Pesticide Water Calculator (Version 1.52) and VVWM model.

Direct water applications were simulated in PWC for all available scenarios. This modeling approach considers the geographic variability in both aquatic degradation and reservoir flow rates. The modeling was conducted using single application rates of 3.75 and 8 lb a.e./A. The labels with direct aquatic uses do not specify a target concentration as the aquatic label application rates are expressed as lbs ae/A. Direct water applications were modeled in PWC by using the label application rate with a spray drift of application efficiency of 0 and drift fraction of 1.0. This modeling approach assumes that 100% of the pesticide application rate drifts into the reservoir. The glyphosate labels, however, recommend that no more than 50% of water area be treated to limit oxygen depletion from decaying aquatic vegetation.

The maximum EDWCs for direct water use simulations are shown in Table 10. The PWC output is shown in Appendix A. As expected, the highest EDWCs (peak=438 µg/L) for direct water applications are associated with the application of 8 lbs a.e./A in the MI asparagus and WAorchard scenarios. These EDWCs are expected to be conservative because they assume 100% of the reservoir area is treated with glyphosate. More realistic EDWCs require factoring in the label restriction for a maximum of 50% treated area in the waterbody for any direct water applications.

It is important to note the following label language regarding direct application to water:
"*To make aquatic applications around and within ½ mile of active potable water intakes, the water intake must be turned off for a minimum period of 48 hours after the application. The water intake may be turned on prior to 48 hours if the glyphosate level in the intake water is below 0.7 parts per million as determined by laboratory analysis.*" This concentration is the USEPA maximum contaminate level (MCL) for glyphosate.

Based on label recommendations, EDWCs for direct water applications of glyphosate are not expected to exceed 700 µg/L in surface source drinking water. Because this concentration is greater than EDWCs from modeling, it represents the most conservative EDWCs from direct water applications.

Table 10. Predicted Glyphosate Concentrations from Direct Applications into the Index Reservoir

Single Application Rate (lb a.e./A)	Treated Area Assumption (100%)	EDWC				
		1 in 10 year				30 Year Annual Average
		Peak	Daily Average Peak	90 day Average	Annual Average	
		µg/L				
3.75	100	206	201	98	70	66
8	100	438	428	208	150	140
3.75	50	103	101	49	35	33
8	50	219	214	104	75	70

Aquatic Food Crop Uses (Rice and Cranberry)

EDWCs for glyphosate use on aquatic food crop use sites (rice and cranberry) were predicted using the PFAM model (version 2). Glyphosate is used in rice and wild rice as a pre-plant

herbicide for control of red rice. The labels recommend a single glyphosate application of 0.375 to 1.5 lbs ae/A at 8 days prior to planting rice. For cranberries, glyphosate applications can be applied as a spot treatment around cranberry bogs or as a post-harvest application using a spot or wiper applications. The maximum specified application rate for cranberry is 3 lbs ae/A. Additionally, the label requires that only 10% of the bog is treated. For both the rice and cranberry uses, direct water applications of glyphosate are not allowed. Because the glyphosate labels for rice and cranberry restrict direct glyphosate applications to water, the Tier 1 rice model was not used.

PFAM modeling for rice was conducted using the drinking water standard scenarios for rice in CA and MO. These scenarios were designed to mimic a rice growing watershed draining to a community water system (CWS) intake. The cranberry scenarios for PFAM, however, have been designed for ecological exposure assessment. Therefore, the EDWCs for cranberry uses are expected to be highly conservative because they do not account for dilution and dissipation pathways between the treated field and the drinking water intake.

The maximum EDWCs for glyphosate use on rice and cranberry are shown in Table 11. The PFAM output is shown in Appendix B. The highest EDWCs are associated with the MO preflood no-hold scenario for glyphosate applications to rice. Although the cranberry modeling was conducted at a higher application rate than rice and represents edge of bog concentrations, the PFAM cranberry EDWCs are substantially lower than the PFAM rice EDWCs. A possible explanation is the difference in water management practices for rice and cranberry production.

EDWCs for glyphosate use on rice and cranberry are not expected to exceed 162 µg/L for the 1 in 10 year daily average peak concentration, 13.8 µg/L for the 1 in 10 year 90 day average concentration, 5.12 µg/L for the 1 in 10 year annual average concentration, and 3.6 µg/L for the 30 year annual average concentration.

Table 11. Predicted Glyphosate Concentrations from Applications to Rice and Cranberry Use Sites

Single Application Rate (lb a.e./A)	Crop	EDWC			30 Year Annual Average
		1 in 10 year			
		Daily Average	90 day Average	Annual Average	
		µg/L			
1.5	Rice	162	13.8	5.2	3.6
3.0	Cranberry	12.9	12.1	3.0	NR

1-NR=Not reported in PFAM output

Surface Water Monitoring Data

A search for available surface water monitoring data from 2014 to present for glyphosate and AMPA was conducted in the Water Quality Portal (accessed 4/18/2017), USGS NAWQA (accessed 1/4/2014), CADPR SWAMP (accessed 4/11/2017), CADPR SURF (accessed 4/11/2017), USDA PDP, and USGS-EPA Pilot Reservoir Monitoring Program, and the Washington Department Agriculture Salmonid Monitoring Program (accessed 6/12/2017). Additionally, open literature was also considered in this analysis.

The surface water monitoring data were analyzed on a site-year basis where each site-year combination is used to derive exposure endpoints. The surface water data were evaluated to ensure each observation had consistent concentration units (µg/L), defined detection limits, sampling station number, and sampling date. These data were evaluated using a computer program (Chemograph Generator 2.0.2) designed to derive sampling data on a site-year basis. Sampling data includes site identification, sample year, number of samples in a site-year, number of non-detects in a site-year, and relevant exposure concentrations, such as the daily peak, 90-day average, and annual average. Data points reported as the limit of quantification (LOQ) or limit of detection (LOD) were adjusted to 1/2 of LOD or LOQ, whichever is reported in the data. The daily peak concentrations represent the highest daily concentration for a site-year. Time weighted concentrations such as the 90-day average and annual average concentrations were derived using a forward "hot deck" stair-step imputation process from the first sampling date to the last sampling date in each site-year chemograph.

In order to adequately compare the monitoring data with model predictions of a 1 in 10 year concentration at a 90th percentile site, the monitoring data were analyzed using joint temporal-spatial distributional analysis. This analysis was completed using the site-year summary statistics from Chemograph Generator 2.0.2. All monitoring data were included in the analysis of daily peak concentrations. Monitoring data with 4 or more samples per year were used to calculate 90-day and annual average concentrations. The selected data for each appropriate endpoint (daily peak, 90 day-day average, and annual average) were log transformed to approximate a normal distribution. The assumption is that environmental monitoring data are commonly log-normally distributed. The average and standard deviation for each site were calculated using R commander (Version 3.03, 3/6/14). These summary statistics were then used in the Student t approximation of a normal distribution to represent the 1 in 10 year value (90th percentile) based on lognormal average and standard deviation at each site. These transformed data were combined to determine the 90th percentile site. The calculated 1 in 10 year value at a 90th percentile site will be compared to the model predictions.

It is important to note that the monitoring data have not been corrected for bias due to low sampling frequency. However, glyphosate bias factors were generated from the single data set of USGS stream data with 2-day sampling frequency at sampling sites in MO for 2013 (Mahler et al., 2017). These bias factors provide some context on the extent of bias (underestimation) in the glyphosate occurrence concentrations. Bias factors were generated using the EXCEL program Chemograph Generator 2.0.2.

Glyphosate

Surface water monitoring data for glyphosate were derived from the Water Quality Portal, USGS NAWQA, CADEPA SWAMP, CADPR SURF, and Washington Department of Agriculture (WDA). Attributes of the general monitoring programs are shown in Table 12. The available monitoring data for glyphosate represent state and federal monitoring programs. The monitoring data represent a range of spatial and temporal distribution with the WQP, representing 20,466 site-years over 46 states to 1,638 site-years in single state (California). Most of the monitoring data represent glyphosate concentrations in dissolved or filtered surface water samples. For purposes of this analysis, dissolved glyphosate or glyphosate in filtered samples are equivalent.

NAWQA and USGS Stream monitoring data were the only monitoring programs to describe the major land use in the watershed of the sampling sites. The limits of detection (LOD) were generally low (<0.150 µg/L) for dissolved glyphosate concentrations. However, there were some monitoring data with high LODs (4-300 µg/L). These data were generally representative of older information (pre-2000).

Table 12. Attributes of Surface Water Monitoring Programs for Glyphosate

Monitoring Program Description	Years	Sites	States	Water Type[1]	Range of LOD µg/L
Water Quality Portal					
General Monitoring-Dissolved Water	18	1137	46	Dissolved	0-4 (0.02)[2]
General Monitoring-Total Water	23	442	3	Total	0-100 (10)
General Monitoring-Recoverable Water	5	35	6	Recoverable	5-10 (5)
USGS Streams					
2 Day Sample Frequency	1	5	1	Filtered	0.04
Weekly Sample Frequency – LC	1	27	9	Filtered	0.04
Weekly Sample Frequency– Elisia	1	100	12	Filtered	0.04
NAWQA					
All Sites	12	64	20	Filtered	0.02-.150 (0.1)
Agricultural Use Monitoring Sites	12	17	13	Filtered	0.02-.150 (0.1)
Urban Use Monitoring Sites	9	12	13	Filtered	0.02-.150 (0.1)
Mixed Use Monitoring Sites	9	17	15	Filtered	0.02-.150 (0.02)
Other Use Monitoring Sites	9	18	7	Filtered	0.02-.150 (0.02)
CA SWAMP					
CA Monitoring Sites	9	182	1	Filtered	1-300 (5)
CA SURF					
CA Monitoring Sites	16	291	1	Filtered	0.02-400 (5)
WDA					
Salmonid Monitoring Program	1	14	1	Total	0.008

1-Water Handling: Filtered is residues in filtered waters; Total is total residues detected in unfiltered sample; and Extractable is extracted residues from water sample.
2-Represents reported range of LOD or LOQ with (median)

Descriptive statistics for glyphosate occurrence in surface water are shown in Table 13. The median detection frequency ranged from 0 to 100%. A median detection frequency of 0% illustrates that 50% of the site-years had no glyphosate detections. In contrast, a median detection frequency of 100% illustrates that 50% of the site-years had glyphosate detections in every sample. This interpretation illustrates that glyphosate is commonly detected in surface waters. Although the ability to correlate detection frequency to land use is limited to the monitoring data from NAWQA, the highest median detection frequency (72.1%) was found in watersheds with undefined land use (i.e., mixed or other).

The highest glyphosate concentration in the monitoring data (257 µg/L) is from a Goshen Ditch sampling station (558GSDSP6) in the CA SURF database. This monitoring station is a sampling site in the irrigated lands monitoring program. Similar glyphosate concentrations (180 to 200 µg/L) were detected in the Drain 11@ Waisal Slough (53XXXD11) and Drain 14@ Lone Tree

Creek (544XXXD14) in CA. The highest concentration of glyphosate in the WQP monitoring program is 200 µg/L from a tributary in the Deep Hollow Lake watershed (USG 0728711610) near Sidon, MS. (https://archive.usgs.gov/archive /sites/ms.water.usgs.gov /projects/MDMSEA/index.html). The watershed of the tributary is comprised of 42.1 acres of soybean and cotton fields in conservation tillage and winter cover crops for Best Management Practices. The sampling site at the entrance of the tributary had a culvert with a weir. Similar concentrations of glyphosate (156 µg/L) also were observed in another tributary of the Deep Hollow Lake watershed (USGS-0728711620). The watershed of this tributary is comprised of 25.4 acres of soybean and cotton fields in conservation tillage. Although there are high glyphosate detections in surface water monitoring programs, the aforementioned sampling sites are not expected to be representative of drinking water intake locations.

Table 13. Maximum EDWCs for Glyphosate from Surface Water Monitoring Programs

Monitoring Program	Median Detection Frequency (%)	Peak	90-Day Average[1]	TW Annual Average[1]
		µg/L		
Water Quality Portal[2]				
Dissolved	50	200	87.4	57.8
Total	0	24.4	3.0	5.3
Recoverable	0	<LOD	<LOD	<LOD
USGS Streams				
2 Day Sample Frequency-Filtered	38.5	16.5	1.2	1.3
Weekly Sample Frequency – LC -Filtered	100	11.0	3.5	3.3
Weekly Sample Frequency– Elisia-Filtered	41.7	27.8	3.7	2.8
NAWQA[2]				
All Sites	61.5	73	31.3	6.1
Agricultural Use Monitoring Sites	56.5	73	31.3	4.0
Urban Use Monitoring Sites	38.9	5.9	1.6	0.9
Mixed Use Monitoring Sites	72.1	3.1	0.9	0.6
Other Use Monitoring Sites	72.1	38	7.3	6.1
CA SWAMP				
CA Monitoring Sites	0	200	106	59.7
CA SURF				
CA Monitoring Sites	0	257	106	59.7
WDA				
Salmonid Monitoring Program	100	1.5	NC[3]	NC

1-Represents site-years with 4 or more samples per year
2- Represent monitoring programs with monitoring sites capable of supporting a surface source community water system. Monitoring sites with dissolved glyphosate data and watershed areas greater or equal to 0.04 km2 are assumed to be capable of supporting a CWS. A watershed area of 0.04 km^2 represents a lower bound watershed area for a surface source drinking water.
3-Not calculated because there are only 2 samples per site-year.

Distributional analysis was conducted to provide a probabilistic estimate of the 1 in 10 glyphosate concentration at a 90th percentile use site from the monitoring data. Site-year descriptive statistics for non-bias factor adjusted monitoring data were used to estimate the 1 in 10 year glyphosate concentration at 90th percentile site. Table 14 shows the 1 in 10 year concentrations for dissolved glyphosate at a 90th percentile for monitoring sites with dissolved

glyphosate concentrations data and watershed areas greater or equal to 0.04 km^2 from the WQP and NAWQA monitoring programs. These monitoring sites were selected in distributional analysis because their watersheds are comparable to or greater than a lower bound watershed area (0.04 km^2) for an actual surface source CWS. More importantly, the WQP and NAWQA monitoring data were used because most of the data are not routinely representative of non-drinking water source waters such as irrigation ditches, canals, and shallow streams. An assumption in determining the watershed area for individual monitoring sites is the linkage of monitoring site location to the National Hydrologic Database (NHD).

The distributional analysis indicates that daily maximum peak EDWCs from PWC modeling are comparable to the 95th site percentile in the NAWQA monitoring program and 99th site percentile in the WQP monitoring data. Additionally, the median (typical) EDWCs from PWC were generally comparable or higher than the 1 in 10 year glyphosate concentrations for the 90th percentile sites in the monitoring data. These data illustrate that the EDWCs from PWC modeling are reasonably conservative when compared to non-bias factor adjusted monitoring data.

Table 14. Comparison of glyphosate concentrations from non-bias factor adjusted surface water monitoring programs and EDWCs from PWC for Terrestrial Crop and Non-agricultural Uses

Monitoring Program	Exposure Endpoint	1 in 10 year Glyphosate Monitoring Concentration (µg/L)			1 in 10 year Glyphosate PWC Concentrations[1] (µg/L)		
		Site Percentile			Minimum	Median	Maximum
		90th	95th	99th			
WQP	Daily Peak	13.98	35.60	205.57	35.1	51.9	171
	90-Day Average	13.47	49.22	559.25	15.9	26.4	88.5
	Annual Average	2.82	6.01	24.90	5.4	14.7	45.2
NAWQA	Daily Peak	35.09	93.50	587.74	35.1	51.9	171
	90-Day Average	2.94	4.00	10.10	15.9	26.4	88.5
	Annual Average	0.98	1.46	3.10	5.4	14.7	45.2

1- PWC concentrations for two pre-emergent applications of 3.75 lb ae/A.

The bias factors for glyphosate show considerable variation (CV=64 to 129%) among the monitoring sites in the USGS stream monitoring program (Mahler et al., 2017) (Table 15). Although these bias factors were not factored into the distribution analysis, the bias factor adjustment of the monitoring data will inflate the differences between monitoring data and PWC modeling. The median sample frequency is 14 days in the WQP and NAWQA monitoring programs. These data suggest that bias factors for glyphosate could be 24.5 to 39.1X for daily peak glyphosate concentrations and 3.7X for 90-day average concentrations. Mahler et al., 2017 found that glyphosate concentrations from 2-day samples could be approximately 8 times higher than glyphosate concentrations from weekly samples. Using similar data, the BFs for 2-day peak concentrations could be underestimated from 12 to 19.5X lower for a 7-day sampling interval.

Although these data provide quantification on the potential extent of underestimation in glyphosate occurrence concentrations, there are insufficient data (≥100 site-years) to allow for spatial and temporal extrapolation of bias factors (US EPA, 2012).

Table 15. Bias factors estimated from USGS Small Stream Monitoring Data

Endpoint	Sampling Interval			
	7-day	14-day	21-day	28-day
Daily Peak	19.5±27.6	39.1±47.1	43.5±61	54.2±70.7
4-day average	12±15.4	24.5±25.7	25.9±38.8	33±37.3
90-day average	2.5±1.6	3.7±2.4	3.4±2.0	4.2±2.4

AMPA

Surface water monitoring data for AMPA were derived from the USGS NAWQA, CADEPA SWAMP, USGS Streams, and WDA. Attributes of the general monitoring programs are shown in Table 16. The available monitoring data for AMPA represent state and federal monitoring programs. The AMPA monitoring data represent a range of spatial and temporal dispersion with the WQP representing 846 site-years over 20 states to 180 site-years in a single state (California). Most of the monitoring data represent AMPA concentrations in dissolved or filtered surface water samples. NAWQA monitoring data was the only monitoring program to describe the major land use in the watershed of the sampling sites. The limits of detection (LOD) were generally low (<0.31 µg/L) for dissolved glyphosate concentrations. However, the CA SWAMP monitoring program had higher LODs (10 µg/L).

Table 16. Attributes of Surface Water Monitoring Programs for AMPA

Monitoring Program Description	Years	Sites	States	Water Type[1]	Range of LOD µg/L
USGS Streams					
Weekly Sample Frequency – LC	1	27	10	Filtered	0.02
NAWQA					
All Sites	13	65	20	Filtered	0.02-0.31 (0.1)
Agricultural Use Monitoring Sites	12	18	13	Filtered	0.02-0.31 (0.1)
Urban Use Monitoring Sites	9	7	7	Filtered	0.02-0.31 (0.1)
Mixed Use Monitoring Sites	10	18	15	Filtered	0.02-0.31 (0.1)
Other Use Monitoring Sites	9	19	6	Filtered	0.02-0.1 (0.1)
CA SWAMP					
CA Monitoring Sites	5	36	1	Filtered	10
WDA					
Salmonid Monitoring Program	1	14	1	Total	0.008

1-Water Handling: Filtered= Water samples filtered prior to chemical analysis; Total= Total residues detected in unfiltered sample; and Extractable-Extracted residues from water sample.
2-Zero was used as the LOD and LOQ

Descriptive statistics for AMPA occurrence in surface water are shown in Table 17. The median detection frequency for AMPA ranges from 83.4 to 100% with the exception of the CA SWAMP monitoring program. The high detection frequencies of AMPA were expected because it is more mobile and persistent than glyphosate. The highest median detection frequency (72.1%) was found in watersheds with undefined land use (i.e., mixed or other).

The highest AMPA concentration in the monitoring data (28 µg/L) is from a USGS sampling site on Bogue Phalia near Leland, MS (USGS 7288650). This site has a watershed area of

484 mile^2 with the major crop production in soybeans https://waterdata.usgs.gov/nwis/inventory/?site_no=07288650&agency_cd=USGS and Coupe et al, 2011).

Table 17. Maximum EDWCs for AMPA from Surface Water Monitoring Programs

Monitoring Program	Median Detection Frequency (%)	Peak	90-Day Average[1]	TW Annual Average[1]
			µg/L	
USGS Streams				
Weekly Sample Frequency – LC -Filtered	100	5.2	2.8	3.0
NAWQA				
All Sites	100	28	7.0	4.3
Agricultural Use Monitoring Sites	95.23	8.7	5.1	3.1
Urban Use Monitoring Sites	83.4	3.5	1.3	0.7
Mixed Use Monitoring Sites	100	4.4	1.5	1.0
Other Use Monitoring Sites	100	9.7	3.9	3.1
CA SWAMP				
CA Monitoring Sites	0	4.4	0.9	0.5
WDA				
Salmonid Monitoring Program	100	0.38	NC[2]	NC

1-Represents site-years with 4 or more samples per year
2-Not calculated because there are only 2 samples per site-year

Groundwater Modeling

Ground water concentrations are estimated using the PRZM-GW model in the Pesticide Water Calculator (Version 1.52). PRZM-GW uses leaching algorithms (tipping bucket) from the PRZM model to predict pesticide leaching into shallow groundwater on vulnerable sites (*i.e.*, sandy soils), with the shallow well located directly adjacent to the treated area. The model construct assumes that the aerobic soil metabolism rate decreases linearly to zero at a 1 meter depth in the surface soil, and that abiotic hydrolysis is the only degradation process deeper than 1 meter. Lateral flow is not considered in the modeling. Currently, six regionally-specific scenarios of vulnerable soils are used in the groundwater modeling. Detailed description, documentation, and direct links for running these models can be found in: https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/about-water-exposure-models-used-pesticide.

A modeling strategy using PWC to estimate EDWCs for glyphosate using all crop and non-crop scenarios was developed. The application rate used in modeling was 40 lbs ae/A. Although the application rate of 40 lbs ae/A is calculated from a residential spot treatment application rate, it is expected to provide the most conservative EDWCs in ground source drinking water. The application date for the residential spot treatment of glyphosate was set to be May 1st because there is no clear emergence date for turf and residential areas.

The Tier 1 simulation indicates that glyphosate is not expected to breakthrough into groundwater during a 100-year simulation. The PRZM-GW output is shown in Appendix C.

Glyphosate Groundwater Monitoring Data

Ground water monitoring data for glyphosate were derived from the Water Quality Portal and USGS NAWQA. Attributes of the general monitoring programs are shown in **Table 17**. The available monitoring data for glyphosate represent state and federal monitoring programs. The glyphosate monitoring data represent a range of spatial and temporal dispersion with the WQP representing 20,349 site-years over 30 states. Most of the monitoring data represent glyphosate concentrations in dissolved or filtered surface water samples. For purposes of this analysis, dissolved glyphosate or glyphosate in filtered samples are assumed to be equivalent. NAWQA monitoring data was the only monitoring program to describe the major land use in the watershed of the sampling sites. The limits of detection (LOD) were generally low (<0.6) µg/L) for dissolved glyphosate concentrations. However, LODs were higher (3 to 5 µg/L) for monitoring data for total and recoverable glyphosate fractions in groundwater.

Table 17. Attributes of Groundwater Monitoring Programs for Glyphosate

Monitoring Program Description	Years	Sites	States	Water Type[1]	Range of LOD µg/L
Water Quality Portal					
General Monitoring-Dissolved Water	17	1197	30	Dissolved	0.02-0.6 (0.02)
General Monitoring-Total Water	3	22	1	Total	3.0-3.1
General Monitoring-Recoverable Water	2	51	2	Recoverable	5.0
NAWQA					
All Sites	12	745	30	Filtered	0.02-0.15 (0.1)
Agricultural Use Monitoring Sites	9	294	18	Filtered	0.02-0.15 (0.1)
Urban Use Monitoring Sites	10	44	19	Filtered	0.02-0.15 (0.1)
Mixed Use Monitoring Sites	3	24	7	Filtered	0.02-.1 (0.1)
Other Use Monitoring Sites	9	23	13	Filtered	0.02-.1 (0.02)

1-Water Handling: Filtered is residues in filtered waters; Total is total residues detected in unfiltered sample; and Extractable is extracted residues from water sample.
2-Represents reported range of LOD or LOQ with (median)

Descriptive statistics for glyphosate occurrence in groundwater are shown in Table 18. The median detection frequency of glyphosate was < 0.1%. These data indicate that glyphosate is not typically detected in groundwater. Most of the monitoring sites had low peak concentrations (0.1-2.2 µg/L).

The highest glyphosate concentration (285 µg/L) in groundwater is from a subsurface drain in Hamilton County, IA (USGS 423232093351801), which is not representative of a drinking water intake location.

Table 18. Maximum EDWCs for Glyphosate from Groundwater Monitoring Programs

Monitoring Program	Median Detection Frequency (%)	Peak	TW Annual Average[1]
		μg/L	
Water Quality Portal			
Dissolved	0	280	22.77
Total	0	<LOD	<LOD
Recoverable	0	<LOD	<LOD
NAWQA			
All Sites	0	285	20.6
Agricultural Use Monitoring Sites	0	1.2	NE
Urban Use Monitoring Sites	0	2.2	0.3
Mixed Use Monitoring Sites	0	0.1	NE
Other Use Monitoring Sites	0	285	14

1-Represents sites with 4 or more samples per year

AMPA Groundwater Monitoring Data

Groundwater monitoring data for AMPA were derived from USGS NAWQA. Attributes of the general monitoring programs for AMPA are shown in Table 19. The available monitoring data for AMPA represent state and federal monitoring programs. The AMPA monitoring data represent a range of spatial and temporal distribution with the WQP representing 1164 site-years over 30 states. The monitoring data represent AMPA concentrations in filtered surface water samples. The limits of detection (LOD) were generally low (<0.31) μg/L for dissolved AMPA concentrations.

Table 19.Attributes of Groundwater Monitoring Programs for AMPA

Monitoring Program Description	Years	Sites	States	Water Type[1]	Range of LOD
					μg/L
NAWQA					
All Sites	12	97	30	Filtered	0.02-.31 (0.1)
Agricultural Use Monitoring Sites	9	69	18	Filtered	0.02-.31 (0.1)
Urban Use Monitoring Sites	10	44	19	Filtered	0.02-.31 (0.1)
Mixed Use Monitoring Sites	4	18	8	Filtered	0.1
Other Use Monitoring Sites	10	24	14	Filtered	0.02-0.31 (0.02)

1-Water Handling: Filtered= Water samples filtered prior to chemical analysis; Total= Total residues detected in unfiltered sample; and Extractable-Extracted residues from water sample.
2-Zero was used as the LOD and LOQ

Descriptive statistics for AMPA occurrence in ground water are shown in Table 20. The median detection frequency of glyphosate was 0%. These data indicate that AMPA is not typically detected in groundwater. Peak AMPA concentrations in groundwater range from 1.4- 397 µg/L. The highest AMPA concentration (397 µg/L) in groundwater is from a site in IA (Coupe et al.,

2011). Although there are high AMPA detections in groundwater monitoring programs, the aforementioned sampling site is not representative of a drinking water intake location.

Table 20. Maximum EDWCs for AMPA from Groundwater Monitoring Programs

Monitoring Program	Median Detection Frequency (%)	Peak	TW Annual Average[1]
		μg/L	
NAWQA			
All Sites	0	397	17
Agricultural Use Monitoring Sites	0	1.4	0.2
Urban Use Monitoring Sites	0	37	5.3
Mixed Use Monitoring Sites	0	<LOD	<LOD
Other Use Monitoring Sites	0	397	17

Open Literature

The USGS conducted studies to assess glyphosate and AMPA concentrations in surface water as well as wastewater effluent from treatment plants.

A total of 154 water samples were collected by the U.S. Geological Survey during a 2002 study in nine Midwestern States (Illinois, Indiana, Iowa, Kansas, Minnesota, Missouri, Nebraska, Ohio, and Wisconsin) (Scribner *et al*., 2003 and Lee *et al*., 2001), where glyphosate is extensively used on corn. Glyphosate was detected in 36 percent of the samples, while its metabolite AMPA was detected in 69 percent of the samples. The highest measured concentration of glyphosate was 8.7 μg/L. The highest AMPA concentration was 3.6 μg/L.

Treated effluent samples were collected from 10 wastewater treatment plants (WWTPs) in Arizona, Colorado, Georgia, Iowa, Minnesota, Nevada, New Jersey, New York, and South Dakota to study the occurrence of glyphosate and AMPA (Kolpin *et al*., 2006). Stream samples were collected upstream and downstream of the 10 WWTPs. Two reference streams were also sampled. The results document the apparent contribution of WWTP effluent to stream concentrations of glyphosate and AMPA, with roughly a two-fold increase in their frequencies of detection between stream samples collected upstream and those collected downstream of the WWTPs. Thus, urban use of glyphosate contributes to glyphosate and AMPA concentrations in streams in the United States.

Glyphosate or its degradate AMPA were commonly detected in the stream and WWTP effluent samples, being present in 67.5% of the 40 samples collected. Concentrations were generally low, although nine detections of AMPA (maximum concentration=3.9 μg/L) and three detections of glyphosate (maximum concentration=2.2 μg/L) exceeded 1 μg/L. AMPA was detected much more frequently (67.5%) than glyphosate (17.5%).

Both AMPA and glyphosate had the greatest frequency of detection in the WWTP effluent samples, with roughly a two-fold increase in the frequency of detection for both AMPA and

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glyphosate between stream samples located upstream and those located downstream of the WWTPs.

It should be noted, however, that AMPA can also be derived from the degradation of phosphonic acids (such as EDTMP and DTPMP) in detergents. Thus, part of the AMPA detections from this study could be potentially derived from a detergent source. Other components of detergents, such as 4-nonylphenol diethoxylate and 4-nonylphenol monoethoxylate were also measured in the samples collected for this study. However, AMPA was always present in samples that had detections of glyphosate, which suggests that at least part of the AMPA concentrations in this study were derived from the degradation of glyphosate.

From 2003 to 2008, Coupe *et al*, 2011 conducted surface water monitoring of glyphosate and AMPA in agricultural surface waters in MS, IA, IN, and France. This monitoring was targeted to watersheds with a high percentage of agricultural crops (68 to ~100% basin in agriculture). The major crops in the watershed were soybeans, corn, cotton, rice, and grapes (France only). For the larger surface water bodies in the United States, samples were taken bimonthly during most of the year with weekly sampling during the growing season from April to August. Additionally, some samples were collected during selected storm events. Monitoring in France and some smaller basins in the U.S. were taken using an automatic sampler. Filtered water samples were analyzed using HPLC/MS. The reporting levels were 0.02 µg/L for samples from the United States and 0.1 µg/L for the French samples. Detection frequencies of glyphosate and AMPA ranged from 59 to 100% and 92 to 100%, respectively. The maximum concentration of glyphosate was 430 µg/L (median 380 µg/L) at an overland flow site in the Sugar Creek, IN monitoring site from May 19-21, 2004. The maximum concentration of AMPA was 29 µg/L (median 26 µg/L) at the overland flow site.

Mahler, et al. 2017 conducted a Midwest Stream Quality Assessment (MSQA) on 100 sites of shallow streams (<1 meter deep) across the U.S. Midwestern Corn Belt. The land use within the sample sites was 54% row crops, 11% pasture and hay, 8% urban land use, and the remainder in woodlands and grasslands. The highest detections of glyphosate (63%) were from urban watersheds. The maximum glyphosate concentration from weekly samples was 27.8 µg/L (median 1.68 µg/L). The maximum glyphosate concentration from 2-day sampling intervals was 35.2 µg/L.

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Quaghebeur, D., De Smet B., De Wulf, E., Steurbaut, W., 2004. Pesticides in rainwater in Flanders, Belgium: results from the pesticide monitoring program 1997-2001. Journal of Environmental Monitoring 6: 182-190

Scribner, E.A., Battaglin, W.A., Dietze, J.E., and Thurman, E.M., 2003. Reconnaissance Data for Glyphosate, Other Selected Herbicides, their Degradation Products, and Antibiotics in 51 Streams in Nine Midwestern States, 2002. U.S. Geological Survey Open File Report 03-217

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APPENDIX A. Terrestrial Crop and Non-Agricultural Terrestrial Use Sites

Variable Volume Water Model, Version   1.02000000000000

 ****
Performed on: 5/ 4/2017 at 16:28

Peak 1-in-10.0   = 206.   ppb
Chronic 1-in-10.0 = 42.3   ppb
Simulation Avg   = 25.1   ppb
4-d avg 1-in-10.0 = 183.   ppb
21-d avg 1-in-10.0 = 134.   ppb
60-d avg 1-in-10.0 = 101.   ppb
90-d avg 1-in-10.0 = 87.7   ppb
1-d avg 1-in-10.0 = 199.   ppb
Benthic Pore Water Peak 1-in-10.0   = 80.2   ppb
Benthic Pore Water 21-d avg 1-in-10.0 = 79.6   ppb
Benthic Conversion Factor   = 157.   -Pore water (ug/L) to (total mass, ug)/(dry sed mass,kg)
Benthic Mass Fraction in Pore Water = 0.235E-02

YEAR	Peak	4-day	21-day	60-day	90-day	Yearly Avg	Benthic Pk	Benthic 21-day
1	4.37E+01	3.74E+01	2.56E+01	2.04E+01	1.89E+01	9.72E+00	1.65E+01	1.63E+01
2	1.57E+02	1.44E+02	1.08E+02	7.77E+01	6.70E+01	3.08E+01	6.32E+01	6.26E+01
3	5.52E+01	4.88E+01	3.62E+01	3.29E+01	2.98E+01	1.81E+01	2.89E+01	2.86E+01
4	1.42E+02	1.29E+02	1.07E+02	8.14E+01	7.04E+01	3.33E+01	6.61E+01	6.55E+01
5	5.61E+01	4.98E+01	3.57E+01	2.48E+01	2.17E+01	1.36E+01	2.09E+01	2.09E+01
6	7.00E+01	6.33E+01	5.26E+01	4.43E+01	3.92E+01	2.03E+01	3.84E+01	3.80E+01
7	8.27E+01	7.52E+01	5.86E+01	4.63E+01	4.15E+01	2.33E+01	4.21E+01	4.18E+01
8	1.19E+02	1.07E+02	8.36E+01	6.64E+01	5.91E+01	2.99E+01	5.49E+01	5.44E+01
9	1.35E+02	1.21E+02	8.81E+01	6.37E+01	5.58E+01	2.90E+01	5.53E+01	5.49E+01
10	5.44E+01	4.80E+01	3.69E+01	3.30E+01	2.99E+01	1.72E+01	2.90E+01	2.87E+01
11	9.90E+01	8.85E+01	7.27E+01	5.78E+01	5.06E+01	2.57E+01	4.99E+01	4.95E+01
12	5.91E+01	5.37E+01	4.57E+01	3.55E+01	3.30E+01	1.88E+01	3.37E+01	3.34E+01
13	1.42E+02	1.31E+02	9.45E+01	7.02E+01	6.16E+01	3.00E+01	5.93E+01	5.86E+01
14	1.45E+02	1.29E+02	9.47E+01	6.76E+01	5.94E+01	3.09E+01	5.70E+01	5.67E+01
15	7.13E+01	6.58E+01	5.66E+01	4.66E+01	4.33E+01	2.46E+01	4.36E+01	4.31E+01
16	6.18E+01	5.66E+01	4.63E+01	3.81E+01	3.43E+01	2.03E+01	3.59E+01	3.55E+01
17	1.69E+02	1.49E+02	1.08E+02	7.98E+01	6.91E+01	3.29E+01	6.44E+01	6.39E+01
18	6.85E+01	6.47E+01	5.63E+01	4.65E+01	4.35E+01	2.44E+01	4.45E+01	4.41E+01
19	2.10E+02	1.87E+02	1.37E+02	1.03E+02	8.96E+01	4.33E+01	8.17E+01	8.11E+01
20	2.18E+02	2.02E+02	1.50E+02	1.06E+02	9.14E+01	4.53E+01	8.71E+01	8.64E+01
21	6.68E+01	6.03E+01	4.49E+01	3.64E+01	3.58E+01	2.27E+01	3.62E+01	3.57E+01
22	1.10E+02	9.78E+01	7.36E+01	5.26E+01	4.68E+01	2.48E+01	4.59E+01	4.55E+01
23	2.37E+02	2.19E+02	1.70E+02	1.18E+02	1.02E+02	4.82E+01	9.23E+01	9.15E+01
24	8.13E+01	7.27E+01	5.64E+01	5.02E+01	4.58E+01	2.71E+01	4.47E+01	4.45E+01
25	5.30E+01	4.68E+01	3.65E+01	2.70E+01	2.35E+01	1.37E+01	2.18E+01	2.16E+01
26	4.83E+01	4.27E+01	3.64E+01	2.83E+01	2.51E+01	1.44E+01	2.64E+01	2.61E+01
27	4.97E+01	4.44E+01	2.94E+01	2.61E+01	2.47E+01	1.40E+01	2.29E+01	2.27E+01
28	1.37E+02	1.21E+02	8.15E+01	6.29E+01	5.44E+01	2.57E+01	5.05E+01	5.01E+01
29	7.31E+01	6.74E+01	5.46E+01	4.39E+01	3.99E+01	2.27E+01	4.00E+01	3.97E+01
30	5.61E+01	5.17E+01	4.16E+01	3.62E+01	3.39E+01	1.91E+01	3.41E+01	3.36E+01

****
Effective compartment halflives averaged over simulation duration:

washout halflife (days) =   48.1966144835075
water col metab halflife (days) =   560.436578988054
zero hydrolysis   0
zero photolysis   0
volatile halflife (days) =   15373857038.0289
total water col halflife (days) =   44.3800074522735

zero burial   0
benthic metab halflife (days) =   306.313158027487
zero benthic hydrolysis   0
total benthic halflife (days) =   306.313158027487
****
Fractional Contribution of Transport Processes to Waterbody & Total Mass (kg):

 Due to Runoff =   0.1158   119.1

Due to Erosion =   0.6985   718.2
Due to Drift =   0.1857   190.9
****
Flow in/out Characteristics of Waterbody:
Average Daily Runoff Into Waterbody (m3/s) = 2.398982023910145E-002
Baseflow Into Waterbody (m3/s)   = 0.000000000000000E+000
Average Daily Flow Out of Waterbody (m3/s) = 2.398982023910173E-002
****
Inputs:
3925.   = oc partitioning coefficient
381.0   = water column half Life
25.00   = reference temp for water column degradation
208.2   = benthic Half Life
25.00   = Reference temp for benthic degradation
2.000   = Q ten value
0.000   = photolysis half life
0.000   = reference latitude for photolysis study
0.000   = hydrolysis half life
169.1   = molecular wt
0.9750E-09 = vapor pressure
0.1200E+05 = solubility
0.1728E+07 = field area
0.5260E+05 = water body area
2.740   = initial depth
2.740   = maximum depth
3   1=vvwm, 2=usepa pond, 3 = usepa reservoir, 4 = const vol no flow, 5 = const vol w/flow
F T = burial, else no burial
0.1000E-07 = mass transfer coefficient
0.5000   = PRBEN
0.5000E-01 = benthic compartment depth
0.5000   = benthic porosity
1.350   = benthic bulk density
0.4000E-01 = OC frcation in benthic sediment
5.000   = DOC in benthic compartment
0.6000E-02 = benthic biomass
1.190   = DFAC
30.00   = SS
0.5000E-02 = chlorophyll
0.4000E-01 = OC frcation in water column SS
5.000   = DOC in water column
0.4000   = biomass in water column
FRACTION AREA CROPPED =   1.00000000000000

Direct Applications to Aquatic Environments

MIasparagusSTD scenario

Variable Volume Water Model, Version   1.02000000000000

** ***
Performed on: 5/ 4/2017 at 16:37

Peak 1-in-10.0   = 577.   ppb
Chronic 1-in-10.0 = 168.   ppb
Simulation Avg   = 152.   ppb
4-d avg 1-in-10.0 = 507.   ppb
21-d avg 1-in-10.0 = 349.   ppb
60-d avg 1-in-10.0 = 254.   ppb
90-d avg 1-in-10.0 = 229.   ppb
1-d avg 1-in-10.0 = 558.   ppb
Benthic Pore Water Peak 1-in-10.0   = 193.   ppb
Benthic Pore Water 21-d avg 1-in-10.0 = 192.   ppb
Benthic Conversion Factor   = 157.   -Pore water (ug/L) to (total mass, ug)/(dry sed mass,kg)
Benthic Mass Fraction in Pore Water = 0.235E-02

YEAR Peak   4-day   21-day   60-day   90-day Yearly Avg Benthic Pk Benthic 21-day

32

```
1    4.44E+02  3.73E+02  2.17E+02  1.26E+02  1.05E+02  4.65E+01  6.65E+01  6.63E+01
2    4.90E+02  4.19E+02  2.62E+02  1.69E+02  1.47E+02  8.75E+01  1.09E+02  1.08E+02
3    5.19E+02  4.48E+02  2.91E+02  1.98E+02  1.75E+02  1.15E+02  1.38E+02  1.37E+02
4    5.37E+02  4.66E+02  3.09E+02  2.14E+02  1.91E+02  1.30E+02  1.54E+02  1.53E+02
5    5.49E+02  4.78E+02  3.20E+02  2.25E+02  2.01E+02  1.41E+02  1.65E+02  1.64E+02
6    5.56E+02  4.86E+02  3.29E+02  2.34E+02  2.10E+02  1.48E+02  1.74E+02  1.73E+02
7    5.62E+02  4.91E+02  3.34E+02  2.39E+02  2.15E+02  1.53E+02  1.79E+02  1.78E+02
8    5.65E+02  4.94E+02  3.37E+02  2.42E+02  2.18E+02  1.57E+02  1.82E+02  1.81E+02
9    5.68E+02  4.97E+02  3.40E+02  2.45E+02  2.21E+02  1.59E+02  1.85E+02  1.84E+02
10   5.71E+02  5.00E+02  3.42E+02  2.46E+02  2.22E+02  1.60E+02  1.86E+02  1.85E+02
11   5.70E+02  5.00E+02  3.42E+02  2.47E+02  2.23E+02  1.61E+02  1.87E+02  1.86E+02
12   5.72E+02  5.01E+02  3.43E+02  2.48E+02  2.24E+02  1.62E+02  1.87E+02  1.86E+02
13   5.74E+02  5.03E+02  3.45E+02  2.50E+02  2.26E+02  1.64E+02  1.90E+02  1.90E+02
14   5.73E+02  5.02E+02  3.45E+02  2.50E+02  2.26E+02  1.64E+02  1.90E+02  1.89E+02
15   5.76E+02  5.05E+02  3.47E+02  2.52E+02  2.27E+02  1.65E+02  1.91E+02  1.90E+02
16   5.72E+02  5.01E+02  3.43E+02  2.48E+02  2.24E+02  1.63E+02  1.88E+02  1.87E+02
17   5.75E+02  5.04E+02  3.45E+02  2.50E+02  2.25E+02  1.64E+02  1.89E+02  1.88E+02
18   5.75E+02  5.04E+02  3.46E+02  2.51E+02  2.26E+02  1.65E+02  1.90E+02  1.89E+02
19   5.76E+02  5.05E+02  3.48E+02  2.53E+02  2.29E+02  1.67E+02  1.92E+02  1.92E+02
20   5.78E+02  5.07E+02  3.50E+02  2.55E+02  2.30E+02  1.68E+02  1.94E+02  1.93E+02
21   5.78E+02  5.07E+02  3.49E+02  2.54E+02  2.29E+02  1.68E+02  1.94E+02  1.93E+02
22   5.79E+02  5.07E+02  3.49E+02  2.54E+02  2.30E+02  1.68E+02  1.93E+02  1.92E+02
23   5.76E+02  5.05E+02  3.47E+02  2.53E+02  2.28E+02  1.65E+02  1.93E+02  1.92E+02
24   5.72E+02  5.02E+02  3.44E+02  2.49E+02  2.25E+02  1.63E+02  1.89E+02  1.88E+02
25   5.72E+02  5.00E+02  3.42E+02  2.47E+02  2.23E+02  1.62E+02  1.86E+02  1.86E+02
26   5.72E+02  5.00E+02  3.43E+02  2.47E+02  2.23E+02  1.62E+02  1.87E+02  1.86E+02
27   5.71E+02  5.00E+02  3.42E+02  2.45E+02  2.20E+02  1.59E+02  1.85E+02  1.84E+02
28   5.68E+02  4.97E+02  3.39E+02  2.43E+02  2.18E+02  1.56E+02  1.83E+02  1.82E+02
29   5.66E+02  4.95E+02  3.37E+02  2.42E+02  2.18E+02  1.57E+02  1.82E+02  1.81E+02
30   5.69E+02  4.98E+02  3.40E+02  2.45E+02  2.21E+02  1.60E+02  1.85E+02  1.84E+02
```
****

Effective compartment halflives averaged over simulation duration:

```
zero washout                0
water col metab halflife (days) =      972.604153253890
zero hydrolysis             0
zero photolysis             0
volatile halflife (days)  =        10193410081.3359
total water col halflife (days) =      972.604060452880


zero burial                 0
benthic metab halflife (days) =        531.588159773203
zero benthic hydrolysis     0
total benthic halflife (days) =        531.588159773203
```
****

Fractional Contribution of Transport Processes to Waterbody & Total Mass (kg):

```
Due to Runoff  =    0.0000         0.000
Due to Erosion =    0.0000         0.000
Due to Drift   =    1.0000         268.8
```
****

Flow in/out Characteristics of Waterbody:
Average Daily Runoff Into Waterbody (m3/s) = 5.349566875959242E-005
Baseflow Into Waterbody (m3/s)   = 0.000000000000000E+000
Average Daily Flow Out of Waterbody (m3/s) = 5.349566875959118E-005
****

Inputs:
```
  3925.    = oc partitioning coefficient
  381.0    = water column half Life
  25.00    = reference temp for water column degradation
  208.2    = benthic Half Life
  25.00    = Reference temp for benthic degradation
  2.000    = Q ten value
  0.000    = photolysis half life
  0.000    = reference latitude for photolysis study
  0.000    = hydrolysis half life
  169.1    = molecular wt
0.9750E-09 = vapor pressure
0.1200E+05 = solubility
0.1000E+06 = field area
```

```
 0.1000E+05 = water body area
 2.000    = initial depth
 2.000    = maximum depth
 2       1=vvwm, 2=usepa pond, 3 = usepa reservoir, 4 = const vol no flow, 5 = const vol w/flow
F  T = burial, else no burial
 0.1000E-07 = mass transfer coefficient
 0.5000    = PRBEN
 0.5000E-01 = benthic compartment depth
 0.5000    = benthic porosity
 1.350    = benthic bulk density
 0.4000E-01 = OC frcation in benthic sediment
 5.000    = DOC in benthic compartment
 0.6000E-02 = benthic biomass
 1.190    = DFAC
 30.00    = SS
 0.5000E-02 = chlorophyll
 0.4000E-01 = OC frcation in water column SS
 5.000    = DOC in water column
 0.4000    = biomass in water column
FRACTION AREA CROPPED =   1.00000000000000
```

WAorchardsSTD scenario

Variable Volume Water Model, Version   1.02000000000000

 ****
Performed on: 5/ 4/2017 at 16:36

Peak 1-in-10.0   = 438.   ppb
Chronic 1-in-10.0 = 150.   ppb
Simulation Avg   = 140.   ppb
4-d avg 1-in-10.0 = 399.   ppb
21-d avg 1-in-10.0 = 300.   ppb
60-d avg 1-in-10.0 = 228.   ppb
90-d avg 1-in-10.0 = 208.   ppb
1-d avg 1-in-10.0 = 427.   ppb
Benthic Pore Water Peak 1-in-10.0   = 173.   ppb
Benthic Pore Water 21-d avg 1-in-10.0 = 173.   ppb
Benthic Conversion Factor   = 157.   -Pore water (ug/L) to (total mass, ug)/(dry sed mass,kg)
Benthic Mass Fraction in Pore Water = 0.235E-02

YEAR	Peak	4-day	21-day	60-day	90-day	Yearly Avg	Benthic Pk	Benthic 21-day
1	3.24E+02	2.85E+02	1.87E+02	1.16E+02	9.84E+01	5.37E+01	6.32E+01	6.31E+01
2	3.65E+02	3.26E+02	2.28E+02	1.57E+02	1.38E+02	8.97E+01	1.03E+02	1.03E+02
3	3.93E+02	3.54E+02	2.55E+02	1.83E+02	1.65E+02	1.13E+02	1.29E+02	1.29E+02
4	4.09E+02	3.70E+02	2.71E+02	1.99E+02	1.81E+02	1.28E+02	1.45E+02	1.45E+02
5	4.24E+02	3.85E+02	2.86E+02	2.14E+02	1.95E+02	1.39E+02	1.59E+02	1.59E+02
6	4.29E+02	3.90E+02	2.91E+02	2.19E+02	2.00E+02	1.43E+02	1.64E+02	1.64E+02
7	4.29E+02	3.90E+02	2.91E+02	2.18E+02	2.00E+02	1.42E+02	1.64E+02	1.64E+02
8	4.27E+02	3.88E+02	2.90E+02	2.17E+02	1.98E+02	1.42E+02	1.62E+02	1.62E+02
9	4.32E+02	3.93E+02	2.95E+02	2.22E+02	2.03E+02	1.45E+02	1.68E+02	1.68E+02
10	4.33E+02	3.94E+02	2.95E+02	2.23E+02	2.04E+02	1.46E+02	1.68E+02	1.68E+02
11	4.32E+02	3.93E+02	2.95E+02	2.22E+02	2.03E+02	1.46E+02	1.68E+02	1.68E+02
12	4.34E+02	3.95E+02	2.96E+02	2.24E+02	2.05E+02	1.47E+02	1.69E+02	1.69E+02
13	4.35E+02	3.96E+02	2.97E+02	2.25E+02	2.05E+02	1.47E+02	1.70E+02	1.70E+02
14	4.33E+02	3.94E+02	2.95E+02	2.23E+02	2.04E+02	1.47E+02	1.68E+02	1.68E+02
15	4.33E+02	3.94E+02	2.96E+02	2.23E+02	2.04E+02	1.47E+02	1.69E+02	1.69E+02
16	4.34E+02	3.95E+02	2.97E+02	2.24E+02	2.05E+02	1.49E+02	1.70E+02	1.70E+02
17	4.38E+02	3.99E+02	3.00E+02	2.28E+02	2.08E+02	1.50E+02	1.73E+02	1.73E+02
18	4.35E+02	3.96E+02	2.98E+02	2.25E+02	2.05E+02	1.48E+02	1.70E+02	1.70E+02
19	4.38E+02	3.99E+02	3.00E+02	2.27E+02	2.08E+02	1.49E+02	1.73E+02	1.72E+02
20	4.34E+02	3.95E+02	2.96E+02	2.24E+02	2.04E+02	1.47E+02	1.69E+02	1.69E+02
21	4.33E+02	3.94E+02	2.96E+02	2.23E+02	2.03E+02	1.46E+02	1.68E+02	1.67E+02
22	4.33E+02	3.94E+02	2.95E+02	2.23E+02	2.04E+02	1.47E+02	1.68E+02	1.68E+02
23	4.35E+02	3.96E+02	2.97E+02	2.24E+02	2.05E+02	1.48E+02	1.69E+02	1.69E+02
24	4.35E+02	3.96E+02	2.97E+02	2.25E+02	2.05E+02	1.49E+02	1.70E+02	1.69E+02
25	4.39E+02	4.00E+02	3.01E+02	2.29E+02	2.09E+02	1.51E+02	1.74E+02	1.74E+02
26	4.40E+02	4.01E+02	3.02E+02	2.29E+02	2.10E+02	1.52E+02	1.74E+02	1.74E+02

```
27   4.38E+02  3.99E+02  3.00E+02  2.27E+02  2.08E+02  1.50E+02  1.73E+02  1.72E+02
28   4.36E+02  3.97E+02  2.99E+02  2.26E+02  2.07E+02  1.50E+02  1.71E+02  1.71E+02
29   4.37E+02  3.98E+02  2.99E+02  2.27E+02  2.08E+02  1.50E+02  1.72E+02  1.72E+02
30   4.37E+02  3.98E+02  2.99E+02  2.26E+02  2.07E+02  1.49E+02  1.72E+02  1.71E+02
```
****

Effective compartment halflives averaged over simulation duration:

washout halflife (days) =   4842.69650906671
water col metab halflife (days) =   912.130844512108
zero hydrolysis   0
zero photolysis   0
volatile halflife (days) =   17022237093.2060
total water col halflife (days) =   767.559543659740

zero burial   0
benthic metab halflife (days) =   498.535766564833
zero benthic hydrolysis   0
total benthic halflife (days) =   498.535766564833
****
Fractional Contribution of Transport Processes to Waterbody & Total Mass (kg):

Due to Runoff =   0.0000   0.000
Due to Erosion =   0.0000   0.000
Due to Drift   =   1.0000   1414.
****
Flow in/out Characteristics of Waterbody:
Average Daily Runoff Into Waterbody (m3/s) = 2.387570882106416E-004
Baseflow Into Waterbody (m3/s)   = 0.000000000000000E+000
Average Daily Flow Out of Waterbody (m3/s) = 2.387570882106397E-004
****
Inputs:
  3925.   = oc partitioning coefficient
  381.0   = water column half Life
  25.00   = reference temp for water column degradation
  208.2   = benthic Half Life
  25.00   = Reference temp for benthic degradation
  2.000   = Q ten value
  0.000   = photolysis half life
  0.000   = reference latitude for photolysis study
  0.000   = hydrolysis half life
  169.1   = molecular wt
 0.9750E-09 = vapor pressure
 0.1200E+05 = solubility
 0.1728E+07 = field area
 0.5260E+05 = water body area
  2.740   = initial depth
  2.740   = maximum depth
  3   1=vvwm, 2=usepa pond, 3 = usepa reservoir, 4 = const vol no flow, 5 = const vol w/flow
 F T = burial, else no burial
 0.1000E-07 = mass transfer coefficient
 0.5000   = PRBEN
 0.5000E-01 = benthic compartment depth
 0.5000   = benthic porosity
  1.350   = benthic bulk density
 0.4000E-01 = OC frcation in benthic sediment
  5.000   = DOC in benthic compartment
 0.6000E-02 = benthic biomass
  1.190   = DFAC
  30.00   = SS
 0.5000E-02 = chlorophyll
 0.4000E-01 = OC frcation in water column SS
  5.000   = DOC in water column
 0.4000   = biomass in water column
FRACTION AREA CROPPED =   1.00000000000000

APPENDIX B. PFAM Aquatic Food Crop Uses (Rice and Cranberry)

DW CA Preflood nohold Rice Scenario

```
**************************************************************************
Pesticide in Flooded Applications (PFAM)
Version 2
6/15/2017 1:00:11 PM
Variable Volume Water Model: PFAM Compatible    1.01000000000000
Performed on:  6/15/2017  at 13: 0
MIXING CELL, Width =   194.0 Depth=    5.1  Length =    40.0
Parent
**************************************************************************
1-day avg 1-in-10 (ppb) =    162.
4-day avg 1-in-10  =    65.2
21-day avg 1-in-10 =    31.9
60-day avg 1-in-10 =    18.8
90-day avg 1-in-10 =    13.8
Chronic 1-in-10   =    5.12
Overall Average   =   3.62
 **********************************************************************
```

Effective compartment halflives averaged over simulation duration:

```
washout halflife (days) =          1.139782804254377E-003
water col metab halflife (days) =    686.891795253106
hydrolysis halflife (days)  =       103542641.722930
photolysis halflife (days)  =      25930523373.8510
volatile halflife (days)  =        28063375434.6205
total water col halflife (days) =    1.139780912964687E-003
```

```
zero burial
benthic metab halflife (days) =      375.428733447524
benthic hydrolysis halflife (days) =  169658242568.335
total benthic halflife (days) =      375.428732616756
 **********************************************************************
```

Mass Fraction Due to Drift = 0.892E-02

MA cranberry Scenario

```
 Pesticide in Flooded Applications (PFAM)
 Version 2
 5/19/2017 11:28:33 AM
 ******* Summary of Paddy Concentration Rankings ********
```

```
******************************************************
************** Analysis for Parent      *************
Max released concentration (ppb) = 0.173E+05
Index for max concentration     =    4687
```

```
 1-in-10 Year Return Concentrations:
********* WATER COLUMN CONCENTRATION (ug/L) ***********
Water Column Peak          =  13.5
Water Column 1-day Avg     =  12.9
Water Column 4-day Avg     =  12.9
Water Column 21-day Avg    =  12.6
Water Column 60-day Avg    =  12.4
Water Column 90-day Avg    =  12.1
Water Column 365-day Avg   =  3.00
```

```
****** BENTHIC PORE WATER (ug/L) Concentration *********
Benthic Pore Water  Peak      =  31.9
Benthic Pore Water 4-day Avg   =  31.3
Benthic Pore Water 21-day Avg  =  28.0
Benthic Pore Water 60-day Avg  =  22.5
Benthic Pore Water 90-day Avg  =  19.3
 Benthic Pore Water 365-day Avg  =  10.1
```

***** BENTHIC TOTAL CONCENTRATION (Mass/Dry Mass) ******
Benthic Total Conc. Peak   = 0.502E+04
 Benthic Total Conc. 4-day Avg = 0.492E+04
Benthic Total Conc. 21-day Avg = 0.441E+04
Benthic Total Conc. 60-day Avg = 0.354E+04
Benthic Total Conc. 90-day Avg = 0.304E+04
Benthic Total Conc. 365-day Avg = 0.159E+04
****

APPENDIX C. PRZM-GW Output for Residential Spot Treatment Use (40 lbs ae /A)

**** Parent **

GW Run ID	Peak	Breakthru	Thruput	PostBT Avg		Sim Avg
Delmarva_PWC_+0	6.5223E-29		-999999	0.02867823	-999999	6.775729E-30
FL potato_ForQA_+0	1.9012E-21		-999999	0.07528269	-999999	3.324455E-22
FLCitrus_PWC_+0	2.0027E-20		-999999	0.05396811	-999999	3.228578E-21
GA peanuts_ForQA_+0	8.9863E-34		-999999	0.03971326	-999999	5.149908E-35
NCCotton_PWC_+0	1.0738E-31		-999999	0.02014195	-999999	1.154074E-32
WI_corn_ForQA_+0	6.31285E-42		-999999	0.01438171	-999999	3.433181E-43

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON D.C., 20460

September 8, 2015

MEMORANDUM

Subject:	Registration Review – Preliminary Ecological Risk Assessment for Glyphosate and Its Salts (PC Codes: 417300, 103601, 103604, 103607, 103608, 103613, 103603, 103605, 128501; DP Barcode: 417701)
To:	Khue Nguyen, Chemical Risk Manager Neil Anderson, Branch Chief Risk Management and Implementation Branch 1 Pesticide Re-Evaluation Division
Through:	Dana Spatz, Branch Chief Environmental Risk Branch 3 Environmental Fate and Effects Division
From:	James Hetrick, Ph.D., Senior Advisor Environmental Risk Branch 3
	Amy Blankinship, Chemist Environmental Risk Branch 6 Environmental Fate and Effects Division
Peer Review:	Melissa Panger, Ph.D., Senior Advisor Environmental Risk Branch 2
	Rosanna Louie-Juzwiak, Risk Assessment Process Leader Environmental Risk Branch 3 Environmental Fate and Effects Division

JAMES HETRICK — Digitally signed by JAMES HETRICK
DN: c=US, o=U.S. Government, ou=USEPA, ou=Staff, cn=JAMES HETRICK, dnQualifier=0000005599
Date: 2015.09.09 07:55:06 -04'00'

AMY BLANKINSHIP — Digitally signed by AMY BLANKINSHIP
DN: c=US, o=U.S. Government, ou=USEPA, ou=Staff, cn=AMY BLANKINSHIP, dnQualifier=0000040917
Date: 2015.09.08 17:20:08 -04'00'

MELISSA PANGER
2015.09.09 06:57:26 -04'00'

The Environmental Fate and Effects Division (EFED) has completed a preliminary ecological risk assessment conducted as part of the registration review of glyphosate. The purpose of this assessment was to evaluate the potential risks of glyphosate and its salts (hereafter referred to as glyphosate) to non-target organisms. This risk assessment incorporates the available exposure and effects data, and most current modeling and risk methodologies, some of which may not have been available at the time previous risk assessments were conducted.

Through this assessment, the following conclusions were drawn:

- Exposure to glyphosate residues in water resulting from spray drift is not anticipated to impact survival, growth or reproduction of aquatic invertebrates, fish, aquatic non-vascular plants, or submerged vascular plants in surface waters adjacent to a treated field.

- Exposure to glyphosate residues from its application to aquatic environments is not anticipated to impact survival, growth or reproduction of aquatic invertebrates or fish in treated surface waters.

- Exposure to glyphosate residues in water resulting from spray drift or application to aquatic environments may impact survival and/or biomass of aquatic emergent vascular and non-vascular plants (application to aquatic environments only) in surface waters adjacent to a treated field or in the treated water body.

- While acute adult contact and oral and semi-field honeybee toxicity data are available which suggest toxicity from glyphosate exposure is low, the calculated EECs are greater than highest concentrations tested in honeybee toxicity tests. Due to lack of toxicity data conducted at higher test concentrations, it is unclear if exposure to glyphosate residues on foliage resulting from direct deposition or spray drift at application rates ≥1.92 lb a.e./A could impact survival, growth and/or reproduction of honeybee larvae. Also due to lack of toxicity data at higher test concentrations, it is uncertain if there could be potential acute effects to adult honeybee at application rates >5.7 lb a.e./A. Additional toxicity studies with other types of terrestrial invertebrates (*i.e.*, predatory mites, earthworms, parasitic wasps) are also available, with generally no effects reported up to the highest dose tested. In a study with a predatory mite, the 7-d LD_{50} value was reported as 1200 g a.e./ha (1.1 lb/A) (MRID 45767105)

- Exposure to glyphosate residues on foliage resulting from direct deposition or spray drift may impact growth of birds for all uses (surrogates to terrestrial-phase amphibian), but may not impact reproductive parameters.

- Exposure to glyphosate residues on foliage resulting from direct deposition or spray drift may impact growth and reproduction to terrestrial mammals for aerial application to sugar cane as well as for most uses generally applied by ground applications up to the combined maximum annual rate.

- Exposure to glyphosate residues on foliage resulting from spray drift may impact survival and/or biomass of upland plants and riparian/wetland plants in areas adjacent to a treated field.

Preliminary Ecological Risk Assessment in Support of the Registration Review of Glyphosate and Its Salts
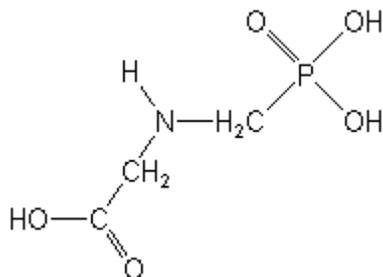
Glyphosate (CAS 1071-83-6)
N-(phosphonomethyl)glycine

Table of Contents

1. Executive Summary

1.1 Introduction

The purpose of this assessment is to evaluate the potential risks of glyphosate and its salts (hereafter referred to as glyphosate) to non-target organisms. This risk assessment incorporates the available exposure and effects data, and most current modeling and risk methodologies, some of which may not have been available at the time previous risk assessments were conducted. This risk assessment focuses on potential adverse effects to non-listed organisms.

Glyphosate acid (CAS number 1071-83-6) [N-(phosphonomethyl)glycine] is an herbicide belonging to the phosphono amino acid class of pesticides. Glyphosate is an acid which can be associated with different counter cations to form salts. For comparison purposes, in this assessment, each salt is considered in terms of its "glyphosate equivalent," (acid equivalent; ae) as determined by multiplying the glyphosate salt endpoint value by the acid equivalence ratio (the ratio of the molecular weight of N-(phosphonomethyl)glycine to the molecular weight of the salt). For the assessment of risk to glyphosate, both application rates and the toxicity endpoint values are expressed as acid equivalents.

1.2 Exposure Assessment

Evaluation of potential risk to aquatic non-target organisms was assessed by estimating exposure from:

- Glyphosate only (spray drift, spray drift and runoff, direct application to water)
- Glyphosate formulations (spray drift, direct application to water)
- Surfactant only (POEA) (spray drift)

Exposure to glyphosate formulations was evaluated because some of the formulations are more toxic than the active ingredient alone. Terrestrial uses allow for application of formulations that may contain a surfactant that is toxic to aquatic organisms (polyethoxylated tallow amines (POEA)), whereas the toxic surfactant is not allowed in formulations designated for direct aquatic use. Therefore, in assessing potential risk to aquatic organisms, exposure was estimated from glyphosate formulations that do or do not contain POEA (designation of containing POEA or not based on available information for the formulation tested).

Evaluation of potential risk to terrestrial non-target organisms was assessed by estimating exposure from:

- Glyphosate only (spray drift, direct contact)
- Glyphosate formulations (spray drift, direct contact)

Glyphosate is stable towards abiotic hydrolysis and direct photolysis in water. Its major route of transformation identified in laboratory studies and in the field is microbial degradation, where the major metabolite is aminomethyl phosphonic acid (AMPA). Glyphosate is very soluble in

water. It has low potential to volatilize from soil or water, as suggested by its low vapor pressure and Henry's Law Constant. Glyphosate adsorbs strongly to soils and sediments. Based on its strong adsorption to soil/sediments alone, leaching to ground water or entering surface water dissolved in runoff would be minimized. However, surface water can be contaminated by transport of suspended soil particulates, followed by desorption from the soil particulates and/or from sediments.

Offsite exposure is also possible via spray drift, colloidal transport, inadvertent direct overspray and wind transport of soil particulates loaded with adsorbed glyphosate residues. Glyphosate is very hydrophilic and is unlikely to bioconcentrate in fish (Log Kow < -3).

1.3 Dose-Response Assessment

Toxicity data are available for technical glyphosate including its salts, as well as for glyphosate formulations. Toxicity data are also available for certain surfactants contained in some glyphosate formulations, as well as for the major degradate AMPA.

Glyphosate alone is slightly acutely toxic to freshwater fish and invertebrates and estuarine/marine fish, practically non-toxic to estuarine/marine invertebrates and terrestrial invertebrates (honeybee contact), and no more than slightly acutely toxic to birds and mammals. There were no effects reported up to the highest concentration tested in the chronic reproduction avian studies for bobwhite quail (830 mg a.e./kg-diet), but indications of body weight effects in male and offspring mallard ducks at 501 mg a.e./kg-diet. There were no effects in the chronic freshwater fish study (25.7 mg a.e./L). In a chronic mammalian reproduction study, the NOAEL was 408 mg/kg/day based on delayed male offspring maturation and body weight. The NOAEC value for chronic freshwater invertebrates was 9.22 mg a.e./L, based on the use of an acute to chronic ratio, using *Daphnia magna* toxicity data, and the most sensitive acute toxicity value (midge). For terrestrial plants (vegetative vigor), the most sensitive monocot species was sorghum (*Sorghum bicolor*) with a reported IC_{25} value of 0.16 lb a.e./A and a NOAEC of 0.07 lb a.e./A (MRID 44125715). For dicots, the most sensitive species was cucumber (*Cucumis sativus*) with a reported IC_{25} of 0.074 and NOAEC of 0.049 lb a.e./A (MRID 44320636). For aquatic vascular plants, the 14-d EC_{50} is 11.9 mg a.e./L, and for aquatic non-vascular plants, the 4-d EC_{50} is 11.4 mg a.e./L.

1.4 Risk Characterization

The risk conclusions for direct effects to non-listed terrestrial and aquatic organisms are summarized as follows.

1. Freshwater and Estuarine/marine Fish and Aquatic Invertebrates:
   a. Likelihood of risk from acute and chronic exposure from use of glyphosate anticipated to be low (RQs<LOC). Using the LOC and standard exposure methodology, direct effects to listed aquatic vertebrates and invertebrates are not anticipated.

2. Aquatic Plants
    a. Likelihood of risk to aquatic non-vascular and submerged aquatic plants from spray drift and runoff from terrestrial uses anticipated to be low (RQs <LOC);
    b. For emergent aquatic vascular plants, potential for risk from exposure to spray drift from terrestrial uses, and necessary off-site distances to be below toxicity threshold up to over 1000 feet depending on use. Based on available aquatic vascular plant data, LOCs for direct application are not exceeded. However, glyphosate is registered for application to aquatic environments in an effort to control aquatic vegetation, therefore, it is anticipated that emergent aquatic vascular plants could be adversely affected.
    c. For application to aquatic environments, there is a potential for adverse effects to aquatic non-vascular plants at ≥8.25 quarts formulation/A (RQ = 1.8; based on the use of the standard farm pond volume). However, there is uncertainty in the toxicity value used for this evaluation as it is not definitively known if the formulation tested is allowed for use in aquatic environments. Additionally, maximum single application volumes for formulated product do not appear to exceed 8 quarts formulation/A.

3. Birds (surrogates for terrestrial-phase amphibians and reptiles)
    a. Likelihood of risk from acute exposure to glyphosate alone at application rates less than 8 lbs. a.e./A is anticipated to be low (LD_{50}>highest concentration tested). For the canary and bobwhite quail, at the application rate of 8 lb a.e./A, the highest EEC is less than the highest dose tested (using the most conservative comparison (20g bird): EEC = 2187 mg ae/kg-bw; Highest Dose= 3139 mg a.e./kg-bw for canary and 2302 mg a.e./kg-bw for bobwhite).
    b. Acute toxicity data from the only available study using a formulation had RQs above the non-listed acute LOC. However, it is uncertain how representative this formulation toxicity is for the large number of registered end-use products.
    c. For chronic exposure, decreases in body weight were observed in the mallard at concentrations down to 501 mg a.e./kg-bw (lowest concentration tested). There is evidence to suggest that reproductive parameters including eggs laid, embryo viability and eggshell thickness may not be impacted by glyphosate exposure (EECs (1920 mg a.e./kg-bw) < NOAEC (2160 mg a.e./kg-diet) from mallard duck reproduction study and no effect up to 830 mg a.e./kg-diet for bobwhite quail).

4. Mammals
    a. Likelihood of risk from acute exposure to glyphosate alone anticipated to be low (LD_{50}>highest concentration tested). For any of the uses at application rates up to the rate of 8 lbs a.e./A, the EEC values are less than half the highest dose tested in the acute oral study.
    b. Acute toxicity data with discrete toxicity values were available from several studies using a formulation (n=4). Results from one study showed an RQ of 2.1. However, the LD_{50} value for the majority of the end-use products was greater than the highest dose tested (limit dose).
    c. For chronic exposure to technical glyphosate, potential risks on a dietary basis is anticipated to be low (RQs <LOC). However, dose-based chronic RQs did

exceed the LOC for small mammals consuming short grass for aerial application to sugar cane as well as for most uses generally applied by ground applications up to the combined maximum annual rate (RQs 1.02-10.2).

d. Effects on reproductive parameters were observed in a screening mammalian reproduction study for POEA for which EECs were greater than the NOAEL. This may impact risk to mammals following chronic exposure to one of the formulations containing the POEA surfactant.

5. Terrestrial Invertebrates

a. Acute oral and contact LD_{50} values for adult honeybees are greater than the highest dose tested (103 (contact) and 182 (oral) µg a.i./bee).

b. Application rates greater than 5.7 lb a.e./A exceed this highest tested oral concentration, and therefore, there is uncertainty in potential acute risk to adult honeybees at rates above 5.7 lb a.e./A.

c. No effects on honeybee colony adult and larvae mortality and larvae weight were reported after oral exposure at concentrations based on an application rate of 1.92 lb a.e./A. Larvae were exposed to glyphosate via normal hive activity. Toxicity data to larvae under conditions to evaluate response of individual larvae after exposure to a known concentration of glyphosate are not available.

d. Additional toxicity studies with other types of terrestrial invertebrates (i.e., predatory mites, earthworms, parasitic wasps) are also available, with generally no effects reported up to the highest dose tested. In a study with a predatory mite, the 7-d LD50 value was reported as 1200 g a.e./ha (1.1 lb/A) (MRID 45767105). Using additional terrestrial invertebrate data, the estimated distance off-field needed to be below the toxicity threshold (1.1 lb a.e/A), is up to 69 feet.

6. Terrestrial Plants

a. Potential for adverse effects from spray drift, but not anticipated from exposure to runoff. Estimated distance off-field needed to be below toxicity threshold is up to 459 feet for monocots and over 1000 feet for dicots.

2. Problem Formulation

The preliminary problem formulation for this ecological risk assessment was posted in the Registration Review docket for glyphosate on July 22, 2009 [www.regulations.gov, Docket ID http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OPP-2009-0361-0007].

EFED's response to public comments on the preliminary problem formulation was posted on December 30, 2009. [www.regulations.gov, Docket ID EPA-HQ-OPP-2009-0361-0040].

2.1. Introduction

Glyphosate [*N*-(phosphonomethyl)glycine] is an acid, and it can also be associated with different counter cations to form salts. Glyphosate acid will be a zwitterion (presence of both negative (anionic) and positive (cationic) electrostatic charges) in the environment because of the presence of a carboxylate, phosphonate, and amine functional groups. These functional groups allow glyphosate to form metal-ligand complexes with Fe, Cu, Mn, Zn, Al, Ca in soil, sediment, and aquatic environments. (Popvoc, *et al*., 2001).

Several salts of glyphosate are currently marketed, as well as the acid, and are considered as the active ingredient in end-use products. The parent acid is the chemical species that exhibits herbicidal activity and so is the actual chemical stressor considered in this risk assessment regardless of the salt, unless otherwise specified.

In order to have comparable results, each salt is considered in terms of its glyphosate equivalent, (acid equivalent; a.e.), determined by multiplying the application rate by the acid equivalence ratio, defined as the ratio of the molecular weight of *N*-(phosphonomethyl)glycine to the molecular weight of the salt. Table 1 shows the salts of glyphosate that may be used as the source of the actual herbicide-active chemical species. For the purpose of this assessment, the acid and all salt species are referred to collectively as "glyphosate" throughout this document.

Table 1. Identification of Glyphosate and its Salts

Counter Cation	PC Code	CAS No.	Acid Equivalence Ratio
Glyphosate acid (no counter cation)	417300	1071-83-6	1
Isopropyl amine	103601	38641-94-0	0.74
Monoammonium	103604	114370-14-8	0.94
Diammonium	103607	40465-66-5	0.83
N-methylmethanamine	103608	34494-07-7	0.79
Potassium	103613	39600-42-5; 70901-20-1	0.81

2.1.1 Surfactants and Other Potential Components in Tank Mixtures

Pesticides of high solubility in water, such as glyphosate, do not "wet" (cover) properly the waxy (hydrophobic) surfaces of plants. To attain proper coverage of plant surfaces and distribution of the herbicide, surfactants are added into the formulation of the pesticide. Proper coverage arises from hydrophobic interactions between the surfactant tail (usually long carbon chains) and the waxy surfaces of plants. Therefore, the ecological effects of the pesticide-surfactant combination may differ from that of the single pesticide or the single surfactant. Glyphosate labels also recommend using a nonionic surfactant in the tank mix to further enhance the "wettability" of glyphosate.

Toxicity studies, particularly acute aquatic toxicity studies, show that these formulated products can be more toxic than the glyphosate active ingredient alone and so toxicity studies using formulated products are considered independently of those containing only the active ingredient.

One class of surfactants used in glyphosate formulations are the polyethoxylated tallow amines (POEA) and this class has been shown to be more toxic to aquatic animals than glyphosate alone. However, other formulations may contain a different class of surfactant. The nature of the surfactant included in the formulation is considered to be Confidential Business Information (CBI) and is not included on product labels.

In addition to the use of surfactants, glyphosate use labels generally recommend the addition of ammonium sulfate (AMS) to the spray mixture, particularly in cases when using hard water[1] (Peterson and Thompson 2009). AMS is added to the spray solution in an effort for the sulfate ion to competitively bind with the positively charged elements commonly found in hard water (*i.e.,* calcium, magnesium, and iron) that may otherwise bind to the negatively charged glyphosate ion. The formation of glyphosate-cation complexes may reduce the efficacy of glyphosate by inhibiting adsorption into the leaves. In addition, it is thought that the ammonium ion may combine with the glyphosate ion which may improve movement across the leaf membrane. The potential influence of this chemical in a spray mixture is discussed in the Uncertainty section.

2.1.2 Physical and Chemical Properties of Glyphosate

The physical and chemical properties of glyphosate are shown in Table 2. The formation of glyphosate-metal complexes with iron and aluminum promotes a high sorption affinity of glyphosate on the surfaces of Fe and Al oxides in soils and sediments (McBride, 1994). Glyphosate can form various metal complexes (Popov, *et al.,* 2001).

Based on the physical and chemical properties alone, glyphosate has low potential to volatilize from soils (vapor pressure) or from water (Henry's Law Constant). It is also unlikely to bioaccumulate in fish given the low value of the Log *n*-octanol/water partition coefficient.

Appendix A provides the structure and further chemical/molecular information on glyphosate. The molecular structure characteristics of glyphosate are important as they help in understanding

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1 http://www.monsantoito.com/docs/PROMAX_Amonium_Sulfate_use_Hard_Water_issue_TUG.pdf

its mode of action at a molecular level as well as the binding of glyphosate to soil/sediment particulates.

Table 2. Physical and Chemical Properties of Glyphosate

Physical/Chemical Property	Value
Molecular Formula	$C_3H_8NO_5P$
Molecular Weight	170.8 g/mole
Melting Point	210-212° C (tech.) 215-219° C (pure)
Solubility in water, 25° C	12,000 mg L^{-1}
Vapor Pressure, Pa	1.3×10^{-7} (25° C)
Henry's Law Constant, Pa $\cdot m^3 \cdot mol^{-1}$	2.1×10^{-9}
Log K_{ow}	< -3
Dissociation Constants	$pKa_1 = 0.8$ $pKa_2 = 2.35$ $pKa_3 = 5.84$ $pKa_4 = 10.48$

2.2. Mechanism of Action

Glyphosate acid (CAS number 1071-83-6) [*N*-(phosphonomethyl)glycine] is an herbicide belonging to the phosphono amino acid class of pesticides. Glyphosate is a foliar, non-selective, systemic herbicide widely used to control weeds in agricultural crops and non-agricultural sites. Glyphosate is a potent and specific inhibitor of the enzyme 5-enolpyruvylshikimate 3-phosphate (ESPS) synthase. This enzyme is the sixth enzyme on the shikimate pathway and it is essential for the biosynthesis of aromatic amino acids (e.g., tyrosine, tryptophan, and phenylalanine) and other aromatic compounds in algae, higher plants, bacteria and fungi. Inhibition of this enzyme leads to plant cell death. The shikimate pathway is absent in mammals.

2.3. Use Statistics

Glyphosate is used as a non-selective foliar systemic herbicide in both aquatic and terrestrial environments on a wide variety of food and feed crops, non-food and non-feed crops and for other uses including forestry, greenhouse, non-crop, and residential. Based on usage data provided by the Biological and Economic Analysis Division (BEAD), on average, roughly 196,355,300 pounds of glyphosate are applied annually to agricultural crops (Table 3). Glyphosate usage is highest on soybeans, with annual average applications of 100,000,000 lbs a.i. applied (representing nearly 51% of the total use on agricultural crops). The crop with the highest average percent crop treated with glyphosate is soybeans (95%), followed by oranges (90%), and then almonds, cotton, grapefruit, and pistachios (85%). No usage data are available on the non-agricultural uses for glyphosate.

Table 3. **Screening Level Estimates of Agricultural Uses of Glyphosate**
(Source: BEAD SLUA report April 1, 2014)

Crop	Lb. A.I.	Percent Crop Treated	
		Average	Maximum
Alfalfa	400,000	<2.5	5
Almonds	2,100,000	85	95
Apples	400,000	55	70
Apricots	10,000	60	80
Artichokes	1,000	10	15
Asparagus	30,000	55	70
Avocados	80,000	45	65
Barley	600,000	25	40
Beans, Green	70,000	15	25
Blueberries	10,000	20	25
Broccoli	3,000	<2.5	<2.5
Brussels Sprouts *	<500	N/C	N/C
Cabbage	20,000	10	25
Caneberries	3,000	10	25
Canola	500,000	65	80
Cantaloupes	20,000	10	25
Carrots	3,000	5	10
Cauliflower	1,000	<2.5	5
Celery	1,000	5	10
Cherries	200,000	65	85
Chicory*	<500	N/C	N/C
Corn	59,300,000	60	85
Cotton	18,300.000	85	95
Cucumbers	30,000	20	35
Dates	3,000	20	25
Dry Beans/Peas	600,000	25	45
Fallow	8,400,000	55	65
Figs	5,000	40	70
Garlic	4,000	10	25
Grapefruit	400,000	85	95
Grapes	1,400,000	70	80
Hazelnuts	30,000	65	90
Kiwifruit	2,000	30	40
Lemons	200,000	75	90
Lettuce	10,000	<2.5	10
Nectarines	20,000	45	70
Oats	100,000	5	10
Olives	20,000	45	50

Crop	Lb. A.I.	Percent Crop Treated	
		Average	Maximum
Onions	40,000	30	40
Oranges	3,200,000	90	95
Pasture	700,000	<1	<2.5
Peaches	100,000	55	70
Peanuts	300,000	20	35
Pears	100,000	65	90
Peas, Green	20,000	10	20
Pecans	400,000	35	45
Peppers	30,000	20	35
Pistachios	500,000	85	95
Plums/Prunes	200,000	65	80
Pluots*	1,000	N/C	N/C
Pomegranates*	40,000	N/C	N/C
Potatoes	80,000	10	15
Pumpkins	20,000	20	25
Rice	800,000	30	50
Sorghum	2,800,000	40	60
Soybeans	100,000,000	95	100
Spinach	2,000	<2.5	10
Squash	10,000	20	40
Strawberries	10,000	10	20
Sugar Beets	1,200,000	55	100
Sugarcane	300,000	45	50
Sunflowers	1,100,000	55	75
Sweet Corn	100,000	15	25
Tangelos	9,000	55	80
Tangerines	60,000	65	80
Tobacco	9,000	5	10
Tomatoes	100,000	35	45
Walnuts	600,000	75	85
Watermelons	30,000	15	25
Wheat	8,500,000	25	70

All numbers rounded.
<500 indicates less than 500 pounds of active ingredient.
<2.5 indicates less than 2.5 percent of crop is treated.
<1   indicates less than 1 percent of crop is treated.
* Based on CA DPR data only; N/C = not calculated, only lb a.i. available

The survey data included in the SLUA report does not differentiate between which exact chemical code(s) are included from the Case. Data years 2004-2012

SLUA data sources include:
USDA-NASS (United States Department of Agriculture's National Agricultural Statistics Service),
Private Pesticide Market Research, and California Department of Pesticide Regulation data.
These results reflect amalgamated data developed by the Agency and are releasable to the public.

As shown in Figure 1, based on U.S. Geological Survey (USGS) National Water Quality
Assessment Program (NAWQA) data from 2011, glyphosate is used on agricultural crops across

most of the U.S., but predominantly in California, Midwestern states, Arkansas, Tennessee, Mississippi, Louisiana, and Southeastern states from Maryland to Florida.

Estimated Agricultural Use for Glyphosate , 2011

EPest-High

Estimated use on agricultural land, in pounds per square mile

- < 2.58
- 2.58 - 9.64
- 9.65 - 29.14
- 29.15 - 92.77
- > 92.78
- No estimated use

Figure 1. Map of Estimated Annual Agricultural Use of Glyphosate in 2011
(Source: http://water.usgs.gov/nawqa/pnsp/usage/maps/show_map.php?year=2011&map=GLYPHOSATE&hilo=L)

2.4. Application Methods and Rates

Target pests include a broad spectrum of emerged grass and broadleaf weeds, both annual and perennial. Glyphosate is formulated as water-dispersible granules (WG) (80% active ingredient), emulsifiable concentrate (EC) (13.4% - 36.5% active ingredient), water-dispersible liquids (L) (5% - 14.6% active ingredient), ready to use (RTU) (0.81% active ingredient), and soluble concentrate/solid (SC/S) (95.2% - 96.7% active ingredient). Application equipment includes aircraft and various ground equipment (boom sprayer, hand held hydraulic sprayer, hand held sprayer, high volume ground sprayer, hooded sprayer, hose-end sprayer, low volume ground sprayer, low volume sprayer, motor driven sprayer, product container, ready-to-use spray container, shielded applicator, sprayer, tank-type sprayer, wick applicator, and wiper applicator). Application is via band treatment, broadcast, crack and crevice treatment, directed spray, edging treatment, ground spray, high volume spray (dilute), low volume spray (concentrate), perimeter treatment, soil broadcast treatment, spot treatment, spray, strip treatment, stump treatment, and wipe-on/wiper treatment. Single application rates are up to 8 pounds active ingredient (as acid equivalents)/acre (lb a.e./A), but are generally 1.55 lb a.e./A for aerial applications and 3.75 lb a.e./A for ground application. Maximum combined annual application rates are up to generally 6 to 8 lbs a.e./A. For some uses, the single application rates were calculated as up to 40 lbs a.e./A, however, these applications are intended for spot treatment or treatment over areas much smaller than an acre. In these cases the application rate is also expressed in terms of the smaller coverage area.

The label data used in this assessment were derived label and use information compiled by the Joint Glyphosate Task Force (JGTF). The Agency requested that the JGTF submit label information to clarify non-specified information in the LUIS report. The non-specified information clarified included maximum number of applications in a crop cycle, maximum number of applications per year, maximum application rate per year, and the minimum retreatment intervals. Table 4 and Table 5 show the maximum single application rates for glyphosate from the JGTF.

Table 4. Maximum Single Application Rates for Ground Applications of Glyphosate from the JGTF Use Matrix

Crop Group	Max Single App Rate (lb a.e./A)	Max Apps	Min Interval (days)	Max Annual App Rate Crop Cycle (lb a.e./A)	Max Combined Annual App Rate (lb a.e./A)
Round Ready 2 Yield Soybeans	3.75	3	10	3.75	6
Root Tuber Vegetables	3.75	3	7	6	6
Rangelands	0.38	6	7	2.25	2.25
Pome Fruits	3.75	10	7	8	8
Pastures	8	4	7	8	8
Oilseed Crops	3.75	3	7	6	6
Non-Food Tree Crops	8	30	7	8	8
Miscellaneous Tree Crops	3.75	10	7	8	8
Miscellaneous Crops	3.75	3	7	6	6
Legume Vegetables	3.75	6	7	6	6
Leafy Vegetables	3.75	6	7	6	6
Herbs and Spices	3.75	6	7	6	6
Grass/Turfgrass/Sod Production	3.75	3	7	6	6
Grain Sorghum	3.75	3	7	6	6
Fruiting Vegetables	3.75	6	7	6	6
Forestry	8	5	7	8	8
Fallow	3.75	3	7	6	6
Cucurbits Vegetables/Fruit	3.75	6	7	6	6
Cotton	3.75	5	7	6	6
Corn (Field, Seed, Silage, Popcorn)	3.75	3	7	6	6
Conservation Reserve Program	3.75	3	7	6	6
Citrus Fruit Crop	3.75	10	7	8	8
Cereal and Grain Crop	3.75	3	7	6	6
Bulb Vegetables	3.75	6	7	6	6
Brassica Vegetable	3.75	6	7	6	6
Round-up Ready Flex Cotton	3.75	3	10	3.75	6
Round-up Ready Cotton	3.75	3	10	3.75	6
Round-up Ready Corn (GA-21)	3.75	3	10	3.75	6
Round-up Ready Corn 2 (NK603)	3.75	3	10	3.75	6
Round-up Ready Alfalfa	1.55	3	10	4.61	6
Round-up Ready Sugarbeets	3.75	3	10	3.75	6
Tropical/Subtropical Trees/Fruits	3.75	3	10	8	8
Tree Nut Crops	3.75	3	10	8	8
Sweet Corn	3.75	3	7	6	6
Sugar Cane	3.75	3	7	6	6
Stone Fruit	3.75	3	7	8	8

Crop Group	Max Single App Rate (lb a.e./A)	Max Apps	Min Interval (days)	Max Annual App Rate Crop Cycle (lb a.e./A)	Max Combined Annual App Rate (lb a.e./A)
Round-Up Ready Canola(Winter Varieties)	1.55	3	10	1.55	6
Soybeans	3.75	3	7	6	6
Sweet Corn with Round-Up Ready 2 Technology	3.75	3	10	3.75	6
Round-Up Ready Canola (Spring Varieties)	1.55	3	10	1.55	6
Vine Crops	3.75	3	7	8	8
Non Crop	8	10	7	8	8
Aquatic	8	4	1	8	8
Alfalfa, Clover, and Other Forage Legume	3.75	3	7	6	6
Berry and Small Fruit Crops	3.75	3	7	8	8
Residential	40	12	7	40	40

Table 5. Maximum Single Application Rates for Aerial Applications of Glyphosate from the JGTF Use Matrix

Crop Group	Max Single App Rate (lb a.e./A)	Max Apps	Min Interval (days)	Max Annual App Rate Crop Cycle (lb a.e./A)	Max Combined Annual App Rate (lb a.e./A)
Round Ready 2 Yield Soybeans	1.55	3	10	3.75	6
Root Tuber Vegetables	1.55	3	7	4.65	6
Rangelands	0.38	6	7	2.25	2.25
Pome Fruits	1.55	3	7	4.65	8
Pastures	8	4	7	8	8
Oilseed Crops	1.55	3	7	4.65	6
Non-Food Tree Crops	8	3	7	4.65	8
Miscellaneous Tree Crops	1.55	3	7	4.65	8
Miscellaneous Crops	1.55	3	7	4.65	6
Legume Vegetables	1.55	6	7	4.65	6
Leafy Vegetables	1.55	6	7	4.65	6
Herbs and Spices	1.55	6	7	6	6
Grass/Turfgrass/Sod Production	1.55	3	7	4.65	6
Grain Sorghum	1.55	3	7	4.65	6
Fruiting Vegetables	1.55	6	7	4.65	6
Forestry	8	2	7	8	8
Fallow	1.55	3	7	4.65	6
Cucurbits Vegetables/Fruit	1.55	6	7	4.65	6
Cotton	1.55	3	7	4.65	6
Corn (Field, Seed, Silage, Popcorn)	1.55	3	7	4.65	6

Crop Group	Max Single App Rate (lb a.e./A)	Max Apps	Min Interval (days)	Max Annual App Rate Crop Cycle (lb a.e./A)	Max Combined Annual App Rate (lb a.e./A)
Conservation Reserve Program	1.55	3	7	4.65	6
Citrus Fruit Crop	1.55	3	7	4.65	6
Cereal and Grain Crop	1.55	3	7	4.65	6
Bulb Vegetables	1.55	6	7	4.65	6
Brassica Vegetable	1.55	6	7	4.65	6
Round-up Ready Flex Cotton	1.55	3	10	3.75	6
Round-up Ready Flex Cotton	1.125	6	10	4.5	6
Round-up Ready Cotton	1.55	3	10	3.75	6
Round-up Ready Corn (GA-21)	1.55	3	10	3.75	6
Round-up Ready Corn 2 (NK603)	1.55	3	10	3.75	6
Round-up Ready Alfalfa	1.55	3	10	4.61	6
Round-up Ready Sugarbeets	1.55	3	10	3.75	6
Tropical/Subtropical Trees/Fruits	1.55	3	10	4.65	8
Tree Nut Crops	1.55	3	10	4.65	8
Sweet Corn	1.55	3	7	4.65	6
Sugar Cane	2.25	3	7	6	6
Stone Fruit	1.55	3	7	4.65	8
Round-Up Ready Canola (Winter Varieties)	1.55	3	10	1.55	6
Soybeans	1.55	3	7	4.65	6
Sweet Corn with Round-Up Ready 2 Technology	1.55	3	10	3.75	6
Round-Up Ready Canola (Spring Varieties)	1.55	3	10	1.55	6
Vine Crops	1.55	3	7	4.65	8
Non Crop	8	10	7	8	8
Aquatic	8	4	1	8	8
Alfalfa, Clover, and Other Forage Legume	1.55	3	7	4.65	6
Berry and Small Fruit Crops	1.55	3	7	4.65	8

3. Exposure Assessment

3.1. Exposure Assessment Strategy

The aquatic exposure strategy is based on the premise that runoff/erosion and spray drift are important dissipation pathways for terrestrial uses of glyphosate (Figure 2). These dissipation processes were modeled using the Tier 1 GENEEC model (Version 2). Exposure to glyphosate formulations also was evaluated because some of the formulations are more toxic than the active ingredient alone. Terrestrial uses of glyphosate allow for application of formulations that contain a surfactant that is toxic to aquatic organisms (polyethoxylated tallow amines (POEA)), whereas the toxic surfactant is not allowed in formulations designated for direct aquatic use. Because glyphosate formulations with POEA are allowed to be used in terrestrial use patterns and that chemical constituents in glyphosate formulation (*i.e.*, POEA, etc) are expected to rapidly degrade in soil, spray drift is an important off-site dissipation pathway into aquatic environments for glyphosate formulations and the surfactant POEA. The AgDrift model (Version 2.1.1**)** was used to estimate exposure from off-site movement through spray drift. Direct applications to water were considered for glyphosate and the glyphosate formulations without POEA using a Tier 1 dilution model in the standard pond and the rice paddy. The Tier 1 dilution modeling approach was conducted to provide conservative estimated environmental concentrations in standard water bodies used in ecological risk assessments.

Figure 2 shows the expected exposure pathways and the aquatic modeling strategy for each stressor including glyphosate, glyphosate formulations, and POEA.

Exposure Route	Terrestrial Applied Runoff & Spray	Terrestrial Applied Spray Drift	Directly Applied to Water
Model Used	GENEEC	AgDrift	Tier 1 Rice Paddy Model with Degradation and Sorption
Stressor	Glyphosate	• Glyphosate • Formulation with POEA • POEA	• Glyphosate • Formulation without POEA
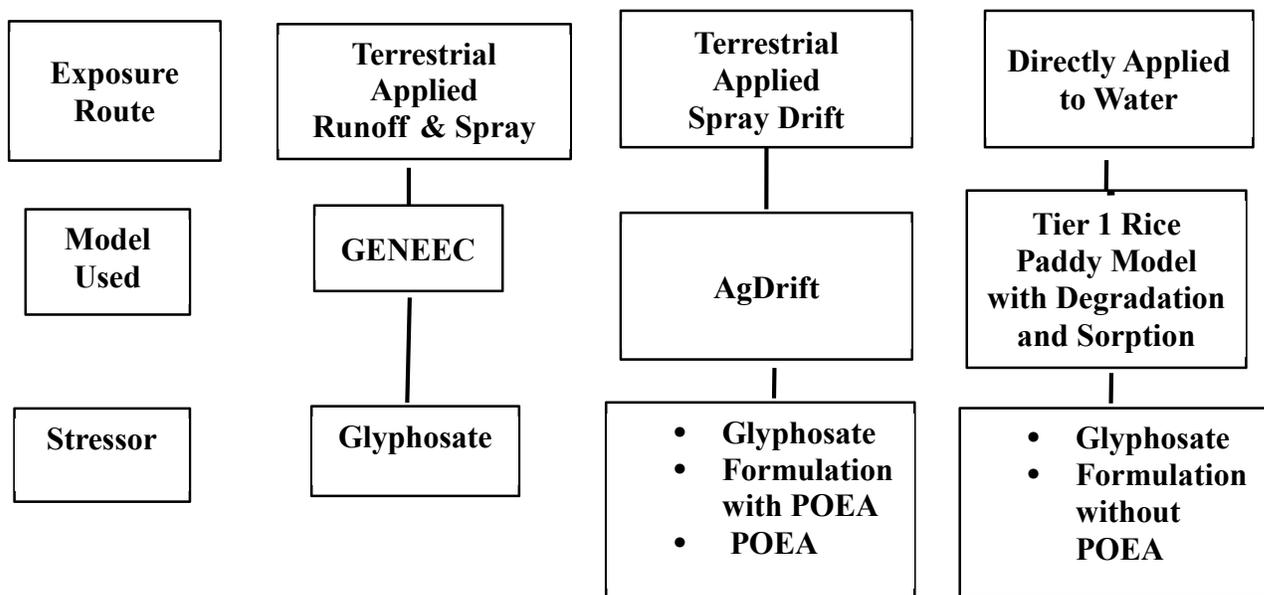
Figure 2: Exposure Pathways for Various Glyphosate Stressors and the Exposure Modeling Strategy

The terrestrial exposure strategy is based on the premise that direct contact and spray drift are important exposure pathways for terrestrial uses of glyphosate and glyphosate formulation with POEA. Direct contact was modeled using the T-REX model (Version 1.5.2). Spray drift exposure was modeled using AgDrift model (Version 2.1).

3.2 Environmental Fate Assessment

It is assumed that the glyphosate salts dissociate rapidly to form glyphosate acid and the counter ion. Because glyphosate acid will be a zwitterion (presence of both negative (anionic) and positive (cationic) electrostatic charges) in the environment, it is expected to speciate into dissociated species of glyphosate acid as well as glyphosate-metal complexes in soil, sediment, and aquatic environments. The environmental fate data for glyphosate, with the exception of a photodegradation study (MRID 44320643), did not address the impact of environmental fate processes on different species of glyphosate acid.

The major route of transformation of glyphosate identified in laboratory studies is microbial degradation (Table 6). In soils incubated under aerobic conditions, the half-life of glyphosate ranges from 1.8 to 109 days and in aerobic water-sediment systems is 14 - 518 days. However, anaerobic conditions limit the metabolism of glyphosate (half-life 199 - 208 days in anaerobic water-sediment systems).

In laboratory studies, glyphosate was not observed to break down by abiotic processes, such as hydrolysis, direct photolysis on soil, or photolysis in water at pH 7. In the field, soil dissipation half-lives for glyphosate were measured to be 1.4 to 142 days. Although the variability in glyphosate dissipation rates cannot be statistically correlated to any specific test site properties, dissipation half-lives tend to be higher at test sites in the central to northern United States. Along with significant mineralization to carbon dioxide, the major metabolite of glyphosate is aminomethylphosphonic acid (AMPA).

The degradation product AMPA is a major degradation product from glyphosate. It was detected in all laboratory studies except for the abiotic hydrolysis studies. This degradation product is ionic because it retains the phosphonate and amine functional groups. Because of these functional groups, AMPA will form metal complexes with Ca^{2+}, Mg^{2+}, Mn^{2+}, Cu^{2+}, and Zn^{2+} (Popov, et al., 2001). Batch equilibrium data for AMPA indicate high sorption to soils. Freundlich sorption coefficients range from 10 to 509 with exponents (1/n) of .78 to 0.98. The laboratory and field dissipation data indicate that AMPA is substantially more persistent than glyphosate.

Table 6. Environmental Fate Data for Glyphosate

Study	Value	Major Degradates[1], Comments	MRID #
Abiotic Hydrolysis Half-life	Stable	None	00108192 44320642
Direct Aqueous Photolysis	Stable (t1/2=216 days)	AMPA (6.6% of AR)	41689101 44320643
Soil Photolysis Half-life	Stable (for at least 30 days)	Degradation in dark control was equal to that in irradiated samples	44320645
Aerobic Soil Metabolism Half-life	1.8 days (sandy loam; 25°C) 2.6 days (silt loam; 25°C) 7.5 days (sandy loam; 25°C) 2.04 days (sandy loam; 25°C) 19.3 days (sandy loam;20°C) 27.4 days (scl loam; 20°C) 7.78 days (clay loam;20°C) 109 days (silt loam;20°C)	AMPA (24-32% of AR) CO_2 (53 to >70% of AR)	42372501 44320645 44125718 PMRA1161813 Al-Rajab and Schiavon, 2010
Anaerobic Aquatic Metabolism Half-life	208 days 203 days 199 days	AMPA (21.9-31.6% of AR) CO_2 (23-35% of AR) AMPA and glyphosate were detected in sediment at 1 year posttreatment	41723701 42372502 44125718
Aerobic Aquatic Metabolism Half-life	14.1 days (25°C) 267 days (20°C) 518 days (20°C)	AMPA (25% of applied AR) CO_2 (≥ 23% of applied AR) a	41723601; 42372503 PMRA 161822

Study	Value				MRID #
Batch Equilibrium	*Soil*	K_F	*1/n*	K_{Foc}	44320646
	sand	64	0.75	22,000	
	sandy loam	9.4	0.72	1,600	
	sandy loam	90	0.76	5,000	
	silty clay loam	470	0.93	21,000	
	silty clay loam	700	0.94	33,000	
	Silty clay loam	62	0.90	3,172	00108192
	Silt	90	0.94	13,050	
	Sandy loam	70	0.95	5,075	
	Sandy loam	22	0.78	5,468	
	Sediment	175	1.0		

Study	Value			MRID #
Terrestrial Field Dissipation Half-life	Glyph. AMPA 1.7 d 131 d (TX) 7.3 d 119 d (OH) 8.3 d 958 d (GA) 13 d 896 d (CA) 17 d 142 d (AZ) 25 d 302 d (MN) 114 d 240 d (NY) 142 d no data (IA)		Bare ground studies. Glyphosate and AMPA were found predominantly in the 0 to 6 inch layers	42607501 42765001
	Glyph. AMPA 2.79 d 48d (CA) 31 d ND (NC)		Bareground Studies Glyphosate and AMPA were found predominantly in the surface soil layers	44125719 44422201
	Glyph AMPA 3.9 d ND Bareground 1.4 d ND Turf		Bareground and turf plots in MS Glyphosate and AMPA were found predominantly in the surface soil layers	44320648
	Glyph AMPA 19 d ND Bareground 12 d ND Turf		Bareground and turf plots in CA Glyphosate and AMPA were found predominantly in the surface soil layers	44320649 44320650
Aquatic Field Dissipation Half-life	7.5 d – water 120 d- sediment		In a farm pond in Missouri. At 3 sites (OR, GA, MI), half-lives could not be calculated due to recharging events.	40881601
	Water: Dissipated rapidly immediately after treatment. Sediment: Glyphosate remained in pond sediments at $\geq$ 1 ppm at 1 year post treatment.		In ponds in Michigan and Oregon and a stream in Georgia Accumulation was higher in the pond than in the stream sediments	41552801
Forestry Dissipation	Foliage: < 1 day Ecosystem: Glyphosate: 100 d AMPA: 118 d		3.75 lb a.e./A, aerial application	41552801
Bioaccumulation in Fish	0.38X in edible tissue 0.63X in nonedible tissue 0.52X in whole fish			41228301

[1] Major degradates are defined as those which reach >10% of the applied.

The available laboratory data indicate that both glyphosate and AMPA sorb strongly to soil. The formation of glyphosate-metal complexes promotes a high sorption affinity of glyphosate to Fe and Al oxide surfaces on soils and sediments (McBride, 1994; Popov, *et al*. 2001). AMPA is also expected to form similar metal-ligand complexes (Popov, *et al*. 2001). Freundlich partitioning coefficients (K_f) for glyphosate ranged from 9.4 to 479 with exponents of 0.72 to 1, which corresponding organic carbon partitioning coefficients (Kf_{oc}) of 1,600 to 33,000 mL/g_{oc}. Freundlich sorption coefficients for AMPA range from 10 to 509 with exponents (1/n) of .78 to

0.98. Because the Freundlich exponents for glyphosate and AMPA are not equal to 1, the sorption process is non-linear and, therefore, sorption coefficients are dependent on the concentration in soil solution or aquatic environments. Although this non-linearity in sorption is not captured in the exposure modeling, it is expected to reduce the exposure concentrations in aquatic exposure modeling.

Although the coefficient of variation for K_{foc} is less than the coefficient of variation for K_f, indicating that pesticide binding to the organic matter fraction of the soil may explain some of the variability among the adsorption coefficients, the physicochemical properties of glyphosate (ionic) and the propensity for glyphosate and AMPA to form metal-ligand complexes on surfaces of iron and aluminum oxides would suggest the Freundlich model is the most appropriate partitioning model. This model would account for sorption on both mineral and organic constituents in soils and sediments. Based on measured K_{oc} values, glyphosate is classified as slightly mobile to hardly mobile according to the FAO classification scheme and would not be expected to leach to groundwater or to move to surface water at high levels through dissolved runoff. However, glyphosate does have the potential to contaminate surface water from spray drift or transport of residues adsorbed to soil particles suspended in runoff. It is expected to be persistent in anaerobic sediments.

The potential for volatilization of glyphosate from soil and water is expected to be low due to the low vapor pressure and low Henry's Law constant. Several studies have shown both glyphosate and AMPA detections in rainwater near use locations. In most cases, these detections were found during the spraying season in the vicinity of local use areas and can be attributed to spray drift rather than to volatilization or long range transport (Baker *et al.*, 2006; Quaghebeur *et al.*, 2004). The highest concentrations were found in urban locations. At one site in Belgium that was 5 m from a spraying location in an urban parking lot, glyphosate was detected in rainwater for several months following a single application (Quaghebeur *et al.*, 2004). Deposition was measured to be 205 µg a.i./m^2 at one week after spraying and 0.829 µg/m^2 two months after spraying. These data suggest that volatilization of glyphosate from hard surfaces is possible despite its low vapor pressure.

3.3. Aquatic Exposure

3.3.1. Terrestrial Applications

Surface water modeling was conducted using GENEEC (version 2). Model input parameters for glyphosate are shown in Table 7. Terrestrial uses of glyphosate were modeled using the maximum application rate with minimum application intervals (Table 8). Output files for GENEEC model simulations are shown in Appendix B.

Table 7. GENEEC Modeling Inputs for Glyphosate

PARAMETER	Measured VALUES	VALUE	COMMENT	SOURCE
Spray Drift Fraction	NA	AgDrift Default Spray Drift	Default ground and aerial droplet size spectrum in GENEEC	AgDrift Routines in GENEEC
Aerobic Soil Metabolism Half-life (days)	1.8 days 2.6 days 7.5 days 2.0 days 13.6 days[b] 19.4 days[b] 5.5 days[b] 77.1 days[b]	29 days	Upper 90th percentile confidence bound of the mean half-life= $16.19+(1.415*25.37)/SQR(8)$ Average=16.19 SD=25.37 $T_{n-1,90}$ =1.415 n=8	MRID 44320645 MRID 44125718 MRID 42372501 PMRA 1161813 Al-Rajab and Schiavon, 2010
Organic Carbon Partition Coefficient (Koc) (mL/ goc)		157	Mean K_F[a]	MRID 44320646 MRID 00108192
Aerobic Aquatic Half-Life (days)	14 days 188 days[b] 366 days[b]	381 days	Upper 90th percentile confidence bound of the mean half-life= $189.7+(1.886*175.8)/SQR(3)$ Average=189.7 SD=175.8 $T_{n-1,90}$ =1.886 n=3	MRID 41723601 PMRA 1161822
Aqueous Photolysis half-life (days)		Stable	Represents photo-degradation rate at pH 7	MRID 41689101, 44320643
Hydrolysis half-life (days)		Stable		MRID 00108192, 44320642
Molecular Weight (g/mole)		169.08		Calculated
Water Solubility @ 25°C (mg/L)		12,000		Product Chemistry

a=Data derived according to Guidance of Selecting Input Parameters in Modeling Environmental Fate and Transport of Pesticides Version 2.1 (10/22/2009)
b=Half-lives corrected from 20°C to 25°C using Q10 temperature correction equation.

Table 8. Maximum Application Rates for Terrestrial Uses of Glyphosate

Application Method	Single Application Rate (lb a.e./A)	Number of Applications	Application Interval (days)	Annual Application Rate (lb a.e./A)
Aerial Spray	3.75	2	7	8
	8	1	NA	8
Ground Spray	8	1	NA	8
	40	1	NA	40

The highest EEC for terrestrial crop uses of glyphosate is associated with residential spot treatments because of the extrapolation of a spot treatment rate to a broadcast application rate (40 lb a.e./A). Estimated environmental concentrations (EECs) from the glyphosate use from residential spot treatments are not expected to exceed 246.4 µg/L for the daily peak, 185.2 µg/L for the 21-day average, and 115.7 µg/L for the 60-day average.

Estimated environmental concentrations from aerial spray applications are not expected to exceed 59.6 µg/L for the daily peak, 45.1 µg/L for the 21-day average, and 28.2 µg/L for the 60-day average.

Estimated environmental concentrations from ground spray applications are not expected to exceed 49.3 µg/L for the daily peak, 37 µg/L for the 21-day average, and 23.1 µg/L for the 60-day average. Glyphosate EECs are shown in Table 9.

Table 9. Tier I GENEEC Estimated Environmental Concentrations of Glyphosate in Surface Water from Terrestrial Uses

Application Method	Spray Drift Buffer (feet)	Single Application Rate (lb a.e./A)	EEC (ug/L)		
			Peak	21-day Average	60- day Average
Aerial Spray	0	3.75[1]	53.3	40.3	25.2
	0	8	59.6	45.1	28.2
	500[3]	3.75	33.4	25	15.5
	500[3]	8	38.4	28.7	17.9
Ground Spray	0	8	49.3	37	23.1
	0	40[2]	246.4	185.2	115.7

1-2 applications @ 7 day interval
2-Residential Spot Treatment- Application rates are expressed as lbs ae/A.
3-Spray Drift Buffer for CA and AR

3.3.1.1. Spray Drift Transport from Terrestrial Applications

Spray drift from ground and aerial applications may enter aquatic systems. For terrestrial application of end use products, partitioning and degradation properties for each formulation component in runoff suggest that the final proportion of the residues of these components in the receiving surface waters would not represent what was introduced and what was tested in an aquatic organism toxicity study using the formulated product. For this reason, spray drift is assumed to be the only route of aquatic exposure to the formulation as introduced.

Spray deposition curves as calculated by AgDrift are provided in Figure 3 and 4. When multiplied by the appropriate single maximum application rate, these values can be used to determine the distance from the edge of the field where effects to non-target organisms are no longer of concern.
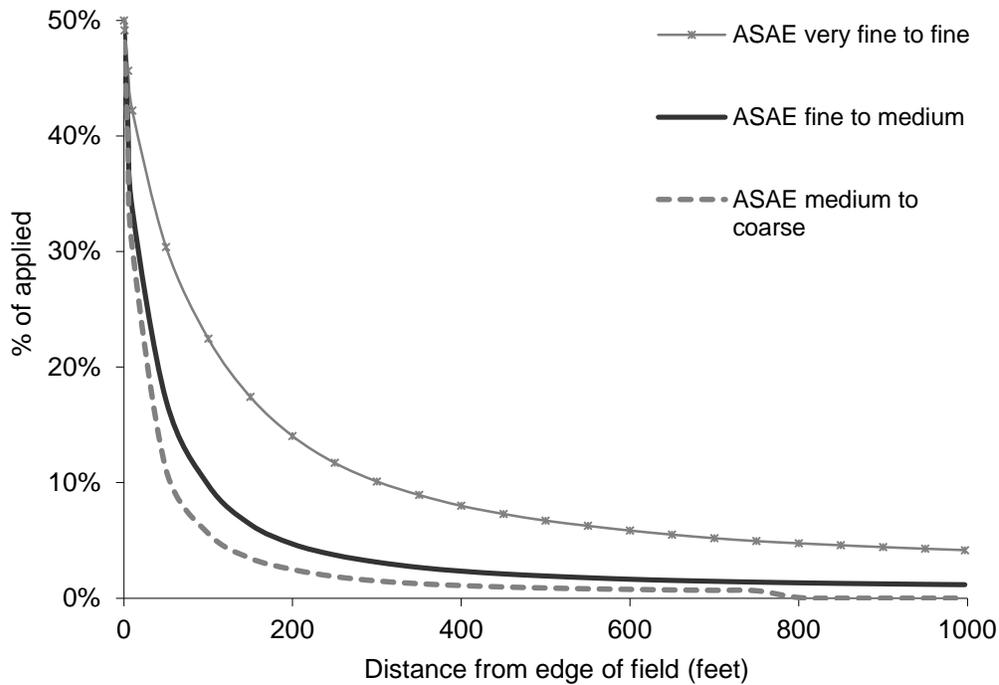
Figure 3. Percent of applied pesticide at different distances from the edge of the field treated by <u>aerial</u> methods (calculated using AgDrift).
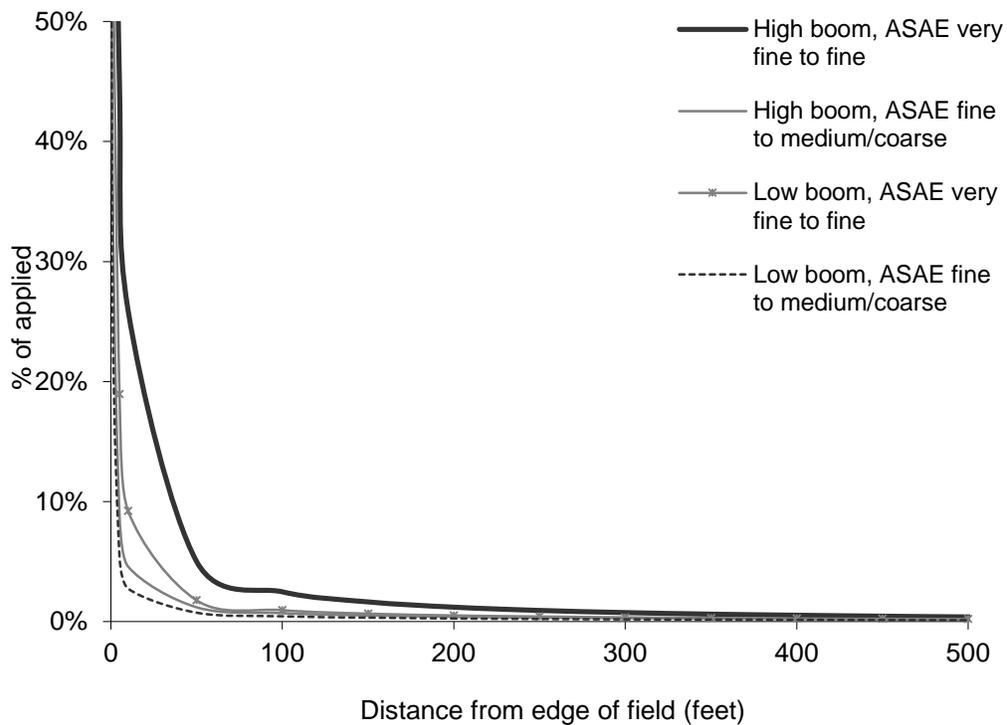
Figure 4. Percent of applied pesticide at different distances from the edge of the field treated by <u>ground</u> methods (calculated using AgDrift).

For the aquatic exposure assessment, the aquatic deposition tool AgDrift was used to estimate the pesticide concentrations in the standard farm pond (immediately adjacent to a treated field) from spray drift only, following aerial and ground foliar spray applications made at the maximum rates and using the default droplet size spectrum in AgDrift. For aerial applications, the maximum rates of 1.55 and 8 lb a.e./A (most crops and forestry, respectively) yielded EECs of 11.0 and 56.7 µg a.e./L, respectively. For ground applications, the maximum rates of 3.75 and 8 lb a.e./A (most crops and forestry, respectively) yielded EECs of 13.0 and 27.6 µg a.e./L, respectively.

3.3.1.2. Glyphosate Formulated Products

The volume of formulation applied in an application was also determined to help inform the risk assessment by evaluating potential risk on a formulation basis (as oppose to strictly adjusting toxicity and exposure values to acid equivalents). The volume of formulated product applied per acre was provided by the LUIS report. In the LUIS report, some values were reported on a mass of formulated product per area. In an effort to determine volume per area, for purposes of this estimate, the density was assumed to be equal to water (1000 grams per liter). This is recognized as an uncertainty in this calculation. Additionally, the LUIS report calculated the volume or mass per acre for certain uses such as spot treatments, tree injections or stump applications. This reported volume on an acre basis is anticipated to be overestimated, as it is unlikely that the area of an entire acre is treated in a single application. The volume of formulation applied in a single application, using the LUIS reports, resulted in application volumes of < 1 quart up to 10 quarts per application. The yearly or seasonal application volume appeared to have a maximum volume rate of 10.6 quarts per acre. For certain uses such as spot treatments, tree injections, stump applications, sometimes greater application rates were calculated. However, these volumes were extrapolated from uses intended to be spot treatments and therefore, the volumes calculated are likely overestimated as the application rates were calculated as lb/A. Additionally, there are registered uses in which the formulation is applied as a wipe-on or as a wiper application. Spray drift from this use as well as from the spot treatments is anticipated to be limited.

The EECs for the glyphosate formulated products and POEA are shown in Table 10. These EECs were calculated using a range of volumes of formulated product applied for which a few selected volumes are presented in Table 10. The EECs are based on a volume of formulation applied per acre, a spray drift fraction, and the simple dilution equation (using the standard pond scenario). Spray drift EECs were calculated using the spray drift fraction for the default droplet size (EFED off-site transport guidance 2013). Concentrations of formulated product and POEA in the standard farm pond (2 x10^7 Liters) were calculated for both aerial and ground applications. Additionally, concentrations of formulated product and POEA were also calculated for a shallower body of water (1 x 10^6Liters, which is the depth used when modeling a rice paddy water concentration). It is noted that glyphosate is not currently registered for use on rice, but rather this default water body depth was used to provide results for a shallow body of water. In the table below, the percentage of POEA in the formulated product was taken from a document available in the open literature and was assumed to be 15% (Diamond and Durkin, 1997). These EECs represent the spray drift load from a single aerial or ground spray application. Runoff was not considered because it is assumed the formulated product and the POEA will dissipate in soil and will not reach the aquatic environment as a complete formulation. Although there is limited information on the fate properties of POEA, nonionic

surfactants have been reported to readily biodegrade or sorb in soil (Krogh *et al*., 2003). Figures 5 and 6 depict the concentration of POEA in the standard pond and shallower water body, respectively. The volume of applied formulation as well as the percentage of POEA necessary to exceed levels of concern is discussed in the Risk Description section.

Table 10. Estimated Environmental Concentration (EEC) of Formulated Product and POEA from Spray Drift.

Application Method / Receiving water body	Spray Drift Fraction	Single Application of Formulated Product (Qts/A)	Peak EEC of Formulated Product (µg/L)[1]	Peak EEC of POEA (µg/L)[2]
Aerial / Standard farm pond (2E7 Liters)	0.1266	1	5.98	0.90
		5	29.9	4.49
		10	59.9	8.98
		20	120	18.0
Ground / Standard farm pond	0.0616	1	2.91	0.44
		5	14.6	2.18
		10	29.1	4.37
		20	58.2	8.74
Aerial / Paddy (1E6 Liters)	0.1266	1	120	18.0
		5	598	89.8
		10	1197	180
		20	2394	359
Ground / Paddy (1E6 Liters)	0.0616	1	58.2	8.74
		5	291	43.7
		10	582	87.4
		20	1165	175

1- [qts. formulated product/A* 1 gal/4 qts.*density of formulated product (lbs gal)*0.01*454E6 ug/lb]/2E7 liters (standard pond) or 1E6 liters (shallower body of water); density assumed to be 8.33 lb/gal.

2- Peak EEC for formulated products*percent of POEA
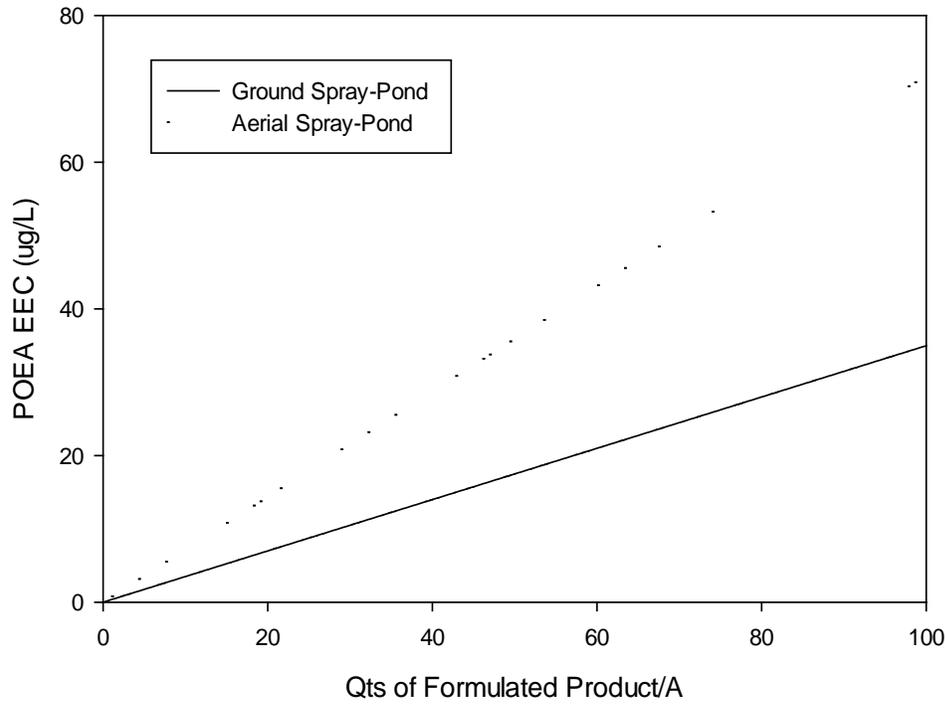
Figure 5. The Concentration of POEA in an Adjacent Water Body (standard pond) Based on Spray Drift and the Volume of a Terrestrial Formulated Product Applied by Either Ground or Aerial Application. Percentage of POEA in formulation assumed to be 15%.
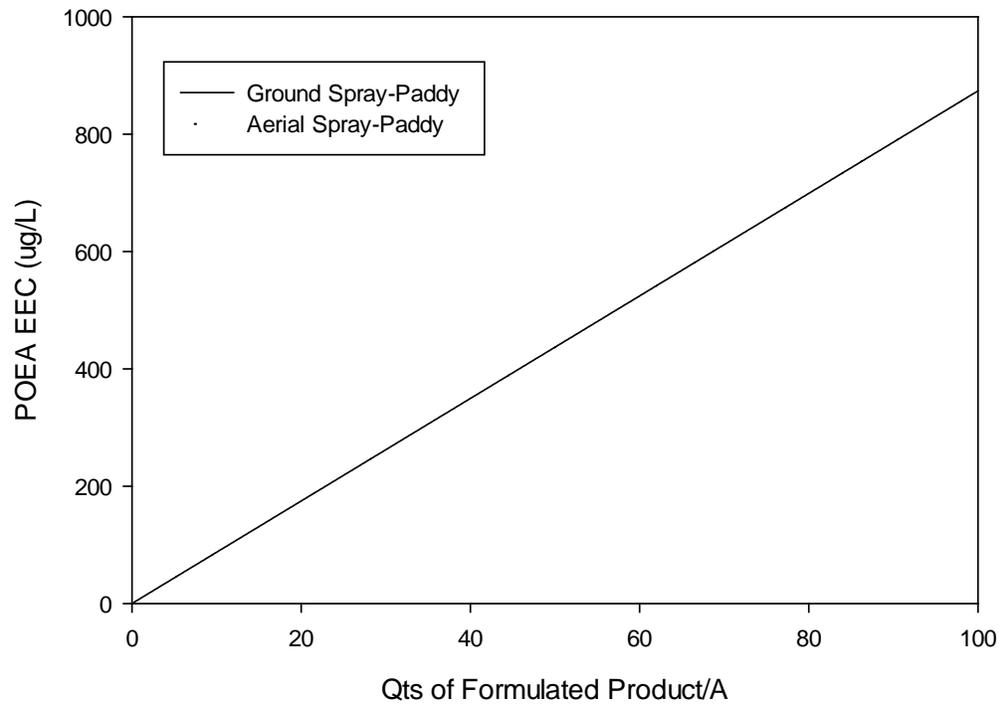
Figure 6. The Concentration of POEA in an Adjacent Water Body (water depth equivalent to default rice paddy depth) Based on Spray Drift and the Volume of a Terrestrial Formulated Product Applied by Either Ground or Aerial Application. Percentage of POEA in formulation assumed to be 15%.

3.3.2. Applications to Aquatic Environments

The glyphosate concentration in surface water from direct aquatic applications was estimated using the standard pond and rice paddy scenario. The Tier 1 rice model with degradation was used to provide conservative estimated environmental concentrations in the standard pond and rice paddy. Aerobic aquatic metabolism and sorption were assumed to control the dissipation rate of glyphosate. The modeling was conducted using maximum broadcast application rates of 3.75 and 8 lb a.e./A. The labels with direct aquatic uses do not specify a target concentrations as the aquatic label application rates are expressed as lbs ae/A. Estimated environmental concentrations of glyphosate from direct surface water applications are shown in Table 11.

Table 11. Predicted Glyphosate Concentrations from Direct Applications into the Standard Pond and Rice Paddy

Application Rate (lb a.e./A)	Waterbody	Concentration (µg/L)[1]		
		Peak[1]	21 day Average	60 day Average
3.75	Standard Pond	103.8	101.8	98.4
8		221.5	217.5	210
3.75	Rice Paddy	195.7	192.2	185.6
8		417.5	410	395.9

1-EEC = (App rate * 100 / (dw + (dsed * (θ + (ρ * Kd / 1000))))) * exp (-day * k_{AAM})
Where: App Rate= Application Rate (kg/ha)
Dw = Water Depth (meters) = 2 meters for standard pond or 0.1 meter for rice paddy
Dsed = Sediment Bulk Density = 1300 kg/m3
Θ = Sediment Porosity=0.509
P = organic carbon fraction=0.01
Kd = Soil:water partitioning coefficient
K_{AAM} = aerobic aquatic rate constant (day-1)
Day = time (days after application)

Formulation EECs for application to aquatic environments (mg formulated product/L) were also calculated using the same approach as described above for terrestrial applications and uses the simple dilution model. In Table 12, the EECs for formulated product for a few representative application rates are presented. As the rate of dissipation in the water body for the different components of the formulation in the water body are anticipated to vary, chronic EECs for formulated product are not calculated.

Table 12. Estimated Environmental Concentration (EEC) of Formulated Product from Application to Aquatic Environments

Application Method / Receiving waterbody	Single Application of Formulated Product (Qts/A)	Peak EEC of Formulated Product (µg/L)[1]
Direct Application / Standard farm pond (2E7L)	1	47.3
	5	236
	10	473
	20	945
Direct Application / Paddy (1E6L)	1	945
	5	4727
	10	9455
	20	18909

1- [qts. formulated product/A* 1gal/4 qts.*density of formulated product (lbs gal)*454E6 ug/lb]/2E7 liters (standard pond) or 1E6 liters (shallower body of water); density assumed to be 8.33 lb/gal.

3.4. Surface Water Monitoring Data

A search for available surface water monitoring data for glyphosate and AMPA was conducted in the USGS NAWQA, CADPR SWAMP, USDA PDP, and USGS-EPA Pilot Reservoir Monitoring Program databases. Additionally, open literature was also considered in this analysis. Glyphosate and AMPA concentrations were only measured in the USGS NAWQA and CADPR SWAMP monitoring programs. A summary of monitoring data are shown in Table 13. The maximum concentration of glyphosate and AMPA in surface water was 200 µg/L and 28µg/L, respectively.

Table 13. Summary of Surface Water Monitoring Data for Glyphosate and AMPA (Data extracted from USGS, CADPR on 1/4/2014).

Monitoring Program	Watershed Land Use	Analyte	N	Detection Frequency (%)	Maximum Concentration (µg/L)		Station ID	State
					Daily Peak	Arithmetic Annual Average		
USGS NAWQA	All Land Uses	glyphosate	1903	61	73	4.03	7288650	MS
		AMPA	1903	81	28	4.25	7288650	MS
	Ag	Glyphosate	574	61	73	4.03	7288650	MS
		AMPA	574	61	28	4.25	7288650	MS
	Mixed	glyphosate	677	61	3.08	0.71	5331580	MN
		AMPA	677	88	4.43	1.39	11303500	CA
	Urban	glyphosate	351	54	5.9	0.86	40869415	WI
		AMPA	351	73	3.51	1.53	6713500	CO
	Other	glyphosate	301	72	38	4.95	3.3315E14	MS
		AMPA	301	88	9.74	2.65	3.3315E14	MS
CADPR	Not Specified	Glyphosate	1908	4	200	112.5	03_2 (100)	CA
		AMPA	183	8	4.43	0.54	39 17(103)	CA

In 2002, two USGS studies were conducted to assess glyphosate and AMPA concentrations in surface water as well as wastewater effluent from treatment plants.

A total of 154 water samples were collected by the U.S. Geological Survey during a 2002 study in nine Midwestern States (Illinois, Indiana, Iowa, Kansas, Minnesota, Missouri, Nebraska, Ohio, and Wisconsin) (Scribner *et al*., 2003 and Lee *et al*., 2001), where glyphosate is extensively used on corn. Glyphosate was detected in 36 percent of the samples, while its metabolite aminomethylphosphonic acid (AMPA) was detected in 69 percent of the samples. The highest measured concentration of glyphosate was 8.7 µg/L, well below the Maximum Contaminant Level, MCL, of 700 micrograms per liter. The highest AMPA concentration was 3.6 µg/L. There is no MCL for AMPA.

Treated effluent samples were collected from 10 wastewater treatment plants (WWTPs) in Arizona, Colorado, Georgia, Iowa, Minnesota, Nevada, New Jersey, New York, and South Dakota to study the occurrence of glyphosate and AMPA (Kolpin *et al*., 2006). Stream samples were collected upstream and downstream of the 10 WWTPs. Two reference streams were also sampled. The results document the apparent contribution of WWTP effluent to stream concentrations of glyphosate and AMPA, with roughly a two-fold increase in their frequencies of detection between stream samples collected upstream and those collected downstream of the

WWTPs. Thus, urban use of glyphosate contributes to glyphosate and AMPA concentrations in streams in the United States.

Glyphosate or its degradate AMPA were commonly detected in the stream and WWTP effluent samples, being present in 67.5% of the 40 samples collected. Concentrations were generally low, although nine detections of AMPA (maximum concentration=3.9 µg/L) and three detections of glyphosate (maximum concentration=2.2 µg/L) exceeded 1 µg/L. AMPA was detected much more frequently (67.5%) than glyphosate (17.5%).

Both AMPA and glyphosate had the greatest frequency of detection in the WWTP effluent samples, with roughly a two-fold increase in the frequency of detection for both AMPA and glyphosate between stream samples located upstream and those located downstream of the WWTPs.

It should be noted, however, that AMPA can also be derived from the degradation of phosphonic acids (such as EDTMP and DTPMP) in detergents. Thus, part of the AMPA detections from this study could be potentially derived from a detergent source. Other components of detergents, such as 4-nonylphenol diethoxylate and 4-nonylphenol monoethoxylate were also measured in the samples collected for this study. However, AMPA was always present in samples that had detections of glyphosate, which suggests that at least part of the AMPA concentrations in this study were derived from the degradation of glyphosate.

From 2003 to 2008, Coupe *et al*, 2011 conducted surface water monitoring of glyphosate and AMPA in agricultural surface waters in MS, IA, IN, and France. This monitoring was targeted to watersheds with a high percentage of agricultural crops (68 to ~100% basin in agriculture). The major crops in the watershed were soybeans, corn, cotton, rice, and grapes (France only). For the larger surface water bodies in the United States, samples were taken bimonthly during most of the year with weekly sampling during the growing season from April to August. Additionally, some samples were collected during selected storm events. Monitoring in France and some smaller basins in the U.S. were taken using an automatic sampler. Filtered water samples were analyzed using HPLC/MS. The reporting levels were 0.02 µg/L for samples from the United States and 0.1 µg/L for the French samples. Detection frequencies of glyphosate and AMPA ranged from 59 to 100% and 92 to 100%, respectively. The maximum concentration of glyphosate was 430 µg/L (median 380 µg/L) at an overland flow site in the Sugar Creek, IN monitoring site from May 19-21, 2004. The maximum concentration of AMPA was 29 µg/L (median 26 µg/L) at the overland flow site.

3.5. Terrestrial Exposure

For glyphosate application to crops, forestry, and other non-crop uses (*i.e.,* rights of way), foliar applications in T-REX was modeled. The input parameters for birds and mammals are presented in Table 14. For the preliminary assessment, terrestrial EECs for glyphosate were derived using the maximum application rates. Application rates are based on acid equivalents for glyphosate (a.e.). Based on the application scenario information presented in Section 2.5, several uses are reported as having the same application pattern. As such, calculations of terrestrial exposure for

terrestrial animals were conducted using generic application patterns which reflect use patterns for one or more registered uses.

For ground application, the maximum annual application rate per crop cycle is the same as the maximum combined annual application rate, except for Roundup Ready crops. However, for aerial applications, the maximum annual application rate per crop cycle is typically lower than the maximum combined annual application rate for most uses, except for rangeland, pastures, forestry, herbs and spices, sugar cane, non-crop and aquatic uses. As such, for aerial applications, EECs were calculated based on the maximum annual application rate per crop cycle and the maximum combined annual application rate using 7 days between applications (minimum re-application interval provided by the JGTF), except for Roundup Ready crops where the reported re-application interval is 10 days. This may be a conservative estimate for aerial application, as subsequent glyphosate applications pre/post crop cycle may be greater than 7 days. This approach was also taken for the ground applications to the Roundup Ready crops. Application via ground application have the higher single maximum application rate compared to aerial application and will result in greater terrestrial EECs for birds and mammals using T-REX.

An evaluation into a potential foliar dissipation half-life rate was conducted. Foliar dissipation data were available for glyphosate use on alfalfa (2 crop residue trials; MRID 45646001) in which the foliar dissipation half-lives for the two trials were 4.1 and 7.5 days. Additionally, in the paper by Willis and McDowell (1987), the reported foliar dissipation half-life based on forest foliage, was 14.4 days. Furthermore, in another paper by Feng and Thompson (1989), foliar dissipation on forestry brush foliage on two shrubs was examined and the calculated (by reviewer) foliar dissipation half-life was 4.9 days for each plant. These five values were used to calculate a 90th percentile upper confidence limit foliar dissipation half-life of 12 days. This foliar dissipation half-life rate was used as the input value for T-REX. A representative output for T-REX is presented in Appendix C.

Table 14. Input Parameters for T-REX Modeling for the Scenarios

INPUT PARAMETERS	CROP		SOURCE
Single Application Rate (lb a.e./A)	Rangeland	0.38	Use tables in Section 2.5
	Most crops using *aerial* application (*e.g.*, Roundup ready, trees crops, veg., beans)	1.55	
	Sugar cane using *aerial* application	2.25	
	Most crops using *ground* application (Roundup ready, nut, fruit trees, veg. beans)	3.75	
	Forestry, pastures, non-crop (rights-of-ways)	8	
Foliar Half-life	12 days		Calculated (see above)
Number of Applications: rates (lb a.e./A) (Interval between Applications, days)	Roundup Ready Crops (aerial – max rate/crop cycle)	3: 1.55, 1.55, 0.65 (10)[1]	Use tables
	Rangeland	6: 0.38 (7)	
	Roundup Ready Crops (aerial- max combined annual rate	5: 1.55, 1.55, 0.65, 1.55, 0.7 (10)	
	Most crops (aerial- max rate/crop cycle)	3: 1.55 (7)	
	Most crops (aerial- max combined annual rate)	4: 3 @ 1.55, 1.35 (7)	
	Tree crops (aerial- max combined annual rate)	6: 5 @ 1.55, 0.25 (7)	
	Sugarcane (aerial- max rate/crop cycle and max combined annual rate)	3: 2.25, 2.25, 1.5 (7)	
	Roundup Ready Crops (ground – max rate/crop cycle)	1: 3.75 (NA)	
	Roundup Ready Crops (ground- max combined annual rate	2: 3.75, 2.25 (10)	
	Most crops (ground- max rate/crop cycle and max combined annual rate)	2: 3.75, 2.25 (7)	
	Food tree, vine, berry & small fruit crops (ground- max combined annual rate)	3: 2 @ 3.75, 0.5 (7)	
	Forestry, pastures, non-crop (rights-of-ways)	1: 8 (NA)	

[1] For interpreting this column, for calculating EECs, for example, for Roundup Ready Crops (aerial-max rate/crop cycle), there are 3 applications, with the first and second applications at 1.55 lb a.e./A and the third application at 0.65 lb a.e./A (for a total combined maximum rate per crop cycle of 3.75 lb a.e./A) with 10 days between applications. These rates are based on the single maximum application rate and the maximum annual and/or crop cycle rate.

4. Dose-Response Assessment

4.1. Overview

Both terrestrial and aquatic non-target organisms are ecological receptors that may be at risk from potential exposure to glyphosate. Aquatic ecosystems that may be exposed include ponds, streams, and other water bodies receiving runoff and drift from direct applications to growing crops or aquatic systems. Terrestrial ecosystems include those that receive direct applications to growing crops or drift from those areas.

This risk assessment relies on a surrogate species approach. Toxicological data generated from surrogate test species, which are intended to be representative of broad taxonomic groups, are used to extrapolate to potential effects on a variety of species (receptors) included under these taxonomic groupings.

Acute and chronic toxicity data from studies submitted by pesticide registrants along with the available open literature were used to evaluate the potential direct and indirect effects of glyphosate on aquatic and terrestrial receptors. Toxicity studies for the technical grade active ingredient (TGAI), the typical end-use product (TEP), and the AMPA degradate are all considered in the ecological risk assessment. Open literature studies were identified using EPA's ECOTOX database[2], which employs a literature search engine for locating chemical toxicity data for aquatic life, terrestrial plants, and wildlife. Research papers accepted into the ECOTOX database were screened using standard procedures to ensure consistent, high quality information; these studies were considered during the 'Analysis' phase of risk assessment process. The Incident Data System (IDS), which tracks incident reports submitted to EPA, was used to identify supportive, line of evidence information on exposure of aquatic and terrestrial receptors. Data from all of these sources can also provide insight into the direct and indirect effects of glyphosate on biotic communities from loss of species that are sensitive to the chemical and from changes in structure and functional characteristics of the affected communities.

This section briefly summarizes the available toxicity data for glyphosate and its salts as well surfactant data. A list of available data for glyphosate and its salts and AMPA and degradate studies are provided in Appendix D. Toxicity data were obtained from registrant-submitted studies and the scientific literature. In addition, the EIIS, AIMS and aggregate incident databases were searched for reports. Open scientific literature studies were searched using the ECOTOXicology database (ECOTOX). ECOTOX searches for glyphosate were obtained in August 2013 as well as in October 2008 and prior. The studies discussed in the following paragraph represent studies from post October 2008 to August 2013. Open literature studies prior to those dates are listed in Appendix D and with many discussed in the 2008 risk assessment for the California red-legged frog (USEPA 2008).

For aquatic uses, an attempt was made to select endpoints from studies on formulations that do and do not contain the POEA surfactant to reflect exposure from spray drift (formulations can contain POEA) and from direct application (formulations do not contain POEA).

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[2] http://www.epa.gov/ecotox

4.2 Assessment Endpoints

Generally, assessment endpoints include survival, growth, and reproductive success of the surrogate ecological receptors. Toxicity values used to assess survival from short-term (acute) exposures are glyphosate levels associated with statistically estimated 50% survival rates. Toxicity values used to assess potential reproductive effects are the highest levels tested that did not induce reproductive or growth effects (No Observable Adverse Effect Concentration: NOAEC; Lowest Observable Adverse Effect Concentration: LOAEC).

The following paragraphs summarize the assessment endpoints used to assess risk to the organisms within the ecosystems, and the surrogate species and toxicity values used to assess risk. Data were obtained from registrant submitted studies or from literature studies identified by ECOTOX. The ECOTOXicology database (ECOTOX) was searched in order to provide more ecological effects data and in an attempt to bridge existing information gaps. ECOTOX is a source for locating single chemical toxicity data for aquatic life, terrestrial plants, and wildlife. ECOTOX was created and is maintained by the USEPA, Office of Research and Development, and the National Health and Environmental Effects Research Laboratory's Mid-Continent Ecology Division. ECOTOX search results were obtained in October 2008 and August 2013. For additional details on studies used in this assessment, refer to Appendix E. For the results of the ECOTOX search, refer to Appendix E.

The following sections present toxicity data for aquatic and terrestrial organisms for glyphosate, glyphosate end use products, surfactants, and the major degradate AMPA.

4.2.1. Aquatic Organisms

4.2.1.1. Fish and Aquatic-phase Amphibians

Several fish acute toxicity studies are available for glyphosate acid and its salts. These acute LC_{50} values for freshwater and estuarine/marine fish are classified as slightly toxic to practically non-toxic with values of ≥ 10 mg a.e./L. Additionally, there are acute toxicity studies for many glyphosate formulations (containing POEA or not). Given the potential differential toxicity of the components in the formulations, the range of acute LC_{50} values varies across studies and species with values of 1 mg a.e./L up to >450 mg a.e./L. Acute toxicity testing with particular surfactants contained in some of the glyphosate formulations has also been conducted for freshwater fish. The toxicity between the surfactants varies with acute LC_{50} values from 0.65 mg/L up to >100 mg/L. Finally, acute toxicity testing with the major degradate, AMPA, resulted in an acute LC_{50} value of 499 mg/L using freshwater fish, rainbow trout (MRID 43334713).

In a chronic fish life cycle study conducted with technical glyphosate and fathead minnows, there were no reported effects up to the highest concentration tested, 25.7 mg a.e./L (MRID 00108171). In a study by Le Mer *et al.*, 2013, the effects of technical glyphosate exposure on estuarine/marine threespine stickleback larvae (*Gasterosteus aculeatus*) was examined in two consecutive years. In this study, there was <11% mortality in the fish exposed to glyphosate over the 42-day exposure period, and there were no significant differences in wet weight, body length, sex ratio, or condition of juvenile fish between glyphosate-exposed fish and control in either test

year at concentrations up to 0.100 mg/L. Given that the Le Mer study only tested up to 0.1 mg/L with no effects, an acute to chronic ratio using acute and chronic fathead minnow and acute sheepshead minnow data were used to derive a chronic NOAEC value for estuarine/marine fish. As there were no reported effects in the chronic fathead minnow study, the NOAEC reported was the highest concentration tested. There is uncertainty in using the non-definitive NOAEC value in the ACR calculation and is discussed in the Assumptions and Limitations section.

Acute and chronic studies have been conducted with glyphosate, both technical and formulations on various aquatic-phase amphibian species. These studies indicate that amphibians have similar toxicity values for glyphosate compared to fish. Acute toxicity tests with glyphosate and its salts indicate that the acute LC_{50} values range of $\geq$75 mg a.e./L. For technical glyphosate, the acute toxicity LC_{50} value of 103 mg a.e./L, *Litoria moorei* tadpoles, was used in the risk quotient calculation (MRID 43839601; Bidwell and Gorrie, 1995). While there was a more sensitive acute endpoint of 75 mg a.e./L (adjusted for 96% purity) reported for adult *Crinia insignifera* frogs in this study, there was 20% control mortality at the end of 96 hours, which is greater than the performance criteria of no more than 10% control mortality in the draft OCSPP 850.1075 fish acute toxicity test guideline. Additional acute toxicity testing with these species was reported in Mann and Bidwell, 1999, in which the most sensitive 48-hr LC_{50} value for technical glyphosate was 81.2 mg a.e./L for *L. moorei* tadpoles. However, since raw data were provided in MRID 43839601, the toxicity value of 103 mg a.e./L was used in the risk estimation but this additional study was also considered in the risk characterization.

Additionally, acute aquatic-phase amphibian toxicity data for formulations are similar to fish with acute LC_{50} values ranging from 1 mg a.e./L up to >450 mg a.e./L. Data are also available on the surfactant, POEA. Submitted study (MRID 46650501) tested the green frog (*Rana clamitans*, Gosner stage 25) with technical glyphosate (isopropylamine salt (IPA)), an IPA formulation with 15% POEA, and POEA. The acute LC_{50}'s were >17.9, 2.0 and 2.2 mg/L, respectively, with technical IPA and the IPA formulation expressed in terms of glyphosate acid equivalents. This study indicates that aquatic amphibians are also susceptible to POEA toxicity.

Open literature studies on fish and aquatic-phase amphibians provide additional information for the risk characterization. These studies are summarized in Table 15.

Wan *et al.*, 1989 (ECOTOX 924), examined acute toxicity to four species of juvenile Pacific salmonids and rainbow trout to technical glyphosate, glyphosate formulations (Roundup, MON 8709), and MON 0818 using various dilution water sources (*i.e.*, varying water hardness levels). For technical glyphosate, the lowest 96-hr LC_{50} value was 10 mg a.i./L for chum (species name not given, assumed to be *Oncorhynchus keta*) tested in city (soft) water (range 10 – 211 mg/L). Acute 96-hr LC_{50} values for the two formulations ranged from 11 and 67 mg formulation/L, and the toxicity values for MON 0818 ranged from 1.4 – 4.6 mg MON 0818/L. While this study likely used controls based on referenced protocols, no discussion of control mortality across the studies was reported.

In the acute toxicity to larval amphibian species collected as embryos in the Pacific Northwest (King and Wagner 2010), 24 hour to 15 day toxicity values, using a formulation, ranged from 0.32 to 2.6 mg a.i./L (0.23 – 1.9 mg a.e./L – reviewer calculated). In this study, while control

treatments were used in the study, control performance was not reported; therefore, there is uncertainty in the performance of the control animals.

Ninety day body weight gain and body length in fish, *Leporinius obtusidens*, were significantly decreased (approximately 10-15% decrease in body length and 44-65% decrease in body weight gain) at glyphosate formulation concentrations of ≥1 mg/L (reviewer unsure if reported concentrations reflect concentration of formulation or adjusted to glyphosate) which was the lowest concentration tested (Salbego *et al.* 2010; E161803). Food consumption and condition factor (weight/length) were not affected by glyphosate exposure. Also in this study, the degradate AMPA was measured and the reported concentrations of AMPA were equivalent to the glyphosate concentrations (unsure if based on formulation or glyphosate). Therefore, there is uncertainty in the exposure concentrations for this study.

Effects to wild caught aquatic-phase amphibians (previous exposure history unknown) were reported in Williams and Semlitsch, 2010, using glyphosate formulations in that delays in time to metamorphosis were reported at concentrations of 0.572 mg a.e./L (based on nominal concentrations; concentrations did not appear to be measured). Eighty percent mortality was also observed in the western chorus frog larvae after exposure to Roundup Weathermax at 0.572 mg a.e./L.

Table 15. Open Literature Glyphosate Toxicity Studies on Fish and Aquatic-phase Amphibians

Species	Chemical Form	Endpoint(s)	ECOTOX Ref. No.
4 species juvenile Pacific salmonids (coho, chum, chinook, and pink) and rainbow trout	Glyphosate (tech); Roundup (41% GLY-IPA); MON 8709 (41% GLY-IPA); MON 0818 (75% POEA)	96-hr LC50 range: GLY: 10-211 mg ai/L; Roundup: 11-33 mg form/L; MON 8709: 17-67 mg form/L; MON 0818: 1.4-4.6 mg ai/L	E924/ Wan *et al.* 1989
Piava (*Leporinus obtusidens*)	Roundup (48% glyphosate acid)	90-d LOAEC = 1 mg/L NOAEC < 1 mg/L Based on reduced body length & weight gain	E161803 / Salbego *et al.* 2010
6 amphibian species endemic to the Pacific Northwest (2 salamanders, 1 toad, 3 frogs)	Roundup Regular (50.2% GLY-IPA)	24-h LC_{50} = 0.43 – 2.6 mg ai/L 7-d LC_{50} = 0.32 – 2.08 15-d LC_{50} = 0.30-1.95	E161728 / King and Wagner 2010
Western chorus frog (*Pseudoacris triseriata*)	Roundup WeatherMax (48.8% glyphosate potassium salt)	Chronic exposure LOAEC = 0.572 mg a.e./L NOAEC = 0.0005 mg a.e./L based on decreased survival	E153825 / Williams and Semlitsch 2010; only two concentrations tested (1000X difference in conc)
American Toad (*Bufo americanus*)	Roundup WeatherMax (48.8% glyphosate potassium salt) & Roundup Original (48.7% glyphosate potassium salt)	LOAEC = 0.572 mg a.e./L NOAEC = 0.0005 mg a.e./L based on delayed time to metamorphosis for both formulations	

4.2.1.2. Aquatic Invertebrates

The acute toxicity endpoint for freshwater aquatic invertebrates in the Risk Estimation section is from the study on early fourth instar midge larvae with and EC_{50} value of 53.2 mg a.e./L (MRID 00162296). As with freshwater fish, many studies are available on formulations. One study (MRID 00162296) tested glyphosate technical, a glyphosate IPA formulation and the surfactant, POEA on the midge. The EC_{50}'s were: 53.2 mg a.e./L, 13.3 mg a.e./L and 13 mg/L. As with freshwater fish and amphibians, this study indicates that the increased toxicity of the formulations with the surfactant, POEA are probably due to the surfactant.

An acute toxicity test with *Daphnia magna* and the degradate, AMPA, reported an acute EC_{50} value of 683 mg/L. In a chronic toxicity test with *Daphnia magna* and technical glyphosate IPA salt, the reported NOAEC/LOAEC is 49.9 and 95.7 mg a.e./L, respectively. However, as the acute toxicity test with the midge was the most sensitive, the acute to chronic ratio approach was used using acute and chronic *Daphnia magna* data and acute midge toxicity data. As there were two reliable acute toxicity values for Daphnia, the geometric mean of the two values were used to derive a single acute toxicity value (based on EFED guidance on acute to chronic ratios). The calculated chronic NOAEC for freshwater invertebrates was 9.22 mg a.e./L.

For estuarine/marine invertebrates, acute toxicity testing with technical glyphosate and the Pacific oyster embryos (*Crassostrea gigas*) reported an acute toxicity EC_{50} value of 40 mg a.e./L. Acute toxicity testing with several estuarine/marine invertebrates and glyphosate formulations assumed to contain POEA reported acute LC/EC_{50} values of ≥ 0.765 mg a.e./L, with the most sensitive value for the mysid shrimp (MRID 4893402). Testing of formulations assumed not to contain POEA reported an acute EC_{50} value of 23.2 mg a.e./L using the Pacific oyster (MRID 45374006). Chronic toxicity data for estuarine/marine invertebrates for use in the risk estimation are not available. Therefore, a chronic toxicity value was calculated using the acute to chronic ratio approach using acute and chronic *Daphnia magna* data and acute amphipod data. Acute toxicity data using estuarine/marine mollusks was not used as these endpoint incorporated normal larvae development as oppose to strictly mortality. The calculated chronic NOAEC for estuarine/marine invertebrates was 6.11 mg a.e./L.

Open literature studies on aquatic invertebrates provide additional qualitative information for the risk characterization for glyphosate. These studies are summarized in Table 16.

For the estuarine/marine copopod, *Acartia tonsa*, 48 hr acute LC_{50} toxicity values of 35.5 and 1.77 mg a.e./L were reported for glyphosate acid and Roundup, respectively (Tsui and Chu, 2003); it is noted that analytical recovery was reported as approximately 53% in the saltwater media and test concentrations corrected for percent recovery. Additionally, Tsui and Chu, 2003, examined the effects of environmental conditions on *Ceriodaphnia dubia* in which increases in suspended particles and pH appeared to increase acute toxicity (immobility), whereas increases in temperature and feeding rates did not substantially alter toxicity.

A 48-hr toxicity test by Bringolf *et al*., 2007, with GLY-IPA using early life-stages of the freshwater mussel, *Lampsilis siliquiodea,* reported a 48-hr EC_{50} value of 5.0 mg a.e./L (based on shell closure and initial measured concentrations). In this study, the acute EC_{50} value for

glyphosate with no counter ion and the formulation Aqua Star (for which glyphosate IPA is the active ingredient) were greater than 200 and 148 mg a.e./L, respectively, but the EC_{50} value for IPA (4.6 mg a.e./L) was close to value reported for GLY-IPA. The study authors hypothesized that the observed toxicity was due to the release of ammonia from the amine group in IPA, whereby, other components in Aqua Star may have altered the release of ammonia.

In a study by Mottier *et al.*, 2013, the 48-hr EC_{50} value, based on abnormality rates, for Pacific oyster larvae was reported as 28.3 mg a.e./L (based on nominal) with EC_{50} values of >100 mg a.e./L for mortality and metamorphosis rates (ECOTOX # 161544). Furthermore, for different clones of juvenile *Daphnia magna*, 48-hr EC_{50} values for technical glyphosate (GLY-IPA) ranged from 1.4 to 7.2 mg a.i./L (1.0 – 5.3 mg a.e./L (reviewer calculated)) (Cuhra *et al.*, 2013; ECOTOX # 161204). In this study with the *Daphnia magna*, the same daphnid clones were also exposed to a glyphosate formulation (Roundup Weed and Grass Killer Concentrate Plus® which was reported to also contain 0.73% diquat-dibromide) which was assumed to contain the surfactant POEA. The acute toxicity values in this study using the technical glyphosate were slightly lower than with the formulation which is generally not observed in other studies whereas the POEA containing formulations are more toxic. Therefore, there is uncertainty in these values for the technical glyphosate.

In addition to the acute toxicity testing described above, Cuhra *et al.,* 2013, report a 55-d chronic toxicity test with *Daphnia magna* with technical glyphosate, and the reported NOAEC was 0.45 mg a.i./L (0.33 mg a.e./L- reviewer calculated), based on reduction in fecundity. In this study, the size of the second offspring clutch were significantly smaller than the control at all concentrations tested for technical glyphosate, NOAEC<0.05 mg ae/L; however, offspring size in the first clutch were not significantly smaller. Additionally, significantly reduced fecundity was reported at 0.45 mg a.e./L with a NOAEC of 0.15 mg ae/L when testing the formulation. Additionally, in the chronic test, while not for all endpoints, the reported effects between the technical material and the formulation were similar, based on mg ai/L. Given the variability in the offspring growth, the NOAEC for fecundity was used in this assessment.

There were also studies examining effects to freshwater snails from exposure to glyphosate formulations. Effects on weight gain were examined in Coler *et al.*, 2005, with effects at 0.12 mg/L in one study and at 1.2 mg/L in another study (unsure if units were adjusted for glyphosate). It was noted that there was variability in the weight gain in the controls between the two studies (2X), and there is some uncertainty regarding the test design in the first study. In the other study using freshwater snails, effects on mortality, reproduction, and biochemical endpoints at 0.85 mg/L (unsure if units adjusted for glyphosate). However, environmental conditions in the study were not reported and unsure if there were significant effects on mortality in the study examining biochemical markers.

Acute water column toxicity data to both *Ceriodaphnia dubia* and a sediment-dwelling amphipod, *Hyalella azteca*, exposed to three different glyphosate formulation were available (Tsui and Chu 2004). Based on the available data, two of the formulations do not appear to contain POEA, however, the third formulation, Roundup, was reported to contain POEA. The 48-hr LC_{50} values for *H. Azteca* ranged from 1.5 to 225 mg a.e./L (based on study report, study

deemed valid if control mortality <20%, generally control mortality ≤105 for acute studies is preferred). Toxicity values for *C. dubia* ranged from 5.7-415 mg a.e./L.

A water column exposure bioconcentration study with sediment-dwelling *Lumbriculus variegatus* was available (Contardo-Jara *et al.*, 2009). The study was conducted over a range of concentrations for both technical glyphosate and Roundup Ultra, 0.05-5 mg ae/L, and reported 96-hr BCF values ranged from 1.2 – 2.8 for technical glyphosate and 1.4-5.9 for the formulation. While not reported explicitly in the report, based on the reported data, there did not appear to be any effects on survival at these test concentrations.

In an acute study with oyster embryo-larvae (species not identified) testing glyphosate only, increases in the percent of abnormal D-larvae were observed at 2.5 and 5 µg/L in only in 1 of 3 trials; however, in this trial there was also a greater percentage of abnormalities in control larvae (30%), therefore, there are uncertainties in these results (Akcha *et al*. 2012). No significant embryo-larval developmental effects were observed for Roundup Express at concentrations up to 5 µg glyphosate/L.

Table 16. Open Literature Glyphosate Toxicity Studies on Aquatic Invertebrates

Species	Chemical Form	Endpoint(s)	ECOTOX Ref. No.
Freshwater mussel (*Lampsilis siliquiodea)*	Glyphosate acid; Glyphosate IPA; IPA; Aqua Star; Roundup	48-hr EC_{50} (mg a.e./L (95% CI) GLY: >200; GLY-IPA: 5.0 (3.3-7.6); IPA: 4.6 (1.9-11.1); Aqua Star: >148 Roundup: 2.9 (2.1-3.9)	E100687 / Bringolf *et al.* 2007
Copepod (*Acartia tonsa*)	Glyphosate acid; Glyphosate IPA; Roundup	48-hr LC_{50} (mg ae/L) (95% CI) GLY acid: 35.3 (30.9-40.3); GLY-IPA: 49.3 (38.4-63.1); Roundup: 1.77 (1.33-2.34)	Tsui and Chu 2003
Pacific oyster (*Crassostrea gigas*)	Glyphosate acid (97%); Roundup Express (7.2 g ae/L); AMPA (97.5%)	48 hr EC_{50} mollusk abnormality rates, mortality rates, metamorphosis rate (GLY, AMPA, and GLY-express formulation) All values based on nominal GLY = 28.3 mg ae/L (abnorm), >100 mg ae/L (mort, meta) AMPA = 40.6 mg ae/L (abnorm), >100 mg ae/L (mort, meta) GLY-express = 1.13 (abnorm), 8.5 (mort;) 6.37 (meta) mg a.e./L	E161544 / Mottier *et al*. 2013
Freshwater snail (*Pomaeca lineatua*)	Roundup (480 g/L glyphosate monoisopropylamine gly-IPA)	Weight gain – two studies ; 1st = 8 day LOEC/NOEC 0.12/<0.12 mg formulation/L ; 2nd = 16 day LOEC/NOEC = 2.4/1.2 mg formulation/L (6 reps w/15/rep)	E107038 / Coler et al 2005
Freshwater snail (*Biomphalaria alexandrina*)	Roundup (120 g ae/L)	3 different studies: 1 – 24-hr LC_{50} = 3.15 mg formulation/L;	E161199 / Barky *et al* 2012

		2 – At 0.85 mg formulation/L, after 5 weeks 100% mortality, effects on # eggs, hatchability, and Increased abnormal eggs, no eggs after 4 weeks; 3 – after 4 weeks changes in glycogen, AchE, ALP, GOT and others at 0.85 mg formulation/L	
Daphnia magna	Glyphosate monoisopropylamine (GYL-IPA) (40%); Roundup Weed & Grass Killer concentrate Plus (18% ae; 0.73% diquat-dibromide)	48-h EC_{50} 1.4 – 7.2 mg ai/L (tech); 3.7-10.6 mg ai/L (form) Chronic: technical GYL fecundity NOAEC = 0.45 mg ai/L; Formulation fecundity NOAEC = 0.15 mg a.i./L (<0.05 mg ai/L (F1 growth) (form)	E161204 / Cuhra *et al.* 2013
Sediment-dwelling amphipod (*Hyalella azteca*)	Rodeo (GLY-IPA; % ae NR); Roundup (% ae NR); Roundup Biactive (% ae NR)	Water column 48-hr LC_{50} (mg a.e./L) (95% CI): Rodeo: 225 (151-336); Roundup Biactive: 120 (80.6-180) Roundup: 1.5 (1.0-2.3)	E74234/Tsui and Chu 2004
Ceriodaphnia dubia	Rodeo (GLY-IPA; % ae NR); Roundup (% ae NR); Roundup Biactive (% ae NR)	Water column 48-hr LC_{50} (mg a.e./L) (95% CI): Rodeo: 415 (339-508); Roundup Biactive: 81.5 (67.1-99.2) Roundup: 5.7 (could not be calculated)	E74234/ Tsui and Chu 2004
Sediment-dwelling blackworm (*Lumbriculus variegatus*)	Glyphosate acid (98%); Roundup Ultra (GLY-IPA, 360 g/L)	96-hr Water column BCF: worms exposed to 0.05 – 5 mg ae/L for both technical and formulation; Tech BCFs: 1.2 – 2.8 Roundup BCFs: 1.4-5.9	E115572 Contardo-Jara *et al.* 2009

4.2.1.3. Aquatic Plants

For aquatic vascular plants, the endpoint of 14-d EC_{50} of 11.9 mg a.e./L was selected for technical glyphosate for use in Risk Estimation is from a duckweed study (MRID 44320638). This study is classified as supplemental as it did not report phytotoxicity data but is adequate for quantitative use in the risk assessment. For aquatic non-vascular plants, the endpoint of 4-d EC_{50} of 11.4 mg a.e./L is selected from a toxicity study on green algae (MRID 40236904). Again, as with other aquatic species, some of the formulations appear to be more toxic than the technical material, with a 14-d EC_{50} for vascular plants for a formulation assumed to contain POEA and one assumed to not contain POEA of 1.5 and 7.7 mg a.e./L, respectively. For non-vascular plant, the lowest reported 96-hr IC_{50} was 0.12 mg a.e./L, for which it is uncertain as to whether or not it contains POEA.

Toxicity studies for three species of emergent aquatic plants were available which evaluated survival and growth. Studies were conducted either in a greenhouse or outdoors using a glyphosate formulation (MON 78087; 31.2% glyphosate acid equivalent) in which plants were

over-sprayed. In the freshwater sedge (*Carex comosa*) study, the most sensitive endpoint was fresh weight with an EC_{25} value of 0.26 kg a.e./ha (0.23 lb a.e./A) (PMRA DER 49440). For the pickerel weed (*Pontederia cordata*), the most sensitive endpoint was also fresh weight with an EC_{25} value of 0.53 kg a.e./ha (0.47 lb a.e./A) (PMRA DER 49445). The third species, *Nymphea odorata*, fresh weight was again the most sensitive endpoint (EC_{25} 0.044 kg a.e./ha (0.039 lb a.e./A)) (PMRA 494460). In these studies, variability was observed in both measured test concentrations (in some cases, due to malfunctioning spray equipment) and in plant size and shoot number between replicates (possibly due to using non-domesticated plant species and/or variable exposure). Open literature studies on aquatic plants provide additional qualitative information for the risk characterization for glyphosate. These studies are summarized in Table 17.

For the aquatic vascular plant, *Lemna minor*, growth rate was calculated using an applied coefficient, based on maturation stage, therefore, there is uncertainty in the actual growth rate (absent of a subjective coefficient) in this study (Dosnon-Olette *et al*. 2011). Additionally, in this study, for other photosynthetic parameters (changes in chlorophyll and photochemical quenching), it appears that the study was able to detect about a 1 - 4% difference. These parameters are sensitive and changes in these parameters are not unanticipated. For the aquatic rooted vascular plant, *Myriophyllum aquaticum*, the most sensitive endpoint reported was a 14-day EC_{50} value of 0.222 mg/L (unsure if adjusted for glyphosate), based on the area under the growth curve (Turgut *et al*. 2002), when testing a glyphosate formulation (exact formulation not reported; 35.6% EC formulation). For other endpoints measured in study, the EC_{50} values are approximately 2 mg/L, which is similar to lowest toxicity endpoint from submitted data (duckweed).

For aquatic non-vascular plants, 21-d EC_{50} values for technical glyphosate acid and glyphosate IPA were 249 - >169,000 mg ae/L and 7.1 – 233 mg a.i./L (5.3 – 172 mg a.e./L (reviewer calculated), respectively (Lipok *et al*. 2010).

Table 17. Open Literature Glyphosate Toxicity Studies on Aquatic Plants

Species	Chemical Form	Endpoint(s)	ECOTOX Ref. No.
8 non-vascular species	Roundup 360 SL (% ai NR); Glyphosate acid (% ae NR); Glyphosate isopropylamine (40%)	21-d EC_{50} (growth rate) Roundup = 2.9-118 mg formulation/L Glyphosate acid = 246 - >169,000 mg ae/L GLY-IPA = 7.1-233 mg ai/L	E161695 / Lipok *et al.* 2010
Lemna minor	Sting Pro 2 (400 g a.i/L; glyphosate acid)	96-hr Growth rate inhibition compared to control significant ≥ 20 uL ae/L, inhibition did not exceed 25%; photosynthetic parameters inhibited at ≥20 uL ae/L, inhibition did not exceed 10%, no NOAEC	E156171 / Dosnon-Olette *et al.* 2011
Rooted vascular plant *Myriophyllum aquaticum*	Glyphosate (35.6% emulsifiable concentrate)	14-d EC_{50} Most sensitive endpoint = 0.221 mg/L (area under growth curve); fresh wt, shoot length and root length EC_{50} all about 2 mg/L	E150059 / Turgut *et al.* 2002

4.2.1.4. Freshwater Field/Mesocosm Studies

Several studies under field or mesocosm conditions have been conducted using glyphosate formulations (many reported previously in USEPA 2008).

A study was conducted to examine the effects of glyphosate on the biomass of predators, tadpoles/small herbivores, zooplankton and periphyton, the survival of predators, the abundance of zooplankton, and survival of tadpole species in mesocosm study units (1200L tanks (Relyea, 2005a; ECOTOX ref. 89112)). A simulated application rate of 6.4 mL/m^2 with a 25.2% formulation was used, providing a nominal concentration of 3.8 mg a.i.L. Species used in the mesocosms were reported to be naturally co-occurring and at loading rates similar to what are found in the field. The study was conducted for 13 days under static conditions following a single spray application. Under the conditions tested, species richness was reduced by 22% with Roundup®. Roundup® completely eliminated two species of tadpoles (leopard frogs and gray tree frogs) and nearly eliminated wood frogs (98% mortality), resulting in a 70% decline in the species richness of tadpoles. It is not clear from the methods section which specific formulation of the pesticide was used; however, the study authors state that the formulation of glyphosate (Roundup) contains polyethoxylated tallowamine (POEA). Although Roundup appeared to be associated with a high mortality rate in amphibian larvae, amphibian mortality in controls ranged from approximately 30 to 80%. The relatively high mortality rate with control tadpole species was likely due to predation from spotted salamanders and predacious beetles; however, it is difficult to interpret glyphosate-related mortality given the extent of mortality in controls for some tadpole species. It is noteworthy that while increased mortality of amphibian larvae appeared to be associated with glyphosate treatment, red-spotted salamanders were not affected.

A study was conducted with glyphosate to determine whether or not glyphosate plus the surfactant, polyethoxylated tallow amine (POEA) affects survival of anurans, either in aquatic environments (mesocosms) and/or terrestrial environments (semi-dry tanks; Relyea, 2005b ECOTOX Ref. 86885). The pesticide was applied by a direct overspray. In an aquatic larvae study, a factorial combination of glyphosate present or absent with three different soil treatments (no soil, sand, and loam) was tested. The concentration of glyphosate was reportedly based on the label recommended application rate (*i.e.*, a nominal concentration of 3.8 mg a.i./L (simulated application rate of 1.6 mL a.i./m^2)). Roundup® Weed and Grass Killer was tested (25.2% active ingredient plus POEA surfactant). For the terrestrial juvenile study, glyphosate with POEA surfactant was tested in comparison to a control. The nominal amount tested was 6.5 mL at a rate of 1.6 mg a.i./m^2. There were three replicates, each time with a different amphibian species.

The results of the study suggested that exposure to nominal concentrations of Roundup® Weed and Grass Killer at a rate equivalent to 1.6 mg a.i./m^2 (3.8 mg a.i./L) for 20 days, decreased survival of leopard frogs, American toads and gray tree frogs [aquatic phase] larvae by over 73%. American toad larvae were the most sensitive with only 20% survival followed by gray tree frog (50% survival) and leopard frog (75%) survival compared to controls with >80% survival). It is not clear whether the toxicity can be attributed to glyphosate alone, the surfactant polyethoxylated tallowamine (POEA) alone, or to the combination of glyphosate and POEA. Although the study suggests that presence of soil did not decrease the toxicity of Roundup®, it is also not clear whether the amount of soil added to each of the study units was adequate to test this hypothesis. Exposure of juvenile [terrestrial phase] wood frogs, tree frogs and American

toads to Roundup at a rate of 1.6 mg a.i./m^2 resulted in over 64% decrease in survival across species after 24 hours. It is not clear how the terrestrial exposure of Roundup$^®$ to terrestrial-phase juvenile frogs relates to conditions that may exist in the field. The moist paper towel would likely prolong exposure beyond what may typically be encountered in the field.

A mesocosm study was conducted with a glyphosate formulation (13% a.i.) applied to 1,200L outdoor cattle troughs containing three aquatic-phase amphibian species (leopard frog, gray tree frog and the American toad) with and without predators (red-spotted newt or *Dytiscus* beetles). Exposure was static for 23 days (Relyea *et. al*, 2005 ECOTOX Ref. 86886). Although there was uncertainty associated with the application rates and the specific formulation used, study units were apparently treated at a nominal concentration of 1.3 mg glyphosate/L. Glyphosate treatment reduced overall tadpole survival and biomass. American toad larvae were the most sensitive with only 20% survival followed by gray tree frog (50% survival) and leopard frog (75%) survival compared to controls with >80% survival). Glyphosate had no effect on the survival of red-spotted newts. The study design is not sufficient to determine whether the decreased survival/biomass associated with exposure to Roundup is due to glyphosate or to some other component of the formulated product. While the study authors speculate on the potential role of the surfactant, polyethoxylated tallowamine (POEA), in causing the observed effects on anuran larvae, the study does not test this potential relationship.

Chemical and biological monitoring studies were conducted in 51 different wetlands to quantify the magnitude of contamination by glyphosate formulation Vision$^®$ (Thompson *et. al*, 2004;ECOTOX Ref. 72797). Wetlands were classified as over-sprayed, adjacent, or buffered in relation to the operational target spray blocks. Aqueous concentrations of glyphosate in buffered wetlands were below the level of detection (<0.02 mg a.i./L) in 14 of the 16 buffered wetlands. Mean glyphosate concentrations in the buffered wetlands (0.03 mg a.i./L) were significantly (p<0.05) less than that of either adjacent (0.18 mg a.i./L) or over-sprayed wetlands (0.33 mg a.i./L). Biomonitoring of caged amphibian larvae showed no significant effect on mean 48-hr mortality of either green leopard frogs (*Rana pipiens*) or green frogs (*R. clamitans*) exposed *in situ*. Percent mortality was not significantly correlated with exposure concentrations. The authors conclude that there were no statistically significant differences in mortality between treatment sites; however, leopard frog and green frog larvae had 14.2% and 35.6% mortality in over-sprayed areas. Buffered areas with the lowest mean concentrations (0.03 mg a.i./L) of glyphosate had larval mortality for leopard frog larvae (15%) and green frog larvae (25.7%) roughly similar to over-sprayed areas. The authors conclude that glyphosate exposures typically occurring in forest wetlands are insufficient to induce significant acute mortality in native amphibian larvae. No raw data were included in the study; however, the results suggest that there was a large amount of variability that could have obscured detecting treatment effects especially given that these were naturally occurring wetlands that represented a range of environmental conditions. Additionally, since concentrations of the surfactant (MON 0818) were not measured, it is uncertain as to the extent that this co-formulant was present in any of the aquatic habitats studied.

Two tadpole species (*Rana sylvatica* and *Bufo americanus*) were exposed to Roundup Original MAX in outdoor mesocosms up to concentrations of 3 mg a.e./L under three different exposure scenarios in which glyphosate was applied as a single larger applications or in multiple smaller

application throughout study duration (Jones *et al.* 2010). In this study, the single applications at early or mid-test duration had lower survival (18-d LC_{50} values ranged from 2.10-2.44 mg a.e./L) than the smaller, multiple applications (survival >80% at 3 applications of 0.33 or 1.0 mg a.e./L); the late single application LC_{50} values also were greater than 3 mg a.e./L. Stratification of test chemical was observed in this study with higher concentrations measured closer to water surface. In Jones *et al*. 2011 (ECOTOX# 156497), three different tadpole species in outdoor mesocosms were exposed to glyphosate (Roundup Original MAX) up to 3 mg a.e./L at three different tadpole densities. The 23-d LC_{50} values were similar (ranged from 1.71-2.58 mg a.e./L) across densities for the gray tree frog (*Hyla versicolor*) and green frog (*Rana clamitans*) (84% confidence intervals (CI) overlapped), and were marginally lower at the high density treatment for the bullfrog (*R. catesbeiana*) (medium and high density 84% confidence intervals both reported 1.70 mg a.e./L as lower or upper value, respectively, and at low density the lower CI value was 1.77 mg a.e./L). Additionally, Relyea 2005c (ECOTOX# 80961), tested six species of amphibians using Roundup (25% glyphosate IPA) either in the presence or absence of a predator cue (*i.e.*, red-spotted newts), and the reported 16-d LC_{50} values ranged from 1.32 to 2.52 mg a.i./L, with the exception of 0.55 mg a.i./L for the wood frog in the presence of the caged predator. No interactions of Roundup-by-predator were observed for the other five species.

4.2.1.5. Summary of Aquatic Endpoints

Table 18 summarizes the aquatic toxicity endpoints of technical glyphosate and/or its salts that were used quantitatively in the risk assessment. Uncertainties for glyphosate include chronic marine/estuarine fish and invertebrate toxicity. A chronic toxicity value (NOAEC) was estimated for both marine/estuarine fish and invertebrates using an acute to chronic ratio. For fish, the estimate was calculated from the acute and chronic freshwater fish data and the acute marine/estuarine fish data. For invertebrates, the estimate was calculated from the acute and chronic freshwater invertebrate data and the acute marine/estuarine invertebrate data.

Table 18. Aquatic Toxicity Profile for Glyphosate and/or Its Salts used in Risk Estimation

Assessment Endpoint	Species	Toxicity Values (mg a.e./L)*	Toxicity Category[1]	Citation MRID # /Date	Comment
Acute Toxicity to Freshwater Fish	Bluegill sunfish (*Lepomis macrochirus*)	96-hr. LC_{50}: 43 Slope: NA	Slightly toxic	44320630 /1995 Acceptable	NOAEC = 30.6 mg a.e./L (based on mortalities at 56 mg a.e./L)
Chronic Toxicity to Freshwater Fish	Fathead minnow (*Pimephales promelas*)	NOAEC: 25.7	NA	00108171 /1975 Acceptable	highest concentration tested
Acute Toxicity to Aquatic-phase Amphibians	Australian tree frog (*Litoria moorei*)	96-hr LC_{50}: 103.2 Slope: NR	Practically non-toxic	43839601 / 1995 Supplemental	NOAEC: NR
Chronic Toxicity to Aquatic-phase Amphibians	Leopard frog (*Rana pipiens*)	NOAEC: 1.8	NA	46650501/ 2004 Supplemental	Highest concentration tested

Assessment Endpoint	Species	Toxicity Values (mg a.e./L)*	Toxicity Category[1]	Citation MRID # /Date	Comment
Acute Toxicity to Freshwater Invertebrates	Midge (*Chironomus plumosus*)	48-hr EC$_{50}$: 53.2 Slope: NR	Slightly toxic	00162296 /1979 Acceptable	NOAEC: NR
Chronic Toxicity to Freshwater Invertebrates	Midge (*Chironomus plumosus*)	NOAEC (calculated): 9.22	NA	NA	Based on acute-to-chronic ratio[2]
Acute Toxicity to Estuarine/marine Fish	Sheepshead minnow (*Cyprinodon variegatus*)	96-hr. LC$_{50}$: 240	Practically nontoxic	44320632 /1996 Acceptable	NOAEC = 100 mg a.e./L (based on quiescent fish in 180 mg a.e./L)
Chronic Toxicity to Estuarine/marine Fish	Sheepshead minnow (*Cyprinodon variegatus*)	NOAEC (calculated): 88.9	NA	NA	Based on acute-to-chronic ratio[3]
Acute Toxicity to Estuarine/marine Invertebrates	Mollusk - Pacific oyster (*Crassostrea gigas*)	48-hr EC$_{50}$: 40 Slope: NA	Slightly toxic	44320634 /1996 Acceptable	NOAEC = 32 mg a.e./L (based on % normal larvae at 56 mg a.e./L)
Chronic Toxicity to Estuarine/marine Invertebrates	Amphipod (*Acartia tonsa*)	NOAEC (calculated): 6.11	NA	NA	Based on acute-to-chronic ratio[2]
Acute Toxicity to Non-vascular Aquatic Plants	Bluegreen algae (*Anabaena flos-aquae*)	4-day EC$_{50}$: 11.4 Slope:3.53	NA	40236904 /1987 Acceptable	NOAEC: NR
Acute Toxicity to Toxicity to Vascular Aquatic Plants	Duckweed (*Lemna gibba*)	14-day EC$_{50}$: 11.9 Slope:NR	NA	44320638 /1996 Supplemental	NOAEC:1.3

*a.e. = expressed in terms of acid equivalents for glyphosate; NA = not available; NR = not reported

[1]Categories of acute toxicity for aquatic organisms (U.S. EPA, 2004) based on LC$_{50}$ (mg/L): < 0.1 very highly toxic; 0.1-1 highly toxic; >1-10 moderately toxic; >10-100 slightly toxic; >100 practically nontoxic. Toxicity categories for aquatic plants have not been defined.

[2] Chronic NOAEC value calculated using acute to chronic ratio (ACR) using the following data: chronic *Daphnia magna* NOAEC of 49.9 mg a.e./L (MRID 0124763) and geometric mean of 2 acute *Daphnia magna* EC$_{50}$s: 128.1 mg a.e./L (MRID 44320631; static test system; 95.6% a.e.; EC$_{50}$ based on measured concentrations) and 647.4 mg a.e./L (based on nominal test concentrations; static test system; 83% a.e.) which results in geometric mean acute value of 288 mg a.e./L. ACR = 288/49.9 = 5.77; acute midge LC$_{50}$ = 53.2 mg a.e./L; chronic freshwater NOAEC = 53.2/5.77 = 9.22 mg a.e./L; acute amphipod LC$_{50}$ = 35.3 mg a.e./L; chronic amphipod NOAEC = 35.3/5.77 = 6.11 mg a.e./L.
[3]Chronic NOAEC value calculated using acute to chronic ratio (ACR) using the following data: acute fathead minnow LC$_{50}$ = 69.4 mg a.e./L (MRID 00162296) and chronic fathead minnow NOAEC = 25.7 mg a.e./L; ACR = 69.4/25.7 = 2.7; chronic sheepshead minnow NOAEC = 240/2.7 = 88.9 mg a.e./L.

Table 19 summarizes the aquatic toxicity endpoints of glyphosate formulations that will be used in risk estimation. Some glyphosate formulations have been found to be more toxic to aquatic organisms than technical glyphosate. Formulations containing one class of surfactants, polyethoxylated tallow amines (POEA) tend to be the most toxic to aquatic organisms. Ecological effects studies have been conducted with formulations containing POEA as well as for formulations containing surfactants other than POEA. The toxicities of some of these formulations appear to be either similar to or less toxic than the technical material.

Currently, formulations registered for aquatic uses do not contain POEA surfactants. Therefore, for aquatic organisms, separate endpoints were selected for terrestrial uses where the POEA surfactant is allowed and for aquatic uses where this surfactant is not allowed. For aquatic animals, significant differences in toxicities between the formulations containing POEA and those that do not contain the surfactant are observed.

Table 19. Aquatic Toxicity Profile for Glyphosate Formulations

Assessment Endpoint	Species	Toxicity Value (mg formulation/L)	Toxicity Category[1]	Citation MRID # /Date	Comment
Acute Toxicity to Freshwater Fish	Rainbow trout (*Oncorhynchus mykiss*)	96-hr LC_{50}: 3.17 [2] Slope: NR NOAEC: NR	Moderately toxic	40098001/1986 Supplemental	Roundup: 41% a.i. (GLY-IPA); 96-hr LC_{50}: 1 mg a.e./L
		96-hr LC_{50}: 750 [3] Slope: NR NOAEC: 341	Practically non-toxic	40579303/1985 Supplemental	Rodeo/X-77; 96-hr LC_{50}: 103 mg a.e./L[4]
Acute Toxicity to Aquatic-phase Amphibians	Spring peeper (*Pseudacris crucifer*) larvae	96-hr LC_{50}: 1.64 [2] Slope: NA NOAEC: <2.3	Moderately toxic	E153679 / Relyea and Jones 2009	Roundup Original Max (48.7%); 96-hr LC_{50}: 0.8 mg a.e./L[5]
	Australian frog (*Crinia insignifera*) tadpole	96-hr LC_{50}: 911 [3] Slope: NR NOAEC: NR	Practically non-toxic	E71857 / Mann and Bidwell 1999	Roundup Biactive: 36% (GLY-IPA) ai; 96-hr LC_{50}: 328 mg a.e./L
Acute Toxicity to Freshwater Invertebrates	Water flea (*Daphnia magna*)	48-hr EC_{50}: 5.3 [2] Slope: 5.4 NOAEC: 1.45	Moderately toxic	00070893/1980 Acceptable	Roundup: Glyphosate IPA salt (41.36% a.e.); 48-hr EC_{50}: 1.6 mg a.e./L
		48-hr EC_{50}: 164 [3] Slope: 7.6 NOAEC: 96	Practically non-toxic	45374003/1999 Acceptable	Glyphosate (360 g/L SL) 27.25% a.e.; 48-hr EC_{50}: 44.8 mg a.e./L
Acute Toxicity to Marine/Estuarine Fish	Sheepshead minnow (*Cyprinodon variegatus*)	96-hr LC_{50}: 8.8[2] Slope: NA NOAEC: 6.8	Moderately toxic	48934205/2012 Acceptable	Glyphosate (MON 2139) 30.75% a.e.; 96-hr LC_{50} = 2.7 mg a.e./L
		96-hr. LC_{50}: >180.2[3] NOAEC = 180.2	Practically nontoxic	45374005/2000 Supplemental	Glyphosate SL formulation (28.3% a.e.); limit test no mortality noted; 96-hr LC_{50}: >50.9 mg a.e./L
Acute Toxicity to Marine/Estuarine Invertebrates	Mysid shrimp (*Americamysis bahia*)	96-hr LC_{50}: 2.45[2] Slope: 10.4 NOAEC: 1.66	Moderately toxic	48934002/2012 Acceptable	Glyphosate (MON 2139) 30.75% a.e.; 96-hr LC_{50}: 0.765 mg a.e./L

Assessment Endpoint	Species	Toxicity Value (mg formulation/L)	Toxicity Category[1]	Citation MRID # /Date	Comment
	Pacific oyster (*Crassostrea gigas*)	48-hr. EC_{50}: 82[3] Slope: NR NOAEC: 28.6	Slightly toxic	45374006/2000 Acceptable	Glyphosate SL formulation (28.3% a.e.); 48-hr LC_{50}: 23.2 mg a.e./L
Acute Toxicity to Non-vascular Aquatic Plants	Freshwater diatom (*Navicula pelliculosa*)	96-hr IC_{50}: 0.39[6] Slope: 8.78 NOAEC: 0.27	NA	45666701/2001 Acceptable	Glyphosate (glyphos) 31.0% a.e.; 96-hr IC_{50}: 0.12 mg a.e./L
Acute Toxicity to Vascular Aquatic Plants	Duckweed (*Lemna minor*)	14-day EC_{50}: 4.9 [2] Slope: NR NOAEC: NR	NA	44125714/1984 Supplemental	Roundup: Glyphosate IPA salt (41% a.i.); 14-d IC_{50}: 1.5 mg a.e./L
	Duckweed (*Lemna gibba*)	7-day EC_{50}: 25[3] Slope: 4.69 NOAEC: 7.9	NA	45666704/2001 Acceptable	Glyphosate (Glyphos) (31% a.e.);Based on plant number; 7-d IC_{50}: 7.7 mg a.e./L

[1]Categories of acute toxicity for aquatic organisms (U.S. EPA, 2004) based on EC_{50}/LC_{50} (ppm): < 0.1 very highly toxic; 0.1-1 highly toxic; >1-10 moderately toxic; >10-100 slightly toxic; >100 practically nontoxic. Toxicity classifications in this table based on formulation values, not % a.e. Toxicity categories for aquatic plants have not been defined.

[2] Formulation assumed to contain POEA surfactant

[3] Formulation assumed to not contain POEA surfactants

[4] In this study, it is noted that the pH ranged from 5.5-5.8 in control and 4.4-4.7 in treatments with 100% mortality.

[5] In this study, there were two species with the same LC50 value (bullfrog and spring peeper). The spring peeper was reported in table given tighter 95% CI range.

[6] There are at least two labels with this formulation name. Because the formulations differ, it could not be determined if the formula used in the study was a POEA or non-POEA formulation

Table 20 summarizes submitted acute toxicity studies on freshwater fish and invertebrates with two surfactants, POEA and geronol, an alkyl polyoxy ethylene phosphoric acid ester.

Table 20. Freshwater Fish, Aquatic-phase amphibian, and Invertebrate Acute Toxicity for Surfactants Used with Glyphosate Formulations

Chemical	Species	% a.i.[1]	LC/EC_{50} (mg/L)	Toxicity Category[2]	MRID #/Year; Comment
Polyoxy ethylene fatty amine (POEA) (MON 0818)	Fathead minnow (*Pimephales promelas*)	70[4]	96-hr LC_{50}: 0.7 (0.84 - 1.19)[3] NOAEC and slope not reported	Highly toxic	00162296/1979; MON 0818 LC_{50}: 1 mg/L
Polyoxy ethylene fatty amine (POEA) (MON 0818)	Rainbow trout (*Oncorhynchus mykiss*)	70[4]	96-hr LC_{50}: 1.4 (1.05 – 1.89) NOAEC and slope not reported	Moderately toxic	00162296/1979; MON 0818 LC_{50}: 2mg/L[5]
Polyoxy ethylene fatty amine (POEA) (MON 0818)	Bluegill sunfish (*Lepomis macrochirus*)	70[4]	96-hr LC_{50}: 2.1 (1.75 – 2.59) NOAEC and slope not reported	Moderately toxic	00162296/1979; MON 0818 LC_{50}: 3 mg/L

			96-hr LC$_{50}$: 9.1 (7.0 – 11.9) NOAEC and slope not reported	Slightly toxic	00162296/1979; MON 0818 LC$_{50}$: 13 mg/L
Polyoxy ethylene fatty amine (POEA) (MON 0818)	Channel catfish (*Ictalurus punctatus*)	70[4]	96-hr LC$_{50}$: 9.1 (7.0 – 11.9) NOAEC and slope not reported	Slightly toxic	00162296/1979; MON 0818 LC$_{50}$: 13 mg/L
Surfactant Geronol CF/AR (alkyl polyoxy ethylene phosphoric acid ester)	Zebra fish (*Brachydanio rerio*)	100	96-hr LC$_{50}$: >100 (N.A.) NOAEC and slope not reported	Practically non-toxic	44738201/ Summary from another study
Polyoxy ethylene fatty amine (POEA) (MON 0818)	Green Frog (*Rana clamitans*) Gosner Stg 25	69-73	LC$_{50}$: 2.2 (2.1-2.4) NOAEC: NR Slope: NR	Moderately toxic	46650501/2001
Surfactant Geronol CF/AR (alkyl polyoxy ethylene phosphoric acid)	Daphnia (*Daphnia magna*)	Tech.	48-hr EC$_{50}$: 48	Slightly toxic	44738201/1996
Polyoxy ethylene fatty amine (POEA) (MON 0818)	Midge (*Chironomus plumosus*)	70[4]	48-hr LC$_{50}$: 9.1 (4.97-16.8)	Slightly toxic	00162296/1979; MON 0818 LC$_{50}$: 13 mg/L

[1] a.i. = active ingredient, assumed 100% for technical material
[2] Based on LC$_{50}$ (mg/L): < 0.1 very highly toxic; 0.1-1 highly toxic; >1-10 moderately toxic; >10-100 slightly toxic; >100 practically nontoxic
[3] Range is 95% confidence interval for endpoint.
[4] Based on information provided by Registrant, the test material, MON 0818, contains 70% POEA; (comment from Monsanto Co. September 21, 2009; http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OPP-2009-0361-0013)
[5] In 00162296 (Folmer 1979), for MON 0818, a reported acute 96-hr LC50 toxicity value of 0.65 mg/L was reported for rainbow trout, however, this study was conducted at a pH of 9.5 and therefore, was not used quantitatively

Additional studies testing POEA (or MON 0818) were also available in the open literature. For example, five species of North American anurans were exposed to MON 0818 (69.4% POEA) (E161671; Moore *et al*. 2012). Acute 96-hr LC$_{50}$ values in that study ranged from 0.68 to >1.25 mg MON 0818/L (dose-response data reported in study), with the most sensitive species being *Rana pipiens* (0.68 mg MON 0818/L; 0.47 mg POEA/L). Additionally, in Bringolf *et al.* 2007, 48-hr EC$_{50}$ value of 0.5 mg/L (MON 0818; no dose-response data reported) was reported for the glochidia life-stage of the freshwater mussel, *Lampsilis siliquiodea* (a 48-hr and 28-d EC$_{50}$ value of 3.8 and 1.7 mg/L, respectively, reported for juvenile stage). For *Daphnia magna*, Wang *et al.* 2005 reported an 48-hr EC$_{50}$ value of 2.9 mg/L (MON 0818), and Brausch *et al.* 2007, reported 48-hr EC$_{50}$ values of 0.097-0.894 mg/L depending on the oxide:tallow ratio of POEA (dose-response data not reported in either study). Tatum *et al.* 2011, reported an acute 48-hr EC$_{50}$ value of 0.42 mg/L for *Ceriodaphnia dubia* using the surfactant Entry II which was reported as being similar to POEA (only EC$_{50}$ value reported). While Tsui and Chu, 2003, reported acute LC/IC$_{50}$ values for several taxa for POEA, the endpoints were reported in units of mg acid equivalents/L. Finally, acute toxicity values were also reported for fairy shrimp (*Thamnocephalus platyurus*) for different oxide:tallow ratios of POEA (Brasch and Smith, 2007). The reported 48-hr EC$_{50}$ values ranged from 2.01-5.17 µg/L POEA which were mean toxicity values calculated using LC$_{50}$ values from different strains of fairy shrimp. Brausch *et al*., 2006, also tested fairy shrimp using Roundup Super Concentrate, in which the 48-hr LC$_{50}$ was reported as 1243 µg/L. It was not reported if this toxicity value represented the formulation, active ingredient (glyphosate IPA) or acid equivalents. In an effort to better understand the reported toxicity values for the Roundup Super Concentrate and the POEA-only for the fairy

shrimp, assuming the formulation toxicity value represents mg formulation/L and 15% POEA (the most conservative approach for converting to units in POEA/L), then the LC_{50} value in Brausch *et al.* 2006, based on POEA concentrations, would be 186 µg/L, which is 36 times greater than the POEA-only values in Brausch and Smith 2007; therefore, there is uncertainty in the POEA-only toxicity values with the fairy shrimp. It is acknowledged that it is possible that there could be other factors in the formulation affecting the overall toxicity in the formulation testing. However, the toxicity value reported using the formulation (either as total formulation or adjusted for active ingredient), while on the lower end of the toxicity spectrum, is still in the same relative toxicity range for other aquatic invertebrates suggesting similar sensitivity.

Table 21 shows the acute aquatic toxicity endpoints for the degradate, aminomethylphosphonic acid (AMPA). Based on this data, AMPA appears to be less acutely toxic to aquatic organisms than the parent, glyphosate.

Table 21. Freshwater Acute Toxicity for Aminomethylphosphonic Acid (AMPA) Degradate of Glyphosate

Chemical	Species	% a.i.[1]	96-hour LC_{50} / EC_{50} (mg/L)	Toxicity Category[2]	MRID #/Year
AMPA	Rainbow trout (*Oncorhynchus mykiss*)	94.38	LC_{50}: 499 (391 - 647)	Practically nontoxic	43334713/1991
AMPA	Water flea (*Daphnia magna*)	94.38	EC_{50}: 683 (553 - 1010)	Practically nontoxic	43334715/1991

[1] a.i. = active ingredient, assumed 100% for technical material
[2] Based on LC_{50} (mg/L): < 0.1 very highly toxic; 0.1-1 highly toxic; >1-10 moderately toxic; >10-100 slightly toxic; >100 practically nontoxic
[3] Range is 95% confidence interval for endpoint.

4.2.2. Terrestrial Organisms

4.2.2.1. Birds and Terrestrial-phase Amphibians

Acute toxicity data on selected avian species are available for technical glyphosate, several formulations and the AMPA degradate. Based on these studies, glyphosate is, at the most, only slightly toxic on an acute/sub-acute basis, with acute oral LD_{50} values of >3196 mg a.e./kg-bw for bobwhite quail and >2000 mg a.e./kg-bw for the canary and acute dietary LC_{50} values up to >4971 mg a.e./kg-diet for mallard ducks and bobwhite quail. There was one acute oral toxicity study with a formulation that had a definitive LD_{50} value of 1131 mg a.e./kg-bw using bobwhite quail (MRID 45777402). The AMPA degradate is not more toxic than the parent with acute oral and dietary LD/LC_{50} values of >1976 mg/kg-bw and >4934 mg/kg-diet, respectively. Several avian reproduction studies are available for bobwhite quail and mallard duck. In two studies, treatment-related effects on reproduction or growth were not reported following chronic exposure to either mallards or bobwhite quail up to concentrations of 830 mg a.e./kg-diet (MRID 00111953 and 00108207). However, in an additional mallard duck reproduction study that tested up to 2160 mg a.e./kg, treatment-related decreases were observed for male body weight at all concentrations tested (NOAEC <501 mg a.e./kg; MRID 48876602). Additionally, treatment-related decreases in hatchling and 14-day body weights were observed at the high test concentration; significant decreases in 14-day body weights were also observed at the low treatment, but not at the mid concentration. There were no treatment-related effects on eggs laid,

embryo viability, or eggshell thickness in this study. An additional bobwhite quail reproduction study (MRID 48876601) was not acceptable as control mortality was 19%.

Open literature studies on birds and terrestrial-phase amphibians provide additional qualitative information for the risk characterization for glyphosate. These studies are summarized in Table 22.

In an acute oral study by McComb *et al*. 2008 (E162011), the 96-hr LD_{50} value for field-collected (prior exposure history unknown) rough-skinned newts (*Taricha granulosa*) exposed to glyphosate isopropylamine was greater than 2,600 mg/kg-bw (unsure if adjusted to acid equivalents). Control mortality was not reported in study.

Effects on male and female body weights for domesticated chickens were reported at glyphosate concentrations of 6080 mg/kg-diet (unsure if adjusted for acid equivalents; purity not reported; assumed to be based on nominal concentrations) (Kubena *et al*. 1981).

In a field study (Bernal *et al*. 2009, E11766) where eight species of juvenile frogs (in Columbia) received a direct spray of a mixture of glyphosate formulations Glyphos and Cosmo-flux reported a range of 96-hr LC_{50} values from 4.0 – 20.3 lb a.e./A (reviewer calculated; study author values reported in kg/ha).

Table 22. Open Literature Studies for Glyphosate for Birds and Terrestrial-phase Amphibians

Species	Chemical Form	Endpoint(s)	ECOTOX Ref. No.
Rough-skinned newt (*Taricha granulosa*)	Glyphosate isopropylamine (45.5% solution)	96-h LD_{50} > 2,600 mg/kg-bw	E162011 / McComb *et al.* 2008
8 species frogs in Columbia – juvenile phase	Mixture Glyphos and Cosmo-Flux	96-h LC_{50}: 4.5-22.8 kg ae/ha (direct spray on frogs	E11766 / Bernal *et al* 2009
Chicken (*Gallus gallus domesticus*)	Glyphosate isopropylamine (purity not reported)	Significant 50% reduction in male and female body wt by day 7 at 6080 mg/kg-diet, no effect at 608 mg/kg-diet; 21-d exposure; did not evaluate reproductive parameters	E162010 / Kubena *et al.* 1981

4.2.2.2. Mammals

The acute toxicity studies on the technical material indicate that glyphosate is practically non-toxic to mammals on an acute exposure basis with resulting LD_{50} values greater than the highest concentration tested up to 4,800 mg a.e./kg-bw (MRID 43728003). Many acute toxicity studies are available on formulations for mammals with most of the LD_{50}'s greater than the highest dose tested. The lowest reported LD_{50} acute oral toxicity study using a formulation is 357 mg a.e./kg-bw, which is classified as moderately toxic due in part to the low percentage of a.e. (11.4%) (MRID 46714802).

Two 2-generation mammalian reproduction studies with the rat are available for glyphosate. In the first study (MRID 41621501, 1990), the parental/systemic NOAEL is 500 mg/kg/day in both sexes and the LOAEL is 1,500 mg/kg/day based on soft stools, decreased body weight gain and food consumption. The reproductive NOAEL is 1,500 mg/kg/day in both sexes. The offspring

NOAEL is 500 mg/kg/day in both sexes with a LOAEL of 1,500 mg/kg/day based on decreased body weight gain during lactation. In the second 2-generation reproduction study using the rat (MRID 48865101-48865105, 2007/2012), the parental/systemic NOAEL is 15,000 mg/kg-diet in both sexes (equivalent to 1,234/1,273 mg/kg/day in males/females, respectively) as parental toxicity was not observed. The reproductive NOAEL is 15,000 mg/kg-diet in both sexes; no reproductive toxicity was observed in study. The offspring NOAEL is 5,000 mg/kg-diet (equivalent to 408/423 mg/kg/day in males/females, respectively) with a LOAEL of 15,000 mg/kg-diet based on delayed age at sexual maturation.

Open literature studies on mammals provide additional qualitative information for the risk characterization for glyphosate. These studies are summarized in Table 23.

Two reproduction studies by Romano et al. (2010 and 2012) using Wistar rats reported reproductive effects on male rats. In one study (2010; E155939), newly weaned male rats were orally gavaged with Roundup Transorb from post-natal day 23 to 53. Significant effects on sexual development (increase in age of sexual maturity and hormone changes) were reported at 50 mg a.i./kg-bw (NOAEL = 5 mg a.i./kg-bw). In the other study (E161810), parental females were orally dosed with Roundup Transorb from gestational day 18 to post natal day (PND) 5. Significant sexual development effects at 50 mg a.i./kg-bw were reported in male offspring (decrease in age of sexual maturity, changes in hormone and sexual behavior). It is noted that in the study with the newly weaned rats there was a delay in the age to sexual maturity whereas in the other study, the male offspring were observed to have a decrease in the age to sexual maturity.

In a study using field collected deer mice (prior exposure history unknown), the reported 96-hr LD_{50} value was > 6,000 mg/kg-bw (unknown if adjusted for purity).

Table 23. Open Literature Studies for Glyphosate on Mammals

Species	Chemical Form	Endpoint(s)	ECOTOX Ref. No.
Deer Mouse (*Peromyscus maniculatus*)	Glyphosate isopropylamine (45.5% solution)	96-h LD_{50} > 6000 mg/kg-bw	E162011 / McComb *et al.* 2008
Rat (male Wistar)	Roundup Transorb (480 g glyphosate acid/L)	Significant sexual development effects at 50 mg a.i./kg-bw (NOAEL = 5 mg a.e./kg-bw) increase in age of sexual development, hormone changes Newly weaned male rats oral gavage from post natal day (PND) 23 to PND53	E155939 / Romano *et al.* 2010
Rat (Wistar)	Roundup Transorb (480 g glyphosate acid/L)	Significant sexual development effects at 50 mg a.i./kg-bw for male offspring (decrease in age of sexual development, changes in hormone and sexual behavior Parental females oral gavage and then offspring observed, females dosed from gestational day 18 to PND 5	E161810 / Romano *et al.* 2012

4.2.2.3. Terrestrial Invertebrates

Acute oral and contact studies are available for technical glyphosate, technical glyphosate with an adjuvant, and for glyphosate formulations for the honeybee. The acute oral and contact LD_{50} values for technical glyphosate as well as the acute contact LD_{50} value for a formulation (MON78568) were generally reported as >100 μg/bee. At test termination in the acute contact study with technical glyphosate (LD_{50} >100 μg/bee), there was 38% mortality (27% after correcting for control mortality) at the limit dose (MRID 00026489). The acute oral LD_{50} value for the formulation, MON78568, was reported as >76.33 μg a.e./bee (MRID 4576104). Twenty percent mortality at the limit dose was observed at test termination. The acute contact and oral toxicity studies using technical glyphosate with an adjuvant (Agral 90), reported 48-hour LD_{50} values of >103 and >182 μg a.e./bee. No mortality or clinical signs of toxicity were observed in either study (MRID 48876603). Acute and chronic laboratory-based toxicity data (*i.e.*, mortality and emergence data) for honeybee larvae are not available.

In addition to the acute contact and oral toxicity studies for honeybees, a semi-field study (conducted in greenhouses) is also available (Thompson et al. 2014; also referenced in EFSA 2014 report). A glyphosate formulation (MON 52276; 30.68% a.e. as GLY-IPA), was applied to flowering Phacelia tanacetifolia at 1.92 lb a.e/A (2.88 kg a.e./ha nominal, 2.16 kg a.e./ha measured), and pollen and nectar were collected for 7 days; the plants started to show effects from the application after 4 days. Residues in honeybee larvae were also analyzed on days 4 and 7 post-application. Additionally, honeybee colonies were fed treated sucrose (technical GLY-IPA) with test concentrations based on the mean residue concentration after 3 days, (75 mg a.e/L nominal; 73 mg a.e./L measured), the highest residue concentration (150 mg ae./L nominal; 138 mg a.e./L measured), and twice the highest reside concentration (301 mg a.e./L nominal; 255 mg a.e./L measured); the concentrations were also reported as mg a.e./kg. Evaluation of mortality/morbidity, appearance, larval weight and residue were conducted (16 day test duration). There was no significant effect on survival of eggs, young or old larvae or on larvae weight.

Additional toxicity studies with other types of terrestrial invertebrates (*i.e.*, predatory mites, earthworms, parasitic wasps) are also available, with generally no effects reported up to the highest dose tested. In a study with a predatory mite, the 7-day LD_{50} value was reported as 1200 g a.e./ha (1.1 lb/A) (MRID 45767105).

Open literature studies on terrestrial invertebrates provide additional qualitative information used in the risk characterization for glyphosate. These studies are summarized in Table 24. Note that studies from open literature that did not provide sufficient information to allow for conversion of exposure values to lb a.i./A were not included in this table.

Table 24. Open Literature Studies for Glyphosate for Terrestrial Invertebrates

Species	Chemical Form	Endpoint(s)	ECOTOX Ref. No.
Earthworm (*Eisenia fetida andrei*)	Roundup Ready	56-d sign decrease at 1440 g ai/ha (Roundup applied to soybean field and soil samples collected) in % hatchability of cocoons, # of juveniles, # juv/hatched cocoons Earthworms also sign avoided GLY treated soil in avoidance test; had reduced feeding activity	E160273 / Casabe *et al.* 2007

Parasitoid Wasp (*Trichogramma pretiosum*)	Roundup Ready (972 g glyphosate /ha); Roundup Original (960 g glyphosate/ha)	Roundup Ready at 972 mg a.e./ha - 100% decrease egg viability; Roundup original at 960 mg ae/ha decreased egg (37%) and larvae viability (32%); No effects using Roundup Transorb or Gliz; No effect on pupae stage for all 4 formulations; based on categories of effect (% effect) Only one concentration tested	E110225 / De Freitas Bueno *et al.* 2008

4.2.2.4. Terrestrial Plants

Vegetative vigor and seedling emergence studies were conducted using two glyphosate formulations. Additionally, a vegetative vigor study was conducted using technical glyphosate. For the vegetative vigor studies, the most sensitive monocot species was sorghum (*Sorghum bicolor*) with a reported IC_{25} value of 0.16 lb a.e./A (95% CI 0.126-0.194) and a NOAEC of 0.07 lb a.e./A (MRID 44125715/45045101). For dicots, the most sensitive species was cucumber (*Cucumis sativus*) with a reported IC_{25} of 0.074 and NOAEC of 0.049 lb a.e./A (MRID 44320636). For seedling emergence the IC_{25} values were greater than the highest concentrations tested (up to 5 lb a.e./A), and the corresponding NOAECs were reported as the highest concentration tested or were not reported.

As discussed in Section 2.1.1, registered glyphosate labels may recommend the addition of ammonium sulfate in situations when hard water is used in the spray mixture. This is to allow the sulfate ion to competitively bind to the cations typically present in hard water, and thus increase the efficacy of glyphosate.

With regard to the vegetative vigor studies using a formulation (studies with the lowest toxicity values), the stock solutions used in the foliar application were reported to be prepared with deionized water, which should have limited the development of the glyphosate-cation complex. In one study (MRID 44125715/ 45045101), the stock solution volume was reported to be sufficient to allow for foliar treatment without further dilution of the stock. For the other registrant study (MRID 44320636), while further dilution was not discussed in the report, it was not clear if the stock solution volume was sufficient for application. While the hardness content of water source(s) used for stock preparation/foliar application in the open literature studies was not reported, the collective response between the registrant vegetative vigor studies and the open literature studies is similar. Therefore, it is considered that there is sufficient confidence in the toxicity values used in the assessment to adequately evaluate potential effects of glyphosate exposure for terrestrial plants. The toxicity values from species tested in each of the different vegetative vigor studies are presented in Table 25 for a comparison across the studies.

Table 25. A Comparison of Glyphosate Toxicity Values from Vegetative Vigor Studies

Test Compound (MRID)	Monocot		Dicot	
	IC_{25} (lb a.e./A)	NOAEC (lb a.e./A)	IC_{25} (lb a.e./A)	NOAEC (lb a.e./A)
	Corn		*Cucumber*	
Tech. glyphosate (43088701)	0.43 (dry wt)	0.07	0.46 (dry wt)	0.14
Glygan 80WDG Formulation (44125715/ 45045101)	0.35 (phytotoxicity)	0.18	0.45 (phytotoxicity)	0.16
80WDG Formulation (44320636)	0.227 (phytotoxicity)	0.148	0.074 (phytotoxicity)	0.049

Open literature studies on terrestrial plants provide additional qualitative information used in the risk characterization for glyphosate. These studies are summarized in Table 26 and reflect foliar exposure to glyphosate formulations from overspray. The toxicity values reported in the open literature studies are similar to the most sensitive toxicity value reported from the registrant's vegetative vigor study (IC_{25} 0.074 lb a.e./A). While the reported EC_{50} value from Boutin *et al.*, 2004 is lower than the most sensitive value from the registrant's vegetative vigor study, based on the open literature studies, it appears that the study was essentially conducted again at a later date (Boutin *et al.*, 2010), and the lowest IC_{25} from that study was similar to the lowest toxicity value from the submitted data. It is noted that in both Boutin *et al.* 2004 and 2010, the same species, *Bellis perennis* (English daisy), was reported to be the most sensitive species tested. It is noted that in White and Boutin, 2007, the most sensitive species, based on dry weight, was wheat (*Triticum aestivum*) with a 28-d IC_{50} of 20 g a.i./ha (95% CI: 15-28) [0.0178 lb a.i./A (0.013-0.025)].

In addition to evaluating growth parameters, studies examining reproductive parameters are also available (Table 26). In a study evaluating pea seed production using Roundup Original®, Olszyk et al. 2009, the EC_{25}, based on pea seed weight was 0.0074 lb a.i./A (0.0096 x 833 g a.i./ha), but the reported NOEC (0.01 x 833 g a.i./ha) for the same endpoint was very close to the EC_{25} value. These endpoints appear to be from a combination of four independent studies (two study designs repeated). Healthy leaf area were also affected with EC_{25}s of 0.063 or 0.137 x 833 g a.i./ha. In an additional study comparing the effects of greenhouse versus field grown potatoes (Pfleger *et al.* 2011), generally most endpoints were affected at 0.1 x 832 g/ha and the most sensitive endpoint was above biomass with an EC_{25} of 0.004 x 832 [0.003 lb/A] using plants that were grown in the greenhouse and exposed at tuber initiation; the study author reported that the study results were similar between plants grown inside or outside in pots.

Table 26. Open Literature Studies for Glyphosate for Terrestrial Plants

Species	Chemical Form	Endpoint(s)	ECOTOX Ref. No.
Bellis perennis (most sensitive species; multiple species tested)	Roundup Original or Vision (both containing 356 g glyphosate acid/L)	Biomass (dry wt) 28-d IC_{25} = 0.053 lb a.i./A	E152615 / Boutin *et al* 2010
Bellis perennis (most sensitive species; multiple species tested)	Roundup Bio (360 g/l glyphosate with 480 g glyphosate-isopropylamine salt)	Biomass (dry wt) 28-d EC_{50} = 0.013 lb a.i./A	E87923 / Boutin *et al* 2004

Brassica oleracea (most sensitive species; multiple species tested)	Roundup Original (356 g glyphosate acid/L)	Biomass (dry wt) (assumed to be 28-d) IC_{25} = 0.038 lb a.i./A	E159072 / Boutin *et al.* 2012
Pisum sativum (Garden pea)	Roundup Original	Seed wt EC_{25} = 0.0074 lb ai/A [0.0096 x 833 g ai/ha], NOEC [0.01 x 833]	Rec#8500 / Olszyk *et al.* 2009
Solanum Tuberosum L (Potatoes)	Roundup	Most endpoints (growth and reproductive) affected at 0.1 x 832 g/ha, most sensitive endpoint was above biomass with EC25 of 0.004 x 832 [0.003 lb/A]	Rec# 5780 / Pfleeger et al. 2011
Triticum aestivum (most sensitive species; multiple species tested)	Roundup Original	Biomass (dry wt) (assumed to be 28-d) IC_{25} = 0.0178 lb a.i./A	White and Boutin 2007

4.2.2.5. Summary of Terrestrial Endpoints

Table 27 summarizes the terrestrial toxicity endpoints for glyphosate that were considered to be sufficient for quantitative use in the risk assessment.

Table 27. Terrestrial Toxicity Profile for Glyphosate and/or Its Salts

Endpoint	Species	Toxicity Value	Toxicity Category[1]	Citation MRID#/Date	Comment
Acute Avian Oral Toxicity	Bobwhite quail (*Colinus virginianus*)	LD_{50}: >3196 mg a.e./kg bw NOA.E.L (observed) 1481 mg a.e./kg bw	Practically non-toxic	00108204/1978	Reported slight reduction in body weight gain at 3196 mg a.e./kg bw.
	Canary (Serinus canaria)	LD_{50}: > 2000 mg a.e./kg bw NOAEL (observed) 2000 mg a.e./kg bw	Practically non-toxic	48934206/2012	No frank effects up to highest dose tested
Acute Avian Dietary Toxicity	Bobwhite quail (*Colinus virginianus*)	LC_{50}: >4971 mg a.e../kg diet NOAEC (observed): 4971mg a.e./kg diet	Slightly toxic	44320628/1997	No effects reported
Chronic Avian	Mallard duck (*Anas platyrhynchos*)	Reproduction study NOAEC: <501 mg a.e./kg diet	NA	48876602 / 1999	LOAEC: 501 mg a.e./kg diet (lowest concentration tested), based on effects to male weight gain offspring weight.
	Bobwhite quail (*Colinus virginianus*)	Reproduction study NOAEC: 830 mg a.e./kg diet	NA	108207/1978	LOAEC: >830 mg a.e./kg diet (highest concentration tested).

Endpoint	Species	Toxicity Value	Toxicity Category[1]	Citation MRID#/Date	Comment
Acute mammalian	Rat (*rattus norvegicus*)	LD_{50} >4800 mg/kg bw (limit test)	Practically non-toxic	43728003/1989	No mortalities at limit dose; reduced activity observed in males and females first 9-days of study (14-d duration)
Chronic mammalian	Rat (*rattus norvegicus*)	NOAEL: 408/422 mg/kg bw/day (males/females); NOAEC: 5000 mg/kg-diet Used the lower dose-based value (408 mg/kg bw/day) for risk estimation	NA	48865101-48865105 /2007 & 2012	Reproduction study Offspring toxicity LOAEL: 1234/1273 (males/female) mg/kg bw/day; LOAEC: 15000 ppm (delayed age and increased weight at male sexual development). No observed effects on parental or reproductive toxicity (LOAEL >15000 ppm)
Acute terrestrial invertebrate	Honey bee (*Apis mellifera*)	48 hr LD_{50} (Oral and Contact): >100 μg/bee (>781.25 μg a.i./g bee)	NA	00026489/1972	38% mortality reported at limit dose in acute contact study (27% after control correction)
Terrestrial Plants	Seedling Emergence Monocots	EC_{25}: >5 lb a.e./A	NA	40159301/1987	NA
	Seedling Emergence Dicots	EC_{25}: > 5 lb a.e./A	NA	40159301/1987	NA
	Vegetative Vigor Monocots	EC_{25}: 0.16 lb a.e./A NOAEC: 0.07 lb a.e./A (sorghum)	NA	44125715/45045101/ 1995	NA
	Vegetative Vigor Dicots	EC_{25}: 0.074 lb a.e./A NOAEC: 0.049 lb a.e./A (cucumber)	NA	44320636/1996	NA

For birds and mammals, the endpoints following acute exposure to glyphosate are not discrete and a quantitative estimate of risk cannot be done. However, for registered end-use products, there is at least one avian study and one mammalian study with discrete values. For estimation

of risk, these studies can be matched with the specific labeled rates and uses. Endpoints for the most sensitive studies are summarized in Table 28.

Table 28. Terrestrial Toxicity Profile for Glyphosate Formulations

Endpoint	Species	Toxicity Value	Toxicity Category[1]	Citation MRID#/Date	Comment
Acute Avian Oral Toxicity	Bobwhite quail (*Colinus virginianus*)	LD_{50}: 1651mg formulation/kg bw (1131 mg a.e./kg bw)	Slightly toxic	45777402/1999	Glyphosate monoammonium salt (MON 14420)
Acute Mammalian Toxicity	Rat (*rattus norvegicus*)	LD_{50}: 3132 mg formulation/kg bw (357 mg a.e./kg bw)	Moderately toxic when reported as a.e.	46714802/2003	HM-2028 (Glyphosate 11.4%)

[1] Categories of acute toxicity to terrestrial animals, avian and mammalian (U.S. EPA, 2004). LC_{50} (ppm): < 50 very highly toxic; 50 - 500 highly toxic; 501 - 1000 moderately toxic; 1001-5000 slightly toxic; >5000 practically non-toxic. LD_{50} (mg/kg bw): < 10 very highly toxic; 10 - 50 highly toxic; 51 - 500 moderately toxic; 501-2000 slightly toxic; >2000 practically non-toxic. Toxicity categories for terrestrial plants have not been defined.

Based on the available avian toxicity studies, glyphosate is, at most, only slightly toxic on an acute exposure basis. The AMPA degradate is no more toxic than the parent, glyphosate. Table 29 summarizes these studies.

Table 29. Avian Acute Toxicity for Aminomethylphosphonic Acid (AMPA) Degradate of Glyphosate

Chemical	Species	% a.i.[1]	LD_{50}/ LC_{50} NOAEL/ NOAEC (mg a.e./kg bw or ppm a.e.)[1]	Toxicity Category[2]	MRID #/Year
AMPA	Bobwhite quail (*Colinus virginianus*)	87.8	LD_{50}: >1976 (N.A.) mg/kg NOAEL: 1185	Slightly toxic	43334709/1991
AMPA	Bobwhite quail (*Colinus virginianus*)	87.8	LC_{50}: >4934 (N.A.) PPM NOAEC: 4934	Slightly toxic	43334710/1994
AMPA	Mallard duck (*Anas platyrhynchos*)	87.8	LC_{50}: >4934 (N.A.) PPM NOAEC: 4934	Slightly toxic	43334711/1994

[1] a.i. = active ingredient; a.e. = acid equivalent
[2] Based on LC_{50} (ppm): < 50 very highly toxic; 50 - 500 highly toxic; 501 - 1000 moderately toxic; 1001-5000 slightly toxic; >5000 practically non-toxic; based on LD_{50} (mg/kg bw): < 10 very highly toxic; 10 - 50 highly toxic; 51 - 500 moderately toxic; 501-2000 slightly toxic; >2000 practically non-toxic
[4] Range is 95% confidence interval for endpoint, N.A. = not available

4.3. Adverse Ecological Incidents

A review on February 21, 2014, of the Ecological Incident Information System (EIIS, version 2.1), which is maintained by the Agency's Office of Pesticide Programs, and the Avian Monitoring Information System (AIMS), which is maintained by the American Bird Conservancy, indicates a total of approximately 600 reported ecological incidents associated with the use of glyphosate and its salts (PC Codes 417300, 103601, 103604, 103607 and 103608 and

103613 (all active registrations)). This total excludes incidents classified as 'unlikely' or 'unrelated' and only includes those incidents with certainty categories of 'possible', 'probable' and 'highly probable' (for EIIS) and 'possible', 'probable', 'likely', 'highly likely' and 'certain' (for AIMS). Incidents classified as 'unlikely' the result of or 'unrelated' to glyphosate are not included in this ecological risk assessment conducted for Registration Review.

In addition to the incidents recorded in EIIS and AIMS, additional incidents have been reported to the Agency in aggregated incident reports. Pesticide registrants report certain types of incidents to the Agency as aggregate counts of incidents occurring per product per quarter. Ecological incidents reported in aggregate reports include those categorized as 'minor fish and wildlife' (W-B), 'minor plant' (P-B), and 'other non-target' (ONT) incidents. 'Other non-target' incidents include reports of adverse effects to insects and other terrestrial invertebrates. Unless additional information on these aggregated incidents become available, they are assumed to be representative of registered uses of glyphosate and its salts in the risk assessment. A review of the Office of Pesticide Incident Data System (IDS) for aggregate incident summaries was conducted on February 27, 2014. A total of 269 separate aggregate incident reports were returned which included reports for glyphosate (PC Code 417300; 34 reports), glyphosate IPA (PC Code 103601; 226 reports) and glyphosate ammonium salt (PC Code 103608; 9 reports). However, multiple reports of injury to plants, wildlife or other non-target organisms were sometimes contained within each separate report. It is anticipated that incident reports captured in the IDS may also be captured in the EIIS system.

4.3.1 Animal Incidents

Terrestrial

For glyphosate, in the aggregate database, seven reports of wildlife incidents (unknown if terrestrial animal or fish) were reported for glyphosate.

Five incident reports for glyphosate isopropylamine salt were filed, two in 1993, one in 1996, one in 2004, and one in 2009 for uses on rangeland/pasture, home/lawn and a tree farm. One report did not file a specific use. The certainty indices were from possible to probable. One reported an accidental misuse on corn in which an unknown bird was reported as dead. The incidents considered possibly due to glyphosate were mortality to three birds from drift and mortality to several dogs from runoff. No additional details were provided in the report for the mortality of the dogs, and in the case of the bird mortalities, other chemicals were applied at the same time including atrazine, S-metolachlor and permethrin. The other possible incident was for honeybees in which adult bee mortality by ingestion was reported (number of mortalities not reported but affected three hives). In this incident, it was reported that a herbicide formulation containing sulfometuron methyl (75%) as well as a glyphosate IPA herbicide formulation was applied near flowering areas. Within two days of application, twitching or dead bees were observed near three hives. The probable incident was incapacitation (displayed signs of shock, tremors and depression) of two iguanas following ingestion of dandelions sprayed with glyphosate. In the aggregate database, 37 reports of wildlife incidents (unknown if terrestrial

animal or fish) were reported for glyphosate isopropylamine salt. Additionally, there was one reported incident to other non-target organisms for the glyphosate IPA salt.

Aquatic

For glyphosate, one incident report filed in 2003 was filed in which one carp and one catfish were incapacitated and ten goldfish were killed. Other fish were observed 'gasping' at the surface of the water. The certainty index was possible. Dissolved oxygen concentrations in the water were not measured, however water was collected for chemical analysis. Investigators stated it was not possible to determine a reason for the fish kill based on analytical results and a lack of dissolved oxygen measurements.

For the isopropylamine salt of glyphosate, 11 incident reports were filed from 1990 – 2003. The certainty indices ranged from possible to highly probable. There was one accidental misuse in which thousands of shad were killed upon ingestion. It was not stated what the application method was, but this was the one report that was rated highly probable. Four other misuses were reported and the remainder was either registered uses (majority) or unknown. All of the reports were on fish. The numbers of fish affected ranged from unknown to thousands. In two of the reports that were not reported as misuses, the compound was applied directly to the fish pond. In both cases, report indicated poor water quality may have been reason for fish kills (elevated ammonia, reduced dissolved oxygen due to plant die-off). Additionally, in another incident reported as a registered use, glyphosate was applied at the perimeter of a pond and fish kills were reported two months later. The report indicated overstocking and improper dissolved oxygen may have been the reason for the fish deaths. In two additional incidents which use was reported as undetermined, one report indicated that while glyphosate was applied adjacent to a pond, additional chemicals were also applied and suggested that diuron was reason for fish kill. In the other incident, it was unknown if glyphosate was actually used. In the last incident reporting a registered use, glyphosate was applied to 80 acres next to a fish pond for which it rained the next day. Seven hundred fish were subsequently found dead, and no other details were reported.

4.3.2 Plant Incidents

For glyphosate, 153 incidents were reported for mostly plant damage to a wide variety of plants from either direct treatment or spray drift. The reports were filed from 1992 – 2013 with the certainty code ranging from possible to highly probable. In the aggregate database, 86 reports of plant injury were reported for glyphosate.

For the isopropylamine salt of glyphosate, 449 incident reports (reported as highly probable, probable, and possible) were filed for a wide variety of terrestrial plants, particularly agricultural crops and grass. There were a few incidents of trees being damaged or killed. The reports were filed from 1990 – 2013. Plant damage and mortality were the main effects reported with drift as the main exposure route. For the potassium salt, there was one report for 2005 for plants from a registered use on a right-of-way with a certainty category of highly probable. In the aggregate database, 619 reports of plant injury were reported for glyphosate isopropylamine salt. Nineteen

reports of plant injury were reported for glyphosate dimethylammonium salt were reported in the aggregate database.

5. Risk Characterization

5.1. Risk Hypothesis

Based on the available toxicity data, it appears that the degradate, AMPA, is less toxic than glyphosate and therefore, will not be considered further in this assessment. As certain glyphosate formulations appear to be more toxic than glyphosate technical, which is believed to be due to certain surfactants, potential exposure from glyphosate formulations (from spray drift for terrestrial use formulations and from direct application for aquatic uses) as well as potential exposure using surfactant specific data are evaluated in this assessment. It is noted that glyphosate formulations that are registered for direct aquatic use do not contain POEA, which is a surfactant known to be more toxic to aquatic organisms than technical glyphosate. The following risk hypothesis is presumed for this screening-level assessment:

> *When used in accordance with current labels for terrestrial and aquatic use patterns, glyphosate can move off-site via runoff (both dissolved phase and with eroded sediment) and spray-drift and expose non-target organisms. Polyoxyethylene tallow amine (POEA), a surfactant in some glyphosate formulations, can also move off-site via spray drift and runoff. Application to foliar surfaces and soil may also result in exposure to non-target organisms. Monitoring data indicate detections of glyphosate in surface waters and near field sites from use areas presumably due to current uses. These potential exposure pathways may result in adverse effects on the survival, growth, and/or reproduction of non-target terrestrial and aquatic organisms.*

5.2 Risk Estimation Overview

For this preliminary assessment of glyphosate and its salts, the deterministic risk quotient (RQ) method was used to provide a metric of potential risks. The RQ is a comparison of exposure estimates to toxicity endpoints (*i.e.*, RQ = EEC/toxicity endpoint). The resulting RQs are compared to the Agency's risk levels of concern (LOC), which are the Agency's interpretive policy such that when risk LOCs are exceeded, the need for regulatory action may be considered. These criteria are used to indicate when the use of a pesticide, as directed on the label, has the potential to cause adverse effects to non-target organisms. For acute and chronic exposures to non-listed animals (except for honeybees), the LOCs are 0.5 and 1.0, respectively and for non-listed and listed plants, the LOC is 1.0. For honeybees, the acute non-listed LOC is 0.4 and the chronic LOC is 1. For acute and chronic exposure to listed aquatic animals, the LOCs are 0.05 and 1.0, respectively. For acute and chronic exposure to listed terrestrial vertebrates, the LOCs are 0.1 and 1.0, respectively. For each taxa, RQs are generated.

5.2.1 Aquatic Organisms

5.2.1.1 Terrestrial Uses

5.2.1.1.1   Exposure from Runoff and Spray Drift Concurrently

Risk quotients were calculated by evaluating exposure from terrestrial applications that incorporated both runoff and spray drift. The EECs were calculated using GENEEC and were compared to the toxicity data from studies that used only the active ingredient glyphosate (no formulation data).

Table 30 indicates that neither the acute nor chronic LOCs are exceeded for aquatic plants, freshwater fish or invertebrates, aquatic-phase amphibians, or estuarine/marine fish or invertebrates compared with the highest estimated peak and 21 or 60-day average EEC values (RQs ≤0.06 for animals and RQs ≤0.19 for plants).

Table 30. Acute and Chronic RQs for Aquatic Organisms for Technical Glyphosate and its Salts

Duration	Taxa	EEC (mg a.e./L)	Toxicity Endpoint (mg a.e./L)[2]	RQ
Acute	Freshwater fish	0. 246[1] (peak)	43	<0.01
	Aquatic-phase amphibians		103	<0.01
	Estuarine/marine fish		240	<0.01
	Freshwater invertebrates		53.2	<0.01
	Estuarine/marine invertebrates		40	<0.01
	Aquatic non-vascular plants		11.4 / NR	0.022 / NA
	Aquatic vascular plants		11.9 / 1.3	0.021 / 0.19
Chronic	Freshwater fish	0.116 (60-d average)	25.7	<0.01
	Aquatic-phase amphibians		1.8	0.06
	Estuarine/marine fish		88.9	<0.01
	Freshwater invertebrates	0.185 (21-d average)	9.22	0.02
	Estuarine/marine invertebrates		13.7	0.03

[1] The peak, 21-d and 60-d EECs were the maximum EECs calculated using GENEEC (which incorporates both runoff and spray drift) based on the application rate for spot treatment which was converted into a lb a.e./A basis (40 lb a.e./A) and is assumed to be conservative as treatment of an entire acre at one time is not anticipated.
[2] All toxicity endpoints were adjusted to acid equivalents; acute endpoints refer to LC/EC_{50} values and chronic endpoints refer to NOAEC values for aquatic animals. For aquatic plants, the first toxicity value is the EC_{50} value (non-listed plants) and the second value is the $NOAEC/EC_{05}$ (listed plants). NR= not reported; NA = not applicable

5.2.1.1.2   Exposure from Spray Drift

Technical Glyphosate

Risk quotients were calculated by evaluating exposure from spray drift (alone) from terrestrial applications. EECs were calculated using AgDrift and reported in acid equivalents and were compared to the toxicity data from studies that used only the active ingredient glyphosate (no formulation data).

Table 31 indicates the acute LOCs are not exceeded for aquatic plants, freshwater fish or invertebrates or aquatic-phase amphibians or estuarine/marine fish or invertebrates with the peak EEC value (RQs ≤0.04).

Table 31. Acute RQs for Aquatic Organisms for Glyphosate Formulations (using Spray Drift EECs and Toxicity Data Adjusted to Acid Equivalents)

Duration	Taxa	EEC (mg a.e./L)	Toxicity Endpoint (mg a.e./L)[2]	RQ
Acute	Freshwater fish	0.0567[1] (peak)	43	<0.01
	Aquatic-phase amphibians		103	<0.01
	Estuarine/marine fish		240	<0.01
	Freshwater invertebrates		53.2	<0.01
	Estuarine/marine invertebrates		40	<0.01
	Aquatic non-vascular plants		11.4 / NR	<0.01 / NA
	Aquatic vascular plants		11.9 / 1.3	<0.01 / 0.04

[1] The peak EEC was the maximum EECs calculated based on the application rate for aerial application of a single application of 8 lb a.e./A using the default AgDrift parameters with the receiving body of water as the standard pond.
[2] All toxicity endpoints were adjusted to acid equivalents. For aquatic plants, the first toxicity value is the EC_{50} value (non-listed plants) and the second value is the $NOAEC/EC_{05}$ (listed plants). NR= not reported; NA = not applicable

Glyphosate Formulations

Formulations assumed to contain POEA: Risk quotients were calculated by evaluating exposure from spray drift from terrestrial applications. EECs were calculated using AgDrift and reported in acid equivalents and were compared to acute formulation toxicity values for aquatic organisms. The toxicity values used were for formulations assumed to contain POEA (allowed for terrestrial uses).

Table 32 indicates that the acute non-listed LOCs are not exceeded for either fish or aquatic-phase amphibians, invertebrates or aquatic plants following acute exposure to the formulation through spray drift. However, using a single maximum application rate of 8 lb a.e./A (non-ag uses) with an aerial application scenario, the RQs slightly exceeded the acute endangered species LOC for freshwater fish, aquatic-phase amphibians and estuarine/marine invertebrates (RQs = 0.06-0.07). With 8 lb a.e./A applied by ground application, the spray drift EEC (0.0276 mg a.e./L) result in RQs that are below the acute endangered species LOC for all taxa. The single maximum application rates for all uses other uses (<8 lb a.e./A) results in spray drift EECs for which RQ values are less than the acute endangered species LOC.

Table 32. Acute RQs for Aquatic Organisms for Glyphosate Formulations Assumed to Contain POEA (using Spray Drift EECs and Toxicity Data Adjusted to Acid Equivalents)

Duration	Taxa	EEC (mg a.e./L)	Toxicity Endpoint (mg a.e./L)[2]	RQ
Acute	Freshwater fish	0.0567[1] (peak)	1	**0.06**
	Aquatic-phase amphibians		0.8	**0.07**
	Estuarine/marine fish		2.7	0.02
	Freshwater invertebrates		1.6	0.03
	Estuarine/marine invertebrates		0.765	**0.07**
	Aquatic non-vascular plants		0.12 / 0.084[3]	0.47 / 0.68
	Aquatic vascular plants		1.5 / NR	0.04 / NA

[1] The peak EEC was the maximum EECs calculated based on the application rate for aerial application of a single application of 8 lb a.e./A using the default AgDrift parameters with the receiving body of water as the standard pond.

[2] All toxicity endpoints were adjusted to acid equivalents; data were from formulations assumed to contain POEA. Acute endpoints refer to LC/EC_{50} values for aquatic animals. For aquatic plants, the first toxicity value is the EC_{50} value (non-listed plants) and the second value is the $NOAEC/EC_{05}$ (listed plants). NR= not reported; NA = not applicable

[3] There are at least two labels with this formulation name. Because the formulations differ, it could not be determined if the formula used in the study was a POEA or non-POEA formulation

Formulations assumed to not contain POEA: Risk quotients were calculated by evaluating exposure from spray drift from terrestrial applications. EECs were calculated using AgDrift and reported in acid equivalents and were compared to acute formulation toxicity values for aquatic organisms. The toxicity values used were for formulations assumed to not contain POEA.

Table 33 indicates that the acute non-listed and listed LOCs are not exceeded for either fish or aquatic-phase amphibians, aquatic invertebrates or aquatic plants following acute exposure to the formulation through spray drift using a single maximum application rate of 8 lb a.e./A (non-ag uses) with an aerial application scenario (RQs < 0.01 for animals and ≤0.68 for plants).

Table 33. Acute RQs for Aquatic Organisms for Glyphosate Formulations Assumed to Not Contain POEA (using Spray Drift EECs and Toxicity Data Adjusted to Acid Equivalents)

Duration	Taxa	EEC (mg a.e./L)	Toxicity Endpoint (mg a.e./L)[2]	RQ
Acute	Freshwater fish	0.0567[1] (peak)	103	<0.01
	Aquatic-phase amphibians		328	<0.01
	Estuarine/marine fish		>50.9	<0.01
	Freshwater invertebrates		44.8	<0.01
	Estuarine/marine invertebrates		23.2	<0.01
	Aquatic non-vascular plants		0.12 / 0.084[3]	0.47 / 0.68
	Aquatic vascular plants		7.7 / 2.4	<0.01 / 0.02

[1] The peak EEC was the maximum EECs calculated based on the application rate for aerial application of a single application of 8 lb a.e./A using the default AgDrift parameters with the receiving body of water as the standard pond.
[2] All toxicity endpoints were adjusted to acid equivalents; data were from formulations assumed to not contain POEA. Acute endpoints refer to LC/EC$_{50}$ values for aquatic animals. For aquatic plants, the first toxicity value is the EC$_{50}$ value (non-listed plants) and the second value is the NOAEC/EC$_{05}$ (listed plants). NR= not reported; NA = not applicable
[3] There are at least two labels with this formulation name. Because the formulations differ, it could not be determined if the formula used in the study was a POEA or non-POEA formulation

POEA Only

Risk quotients were calculated by evaluating exposure from spray drift from terrestrial applications. EECs were calculated using a volume of formulation applied per acre, a spray drift fraction, and the simple dilution equation (using the standard pond scenario) and reported in mg POEA per liter. EECs were compared to acute toxicity values for aquatic organisms tested with only POEA.

Table 34 indicates that the acute non-listed LOCs are not exceeded for freshwater animals following acute exposure to the surfactant through spray drift, using an assumed percentage of POEA of 15%, until the single aerial application rate of >260 quarts formulation per acre is applied. For listed animals, the acute LOC is reached when 26 quarts formulation per acre is applied. An evaluation of the volume of formulation applied in a single application, using the LUIS reports, resulted in application volumes of < 1 quart up to 10 quarts per application.

Table 34. Acute RQs for Aquatic Organisms for POEA (using Spray Drift EECs and Toxicity Data Based on mg POEA/L)

Scenario[1]	EEC (mg POEA/L)[2]	Taxa (acute toxicity value (mg POEA/L))[3]		
		FW fish (0.7) (MRID 00162296)	Amphibian (0.47) (ECOTOX# 161671)	FW invert (9.1) (MRID 00162296)
		RQ		
Aerial - Standard Pond / (Qt formulate product/A)				
262	0.235	**0.34**	*0.50*	0.026
26.25	0.0236	0.034	**0.05**	<0.01
10	0.009	<0.01	<0.01	<0.01
5	0.0045	<0.01	<0.01	<0.01
Ground - Standard Pond / (Qt formulate product/A)				
540	0.236	**0.34**	*0.50*	0.026
53.75	0.0235	0.034	**0.05**	<0.01
10	0.004	<0.01	<0.01	<0.01
5	0.002	<0.01	<0.01	<0.01

[1] The scenario refers to the either aerial or ground application and the application rate of the formulation (quarts of formulation per acre).
[2] The peak spray drift EEC was the maximum EECs calculated based on the application rate for aerial/ground application using the defined application rate (Qt product/A) using the default AgDrift parameters with the receiving body of water as the standard pond.
[3] All toxicity endpoints were reported as mg POEA/L. Toxicity tested conducted using only surfactant. Acute endpoints refer to LC/EC$_{50}$ values
Bold values are RQ values that have exceeded listed animal acute LOC (0.05); bold and italicized values are RQ values that exceed the non-listed acute LOC (0.5).

5.2.1.2 Exposure from Application to Aquatic Environments

5.2.1.2.1   Technical Glyphosate

Risk quotients were calculated by evaluating exposure from application to aquatic environments. EECs were calculated using a Tier 1 dilution model in the standard pond and reported in acid equivalents and were compared to the toxicity data from studies that used only the active ingredient glyphosate (no formulation data)

Table 35 indicates that neither the acute nor chronic LOCs are exceeded for aquatic plants, freshwater fish or invertebrates or aquatic-phase amphibians or estuarine/marine fish or invertebrates with the highest estimated peak and 21 or 60-day average EEC values (acute animal RQs ≤0.01; chronic animal RQs ≤0.12; plant RQs ≤0.17).

Table 35. Acute and Chronic RQs for Aquatic Organisms for Technical Glyphosate and its Salts from Application to Aquatic Environments

Duration	Taxa	EEC (mg a.e./L)	Toxicity Endpoint (mg a.e./L)[2]	RQ
Acute	Freshwater fish	0.222[1] (peak)	43	<0.01
	Aquatic-phase amphibians		103	<0.01
	Estuarine/marine fish		240	<0.01
	Freshwater invertebrates		53.2	<0.01
	Estuarine/marine invertebrates		40	<0.01
	Aquatic non-vascular plants		11.4 / NR	0.019 / NA
	Aquatic vascular plants		11.9 / 1.3	0.019 / 0.17
Chronic	Freshwater fish	0.210 (60-d average)	25.7	<0.01
	Aquatic-phase amphibians		1.8	0.12
	Estuarine/marine fish		88.9	<0.01
	Freshwater invertebrates	0.218 (21-d average)	9.22	0.02
	Estuarine/marine invertebrates		13.7	<0.01

[1] The peak, 21-d and 60-d EECs were calculated using a Tier 1 dilution model in the standard pond based on the application rate for a single application of 8 lb a.e./A.
[2] All toxicity endpoints were adjusted to acid equivalents; acute endpoints refer to LC/EC_{50} values and chronic endpoints refer to NOAEC values for aquatic animals. For aquatic plants, the first toxicity value is the EC_{50} value (non-listed plants) and the second value is the $NOAEC/EC_{05}$ (listed plants). NR= not reported; NA = not applicable.

5.2.1.2.2   Formulations assumed to not contain POEA

Risk quotients were calculated by evaluating exposure from application to aquatic environments. EECs were calculated using a Tier 1 dilution model in the standard pond and reported in acid equivalents and were compared to the formulation toxicity values for aquatic organisms. The toxicity values used were for formulations assumed to not contain POEA.

Table 36 indicates that the acute non-listed and listed LOCs are not exceeded for either fish or aquatic-phase amphibians, aquatic invertebrates and aquatic vascular plants following acute exposure to the formulation through aquatic application using a single maximum application rate of 8 lb a.e./A (RQs < 0.01 for animals). However, the LOC for non-listed and listed plants were exceeded (RQs 1.9 & 2.6, respectively).

Table 36. Acute and Chronic RQs for Aquatic Organisms for Formulations Assumed to Not Contain POEA from Application to Aquatic Environments (Toxicity Data Adjusted to Acid Equivalents)

Duration	Taxa	EEC (mg a.e./L)	Toxicity Endpoint (mg a.e./L)[2]	RQ
Acute	Freshwater fish	0.222[1] (peak)	103	<0.01
	Aquatic-phase amphibians		328	<0.01
	Estuarine/marine fish		>50.9	<0.01
	Freshwater invertebrates		44.8	<0.01
	Estuarine/marine invertebrates		23.2	<0.01
	Aquatic non-vascular plants		0.12 / 0.084[3]	**1.9 / 2.6**
	Aquatic vascular plants		7.7 / 2.4	0.03 / 0.09

[1] The peak EEC was calculated using a Tier 1 dilution model in the standard pond based on the application rate for a single application of 8 lb a.e./A.
[2] All toxicity endpoints were adjusted to acid equivalents; data were from formulations assumed to not contain POEA. Acute endpoints refer to LC/EC_{50} values for aquatic animals. For aquatic plants, the first toxicity value is the EC_{50} value (non-listed plants) and the second value is the $NOAEC/EC_{05}$ (listed plants).
[3] There are at least two labels with this formulation name. Because the formulations differ, it could not be determined if the formula used in the study was a POEA or non-POEA formulation
NR= not reported; NA = not applicable
Bolded values exceed the non-listed and listed plant LOC of 1

5.2.2. Terrestrial Organisms

5.2.2.1 Birds

There were no mortalities in any of the acute avian studies with technical glyphosate. Therefore, no RQs were calculated. Additionally, for chronic exposure, the most sensitive endpoint was a non-definitive value from the mallard reproduction study (NOAEC <501 mg a.e./kg-diet). Therefore, chronic RQs using the most sensitive endpoint were no also not calculated in the Risk Estimation section. Potential acute and chronic risk to birds (surrogates for terrestrial-phase amphibians) from exposure to glyphosate is discussed in the Risk Description section.

However, there was one avian study that had a definitive acute toxicity value (LD_{50}: 1651 mg formulation/kg-bw (1131 mg a.e./kg-bw); MRID 45777402). The application rates from the specific label for which this study was submitted indicate an exceedance of the acute avian listed LOC for all use rates, including the highest rate (5.5 lbs formulation/A (industrial outdoors)) to the lowest rate (1.1 lbs formulation/A (ornamental lawns and turf)) (Table 37). The dose-based acute RQs range from <0.01 to 0.25 for the 1.1 lbs formulation/A rate to <0.01-1.26 for the 5.5 lb formulation/A. Single application rates of ≥2.2 and 0.5 lbs formulation/A results in acute non-listed and listed LOC exceedances, respectively (Table 37).

Table 37. Acute Avian RQs for Glyphosate Formulation

| Dose-based RQs (Dose-based EEC/adjusted LD$_{50}$) | Avian Acute RQs Size Class (grams) | | | | | |
| | 1.1 lb formulation/A | | | 5.5 lb formulation/A | | |
	20	100	1000	20	100	1000
Short Grass	*0.25*	*0.11*	0.04	**1.26**	**0.57**	*0.18*
Tall Grass	*0.12*	0.05	0.02	**0.58**	*0.26*	0.08
Broadleaf plants	*0.14*	0.06	0.02	**0.71**	*0.32*	*0.10*
Fruits/pods	0.02	0.01	0.00	0.08	0.04	0.01
Arthropods	*0.10*	0.04	0.01	**0.50**	*0.22*	0.07
Seeds	0.00	0.00	0.00	0.02	0.01	0.00
Bolded values exceed the acute non-listed LOC; bolded and italicized values exceed the acute listed LOC						

5.2.2.2 Mammals

As with birds, there were no definitive acute mammalian toxicity data available for technical glyphosate (LD$_{50}$ > 4800 mg a.e./kg-bw). Therefore, RQ values were not calculated.

Many acute oral toxicity studies with the rat have been conducted with formulations. As with the technical material, most of the LD$_{50}$'s are higher than the highest dose/concentrations tested. However, there were studies in which there are definitive LD$_{50}$'s where glyphosate is the only active ingredient. Label matches were conducted for each of these products to ensure they were still active registrations and had foliar uses. The highest application rate, in terms of pounds of formulated product was modeled and compared to the toxicity value (Table 38). Given that the dissipation rate for the different components in the formulation may differ over time, a single application was modeled to better represent the bolus dose of formulated product the animals received in the toxicity tests. For the formulation with the lowest LD$_{50}$ value (357 mg a.e./kg-bw) along the with the highest application rate of 7.2 lbs formulation/A, RQ values were calculated. The acute dose-based RQs for this acute toxicity value ranged from 0.03 to 2.10.

Table 38. Acute Dose-based RQs for Acute Toxicity tests with Formulations with Definitive LD$_{50}$ values

| Acute Mammalian LD$_{50}$ mg formulation/kg bw / LD$_{50}$ mg ae./kg bw (MRID No.) | Highest Labeled Use / Rate (lb a.e./A) | Acute RQs[1] (dose-based) | | |
		15g	35g	1000g
3803 /1175 (44918601)	Broadcast Bermuda grass, blueweed / 3.7 lb a.e./A	<0.01-0.33	<0.01-0.28	<0.01-0.15
5827 / 3811 (44615₅₀2)	Industrial / 7.53 lb a.e./A	<0.01-0.21	<0.01-0.18	<0.01-0.09
2686 / 1886 (40853903)	Broadcast perennials / 3.86 lb a.e./A	<0.01-0.21	<0.01-0.18	<0.01-0.10
3132 / 357 (46714802)	Broadcast brush / 7.2 lb a.e./A	0.03-2.10	0.02-1.79	0.01-0.96
1 LOC exceedances (acute listed LOC= 0.1; acute non-listed LOC=0.5) 2 Modeled a single application due to potential differences in dissipation rates of the various components in the formulation.				

Chronic mammalian RQs were calculated using the 2-generation mammalian reproduction data and the upper bound EECs. Dietary-based RQ values did not exceed the chronic LOC for any use pattern, except for the spot treatment use for the short grass and broadleaf plants dietary items (RQs = 1.92 and 1.08, respectively). Additionally, dose-based chronic RQs for large mammals did not exceed the LOC, except for the spot treatment use. However, dose-based chronic RQs did exceed the LOC for small mammals consuming short grass for aerial application to sugar cane as well as for most uses generally applied by ground applications up to the combined maximum annual rate (RQs 1.02-10.2). Additionally, for use on forests, pastures and other non-crop uses (rights-of-way), the RQ was exceeded for small mammals consuming broadleaf plants (RQ 1.15). For medium-sized mammals consuming short grass, again the RQs exceeded the LOC for most uses that for which glyphosate is applied by ground application up to the combined maximum annual rate (RQs 1.04-8.72). The RQs are presented in Table 39.

Table 39. Chronic Mammalian Dose-Based RQs for Foliar Application of Glyphosate

Food Item	Rangeland	Roundup ready-aerial, max combined annual	Roundup ready-aerial max rate/crop cycle	Most Crops-aerial max rate/crop cycle	Most crops-aerial max combined annual	Roundup ready ground max rate/crop cycle	Sugar cane-aerial max crop & annual	Tree crops-aerial max combined annual	Roundup ready ground max combined annual	Most crops-ground max crop & annual	Food tree, vine, berry, small fruit ground max combined annual	Forestry, pastures, non-crop	Spot Treatment
15 g Mammal													
Short Grass	0.27	0.68	0.62	0.84	0.90	0.96	**1.02**	**1.03**	**1.11**	**1.21**	**1.60**	**2.04**	**10.2**
Tall Grass	0.12	0.31	0.28	0.38	0.41	0.44	0.47	0.47	0.51	0.56	0.73	0.94	**4.68**
Broadleaf plants	0.15	0.38	0.35	0.47	0.51	0.54	0.57	0.58	0.63	0.68	0.90	**1.15**	**5.74**
Fruits/pods	0.02	0.04	0.04	0.05	0.06	0.06	0.06	0.06	0.07	0.08	0.10	0.13	0.64
Arthropods	0.10	0.27	0.24	0.33	0.35	0.37	0.40	0.40	0.44	0.48	0.62	0.80	**4.00**
Seeds	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.14
35 g Mammal													
Short Grass	0.23	0.58	0.53	0.71	0.77	0.82	0.87	0.88	0.95	**1.04**	**1.36**	**1.74**	**8.72**
Tall Grass	0.10	0.27	0.24	0.33	0.35	0.37	0.40	0.40	0.44	0.47	0.62	0.80	**4.00**
Broadleaf plants	0.13	0.33	0.30	0.40	0.43	0.46	0.49	$0._{50}$	0.53	0.58	0.77	0.98	**4.90**
Fruits/pods	0.01	0.04	0.03	0.04	0.05	0.05	0.05	0.06	0.06	0.06	0.09	0.11	0.54
Arthropods	0.09	0.23	0.21	0.28	0.30	0.32	0.34	0.35	0.37	0.41	0.53	0.68	**3.41**
Seeds	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.12
1000 g Mammal													

Short Grass	0.12	0.31	0.28	0.38	0.41	0.44	0.47	0.47	0.51	0.56	0.73	0.93	**4.67**
Tall Grass	0.06	0.14	0.13	0.18	0.19	0.20	0.21	0.22	0.23	0.25	0.33	0.43	**2.14**
Broadleaf plants	0.07	0.18	0.16	0.22	0.23	0.25	0.26	0.27	0.29	0.31	0.41	0.53	**2.63**
Fruits/pods	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.05	0.06	0.29
Arthropods	0.05	0.12	0.11	0.15	0.16	0.17	0.18	0.19	0.20	0.22	0.29	0.37	**1.83**
Seeds	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.06

5.2.2.3 Terrestrial Invertebrates

Definitive acute contact and oral honeybee LD_{50} toxicity values were not available ($LD_{50}S$ >100 µg/bee). Therefore, RQ values were not calculated in the Risk Estimation section. Evaluation of potential risk to terrestrial invertebrates/pollinators is discussed in the Risk Description section.

5.2.2.4 Terrestrial Plants

No effects on seedling emergence greater than 25% was observed after exposure to glyphosate formulations (IC_{25} > 5 lb a.e./A). Therefore, RQs for non-listed terrestrial plants using the seedling emergence data were not calculated. Additionally, NOAECs were reported as the highest concentration tested or were not reported. Potential risks to vegetative vigor were examined using AgDrift to calculate EECs from spray drift. Spray drift EECs were calculated using AgDrift and compared to the most sensitive vegetative vigor endpoint (IC_{25} for non-listed species and NOAEC for listed species) for both dicots and monocots (Table 40). As droplet size is not specified on the labels for all uses, spray drift EECs were calculated using AgDrift (v2.1.1), using the default droplet size, fine to medium for aerial and very fine to fine for ground (USEPA 2013).

Table 40. Ratio of Spray Drift Loading to Terrestrial Plant Vegetative Vigor Toxicity Endpoints

No. of application and app. rate (lb a.e/.A)	Initial Deposition Fraction (lb a.e./A)	Dicot (VV)[a]		Monocot (VV)[b]		Spray Method
		IC_{25}	NOAEC	IC_{25}	NOAEC	
Ratio of the loading at the edge of field to non-listed (IC_{25}) or listed ($NOAEC/IC_{05}$) toxicity value						
1 @ 3.75	1.87	25.3	38.2	11.7	26.7	Aerial
1 @ 8	4	54.0	81.6	25.0	57.1	
1 @ 3.75	3.75	50.7	76.5	23.4	53.5	Ground
1 @ 8	8	108	163	50.0	114	

[a] Based on reported toxicity in dicot species cucumber, *Cucumis sativus*, at IC_{25} of 0.074 lb a.e./A and NOAEC of 0.049 lb a.e./A in the vegetative vigor test.
[b] Based on reported phytotoxicity in monocot species sorghum, *Sorghum bicolor*, at IC_{25} of 0.16 lb a.e./A and NOAEC of 0.07 lb a.e./A in the vegetative vigor test.
Drift values based on: aerial - droplet size ASA.E. Fine to medium, ground – droplet size ASA.E. very fine to fine, high boom, 90th percentile

5.3 Risk Description

The risk description synthesizes an overall conclusion regarding the likelihood of adverse impacts to non-target taxa. The discussions below for each taxa includes discussion of RQs as well as consideration of additional data and lines of evidence with an overall conclusion of the likelihood of potential adverse effects for non-listed species.

5.3.1. Aquatic Organisms

5.3.1.1 Technical Glyphosate

Based on the lines of evidence for aquatic organisms, using standard screening methodology, the likelihood of direct effects to non-listed species from exposure to *technical glyphosate* based on the registered uses is anticipated to be low.

The RQ values from exposure from both runoff and spray drift and using glyphosate only toxicity data, were below the acute and chronic LOC for non-listed and listed aquatic species (acute animal RQs <0.01; chronic animal RQs ≤0.06; aquatic plant RQs ≤0.19). These RQs were calculated using modeled Tier 1 screening water concentrations. Targeted surface water monitoring data were available for glyphosate for which the highest reported concentration was 0.430 mg a.e./L. When this measured concentration is compared to the toxicity data above, the RQs are below the listed LOC for all taxa for both acute and chronic exposure (RQs: acute ≤0.01 for aquatic animal; chronic ≤0.24 for aquatic animals; aquatic plants ≤0.33).

For exposure from spray drift only, the RQs did not exceed the LOC for all aquatic organisms. While the available toxicity data for aquatic vascular plants do not indicate LOC exceedances, in general, the aquatic vascular plant toxicity studies are conducted with glyphosate exposure in the water column as oppose to overspray. As it is anticipated that emergent aquatic vegetation could be exposed to glyphosate via spray drift in the same manner as terrestrial plants and therefore, there may be potential risk. Toxicity data for three species of emergent aquatic plants using a glyphosate formulation were available and are discussed in the section below pertaining to risk from glyphosate formulations. Additionally, evaluation of glyphosate formulations to terrestrial plants is described in the terrestrial plant section below, and the calculated distances off-site of application would apply to emergent aquatic vegetation as well as terrestrial plants. As there are reported differential sensitivities between terrestrial plant species, as well as for other taxa, it is anticipated that not all emergent aquatic plants may be affected equally following spray drift alone. Based on the terrestrial plant toxicity data and spray drift analysis using AgDrift, off-site distances required to be below toxicity thresholds could be over 1000 feet based on the most sensitive endpoint (cucumber, vegetative vigor).

For application to aquatic environments, neither the acute nor chronic LOCs are exceeded for aquatic plants, freshwater fish or invertebrates or aquatic-phase amphibians or estuarine/marine fish or invertebrates with the highest estimated peak and 21 or 60-day average EEC values (acute animal RQs ≤0.01; chronic animal RQs ≤0.12; plant RQs ≤0.17). However, as discussed above, glyphosate is registered for use to control emergent aquatic vegetation, it is presumed that target and non-target aquatic emerged vegetation may be affected by application to aquatic

environments. Aquatic vegetation is an important component of an aquatic ecosystem, as it provides food and habitat for other aquatic organisms.

Toxicity data using technical glyphosate were available in the open literature. While they were not used in the risk quotient calculations, some of the uncertainties in the studies discussed in the Dose-Response section, they were used to further characterize potential risk. The toxicity values for these studies included acute EC/LC_{50} values for fish (4 species Pacific salmonids 96-hr LC_{50}s 10-211 mg a.i./L); freshwater mussels (48-hr EC_{50} of 5.0 mg a.e./L); estuarine/marine mollusks (Pacific oyster 48 hr EC_{50} of 28.3 mg a.e./L); aquatic non-vascular species (EC_{50}s 7.1->169,000 mg a.e./L); copepods (*Acartia tonsa* 48-hr LC50 of 35.3 mg a.e./L); crustaceans (*Daphnia magna* 48 hr EC_{50}s 1.4 – 7.2 mg a.i./L (unsure if adjusted for acid equivalents) and chronic toxicity data for *Daphnia magna*. In Cuhra *et al.* 2013, a 55-d chronic toxicity test with technical glyphosate, the reported NOAEC was 0.45 mg a.i./L (0.33 mg a.e./L- reviewer calculated), based on reduction in fecundity. Comparing this toxicity value to the chronic 60-d EEC (0.116 mg a.e./L; spot treatment), the toxicity value is greater than the EEC. In regards to acute toxicity, one-twentieth of the reported acute toxicity values (1/20th correlates to acute listed LOC of 0.05) are greater than the calculated EEC for an aerial application of 8 lb a.e./A (1.4/20 = 0.07 mg/L compared to EEC of 0.0596 mg a.e./L). While this 1/20th acute toxicity value is lower than the peak EEC for the spot treatment (0.246 mg a.e./L based on 40 lb a.e./A), given the extrapolation from a spot treatment to an acre application, the EECs are anticipated to be lower than calculated. Therefore, these data are consistent with the data presented above in that it suggests that potential risk to non-listed and listed aquatic animals and aquatic non-vascular plants is low from exposure to glyphosate alone.

Incident data for glyphosate for fish are available. In some of the incidences, concerns with water quality (low dissolved oxygen) or overcrowding were reported as potential reasons for the observed mortalities. It is noted that current glyphosate formulations that are registered for direct application to water do not contain the surfactant POEA, which is known to enhance toxicity in aquatic ecosystems. With regard to potential runoff of POEA from a terrestrial application site, it is anticipated to dissipate quickly and may not be available during runoff events, but it may be available in aquatic systems via spray drift from terrestrial applications. It is unknown to what extent POEA may have been present in the water for the reported incidences, but at least for some of the reports, it appears that stressors other than glyphosate may have contributed to the observed toxicity

5.3.1.2 Glyphosate Formulations

1) Terrestrial Applications

For exposure from spray drift from terrestrial formulations (that may or may not contain POEA; toxicity data adjusted to acid equivalents), the likelihood of direct effects to non-listed aquatic animals and aquatic non-vascular and submerged aquatic vascular plants is anticipated to be low (acute RQs ≤0.07 for animals and RQs ≤0.68 for plants). However, for emergent vascular plants, there is a potential for risk based on toxicity data for both emergent aquatic plant and terrestrial plants and anticipated use profile of glyphosate. Toxicity studies evaluating effects of overspray exposure to three species of emergent aquatic plant species indicated effects on fresh weight for

all three species (most sensitive EC_{25} values for the three species ranged from 0.039-0.47 lb a.e./A). Assuming an application of 8 lb a.e./A, the AgDrift EEC at the edge of field (using default parameters) is approximately 4 lb a.e./A, which is substantially greater than the reported EC_{25} values for the emergent aquatic plants. With respect to the terrestrial plant toxicity data, off-site distances required to be below toxicity thresholds could be over 1000 feet based on the most sensitive endpoint (cucumber, vegetative vigor).

As mentioned above, at the maximum application use rate (8 lb a.e./A aerial application scenario), the acute endangered species LOC is exceeded slightly (0.06-0.07) for freshwater fish, aquatic-phase amphibians and estuarine/marine invertebrates. However, for the ground application scenario, the acute endangered species LOC is not exceeded for any taxa. If applying by air, then application rates of 5.4 lb a.e./A and lower will result in RQs less than the acute endangered species LOCs.

The previous RQs were based on toxicity values for glyphosate formulations that were adjusted to acid equivalents. Calculations of RQs were also conducted for glyphosate formulations calculated using toxicity and spray drift EEC values based on mg formulation/L. RQs for acute exposure for a sub-set of formulation application volumes, application methods and receiving water bodies are presented in Table 41. The application rates presented in the table represent the application rate necessary to exceed the acute listed, non-listed LOC and the non-listed aquatic plant LOC. Based on the amount of formulation necessary to exceed the non-listed LOC, the likelihood of potential risk from spray drift exposure is anticipated to be low. The amount of formulation applied in a single application would need to exceed 13 quarts/A for aerial and 28 for ground application in order to exceed the endangered species LOC. Based on the application volumes derived from the LUIS report, the maximum single application volume was 10 quarts per acre.

Table 41. Acute RQs for Aquatic Organisms for Glyphosate Formulations (using Spray Drift EECs and Toxicity Data Based on mg Formulation/L)

Scenario[1]	Peak EEC (mg form/L)[2]	FW fish (3.17)	Amph. (1.64)	EM fish (8.8)	FW invert (5.3)	EM invert (2.45)	Non-Vasc plant (0.39 / 0.27)	Vas plant (4.9 / NR)
		Taxa (acute toxicity value (mg formulation/L))[3]						
		RQ						
Aerial - Standard Pond /(Qt formulated product/A)								
137	0.82	*0.26*	**0.5**	*0.09*	*0.15*	*0.33*	**2.1 /3.0**	0.17
66	0.395	*0.12*	*0.24*	0.04	*0.07*	*0.16*	**1.01 /1.5**	0.08
45	0.269	*0.08*	*0.16*	0.03	*0.05*	*0.11*	0.69 *1.0*	0.05
13.75	0.082	0.026	*0.05*	0.009	0.015	0.03	0.21 /0.3	0.017
Ground - Standard Pond /(Qt formulated product/A)								
282	0.82	*0.26*	**0.5**	*0.09*	*0.15*	*0.33*	**2.1 /3.0**	0.17
135	0.393	*0.12*	*0.24*	0.04	*0.07*	*0.16*	**1.01 /1.5**	0.08
93	0.271	*0.09*	*0.16*	0.03	*0.05*	*0.11*	0.69 / *1.0*	0.06
28.25	0.082	0.026	*0.05*	0.009	0.015	0.03	0.21 / 0.3	0.017

[1] The scenario refer to the either aerial or ground application and the application rate of the formulation (quarts of formulation per acre).

[2] The peak spray drift EEC was the maximum EECs calculated based on the application rate for aerial/ground application using the defined application rate (Qt product/A) using the default AgDrift parameters with the receiving body of water as the standard pond.

[3] All toxicity endpoints were reported as mg formulation/L; data were from formulations assumed to contain POEA. Acute endpoints refer to LC/EC_{50} values for aquatic animals. For aquatic plants, the first toxicity value is the EC_{50} value (non-listed plants) and the second value is the NOAEC/EC05 (listed plants). NR= not reported; NA = not applicable

Bold values are RQ values that have exceeded the non-listed aquatic animal LOC (0.5) or the non-listed aquatic plant LOC (1); the bold and italicized value is the RQ that exceeds the listed animal LOC (0.05).

As with technical glyphosate, additional glyphosate formulation toxicity data were reported in the open literature that, while not used for calculation in the RQs, were used to characterize risk to aquatic animals and plants. The toxicity values for these studies included acute mortality values for aquatic vertebrates and invertebrates and chronic toxicity data for growth and development of amphibians and invertebrates. Chronic EECs for spray drift were not calculated as the drift event is anticipated to be short in duration (shortly after application), and the peak EEC (0.0567 mg a.e./L based on 8 lb a.e./A) was used as a conservative estimation when comparing to the reported chronic toxicity values. The reported toxicity values for aquatic animals are greater than one-half the calculated EEC, and therefore, these data are consistent with the data presented above in that it suggests that potential risk to non-listed aquatic animals is low from exposure to glyphosate.

Wan *et al*., 1989, reported acute LC_{50} values of ≥11 mg formulation/L (41% glyphosate IPA) for glyphosate formulations for fish, which are substantially greater than the EEC value. Significant decreases in growth (body length and body weight gain) were reported for fish, *Leporinius obtusidens*, at glyphosate formulation concentrations of 1 mg/L which was the lowest concentration tested (Salbego *et al.* 2010). Food consumption and condition factor (weight/length) were not affected by glyphosate exposure. The peak EEC for spray drift was 0.0567 mg a.e./L, which is approximately 18 times lower than the lowest concentration tested in the chronic fish study. For the acute toxicity to larval amphibian species collected as embryos in

the Pacific Northwest (E161728, King and Wagner 2010), the most sensitive LC_{50} values ($LC_{50}s$ 0.30-2.6 mg a.i./L; unsure if adjusted for acid) were greater than one-twentieth the spray drift EEC (corresponds to the acute LOC of 0.05 for listed aquatic animals). While control treatments were used in the study, control performance was not reported; therefore, there is uncertainty in the performance of the control animals. Decreased survival and/or delayed metamorphosis in two amphibian species exposed to glyphosate formulations was reported at a test concentration of 0.572 mg a.e./L (approximately 10X greater than EEC) (E153825, Williams and Semlitsch 2010). Several mesocosm studies which included aquatic-phase amphibians were conducted using glyphosate formulations with reported LC_{50} values ranging around 1 to 3 mg a.i./L, with the exception of 0.55 mg a.i./L for the wood frog in the presence of the caged predator (approximately 10X greater than EEC) (Relyea 2005).

Acute toxicity values were available for different aquatic invertebrates (mussels, copepods, crustaceans, amphipods) with EC/LC_{50} values of ≥ 1.5 mg a.e./L which are greater than the EEC. Additionally, for the Pacific oyster (E16155, Mottier *et al*. 2013), the toxicity value for the abnormality rate (48-hr EC_{50} 1.13 mg a.e./L) was one-twentieth the spray drift EEC, however, the mortality and metamorphosis endpoints were greater than one-twentieth the EEC. In a chronic study with *Daphnia magna* (Cuhra *et al*. 2013), the NOAEC, based on fecundity, was 0.15 mg/L with testing with a formulation and this NOAEC is less than the peak spray drift EEC. The reported effect levels on metamorphosis development in two species of frogs were greater than the EEC.

For the aquatic vascular plant, *Lemna minor*, the reported toxicity values (LOAEC/NOAEC; 0.020 mg/L) are less than the EEC. In this study, growth rate inhibition compared to control did not exceed 25% and the photosynthetic endpoint inhibition did not exceed 10% compared to the control. The growth rate was calculated using an applied coefficient, based on maturation stage, therefore, there is uncertainty in the actual growth rate (absent of a subjective coefficient) in this study. Another study with a rooted macrophyte was available, whereas glyphosate was exposed in the water column (E161695). In this study, it is not known if the formulation contained POEA or not, but the reported toxicity values for growth are similar to other formulations that contain POEA. The lowest toxicity value (14-d EC_{50} of 0.22 mg/L) in this study was higher than the spray drift EEC. However, there is concern for potential risk to emergent aquatic vascular plants as discussed in the above sections.

Sediment toxicity data were not available for glyphosate. However, given the fate properties of glyphosate, it is anticipated that it may bind to soil particles and partition to the sediment from runoff and/or spray drift. Acute water column toxicity data to a sediment-dwelling amphipod, *Hyalella azteca*, exposed to three different glyphosate formulations were available (Tsui and Chu 2004). Based on the available data, two of the formulations do not appear to contain POEA, however, the third formulation, Roundup, was reported to contain POEA. Based on the reported acute toxicity value for *Hyalella*, it appears to be of similar sensitivity to glyphosate formulations as other aquatic animals. Therefore, based on available data indicating relatively similar sensitivity across taxa to glyphosate and glyphosate formulations, the lack of benthic toxicity data is not anticipated to impact the overall risk conclusions for aquatic invertebrates.

While the reported Log K_{ow} value for glyphosate does not suggest that glyphosate would bioaccumulate, a water column exposure bioconcentration study with sediment-dwelling *Lumbriculus variegatus* was available. The reported 96-hr BCF values ranged from 1.2 – 2.8 for technical glyphosate and 1.4-5.9 for the formulation. While not reported explicitly in the report, based on the reported data, there did not appear to be any effects on survival at these test concentrations.

2) Aquatic Applications

For application to aquatic environments**,** the acute non-listed and listed LOCs are not exceeded for either fish or aquatic-phase amphibians, aquatic invertebrates and aquatic vascular plants following acute exposure to the formulation through aquatic application using a single maximum application rate of 8 lb a.e./A (RQs < 0.01 for animals). However, the LOC for non-listed and listed aquatic non-vascular plants were exceeded (RQs 1.9 and 2.6, respectively). For the toxicity value for the non-vascular aquatic plant, it is noted that due to the available formulation information, it is not definitively known whether or not the test material contained POEA. The next lowest toxicity formulation toxicity value for the non-vascular plants was for green algae with an EC_{50} value of 0.68 mg a.e./L (NOAEC 0.43 mg/L) which is greater than the peak EEC (0.210 mg a.e./L). Additionally, while the available toxicity data for aquatic vascular plants do not indicate LOC exceedances, toxicity value for emergent aquatic plants indicate potential effects at application rates of 0.039 to 0.47 lb a.e./A. The maximum single application rate to aquatic environments (direct application to water in an effort to control emergent aquatic vegetation) is 8 lb a.e./A, therefore, non-target aquatic vegetation may be affected. Aquatic vegetation is an important component of an aquatic ecosystem, as it provides food and habitat for other aquatic and other organisms.

Calculations of RQs were also conducted for glyphosate formulations calculated using toxicity and EEC values based on mg formulation/L. RQs for acute exposure for a sub-set of formulation application volumes are presented in Table 42. The acute toxicity values presented in the table are from formulations assumed to not contain POEA, as registrations for direct application to aquatic environments do not contain POEA. The application rates presented in the table represent the application rate necessary to exceed the acute listed, non-listed LOC and the non-listed aquatic plant LOC. For direct application to water, there is a potential for direct effects to non-listed aquatic non-vascular plants for direct applications of 8.25 quarts formulation/A or greater. Based on the LUIS report, the single application volume for the registered labels did not exceed 8 quarts except for one label which was registered for use in aquatic environments. However, the maximum single application volume for aquatic environments is 5 quarts per acre with a product seasonal maximum application rate of 10 quarts per acre.

Table 42. Acute RQs for Aquatic Organisms for Glyphosate Formulations (Using Direct Application EECs and Toxicity Data Based on mg Formulation/L)

Scenario[1]	EEC (mg form/L)[2]	Taxa (acute toxicity value (mg formulation/L))[3]						
		FW fish (750)	Amphib (911)	EM fish (>180)	FW invert (164)	EM invert (82)	Non-Vasc plant (0.39 / 0.27)[3]	Vas plant (25 / 7.9)
		RQ						
Direct application - Standard Pond / (Qt formulated product/A)								
1	0.047	<0.01	<0.01	<0.01	<0.01	<0.01	0.12	<0.01
5.7	0.270	<0.01	<0.01	<0.01	<0.01	<0.01	0.69 / 1.0	<0.01
8.25	0.390	<0.01	<0.01	<0.01	<0.01	<0.01	**1.0 / 1.4**	0.016 / 0.05
19.5	0.922	<0.01	<0.01	<0.01	<0.01	0.011	**2.4 / 3.4**	0.037 / 0.12
86.75	4.1	<0.01	<0.01	<0.01	<0.01	*0.05*	**10.5 / 15**	0.16 / 0.52

[1] The scenario refer to direct application and the application rate of the formulation (quarts of formulation per acre).
[1] The peak EEC was the maximum EECs calculated based on the application rate for direct application using the defined application rate (Qt product/A) using the simple dilution model with the receiving body of water as the standard pond.
[2] All toxicity endpoints were reported as mg formulation/L; data were from formulations assumed to not contain POEA. Acute endpoints refer to LC/EC_{50} values for aquatic animals. For aquatic plants, the first toxicity value is the EC_{50} value (non-listed plants) and the second value is the NOAEC/EC05 (listed plants).
[3] There are at least two labels with this formulation name. Because the formulations differ, it could not be determined if the formula used in the study was a POEA or non-POEA formulation
NR= not reported; NA = not applicable
Bold values are RQ values that have exceeded the non-listed aquatic animal LOC (0.5) or the non-listed aquatic plant LOC (1); the bold and italicized value is the RQ that exceeds the listed animal LOC (0.05).

5.3.1.3 POEA

The acute LOCs are not exceeded for freshwater animals following acute exposure to the surfactant through spray drift, using an assumed percentage of POEA of 15%, until the single aerial application rate of 26 quarts formulation per acre is applied. Based on an evaluation of the potential volume of formulation applied, volumes of 26 quarts or larger are not expected in a single application.

The calculations above for POEA are based on an assumed percentage of POEA in a formulation of 15%. An evaluation was conducting to consider if the actual percentage of POEA in a formulation is different than 15%. Using the acute toxicity value for amphibians (0.47 mg POEA/L), the percentage of POEA in a formulation applied to exceed the non-listed (EEC of 0.235 mg/L corresponds to a LOC of 0.5) and listed (EEC of 0.0235 mg/L; LOC of 0.05) LOC was calculated. These percentages were calculated for both aerial and ground applications using AgDrift to estimate the concentration in an adjacent water body (standard pond) (Table 43). Based on aerial application, a formulated product volume of 8.25 quarts/A (applied as a single application), would require a POEA percentage of 47% to exceed the listed LOC. For ground application, a volume of 8 quarts/A would require 100% POEA to exceed the listed LOC. For non-listed animals, 39 quarts/A would need to be applied for aerial application and 81 quarts/A for ground application with POEA percentages of 100%. While the calculations were based on a single application, given that the allowed re-application interval for most crops is 7 days, there is a possibility of overlap between resident times of the formulation in the aquatic systems.

Therefore, total amount of formulation applied should be considered when consulting this table. However, based on the necessary volume of formulated product needed to exceed the LOC, the likelihood of potential risk to from POEA exposure via spray drift is anticipated to be low based on the parameters used in the analysis.

Table 43. The Percentage of POEA in Terrestrial Formulations to Exceed the Non-listed and Listed LOC for animals.

Quart formulated product/A Applied (as a single application)	Conc in pond (µg formulated product/L)	% of POEA needed to exceed **non-listed** LOC for animals based on lowest acute tox value (0.47 mg/L, Amphibian (470 ug/L))[1]	% of POEA needed to exceed **listed** LOC for animals based on lowest acute tox value	Qt formulated product/A	Conc in pond (ug formulated product/L)	% of POEA needed to exceed **non-listed** LOC for animals based on lowest acute tox value (0.47 mg/L, Amphibian (470 ug/L))	% of POEA needed to exceed **listed** LOC for animals based on lowest acute tox value
Aerial Applications (12.66% spray drift fraction)				Ground Applications (6.16% spray drift fraction)			
39	235	100	15.7	80.75	235	100	10
20	120	>100	19.6	20	58.2	>100	40.3
10	59.8	>100	39.3	8	23.3	>100	100
8.25	49.4	>100	47.6	--	--	--	--
[1] Example calculations: [EEC/0.47 = 0.5] EEC=235; % POEA = (235/Conc formulation in pond) * 100							

5.3.1.4 Characterization for Non-Standard Adjacent Waterbodies

The discussions above for technical, formulated product, and POEA are based on EECs using the standard pond scenario. It is possible that shallower bodies of water may also be exposed to glyphosate via spray drift, runoff, or direct application. As such, for characterization purposes, additional formulated product and POEA spray drift EECs were calculated to represent a shallower body of water (1,000,000 liters) than the pond (20,000,000 liters). Again, the assumption was a 15% POEA concentration. For glyphosate formulations assumed to contain POEA, application rates of 0.69 and 1.4 quarts/A for aerial and ground application, respectively, would result in RQ values that exceed the listed aquatic animal LOC (Table 44). For non-listed animals, application rates of 6.9 and 14.1 quarts/A for aerial and ground application, respectively, would exceed the non-listed acute LOC. For aquatic plants, application rates of around 3 and 7 quarts/A (aerial and ground, respectively) would exceed the non-listed LOC. Based on the evaluation of possible formulation application volumes, volumes of 1 to 2 quarts are possible for a single application. The total applied volumes for some uses on a yearly basis can also reach 10 quarts.

Table 44. Comparisons of Shallow Waterbody EECs to Toxicity Data for Aquatic Organisms for Glyphosate Formulations (using Spray Drift EECs and Toxicity Data Based on mg Formulation/L)

Scenario[1]	EEC (mg form/L)[2]	Taxa (acute toxicity value (mg formulation/L))[3]						
		FW fish (3.17)	Amphib (1.64)	EM fish (8.8)	FW invert (5.3)	EM invert (2.45)	Non-Vasc plant (0.39 / 0.27)	Vas plant (4.9 / NR)
		Comparison of EEC/toxicity value						
Aerial - Shallow Water Body / (Qt formulated product/A)								
6.9	0.826	*0.26*	**0.5**	*0.09*	*0.16*	*0.34*	**2.1 / 3.1**	0.17
3.3	0.395	*0.12*	*0.24*	0.04	*0.07*	*0.16*	**1.01 /1.5**	0.08
2.25	0.269	*0.08*	*0.16*	0.03	*0.05*	*0.11*	0.69 /**1.0**	0.05
0.69	0.0826	0.026	*0.05*	0.009	0.016	0.034	0.21/ 0.31	0.017
Ground - Shallow Water Body / (Qt formulated product/A)								
14.1	0.82	*0.26*	**0.5**	*0.09*	*0.16*	**0.34**	**2.1 / 3.1**	0.17
6.75	0.393	*0.12*	*0.24*	0.04	*0.07*	*0.16*	**1.01 /1.5**	0.08
4.65	0.271	*0.09*	*0.16*	0.03	*0.05*	*0.11*	0.69 / **1.0**	0.06
1.4	0.082	0.026	*0.05*	0.009	0.016	0.034	0.21/0.31	0.017

[1] The scenario refer to the either aerial or ground application and the application rate of the formulation (quarts of formulation per acre).

[2] The peak spray drift EEC was the maximum EECs calculated based on the application rate for aerial/ground application using the defined application rate (Qt product/A) using the default AgDrift parameters with the receiving body of water as a shallower body of water (10E5L).

[3] All toxicity endpoints were reported as mg formulation/L; data were from formulations assumed to contain POEA. Acute endpoints refer to LC/EC_{50} values for aquatic animals. For aquatic plants, the first toxicity value is the EC_{50} value (non-listed plants) and the second value is the NOAEC/EC05 (listed plants). NR= not reported; NA = not applicable

Bold values are values that have exceeded the non-listed aquatic animal LOC (0.5) or the non-listed aquatic plant LOC (1); the bold and italicized value is the value that exceeds the listed animal LOC (0.05).

Comparisons for the POEA toxicity data, based on an assumption of 15% POEA in a formulation, were also calculated. Therefore, the amount of formulation applied that would be required to exceed the endangered species LOC is much lower and would be reasonable for a single application (Table 45).

Table 45. Comparisons of Shallow Waterbody EECs to Toxicity Data for Aquatic Organisms for POEA in Glyphosate Formulations (using Spray Drift EECs and Toxicity Data Based on mg POEA/L)

Scenario[1]	EEC (mg POEA/L)[2]	Taxa (acute toxicity value (mg POEA/L))[3]		
		FW fish (0.7)	Amphibian (0.47)	FW invert (9.1)
		Comparison of EEC/toxicity value		
Aerial - Standard Pond / (Qt formulated product/A)				
13.1	0.235	***0.34***	**0.5**	0.03
1.3	0.0233	0.03	***0.05***	0.003
Ground - Standard Pond / (Qt formulated product/A)				
27	0.235	***0.34***	**0.5**	0.03
2.7	0.0236	0.03	***0.05***	0.003

[1] The scenario refers to the either aerial or ground application and the application rate of the formulation (quarts of formulation per acre).

[2] The peak spray drift EEC was the maximum EECs calculated based on the application rate for aerial/ground application using the defined application rate (Qt product/A) using the default AgDrift parameters with the receiving body of water as the shallower water body (10E5L).

[2] All toxicity endpoints were reported as mg POEA/L. Acute endpoints refer to LC/EC_{50} values

Bold values are values that have exceeded non-listed animal acute LOC (0.5); bold and italicized value is the value that exceeds the listed animal LOC (0.05).

Toxicity data are not currently available for estuarine/marine animals for POEA (Tsui and Chu 2003 tested POEA with the estuarine/marine amphipod, *Acartia tonsa*, but reported toxicity values in terms of mg a.e/L). However, based on reported similar sensitivities to technical glyphosate between freshwater and estuarine/marine fish and invertebrates, differential sensitivity is not anticipated. Other toxicity data for POEA and/or MON 0818 were available, primarily for aquatic invertebrates, in which acute toxicity values were generally similar to the lowest toxicity values used in the evaluations in the Risk Estimation section (approximately 0.5 mg/L or greater). Lower toxicity values were reported for the fairy shrimp (Brausch and Smith, 2007); however, there is uncertainty in these values based on other toxicity data for the fairy shrimp. Therefore, comparing these toxicity values for aquatic invertebrates results in similar conclusions when utilizing the toxicity data for aquatic-phase amphibians.

In regards to direct application to water, the peak EEC for a single application of 1 quart per acre is 0.945 mg formulation/L (Table 12), which is greater than the acute toxicity value for non-listed non-vascular aquatic plants (EC_{50} = 0.39 mg formulation/L). For 10 quarts/A, the EEC (9.45 mg formulation/L) is less than the acute toxicity value for other taxa (based on formulations assumed to not contain POEA).

5.3.2. Terrestrial Organisms

5.3.2.1. Birds (surrogates for terrestrial-phase amphibians)

Acute Exposure

There were no mortalities in any of the acute avian studies with technical glyphosate with the bobwhite quail or mallard duck. A definitive LD or LC_{50} value was not determined for studies using technical glyphosate, therefore, no RQs were calculated. The highest dose/concentrations tested in the acute avian studies were >3196.3 mg a.e./kg bodyweight (83% technical) and >4971.2 mg a.e./kg diet (95.6% technical); both with bobwhite quail. For the bobwhite and mallard toxicity studies using technical material, there were no sublethal effects, except for a slight reduction in body weight gain at the highest dose in acute oral bobwhite quail study (observed NOAEL = 1481 mg a.e./kg-bw). Additionally, for the passerine species, canary, the acute LD_{50} was >2000 mg a.e./kg bodyweight. In this study, there were no mortalities at 2,000 mg a.e./kg-bw with one mortality observed at 3,300 mg a.e./kg-bw (observed NOAEL = 2000 mg a.e./kg-bw). In the study with the canary, regurgitation was observed at 3300 mg a.e./kg-bw (only observed at this dose in the definitive test with almost all the birds exhibiting this effect, however, no birds were observed regurgitating at this dose in rangefinder). An effective dose (ED_{50}), based on regurgitation, was calculated to be 2819 mg ae/kg-bw. The ability to retain food, due to regurgitation, may be an adverse effect, if other uncontaminated food sources are not readily available and/or the bird is unwilling to leave the area due to territorial or reproduction behavior. Additionally, the energetic resources in locating other amendable food sources may have a negative impact on the overall fitness of the bird.

For the canary and bobwhite quail, at the application rate of 8 lb a.e./A, the short grass EEC is less than the highest dose tested (for 20g bird: EEC = 2187 mg ae/kg-bw; Highest Dose= 3139 mg ae/kg-bw for canary and 2302 mg a.e./kg-bw for bobwhite). This EEC (adjusted for a 20g bird) is greater than the observed NOAEL for the bobwhite quail (1067 mg a.e./kg-bw; adjusted for a 20 g bird), and just slightly above the NOAEL for the canary (1902 mg a.e.kg-bw adjusted for a 20 g bird). For the spot treatment application, which was adjusted to a per acre basis of 40 lb a.e./A, the EEC is greater than the highest dose tested (adjusted for 20g bird: EEC = 10,933 mg a.e./kg-bw; Highest dose= 2302 mg ae/kg-bw). However, as it is not expected that an entire acre will be treated using spot treatment methods, this comparison is conservative. If using the ED_{50} value based on regurgitation as a definitive endpoint for calculating RQs using T-REX, at a single application of 8 lb a.e./A, all RQs are <0.5 (LOC for non-listed birds), except for a small exceedance for small birds consuming short grass (RQ=0.82 based on upper bound EECs). The RQs are less than the LOC based on mean EECs. For all other uses (except for extrapolated spot treatment), the RQs are less than the LOC. For the subacute dietary based study, the highest EEC (short grass) from a single application rate of 8 lb a.e./A (1920 mg a.e./kg-diet) is less than the highest concentration tested (4971 mg a.e./kg-diet). Overall, based on this analysis, it appears that the likelihood of acute risk from exposure to glyphosate alone is anticipated to be low.

There was one avian study that had a definitive acute toxicity value (MRID 45777402). The application rates from the specific label for which this study was submitted indicate an

exceedance of the acute avian listed LOC for all use rates (acute RQs <0.01 to 1.26). Single application rates of ≥2.2 and 0.5 lbs formulation/A results in acute non-listed and listed LOC exceedances, respectively.

Chronic exposure

Given that the most sensitive endpoint in an avian reproduction study resulted in a non-definitive NOAEC (effects on mallard duck male (↓127%) and offspring body weight (↓11%) at 501 mg a.e./kg-diet; NOAEC <501 mg a.e./kg; MRID 48876602), chronic avian RQs were not presented in the Risk Estimation section. There were no treatment-related effects on eggs laid, embryo viability, or eggshell thickness in this study up to 2160 mg a.e./kg-diet. In an additional mallard duck reproduction study, there were no reported treatment-related effects on reproduction or growth up to concentrations of 830 mg a.e./kg-diet (MRID 00111953). In this study, body weights were not examined by sex, rather an overall treatment group mean body weight of the exposure birds was reported (5 pens each containing 5 males and 2 females). At 830 mg a.e./kg-diet, body weight gain between test initiation and termination was decreased 25% compared to the control; however, one mortality occurred at this treatment level whereas there were no mortalities in the control (reviewer visual assessment of data; not enough data reported for statistical analysis). In the bobwhite mallard reproduction study, there were also no reported treatment-related effects up to 830 mg a.e./kg-diet (MRID 00108207).

In a study by Kubena *et al*. 1981 (E162010), chickens were exposed to Roundup® in their diet for 21 days. A significant (50%) reduction in male and female body weight by day 7 of the test was reported at 6080 mg/kg-diet which is greater than the highest EEC. No effects were reported at 608 mg/kg-diet, however, it is noted that there was a 10-fold difference in test concentration between the NOAEC and LOAEC therefore, there is uncertainty in where the threshold for an adverse effect may occur.

When modeling the exposure scenario for the forest, pasture and non-crop uses (8 lb a.e./A, the highest single application rate), the EECs (short grass) are greater than the bobwhite NOAEC, which is the highest concentration tested, for a period of about 3 weeks for which the EECs do drop below the NOAEC (Figure 7). The EECs are greater than the non-definitive NOAEC in the mallard study for male and offspring body weights (501 mg a.e./kg-diet) for about 4 weeks. The EECs are less than the highest concentration tested in the mallard (2160 mg a.e./kg-diet) where there were no treatment-related effects on the reproductive parameters including eggs laid, embryo viability or eggshell thickness.
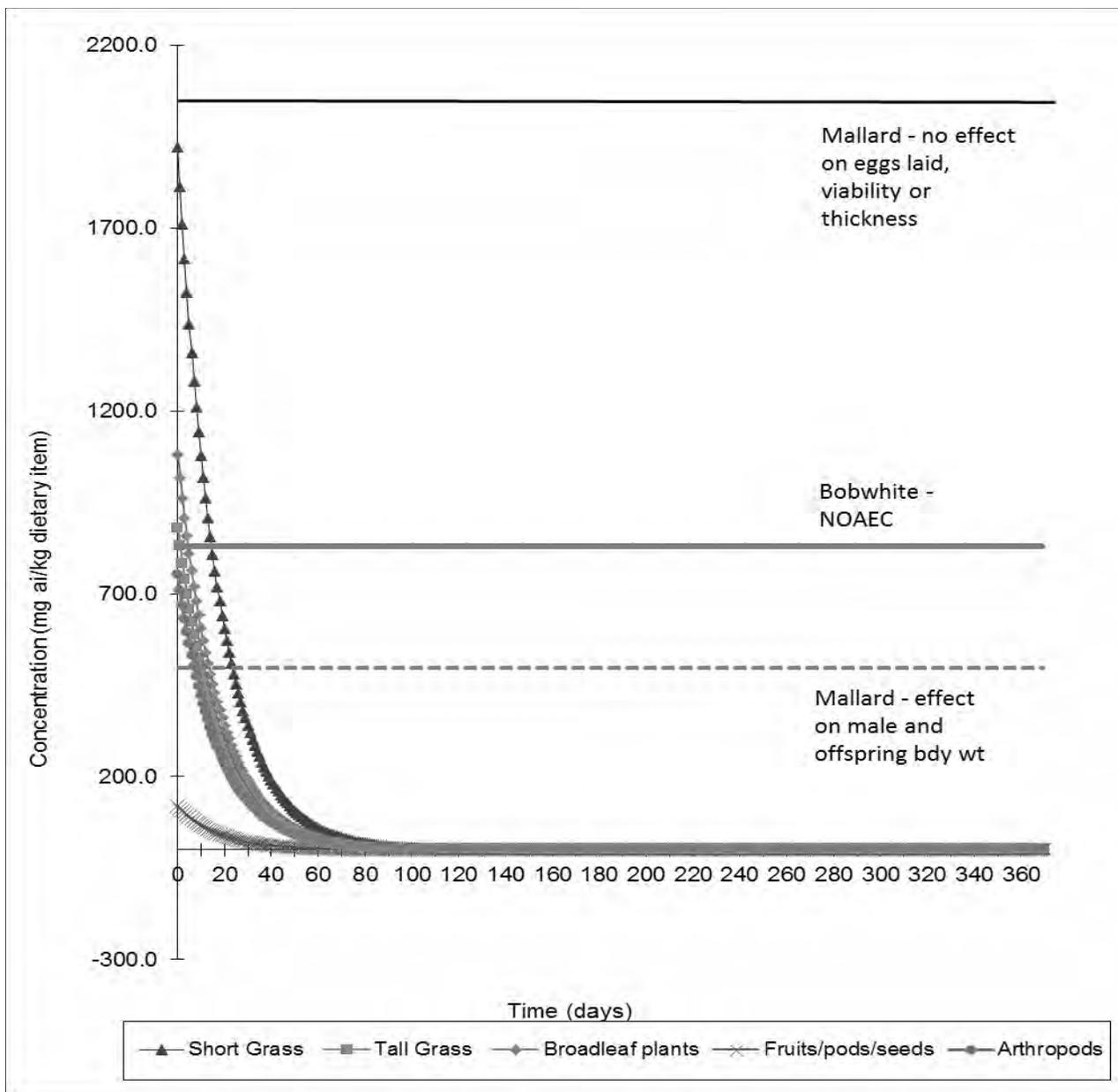
Figure 7. Terrestrial Residues (upper bound estimates) vs Chronic Avian NOAEC/LOAECs (as dietary concentrations) for a single application rate of 8 lb a.i./A.

A similar graph (Figure 8) using a lower application rate (1.55 lb a.e./A application rates used for Roundup-Ready crops), indicates that the short grass EECs exceeds the concentration where effects on mallard body weight were observed for less than one week, and the EECs do not exceed the bobwhite NOAEC nor the concentration where no effects on mallard reproductive parameters were observed.

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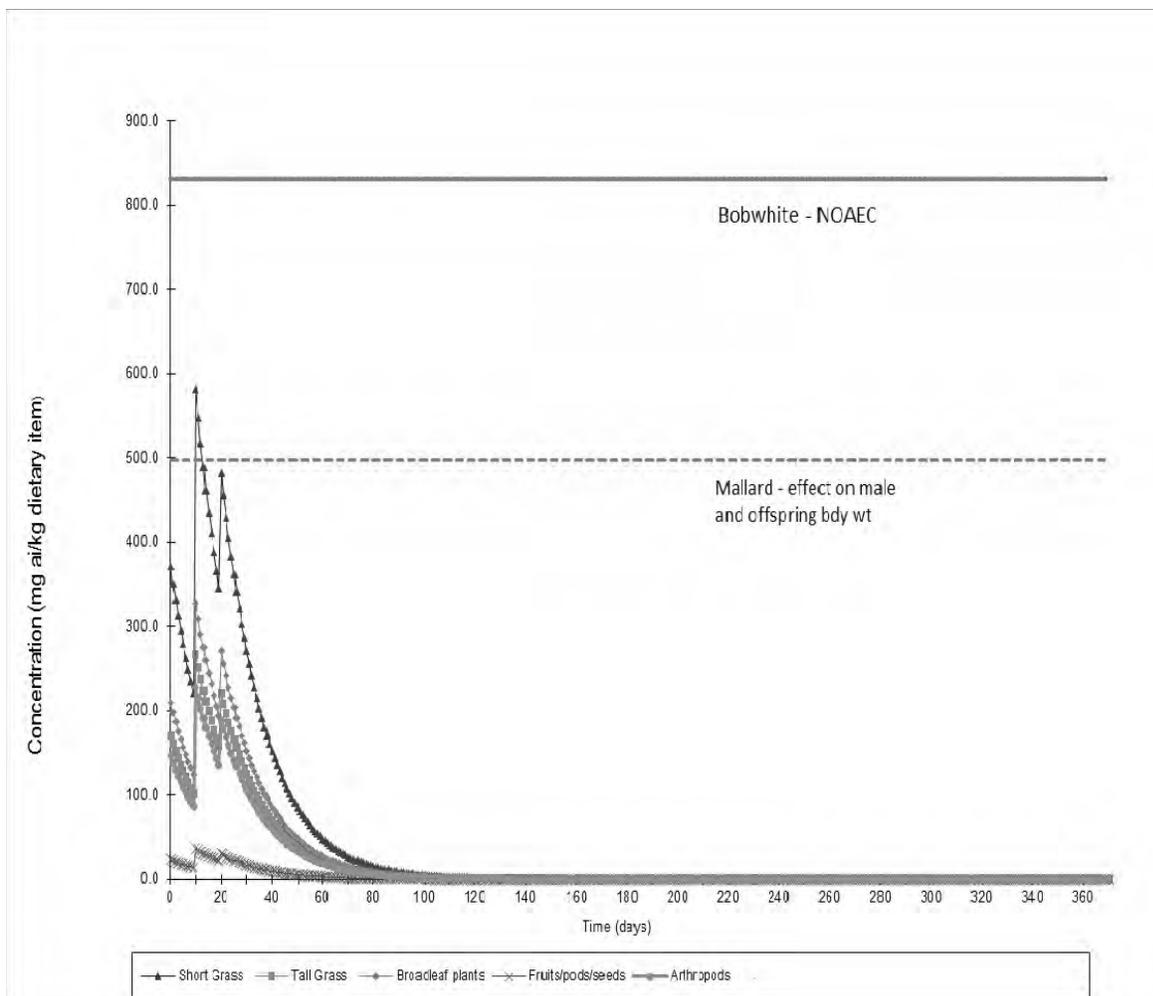
Figure 8. Terrestrial Residues (upper bound estimates) vs Chronic Avian NOAEC/LOAECs (as dietary concentrations) for an application rate of 1.55 lb a.e./A (2 apps of 1.55 and 1 application at 0.65 lb a.e./A)

Although it is noted RQs were not reported in the Risk Estimation section, to further evaluate potential risk to birds, RQs were calculated using the NOAEC from the bobwhite quail study (no reported effects up to and including the highest concentration tested (830 mg a.e./kg-diet)) (Figure 9). For most use patterns, the RQs for the short grass dietary item slightly exceed the chronic LOC of 1, with use on forests, pastures and non-crop area uses with the highest RQs (RQ range 1.02-2.31). Additionally, RQs associated with tall grass and broadleaf plants exceeded the LOC for the forestry, pastures, and non-crop use patterns. The spot treatment use RQs also exceeded the LOC for all dietary items except fruits/pods/seeds (RQs 0.72-11.6). The RQs for a single application of 3.75 lb a.e./A (typical single maximum application rate for most crops using ground application; short grass EEC = 900 mg a.e./kg-diet) just exceeded the LOC for short grass (RQ=1.08). Given that there were no reported effects up to the highest concentration tested, these RQs may be conservative, particularly for most uses, but to a lesser extent for use on forests, pastures and non-crop. While the RQs exceeded the LOC for the spot treatment use, as this application rate was adjusted to a per acre basis, is anticipated to be conservative and may not reflect actual use patterns.

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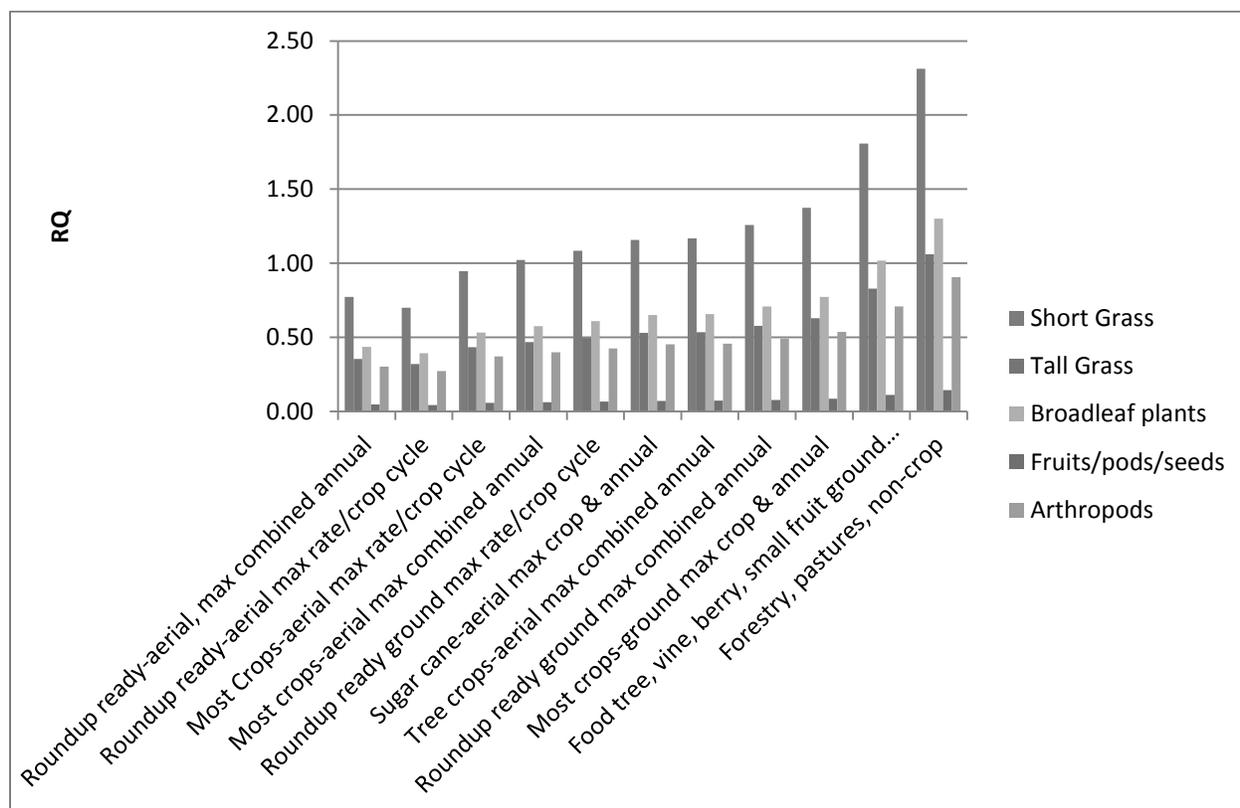
Figure 9. Chronic Avian RQs for Glyphosate (except for the spot treatment use)

In regards to incident reports for the glyphosate isopropylamine, there was a report of mortality to three birds from drift (incident considered possible); however, other chemicals were applied at the same time including atrazine, S-metolachlor and permethrin, therefore, it is unknown if glyphosate was the source of the mortality. There was an additional incident (classified as probable) in which two iguanas were reported as incapacitated (displayed signs of shock, tremors and depression) following ingestion of dandelions sprayed with glyphosate. Other details of the indent are not available. In the aggregate database, wildlife incidents were reported (a total of 44 reports), but it is unknown if these were for terrestrial animal or fish and no other details are available.

Overall, given that decreases in body weight were observed in the mallard at concentrations down to 501 mg a.e.kg-bw, there is concern for potential impacts on growth for exposure to glyphosate, however, there is evidence to suggest that reproductive parameters including eggs laid, embryo viability and eggshell thickness may not be impacted by glyphosate exposure (EECs (1920 mg a.e./kg-bw) < NOAEC (2160 mg a.e./kg-diet) from mallard duck reproduction study and no effect up to 830 mg a.e./kg-diet for bobwhite quail).

5.3.2.2 Terrestrial-phase Amphibians

In the study where juvenile frogs received a direct spray of a glyphosate formulation, 96-hr LC$_{50}$ values ranged from 4.0 – 20.3 lb a.e./A (Bernal *et al*. 2009, E11766). For application rate of 8 lb ae/A, applied by ground, the initial average deposition rate at 6.6 feet would be 4 lb a.e./A using

AgDrift (default drop size distribution, very fine to fine). For aerial application of 8 lb a.e./A, the necessary distance to reach a deposition rate of 4 lb a.e./A would be at the edge of the field (0 feet). The application use for spot treatment is anticipated to result in little spray drift off-site, so the 8 lb a.e./A application rate is anticipated to represent the highest application rate for spray drift.

5.3.2.3. Mammals

Acute exposure

As with birds, there were no definitive acute mammalian toxicity data available for technical glyphosate (LD_{50} > 4800 mg a.e./kg-bw). Therefore, RQ values were not calculated. Reduced activity in the rats for the first nine days was reported in this study at 4800 mg a.e./kg-bw. As was done for the avian acute studies, if comparisons are made between the terrestrial EECs estimated from T-REX and the highest dose tested in the rat acute oral study, the results indicate that all of the EEC values are lower, except for the spot treatment use in which the EECs for short grass and broadleaf plants are greater (EECs 9153 and 5148 mg/kg-diet). For any of the uses at application rates up to the rate of 8 lbs a.e./A, the EEC values (except for spot treatment) are less than half the highest dose tested in the acute oral study.

Many acute oral toxicity studies with the rat have been conducted with formulations. As with the technical material, most of the LD_{50}'s are higher than the highest dose/concentrations tested. The acute dose-based RQs for formulations (n=4) with a definitive LD_{50} values ranged from <0.01 to 0.33 for three of the labels (RQs < acute non-listed LOC) and 0.03 to 2.1 for one label.

Chronic exposure

Chronic mammalian RQs were calculated using the 2-generation mammalian reproduction data and the upper bound EECs. Dietary-based RQ values did not exceed the chronic LOC for any use pattern, except for the spot treatment use for the short grass and broadleaf plants dietary items (RQs = 1.92 and 1.08, respectively). Additionally, dose-based chronic RQs for large mammals did not exceed the LOC, except for the spot treatment use. However, dose-based chronic RQs did exceed the LOC for small mammals consuming short grass for aerial application to sugar cane as well as for most uses generally applied by ground applications up to the combined maximum annual rate (RQs 1.02-10.2). Additionally, for use on forests, pastures and other non-crop uses (rights-of-way), the RQ was exceeded for small mammals consuming broadleaf plants (1.15). For medium-sized mammals consuming short grass, again the RQs exceeded the LOC for most uses that for which glyphosate is applied by ground application up to the combined maximum annual rate (RQs 1.04-8.72). For a single application rate of 3.75 lb a.e./A (typical single maximum application rate for most crops using ground application) the LOC is just barely not exceeded (RQ=0.96). None of the EECs exceed the reported chronic LOAEL (1234 mg/kg/day for males). Additionally, none of the RQs exceed the LOC when the mean Kenaga EECs values are used.

In an additional 2-generation reproduction study in the rat, conducted earlier than the one used for RQ calculations (MRID 41621501), the parental/systemic NOAEL is 500 mg/kg/day in both

sexes and the LOAEL is 1500 mg/kg/day based on soft stools, decreased body weight gain and food consumption. The reproductive NOAEL is ≥ 1500 mg/kg/day (HDT) in both sexes. The offspring NOAEL is 500 mg/kg/day in both sexes with a LOAEL of 1500 mg/kg/day based on decreased body weight gain during lactation. The lowest dose-based NOAEL in this study 500 mg/kg/day is similar to the lowest NOAEL from the other study (408 mg/kg/day) used in the RQ calculations.

Two reproduction studies by Romano et al. (2010 and 2012) using Wistar rats reported reproductive effects on male rats. It is noted that in the study with the newly weaned rats there was a delay in the age to sexual maturity (50 mg a.i./kg-bw) whereas in the other study, the male offspring were observed to have a decrease in the age to sexual maturity. In the registrant's 2-generation rat reproduction study (MRID 48864101-05), the offspring LOAEL (1234 mg/kg/day for males) is based on delayed age to sexual maturity and increased weight at male sexual development.

There is a reproduction/developmental screening study on POEA (MRID 47097401). This has a lower endpoint than the reproduction study on glyphosate (NOAEL: 300 ppm ((14.9 - 16.6 mg/kg bw/day (M) and 18.9 - 19.5 mg/kg bw/day (F)) and LOAEL 1000 ppm (52.8 – 56.1 mg/kg bw/day (M) and 64.9 – 66.6 mg/kg bw/day (F) based on increased mean number of unaccounted-for sites, litter loss, decreased mean number of pups born live, litter size and postnatal survival from birth to post-natal day (PND) 4. The effects were not reproducible in second generation. If a 15% POEA concentration is assumed with a single application rate of 10 qts formulation/A, using the chronic NOAEL values above, the chronic dietary-based and dose-based RQs exceed the LOC (dietary-based RQs ≤2.48; dose-based RQs≤21.7)[3]. Single application rates of 4 quarts/A or less results in dietary-based RQs below the LOC. However, assuming a POEA concentration of 15%, a single application rate of <1 quart/A and above would result in chronic dose-based RQ values that exceed the chronic LOC. The LOC based on the LOAEL is not exceeded using the dietary-based EECs, but is exceeded based on the dose-based EECs.

For the incident reports for glyphosate isopropylamine salt was mortality to several dogs from runoff; no additional details were provided in the report. As mentioned above for birds, additional incidences are available for wildlife, but no additional details are available.

Overall, it is anticipated that the risk following acute exposure to technical glyphosate is low. For chronic exposure to technical glyphosate, potential risks on a dietary basis is anticipated to be low (RQs <LOC). For chronic risk on a dose-basis, the RQs are < LOC or just exceed for small mammals eating short grass (RQs 1.0-1.2); however, RQs are greater than 1.5 for the following uses: food tree, vine, berry, small fruit (ground application, maximum combined annual) and for the non-agricultural uses (non-crop, pastures, forests). Therefore, there is a concern for potential risk for those uses. In regards to POEA and the screening mammalian reproduction study for POEA, based on LOC exceedances, this may impact risk to mammals following chronic exposure to one of the formulations containing the POEA surfactant.

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3 10 quarts/A x [1 gal/4 quarts x 8.33 lb/gal] = 20 lb/A x 0.15 = 3.1 lb/A. Assumed density of 8.33 lb/gal

5.3.2.4. Terrestrial Invertebrates

The acute contact LD_{50} value for the honeybee is >100 µg a.e./bee. However, in the study using technical glyphosate only, there was 38% mortality (27% when corrected for control mortality) reported at this dose level (MRID 00026489). The acute oral 96 h LD_{50} for technical glyphosate with an adjuvant was >182 µg a.e./bee (MRID 48876603). Using the exposure methodology for foliar sprays in the Pollinator Risk Assessment Guidance[4] and the maximum single application rate of 8 lb a.e./A, the exposure estimates for both the contact and dietary exposure route are 21.6 and 257 µg a.e./bee, respectively. The exposure concentration for the acute oral is greater than the highest concentration tested (182 µg a.e./bee); an application rate of 5.69 lb a.e./A equates to an acute oral exposure concentration of 182 µg a.e./bee.

A study examining honeybee colony adult and larvae mortality and larvae weight was available (Thompson et al. 2014). In that study, honeybee colonies were fed a treated sucrose solution at concentrations ranging from 73-255 mg a.e./L (also reported as 73-255 mg a.e./kg and based on residues from an application rate of 1.92 lb a.e./A). In that study, there were no reported effects on adult or larvae survival or larvae weight (the larvae received the glyphosate residues through normal hive activity). While the highest concentration was twice the maximum mean residue, given that the actual application rate was approximately one-fourth of the maximum single application rate allowed (8 lb a.e./A), there is concern that these results may not reflect maximum environmentally relevant concentrations.

In addition to the uncertainty discussed above, there were two incident reports with a possible certainty index. The first was for glyphosate acid, in which mortality to 48 colonies of bees was reported from an undetermined use; analysis of pesticide residues in the bee tissue/ and or pollen included a variety of pesticides including: clothianidin, cyprodinil, ethofumesate, fenbuconazole, methoxyfenozide, thiacloprid, phosmet, captan, and cyhalothrin. For glyphosate isopropylamine salt, a possible incident in which adult bee mortality by ingestion was reported (number of mortalities not reported however incident involved 3 hives); the mortalities were observed within two days of concurrently spraying two herbicides (*i.e.*, a glyphosate herbicide as well as a herbicide containing sulfometuron methyl).

In another terrestrial invertebrate toxicity study with a predatory mite, for which the exposure was via contact, the 7-d LD_{50} value was reported as 1200 g a.e./ha (1.1 lb/A) (MRID 45767105) AgDrift model estimates of how far risks from spray drift exposure extend from the edge of the field for the application rate of 1.1 lb/A are provided in Table 46. These estimates were calculated using default AgDrift parameters for droplet spectrum. For ground application, the distance off-field is 20 feet or less, with effects up to 69 feet for aerial application for uses up to 8 lb a.e./A. For the spot treatment use, drift off-site is anticipated to be limited.

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4 United States Environmental Protection Agency, Office of Pesticide Programs, Washington DC. Memorandum for Guidance for Assessing Pesticide Risks to Bees. June 23, 2014.

Table 46. Distances Off-Site of Application to Terrestrial Invertebrate Endpoint.

Application rate (lb a.e./A)	Application method	Distance from edge of field to endpoint (1.1 lb/A) in feet
0.38	Ground	0
1.13		3.3
1.55		3.3
2.25		6.6
3.75		9.8
8		19.7
0.38	Aerial	0
1.55		0
2.25		3.3
3.75		16.4
8		68.9

5.3.2.5 Terrestrial Plants

No effects on seedling emergence greater than 25% was observed after exposure to glyphosate formulations (IC_{25} > 5 lb a.e./A). Therefore, RQs for non-listed terrestrial plants using the seedling emergence data were not calculated. Additionally, NOAECs were reported as the highest concentration tested or were not reported.

Runoff EECs were calculated using TerrPlant (v1.2.2), and at the highest single application rate of 8 lb a.e./A, the estimated EEC for runoff to dry areas is 0.4 lb a.e./A, whereas the EEC for runoff to semi-aquatic areas is 4 lb a.e./A. Therefore, as the EECs are less than the non-definitive IC_{25} or NOAEC for monocots and dicots, the likelihood of adverse effects to terrestrial plants from runoff is anticipated to be low.

However, as may be expected for glyphosate, vegetative vigor was affected when plants were exposed to both technical glyphosate only and glyphosate formulations. The ratio of glyphosate loading at edge of field from spray drift loading to the most sensitive endpoints ranged from 11.7 to 163. Additionally, the necessary distance off-field to be below the toxicity value for both non-listed and listed plants (IC_{25} for non-listed species and NOAEC for listed species) for both dicots and monocots was calculated for different single application rates. As droplet size is not specified on the labels for all uses, spray drift EECs were calculated using AgDrift (v2.1.1), using the default droplet size, fine to medium for aerial and very fine to fine for ground (USEPA 2013) (Table 47). For monocots, the overlap between EECs and the non-listed toxicity values was 7 feet for rangeland use and 459 feet for the highest application of 8 lb a.e./A for forestry, pasture and non-crop (*e.g.*, rights-of-way) uses. For dicots, which had the more sensitive endpoint, the distance for the non-listed endpoint ranged from 16 to greater than 997 feet. For listed species, the distance is up to over 997 feet for dicots and monocots.

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Table 47. Spray Drift (Terrestrial) Assessment for Terrestrial Plant Species

No. of application and app. rate (lb a.e/.A)	Dicot (VV)[a]		Monocot (VV)[b]		Spray Method
	IC_{25}	NOAEC	IC_{25}	NOAEC	
distance from edge of field to reach non-listed (IC_{25}) or listed (NOAEC/IC_{05}) toxicity value					
1 @ 0.38	33	72	6.6	42.7	Aerial
1 @ 1.13	144	217	66	154	
1 @ 1.55	190	292	95	203	
1 @ 2.25	282	420	131	295	
1 @ 3.75	466	817	220	495	
1 @ 8	>997	>997	459	>997	
1 @ 0.38	16	23	6.6	16.4	Ground
1 @ 1.55	52	79	26	55.8	
1 @ 2.25	79	115	36	82.0	
1 @ 3.75	128	187	59	135	
1 @ 8	253	358	125	266	

[a] Based on reported toxicity in dicot species cucumber, *Cucumis sativus*, at IC_{25} of 0.074 lb a.e./A and NOAEC of 0.049 lb a.e./A in the vegetative vigor test.
[b] Based on reported phytotoxicity in monocot species sorghum, *Sorghum bicolor*, at IC_{25} of 0.16 lb a.e./A and NOAEC of 0.07 lb a.e./A in the vegetative vigor test.
Drift values based on: aerial - droplet size ASA.E. Fine to medium, ground – droplet size ASA.E. very fine to fine, high boom, 90th percentile

In the previous table, the most sensitive species were used to calculate off-field distances. However, it is noted that not all species have the same sensitivity when exposed to glyphosate. Off-field distances using the tested species in the vegetative vigor toxicity study along with the maximum single application rate (8 lb a.e./A) were calculated to evaluate the range of necessary distances from the edge of the application area where the RQ for that endpoint falls below the risk to terrestrial plant LOCs (Table 48). For monocots, the distances range from 98 to 459 feet for non-listed species and from 171 to over 997 feet for listed monocots. Similarly for the dicots, the distance ranges are 86 to >997 feet and 171 to >997 feet for non-listed and listed species, respectively.

Table 48. Distance (feet) from the edge of field where the RQ falls below the risk to terrestrial plant LOC for vegetative vigor endpoints for aerial application of 8 lb a.e./A, based on AgDrift EECs.

Vegetative Vigor*					
Monocots			Dicots		
Species	Non-listed	Listed	Species	Non-listed	Listed
Onion	266	535	Garden pea	86	171
Sorghum	459	>997	Sugarbeet	269, 348	502, 656
Wheat	331, 413	886, >1000	Sunflower	459	>997
Corn	213, 325	407, 502	Radish	312, >997	502, >997
Purple nutsedge	98	171	Soybean	233, 614	656, >997
Oat	364	502	Cucumber	171	459
			Lettuce	335, >997	502, >997
			Rape	992	>997
			Okra	427	>997
*These values are based on toxicity values reported in MRID 44125715/45045101 and 44320636. In cases where there are two distances reported, there were two different toxicity values available for the same species.					

The distance estimates are derived using EFED's AgDrift default values, which include the use of an ASAE droplet size spectrum 'fine to medium.' However, if glyphosate was applied using larger droplets sizes, then the distances off-field would be lower. AgDrift modeling was conducted using an ASAE droplet size spectrum 'medium to coarse.' Using these parameters, the longest distance to an exposure value equal to the most sensitive vegetative vigor IC_{25} and its associated NOAEC is 459 and 791 feet, respectively. While this is still a considerable distance from the edge of the application area, it is appreciably less than the undefined >997 ft distance predicted using the default parameters.

Toxicity data in the open literature suggest that in addition to effects on vegetative vigor, exposure to glyphosate formulations may impact reproductive parameters. In a study evaluating pea seed production the EC_{25}, based on pea seed weight was 0.0074 lb a.i./A using Roundup Original®, Olszyk *et al*. 2009; however, the associated NOEC values was close to the EC_{25} value. In an additional study evaluating growth and reproductive parameters for field grown potatoes (Pfleger *et al*. 2011), generally most endpoints were affected at 0.074 lb a.e./A and the most sensitive endpoint was above biomass with an EC_{25} 0.003 lb/A.

The incident data discussed earlier suggest that, at least for plants, exposure pathways for glyphosate are complete and that exposure levels are sufficient to result in field-observable effects. Therefore, based on the lines of evidence, there is a potential for adverse effects to terrestrial plants.

As there are potential adverse effects to terrestrial plants, potential indirect effects may occur to other taxa that rely on terrestrial plants as a resource for food and/or habitat. This may include both aquatic and terrestrial organisms, including pollinators.

5.3.3   Effects on the Terrestrial Plant, Common Milkweed, and the Impact to the Monarch Butterfly

Publications have highlighted the importance of the common milkweed (*Asclepias syriaca L.*) as critical food resource for monarch butterfly larvae (*Danaus plexippus* L.), with an emphasis on conservation of milkweed to preserve monarch butterfly populations[5]. The agency is initiating efforts to contribute to current efforts to protect the monarch butterfly and its resources[6] and has identified an approach to describe in general terms, how it intends to engage with the public and proceed with the larger government-wide efforts to protect the monarch butterfly[7].

Milkweed is a dicotyledonous perennial plant and is a target weed on glyphosate product labels and as such, may be exposed to glyphosate from direct applications as well as from spray drift and/or runoff. Regarding potential toxicity to milkweed from glyphosate exposure, in a paper by Egan *et al*., 2014, the 28-day ED_{25} value (effective dose), based on biomass, for common milkweed from foliar exposure to Roundup Powermax (540 g a.e./L) in greenhouse experiments

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5 Pleasants and Oberhauser (2012); Hartzler, 2010.
6 http://www.trilat.org/
7 EPA's Risk Management Approach to Identifying Options for Protecting the Monarch Butterfly http://www.epa.gov/oppfead1/cb/csb_page/updates/2015/protecting-monarch-butterfly.html (posted June 24, 2015)

was reported as 141 g a.e./ha (0.126 lb a.e./A, 95% CI of -0.036-0.29). In another study by White and Boutin, 2007, a 28-d IC_{25} value of 46 g a.i./ha (0.04 lb a.i./A, 95% CI of 0.03-0.07), based on biomass) was reported for milkweed after exposure to Round-Up Original. The adsorption, translocation and metabolism of glyphosate in common milkweed were also examined and results indicated that an insignificant amount of metabolism of glyphosate occurred after 20 days in both milkweed roots and leaves above the treated leaves (Wyrill *et al*. 1976).

The reported 28-d $IC(ED)_{25}$ values for milkweed are similar to the most sensitive vegetative vigor terrestrial plant IC_{25} value of 0.074 lb a.e./A for the dicot cucumber. Therefore, the toxicity data used to evaluate potential risk to terrestrial plants in general may be representative for potential adverse effects to common milkweed. Based on the observed toxicity to the vegetative vigor for terrestrial plants and the label application rates, there is overlap between potential exposure rates and toxicity values. As such, the necessary distances off-field required to be below toxicity thresholds were calculated for various labeled single maximum application rates and are presented in Table 49.

Table 49. Spray Drift (Terrestrial) Assessment for Terrestrial Plant Species

No. of application and app. rate (lb a.e/.A)	Species		Spray Method
	Most Sensitive Dicot (VV)[a] IC_{25} (0.074 lb a.e./A)	Common milkweed IC_{25} (0.126 lb a.e./A)	
distance from edge of field to reach non-listed (EC_{25}) toxicity value			
1 @ 0.38	33	13	Aerial
1 @ 1.13	144	89	
1 @ 1.55	190	118	
1 @ 2.25	282	171	
1 @ 3.75	466	279	
1 @ 8	>1000	620	
1 @ 0.38	16	10	Ground
1 @ 1.55	52	33	
1 @ 2.25	79	46	
1 @ 3.75	128	75	
1 @ 8	253	157	

[a] Based on reported toxicity in dicot species cucumber, *Cucumis sativus*, at IC_{25} of 0.074 lb a.e./A and NOAEC of 0.049 lb a.e./A in the vegetative vigor test.
Drift values based on: aerial - droplet size ASA.E. Fine to medium, ground – droplet size ASAE, very fine to fine, high boom, 90th percentile

6. Endocrine Disruptor Screening Program

As required by FIFRA and FFDCA, EPA reviews numerous studies to assess potential adverse outcomes from exposure to chemicals. Collectively, these studies include acute, subchronic and chronic toxicity, including assessments of carcinogenicity, neurotoxicity, developmental, reproductive, and general or systemic toxicity. These studies include endpoints which may be susceptible to endocrine influence, including effects on endocrine target organ histopathology, organ weights, estrus cyclicity, sexual maturation, fertility, pregnancy rates, reproductive loss, and sex ratios in offspring. For ecological hazard assessments, EPA evaluates acute tests and

chronic studies that assess growth, developmental and reproductive effects in different taxonomic groups. As part of registration review for glyphosate, EPA reviewed these data and selected the most sensitive endpoints for relevant risk assessment scenarios from the existing hazard database. However, as required by FFDCA section 408(p), glyphosate is subject to the endocrine screening part of the Endocrine Disruptor Screening Program (EDSP).

EPA has developed the EDSP to determine whether certain substances (including pesticide active and other ingredients) may have an effect in humans or wildlife similar to an effect produced by a "naturally occurring estrogen, or other such endocrine effects as the Administrator may designate." The EDSP employs a two-tiered approach to making the statutorily required determinations. Tier 1 consists of a battery of 11 screening assays to identify the potential of a chemical substance to interact with the estrogen, androgen, or thyroid (E, A, or T) hormonal systems. Chemicals that go through Tier 1 screening and are found to have the potential to interact with E, A, or T hormonal systems will proceed to the next stage of the EDSP where EPA will determine which, if any, of the Tier 2 tests are necessary based on the available data. Tier 2 testing is designed to identify any adverse endocrine-related effects caused by the substance, and establish a dose-response relationship between the dose and the E, A, or T effect.

Under FFDCA section 408(p), the Agency must screen all pesticide chemicals. Between October 2009 and February 2010, EPA issued test orders/data call-ins for the first group of 67 chemicals, which contains 58 pesticide active ingredients and 9 inert ingredients. A second list of chemicals identified for EDSP screening was published on June 14, 2013[8] and includes some pesticides scheduled for registration review and chemicals found in water. Neither of these lists should be construed as a list of known or likely endocrine disruptors.

Glyphosate is on List 1 for which EPA has received all of the required Tier 1 assay data. The Agency has reviewed all of the assay data received for the appropriate List 1 chemicals and the conclusions of those reviews are available in the chemical-specific public dockets (see EPA-HQ-OPP-2009-0361 for glyphosate). The conclusion of the weight of evidence (WoE) evaluation is that glyphosate demonstrates no convincing evidence of potential interaction with the estrogen, androgen or thyroid pathways in mammals or non-mammalian wildlife. Based on weight of evidence considerations, mammalian or wildlife EDSP Tier 2 testing is not recommended for glyphosate. For further information on the status of the EDSP, the policies and procedures, the lists of chemicals, future lists, the test guidelines and Tier 1 screening battery, please visit our website http://www.epa.gov/endo/.

7. Federally Threatened and Endangered (Listed) Species Concerns

In November 2013, the EPA, along with the U.S. Fish & Wildlife Service (USFWS), the National Marine Fisheries Service (NMFS) (collectively, the Services), and the U.S. Department of Agriculture (USDA) released a summary of their joint Interim Approaches for assessing risks to listed species from pesticides. The Interim Approaches were developed jointly by the agencies in response to the National Academy of Sciences' (NAS) recommendations and reflect a common approach to risk assessment shared by the agencies as a way of addressing scientific

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8 See http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OPPT-2009-0477-0074 for the final second list of
   chemicals.

differences between the EPA and the Services. The NAS report outlines recommendations on specific scientific and technical issues related to the development of pesticide risk assessments that EPA and the Services must conduct in connection with their obligations under the Endangered Species Act (ESA) and FIFRA.

The joint Interim Approaches were released prior to a stakeholder workshop held on November 15, 2013.In addition, the EPA presented the joint Interim Approaches at the December 2013 Pesticide Program Dialogue Committee (PPDC) and State-FIFRA Issues Research and Evaluation Group (SFIREG) meetings, and held a stakeholder workshop in April 2014, allowing additional opportunities for stakeholders to comment on the Interim Approaches. As part of a phased, iterative process for developing the Interim Approaches, the agencies will also consider public comments on the Interim Approaches in connection with the development of upcoming Registration Review decisions. The details of the joint Interim Approaches are contained in the white paper "Interim Approaches for National-Level Pesticide Endangered Species Act Assessments Based on the Recommendations of the National Academy of Sciences April 2013 Report," dated November 1, 2013.

Given that the agencies are continuing to develop and work toward implementation of the Interim Approaches to assess the potential risks of pesticides to listed species and their designated critical habitat, this preliminary risk assessment for glyphosate does not contain a complete ESA analysis that includes effects determinations for specific listed species or designated critical habitat. Although EPA has not yet completed effects determinations for specific species or habitats, for this preliminary assessment EPA conducted a screening-level assessment for all taxa of non-target wildlife and plants that assumes for the sake of the assessment that listed species and designated critical habitats may be present in the vicinity of the application of glyphosate. This screening level assessment will allow EPA to focus its future evaluations on the types of species where the potential for effects exists once the scientific methods being developed by the agencies have been fully vetted. This screening-level risk assessment for glyphosate indicates potential risks of direct effects to listed birds (surrogates for aquatic-phase amphibians and reptiles), mammals, terrestrial invertebrates, terrestrial and aquatic vascular plants on some of its registered use sites. Listed species of aquatic animal taxa may also be affected through indirect effects because of the potential for direct effects on listed and non-listed species upon which such species may rely. Potential direct effects on listed birds (surrogates for aquatic-phase amphibians and reptiles), mammals, terrestrial invertebrates, terrestrial and aquatic vascular plants from the use of glyphosate may be associated with modification of Primary Constituent Elements (PCEs) of designated critical habitats, where such designations have been made. Once the agencies have fully developed and implemented the scientific methods necessary to complete risk assessments for endangered and threatened (listed) species and their designated critical habitats, these methods will be applied to subsequent analyses for glyphosate as part of completing this registration review.

8.   Assumptions and Limitations

a) An evaluation into the potential foliar dissipation rate for dietary items that were exposed to glyphosate was conducted for this assessment. Based on the available information, it

appears that glyphosate can dissipate on some types of foliage (i.e., alfalfa and forestry brush foliage, which may be similar to the grasses and broadleaf plant category in T-REX, respectively) with calculated half-lives between 4 and 7.5 days (based on magnitude of residue studies; MRID 45646001 and open literature studies) An evaluation of potential dissipation for all dietary item categories in T-REX (*i.e.*, other types of broadleaf plants and fruits/pods/seeds) could not be completed due to unavailable data. Therefore, there is uncertainty in the potential dissipation rate for these other dietary groups. For a single application of 3.75 lb a.e./A that is not influenced by the foliar dissipation rate, the RQ for chronic dietary exposure for birds just exceeded the LOC for short grass (RQ=1.08). For mammals, using the same single application rate, the LOC is not exceeded (RQ=0.96) on a chronic dose-basis.

b) The avian chronic dietary RQ values exceed the chronic LOC. In the available avian reproduction toxicity studies, there were no reported effects on eggs laid, embryo viability and eggshell thickness up to the highest concentration tested. However, the data do suggest that male body weight and offspring weight may be affected in at least one study, therefore, there is uncertainty in the potential chronic effects of glyphosate on birds.

c) Honeybee larvae were exposed to glyphosate in the available semi-field study through normal hive activity, but the concentrations used in the study may not reflect environmental concentrations (test concentrations based on field application of 1.92 lb a.e./A). Toxicity data to larvae under conditions to evaluate response of individual larvae after exposure to a known concentration of glyphosate is not available. There is uncertainty in the available terrestrial invertebrate data providing an adequate understanding of the potential risk to non-adult life stages for terrestrial invertebrates at currently registered application rates.

d) Chronic toxicity data were not available for estuarine-marine organisms. Risk conclusions were made using an ACR approach. At this time, additional chronic data for estuarine/marine animals is not anticipated to impact the overall risk conclusion for those taxa, as the toxicity data from freshwater animals is considered adequate for evaluating risk to those taxa.

e) To increase efficacy, glyphosate labels may recommend the addition of ammonium sulfate in situations when hard water is used in the spray mixture. This is to allow the sulfate ion to competitively bind to the cations typically present in hard water. It is not known how this phenomenon may impact glyphosate availability for animals, particularly aquatic animals. For terrestrial plants, between the information presented in the registrant's vegetative vigor studies and the collective response between the registrant's vegetative vigor studies and the open literature studies, which are similar, it is considered that there is sufficient confidence in the toxicity values used in the assessment to adequately evaluate potential effects of glyphosate exposure for terrestrial plants.

With regard to aquatic organisms and glyphosate toxicity, the large number of acute toxicity studies is anticipated to represent a spectrum of different water sources and

environmental attributes (*i.e.*, hardness). These studies should provide an adequate understanding of potential glyphosate toxicity. It is noted that for some aquatic invertebrates (*e.g.*, *Daphnia magna*), sufficient water hardness is needed to ensure adequate growth and development. Overall, in environmental situations where the water is characterized as hard, glyphosate-cation complexes may occur which may influence the availability of glyphosate exposure to aquatic organisms, which may alter toxicity.

9.   References

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Appendix A

Structures of Glyphosate and AMPA

Glyphosate Acid
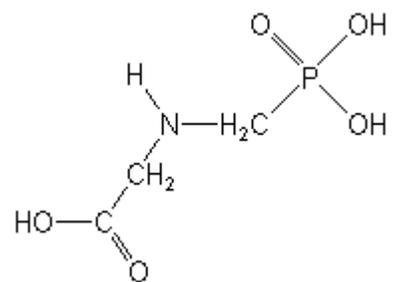
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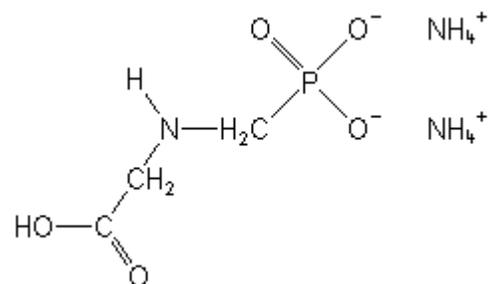
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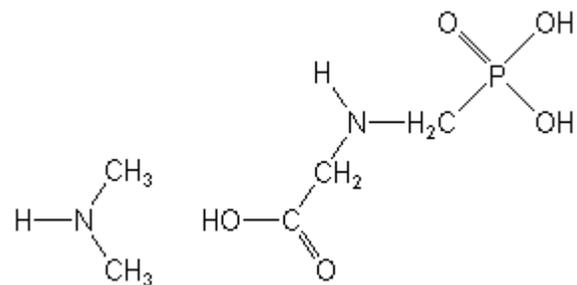
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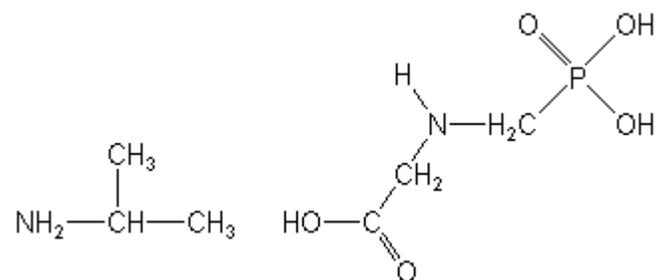
Monoammonium salt glyphosate
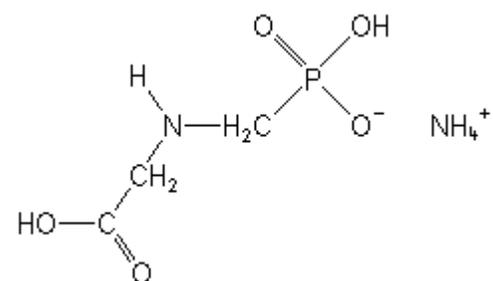
Potassium salt glyphosate
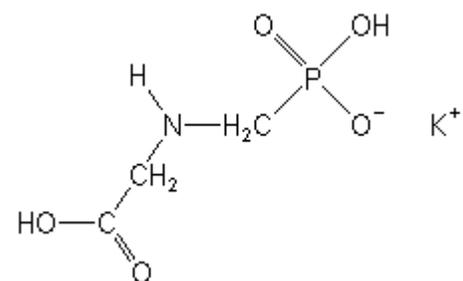
AMPA-Degradation Product
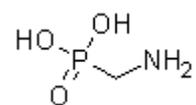
Appendix B

GEENEC OUTPUT

```
RUN No.   1 FOR glyphosate        ON   3.75airnob    * INPUT VALUES *
-----------------------------------------------------------------------
RATE (#/AC)   No.APPS &   SOIL  SOLUBIL   APPL TYPE  NO-SPRAY INCORP
 ONE(MULT)    INTERVAL    Kd    (PPM )    (%DRIFT)   ZONE(FT) (IN)
-----------------------------------------------------------------------
3.750( 6.922)  2   7    157.012000.0   AERL_B( 13.0)  0.0   0.0


FIELD AND STANDARD POND HALFLIFE VALUES (DAYS)
-----------------------------------------------------------------------
METABOLIC  DAYS UNTIL  HYDROLYSIS   PHOTOLYSIS   METABOLIC  COMBINED
 (FIELD)   RAIN/RUNOFF  (POND)     (POND-EFF)    (POND)     (POND)
-----------------------------------------------------------------------
  29.00        2        0.00       0.00-    0.00 381.00      381.00


GENERIC EECs (IN MICROGRAMS/LITER (PPB))     Version 2.0 Aug 1, 2001
-----------------------------------------------------------------------
    PEAK       MAX 4 DAY     MAX 21 DAY    MAX 60 DAY    MAX 90 DAY
    GEEC       AVG GEEC       AVG GEEC      AVG GEEC      AVG GEEC
-----------------------------------------------------------------------
    53.26       51.36          40.27         25.23         19.07


RUN No.   2 FOR glyphosate        ON   8airnobuf     * INPUT VALUES *
-----------------------------------------------------------------------
RATE (#/AC)   No.APPS &   SOIL  SOLUBIL   APPL TYPE  NO-SPRAY INCORP
 ONE(MULT)    INTERVAL    Kd    (PPM )    (%DRIFT)   ZONE(FT) (IN)
-----------------------------------------------------------------------
8.000( 8.000)  1   1    157.012000.0   AERL_B( 13.0)  0.0   0.0


FIELD AND STANDARD POND HALFLIFE VALUES (DAYS)
-----------------------------------------------------------------------
METABOLIC  DAYS UNTIL  HYDROLYSIS   PHOTOLYSIS   METABOLIC  COMBINED
 (FIELD)   RAIN/RUNOFF  (POND)     (POND-EFF)    (POND)     (POND)
-----------------------------------------------------------------------
  29.00        2        N/A        0.00-    0.00 381.00      381.00


GENERIC EECs (IN MICROGRAMS/LITER (PPB))     Version 2.0 Aug 1, 2001
-----------------------------------------------------------------------
    PEAK       MAX 4 DAY     MAX 21 DAY    MAX 60 DAY    MAX 90 DAY
    GEEC       AVG GEEC       AVG GEEC      AVG GEEC      AVG GEEC
-----------------------------------------------------------------------
    59.63       57.48          45.06         28.22         21.32
```

```
RUN No.   3 FOR glyphosate        ON   3.75airbuf   * INPUT VALUES *
  --------------------------------------------------------------------
RATE (#/AC)   No.APPS &   SOIL  SOLUBIL   APPL TYPE  NO-SPRAY INCORP
 ONE(MULT)    INTERVAL    Kd    (PPM )    (%DRIFT)   ZONE(FT) (IN)
  --------------------------------------------------------------------
3.750( 6.922)  2    7     157.012000.0   AERL_B( 1.5) 500.0   0.0


  FIELD AND STANDARD POND HALFLIFE VALUES (DAYS)
  --------------------------------------------------------------------
METABOLIC  DAYS UNTIL  HYDROLYSIS  PHOTOLYSIS   METABOLIC   COMBINED
 (FIELD)   RAIN/RUNOFF  (POND)     (POND-EFF)    (POND)      (POND)
  --------------------------------------------------------------------
  29.00        2         N/A       0.00-    0.00   381.00     381.00


  GENERIC EECs (IN MICROGRAMS/LITER (PPB))    Version 2.0 Aug 1, 2001
  --------------------------------------------------------------------
     PEAK      MAX 4 DAY    MAX 21 DAY   MAX 60 DAY    MAX 90 DAY
     GEEC      AVG GEEC      AVG GEEC     AVG GEEC      AVG GEEC
  --------------------------------------------------------------------
     33.39      31.94        24.95        15.54         11.67


RUN No.   4 FOR glyphosate        ON   8airbuf500   * INPUT VALUES *
  --------------------------------------------------------------------
RATE (#/AC)   No.APPS &   SOIL  SOLUBIL   APPL TYPE  NO-SPRAY INCORP
 ONE(MULT)    INTERVAL    Kd    (PPM )    (%DRIFT)   ZONE(FT) (IN)
  --------------------------------------------------------------------
8.000( 8.000)  1    1     157.012000.0   AERL_B( 1.5) 500.0   0.0


  FIELD AND STANDARD POND HALFLIFE VALUES (DAYS)
  --------------------------------------------------------------------
METABOLIC  DAYS UNTIL  HYDROLYSIS  PHOTOLYSIS   METABOLIC   COMBINED
 (FIELD)   RAIN/RUNOFF  (POND)     (POND-EFF)    (POND)      (POND)
  --------------------------------------------------------------------
  29.00        2         N/A       0.00-    0.00   381.00     381.00


  GENERIC EECs (IN MICROGRAMS/LITER (PPB))    Version 2.0 Aug 1, 2001
  --------------------------------------------------------------------
     PEAK      MAX 4 DAY    MAX 21 DAY   MAX 60 DAY    MAX 90 DAY
     GEEC      AVG GEEC      AVG GEEC     AVG GEEC      AVG GEEC
  --------------------------------------------------------------------
     38.37      36.69        28.66        17.85         13.40


RUN No.   5 FOR glyphosate        ON   8grdnobuff   * INPUT VALUES *
  --------------------------------------------------------------------
RATE (#/AC)   No.APPS &   SOIL  SOLUBIL   APPL TYPE  NO-SPRAY INCORP
 ONE(MULT)    INTERVAL    Kd    (PPM )    (%DRIFT)   ZONE(FT) (IN)
  --------------------------------------------------------------------
```

108

```
 8.000( 8.000)  1  1     157.012000.0  GRHIFI( 6.6)  0.0  0.0


     FIELD AND STANDARD POND HALFLIFE VALUES (DAYS)
     ------------------------------------------------------------------
     METABOLIC  DAYS UNTIL  HYDROLYSIS  PHOTOLYSIS   METABOLIC  COMBINED
      (FIELD)   RAIN/RUNOFF  (POND)     (POND-EFF)    (POND)     (POND)
     ------------------------------------------------------------------
       29.00        2         N/A       0.00-   0.00  381.00    381.00


     GENERIC EECs (IN MICROGRAMS/LITER (PPB))    Version 2.0 Aug 1, 2001
     ------------------------------------------------------------------
        PEAK       MAX 4 DAY     MAX 21 DAY    MAX 60 DAY    MAX 90 DAY
        GEEC       AVG GEEC      AVG GEEC      AVG GEEC      AVG GEEC
     ------------------------------------------------------------------
        49.28       47.32         37.04         23.13         17.43


     RUN No.   6 FOR glyphosate       ON   40grdnobuf   * INPUT VALUES *
     ------------------------------------------------------------------
     RATE (#/AC)  No.APPS &   SOIL  SOLUBIL   APPL TYPE  NO-SPRAY INCORP
      ONE(MULT)   INTERVAL    Kd   (PPM )    (%DRIFT)   ZONE(FT) (IN)
     ------------------------------------------------------------------
 40.000( 40.000)  1  1     157.012000.0  GRHIFI( 6.6)  0.0  0.0


     FIELD AND STANDARD POND HALFLIFE VALUES (DAYS)
     ------------------------------------------------------------------
     METABOLIC  DAYS UNTIL  HYDROLYSIS  PHOTOLYSIS   METABOLIC  COMBINED
      (FIELD)   RAIN/RUNOFF  (POND)     (POND-EFF)    (POND)     (POND)
     ------------------------------------------------------------------
       29.00        2         N/A       0.00-   0.00  381.00    381.00


     GENERIC EECs (IN MICROGRAMS/LITER (PPB))    Version 2.0 Aug 1, 2001
     ------------------------------------------------------------------
        PEAK       MAX 4 DAY     MAX 21 DAY    MAX 60 DAY    MAX 90 DAY
        GEEC       AVG GEEC      AVG GEEC      AVG GEEC      AVG GEEC
     ------------------------------------------------------------------
        246.39      236.61        185.19        115.67        87.13
```

Appendix C
T-REX Output

Upper Bound Kenaga Residues For RQ Calculation

Chemical Name:	glyphosate
Use	nuts, pome, citrus, misc)-ground max comb
Formulation	0
Half-life	12 days
Length of Simulation	1 year
Variable application rates?	yes

Acute and Chronic RQs are based on the Upp... Kenaga Residues.

The maximum single day residue estimation is ... both the acute and reproduction RQs.

RQs reported as "0.00" in the RQ tables be... <0.01 in your assessment. This is due to r... figure issues in Excel.

Endpoints

Avian	Bobwhite quail	LD50 (mg/kg-bw)	3196.00
	Bobwhite quail	LC50 (mg/kg-diet)	4971.00
	Bobwhite quail	NOAEL(mg/kg-bw)	0.00
	Bobwhite quail	NOAEC (mg/kg-diet)	830.00

Mammals	LD50 (mg/kg-bw)	4800.00
	LC50 (mg/kg-diet)	0.00
	NOAEL (mg/kg-bw)	500.00
	NOAEC (mg/kg-diet)	10000.00

Dietary-based EECs (ppm)

	Kenaga Values
Short Grass	1500.68
Tall Grass	687.81
Broadleaf plants	844.13
Fruits/pods/seeds	93.79
Arthropods	587.77

Avian Results

	Avian Class	Body Weight (g)	Ingestion (Fdry) (g bw/day)	Ingestion (Fwet) (g/day)	% body wgt consumed	FI (kg-diet/day)
	Small	20	5	23	114	2.28E-02
	Mid	100	13	65	65	6.49E-02
	Large	1000	58	291	29	2.91E-01
	Granivores	20	5	5	25	5.06E-03
		100	13	14	14	1.44E-02
		1000	58	65	6	6.46E-02

Avian Body Weight (g)	Adjusted LD50 (mg/kg-bw)
20	2302.49
100	2931.19
1000	4140.41

Dose-based EECs (mg/kg-bw)

	Avian Classes and Body Weights (grams)		
	small	mid	large
	20	100	1000
Short Grass	1709.12	974.61	436.35
Tall Grass	783.35	446.70	199.99
Broadleaf plants	961.38	548.22	245.45
Fruits/pods	106.82	60.91	27.27
Arthropods	669.41	381.72	170.90
Seeds	23.74	13.54	6.06

Dose-based RQs (Dose-based EEC/adjusted LD50)	Avian Acute RQs Size Class (grams)		
	20	100	1000
Short Grass	0.74	0.33	0.11
Tall Grass	0.34	0.15	0.05
Broadleaf plants	0.42	0.19	0.06
Fruits/pods	0.05	0.02	0.01
Arthropods	0.29	0.13	0.04
Seeds	0.01	0.00	0.00

Dietary-based RQs (Dietary-based EEC/LC50 or	RQs	
	Acute	Chronic
Short Grass	0.30	1.81
Tall Grass	0.14	0.83
Broadleaf plants	0.17	1.02
Fruits/pods/seeds	0.02	0.11
Arthropods	0.12	0.71

Note: To provide risk management with the maximum possible information,
it is recommended that both the dose-based and concentration-based
RQs be calculated when data are available

glyphosate   tree crops (nuts, pome, citrus, misc)-ground max combined Upper bound Kenaga Residues

Mammalian Results

Mammalian Class	Body Weight	Ingestion (Fdry) (g bwt/day)	Ingestion (Fwet) (g/day)	% body wgt consumed	FI (kg-diet/day)
	15	3	14	95	1.43E-02
Herbivores/	35	5	23	66	2.31E-02
insectivores	1000	31	153	15	1.53E-01
	15	3	3	21	3.18E-03
Grainvores	35	5	5	15	5.13E-03
	1000	31	34	3	3.40E-02

Mammalian Class	Body Weight	Adjusted LD50	Adjusted NOAEL
	15	10549.59	1098.92
Herbivores/	35	8535.74	889.14
insectivores	1000	3691.97	384.58
	15	10549.59	1098.92
Granivores	35	8535.74	889.14
	1000	3691.97	384.58

Dose-Based EECs (mg/kg-bw)	Mammalian Classes and Body weight (grams)		
	15	35	1000
Short Grass	1430.78	988.86	229.27
Tall Grass	655.77	453.23	105.08
Broadleaf plants	804.81	556.23	128.96
Fruits/pods	89.42	61.80	14.33
Arthropods	560.39	387.30	89.80
Seeds	19.87	13.73	3.18

Dose-based RQs (Dose-based EEC/LD50 or	Small mammal 15 grams		Medium mammal 35 grams		Large mammal 1000 grams	
	Acute	Chronic	Acute	Chronic	Acute	Chronic
Short Grass	0.14	1.30	0.12	1.11	0.06	0.60
Tall Grass	0.06	0.60	0.05	0.51	0.03	0.27
Broadleaf plants	0.08	0.73	0.07	0.63	0.03	0.34
Fruits/pods	0.01	0.08	0.01	0.07	0.00	0.04
Arthropods	0.05	0.51	0.05	0.44	0.02	0.23
Seeds	0.00	0.02	0.00	0.02	0.00	0.01

Dietary-based RQs (Dietary-based EEC/LC50 or NOAEC)	Mammal RQs	
	Acute	Chronic
Short Grass	#DIV/0!	0.15
Tall Grass	#DIV/0!	0.07
Broadleaf plants	#DIV/0!	0.08
Fruits/pods/seeds	#DIV/0!	0.01
Arthropods	#DIV/0!	0.06

Note: To provide risk management with the maximum possible information,
it is recommended that both the dose-based and concentration-based
RQs be calculated when data are available

Appendix D

ECOLOGICAL EFFECTS DATA

Note: These tables are in large part extracted from the USEPA 2008 California red-legged frog risk assessment.

Table D-1. Freshwater Fish Acute Toxicity for Technical Glyphosate and Its Salts					
Species	**% Active Ingredient ***	**96-hour LC$_{50}$ NOAEC (mg a.e./L)*/ Slope**	**Toxicity Category[2]**	**MRID #/Year**	**Study Classification**
Bluegill sunfish (*Lepomis macrochirus*)	83	LC$_{50}$: 99.6 (92.1 - 107.9)[1] NOAEC: 83 Slope: Not available	Slightly toxic	00108205/1978	Acceptable
Rainbow trout (*Oncorhynchus mykiss*)	83	LC$_{50}$: 71.4 (58.1-84.8) NOAEC: 34.9 Slope: Not available	Slightly toxic	00136339/1978	Acceptable
Rainbow trout (*Oncorhynchus mykiss*)	95.6	LC$_{50}$: 128.1 (95.6 - 172.1) NOAEC: 30.6 Slope: Not available	Practically nontoxic	44320629/1995	Acceptable
Bluegill sunfish (*Lepomis macrochirus*)	95.6	LC$_{50}$: 43 (30.6 - 53.5) NOAEC: 30.6 Slope: Not available	Slightly toxic	44320630/1995	Acceptable
Fathead minnow (*Pimephales promelas*)	96.7	LC$_{50}$: 69.4 (56.5 - 85.9)[3] NOAEC not reported Slope: Not available	Slightly toxic	00162296/1979	Acceptable
Channel catfish (*Ictalurus punctatus*)	96.7	LC$_{50}$: 93 (78.7 - 114.5)[3] NOAEC not reported Slope: Not available	Slightly toxic	00162296/1979	Acceptable
Rainbow trout (*Oncorhynchus mykiss*)	96.7	LC$_{50}$: 100.2 (85.9 - 121.6)[3] NOAEC not reported Slope: Not available	Practically nontoxic	00162296/1979	Acceptable
Bluegill sunfish (*Lepomis macrochirus*)	96.7	LC$_{50}$: 100.2 (78.7 - 114.5)[3] NOAEC not reported Slope: Not available	Practically nontoxic	00162296/1979	Acceptable
* a.i. = active ingredient; a.e. = acid equivalent [1] Range is 95% confidence interval for endpoint [2]Based on LC$_{50}$ (mg/L): < 0.1 very highly toxic; 0.1-1 highly toxic; >1-10 moderately toxic; >10-100 slightly toxic; >100 practically nontoxic [3] Study conducted with the isopropylamine salt					

Table D-2. Freshwater Fish Acute Toxicity for Glyphosate Formulations

Chemical	Species	% a.i. *	96-hour LC$_{50}$/ NOAEC (mg a.e.*/L)/ Slope	Toxicity Category[1]	MRID #/Year	Study Classification
Glyphosate IPA*	Rainbow trout (*Oncorhynchus mykiss*)	30	LC$_{50}$: 1 (0.8 - 1.2)[2] (3.17 mg formulation/L) NOAEC: N.R.* Slope:N.R.	Highly toxic	40098001/1986	Supplemental
Glyphosate IPA (MON 77360)	Rainbow trout (*Oncorhynchus mykiss*)	30	LC$_{50}$: 1.6 (1.3 - 2.1) NOAEC: 1.3 Slope:NA*	Moderately toxic	45365003/2000	Supplemental
Glyphosate IPA	Fathead minnow (*Pimephales promelas*)	30	LC$_{50}$: 1.7 (1.4 - 2.1) NOAEC: N.R. Slope:N.R.	Moderately toxic	00162296/1979	Supplemental
Glyphosate IPA (Roundup)	Bluegill sunfish (*Lepomis macrochirus*)	31	LC$_{50}$: 1.8 (1.4 - 2.6) NOAEC: 0.7 Slope:N.R.	Moderately toxic	00124760/1982	Acceptable
Glyphosate monoammonium salt (MON78568)	Rainbow trout (*Oncorhynchus mykiss*)	66	LC$_{50}$: 1.9 (1.04 - 2.31) NOAEC: 1.04 Slope:N.R.	Moderately toxic	45767101/2002	Not classified
Glyphosate IPA (MON 77360)	Bluegill sunfish (*Lepomis macrochirus*)	30	LC$_{50}$: 2.2 (1.3 - 3.3) NOAEC: 1.3 Slope:NA	Moderately toxic	45365002/2000	Acceptable
Glyphosate IPA (MON65005)	Bluegill sunfish (*Lepomis macrochirus*)	31	LC$_{50}$: 2.4 (2.0 - 3.5) NOAEC: 1.2 Slope:N.R	Moderately toxic	44538203/1998	Acceptable
Glyphosate IPA (Roundup)	Rainbow trout (*Oncorhynchus mykiss*)	31	LC$_{50}$: 2.5 (2.0 - 3.1) NOAEC: 1.8 Slope:N.R.	Moderately toxic	00124761/1982	Supplemental
Glyphosate IPA (MON65005)	Rainbow trout (*Oncorhynchus mykiss*)	31	LC$_{50}$: 2.5 (1.9 - 3.1) NOAEC: 1.9 Slope:N.R	Moderately toxic	44538202/1998	Acceptable
Glyphosate IPA (Roundup)	Fathead minnow (*Pimephales promelas*)	41	LC$_{50}$: 2.9 (1.7 - 4.9) NOAEC: 1.7 Slope:N.R.	Moderately toxic	00070896/1980	Acceptable
Glyphosate IPA	Bluegill sunfish (*Lepomis macrochirus*)	30	LC$_{50}$: 3 (2.4 - 3.7) NOAEC: N.R. Slope:N.R.	Moderately toxic	40098001/1986	Supplemental
Glyphosate IPA	Rainbow trout (*Oncorhynchus mykiss*)	30	LC$_{50}$: 3.4 (5.2 - 7.3) NOAEC: N.R. Slope:N.R.	Moderately toxic	00162296/1979	Supplemental

Table D-2. Freshwater Fish Acute Toxicity for Glyphosate Formulations

Chemical	Species	% a.i. *	96-hour LC_{50}/ NOAEC (mg a.e.*/L)/ Slope	Toxicity Category[1]	MRID #/Year	Study Classification
Glyphosate IPA(MON 2139, Roundup)	Rainbow trout (*Oncorhynchus mykiss*)	41	LC_{50}: 3.4 (2.7 - 4.3) NOAEC: 2.7 Slope:N.R.	Moderately toxic	00070895/1980	Acceptable
Glyphosate IPA	Bluegill sunfish (*Lepomis macrochirus*)	30	LC_{50}: 3.7 (2.8 - 4.9) NOAEC: N.R. Slope:N.R.	Moderately toxic	00162296/1979	Supplemental
Glyphosate IPA (Roundup)	Bluegill sunfish (*Lepomis macrochirus*)	41	LC_{50}: 4.3 (2.7 - 7.3) NOAEC: 2.7 Slope:N.R.	Moderately toxic	00070897/1980	Acceptable
Glyphosate IPA (Roundup)	Channel catfish (*Ictalurus punctatus*)	41	LC_{50}: 4.9 (2.9 - 8.0) NOAEC: 2.9 Slope:N.R.	Moderately toxic	00070894/1980	Supplemental
Glyphosate IPA (Roundup)	Rainbow trout ((*Salmo gairdneri*)	36	LC_{50}: 5.5 - 9.2 (4.2 - 13) NOAEC: 4.2 Slope:N.R.	Moderately toxic	40579203/1986	Supplemental
Glyphosate IPA (Roundup)	Chinook Salmon (*Oncorhynchus tschawytscha*)	36	LC_{50}: 7.0 (5.4 - 9.9) NOAEC: <1.3 Slope:N.R.	Moderately toxic	40579201/1986	Not classified
Glyphosate IPA (Roundup)	Coho Salmon (*Oncorhynchus kisutch*)	36	LC_{50}: 8.2 (4.2 – 13.4) NOAEC: 3.42 Slope:N.R.	Moderately toxic	40579202/1986	Not classified
Glyphosate IPA with 0.5% "X-77"	Rainbow trout (*Oncorhynchus mykiss*)	5	LC_{50}: 9.4 (7.0 - 12.4) NOAEC: 7 Slope:N.R.	Moderately toxic	00078664/1980	Acceptable
Glyphosate IPA	Channel catfish (*Ictalurus punctatus*)	30	LC_{50}: 9.6 (8.1 - 11.8) NOAEC: N.R. Slope:N.R.	Moderately toxic	00162296/1979	Acceptable
Glyphosate IPA (Roundup with 15 % "W")	Bluegill sunfish (*Lepomis macrochirus*)	41	LC_{50}: >30 (30 - 96.4.) NOAEC: 30 Slope:N.R.	Slightly toxic	00078656/1980	Supplemental
Glyphosate IPA with 0.5% "X-77"	Bluegill sunfish (*Lepomis macrochirus*)	5.3	LC_{50}: 32.4 (24.2 - 62.4) NOAEC: 7.1 Slope:4.2	Slightly toxic	00078665/1980	Acceptable
Glyphosate IPA (Roundup with 15.3 % "AA")	Rainbow trout (*Oncorhynchus mykiss*)	41	LC_{50}: 36.6 (17.1 - 54.9) NOAEC: N.R. Slope:N.R.	Slightly toxic	00078658/1980	Acceptable

Table D-2. Freshwater Fish Acute Toxicity for Glyphosate Formulations

Chemical	Species	% a.i. *	96-hour LC_{50}/ NOAEC (mg a.e.*/L)/ Slope	Toxicity Category[1]	MRID #/Year	Study Classification
Glyphosate IPA (Roundup with 15 % "W")	Rainbow trout (*Oncorhynchus mykiss*)	41	LC_{50}: 45.2 (30.1 - 96.4) NOAEC: 30.1 Slope:N.R.	Slightly toxic	00078655/1980	Acceptable
Glyphosate (360 g/L SL)	Bluegill sunfish (*Lepomis macrochirus*)	28	LC_{50}: >52 (N.A.) NOAEC: 52 Slope:N.A.	Slightly toxic	45374002/2000	Supplemental
Glyphosate(80WDG)	Fathead minnow (*Pimephales promelas*)	79	LC_{50}: 54.3 (47.3 - 79.1) NOAEC: 28.7 Slope:N.R.	Slightly toxic	44125704/1996	Acceptable
Glyphosate(80WDG)	Rainbow trout (*Oncorhynchus mykiss*)	80	LC_{50}: 62.1 (48.2 - 80.0) NOAEC: 28.7 Slope:N.R.	Slightly toxic	44125705/1996	Acceptable
Glyphosate IPA (Rodeo/X-77)	Rainbow trout (*Salmo gairdneri*)	41	LC_{50}: 96.4 (89.0 - 118.7) NOAEC: 37.5 Slope:N.R.	Slightly toxic	40579301/1985	Not classified
Glyphosate IPA (Rodeo/X-77)	Chinook salmon (*Oncorhynchus tschawytscha*)	41	LC_{50}: 103.8 (89.0 - 148.3) NOAEC: 47.5 Slope:N.R.	Practically non-toxic	40579303/1985	Not classified
Glyphosate IPA (Rodeo/X-77)	Rainbow trout ((*Salmo gairdneri*)	41	LC_{50}: 134 (75 - 240) NOAEC: 43 Slope:N.R.	Practically non-toxic	40579306/1987	Not classified
Glyphosate IPA (Rodeo/X-77)	Coho Salmon (*Oncorhynchus kisutch*)	41	LC_{50}: 148.3 (89.0 - 274.4) NOAEC: 88.5 Slope:N.R.	Practically non-toxic	40579302/1985	Not classified
Glyphosate IPA (Rodeo/X-77)	Chinook salmon (*Oncorhynchus tschawytscha*)	40	LC_{50}: 180.2 (133.5 - 240.3) NOAEC: 74.8 Slope:N.R.	Practically non-toxic	40579305/1987	Not classified
Glyphosate (360 g/L SL)	Rainbow trout (*Oncorhynchus mykiss*)	27	LC_{50}: 224.5 (160.1 - 280.0) (824 mg formulation/L) NOAEC: 160 Slope:N.R.	Practically non-toxic	45374001/1999	Supplemental
Trisodium diglyphosate/Urea (Polado formula) - MON 8000	Bluegill sunfish (*Lepomis macrochirus*)	75	LC_{50}:>315 (N.R.) NOAEC: 315 Slope:N.R.	Practically non-toxic	00079146/1980	Supplemental

Table D-2. Freshwater Fish Acute Toxicity for Glyphosate Formulations

Chemical	Species	% a.i.*	96-hour LC_{50}/ NOAEC (mg a.e.*/L)/ Slope	Toxicity Category[1]	MRID #/Year	Study Classification
Trisodium diglyphosate/Urea (Polado formula) - MON 8000	Rainbow trout (*Oncorhynchus mykiss*)	75	LC_{50}: >315 (N.R.) NOAEC: 315 Slope:N.R.	Practically non-toxic	00085637/1980	Supplemental
Glyphosate IPA (Rodeo)	Rainbow trout ((*Salmo gairdneri*)	41	LC_{50}: 430.1 (341 - 541) NOAEC: 157 Slope:N.R.	Practically non-toxic	40579301/1985	Not classified
Glyphosate IPA (No surfactant)	Rainbow trout (*Oncorhynchus mykiss*)	62	LC_{50}: >461.8 (N.R.) NOAEC: N.R. Slope:N.R.	Practically non-toxic	00078661/1980	Acceptable
Glyphosate IPA (No surfactant)	Bluegill sunfish (*Lepomis macrochirus*)	62	LC_{50}: >461.8 (N.R.) NOAEC: N.R. Slope:N.R.	Practically non-toxic	00078662/1981	Supplemental
Glyphosate IPA (MON77945 Manufacturing concentrate)	Rainbow trout (*Oncorhynchus mykiss*)	46	LC_{50}: >977 (N.A.) mg formulation/L NOAEC: 591 Slope:N.A.	Practically non-toxic	44715409/1998	Not classified
Glyphosate IPA with Geronol CF/AR	Rainbow trout (*Oncorhynchus mykiss*)	10	LC_{50}: > 450 (N.A.) mg a.e./L or > 1000 mg formulation/L NOAEC: 1000 mg formulation/L Slope:N.A.	Practically non-toxic	44738201/1996	Not classified
Glyphosate IPA with Geronol CF/AR	Rainbow trout (*Oncorhynchus mykiss*)	36	LC_{50}: >1000 (N.A.) mg formulation/L NOAEC: 800 Slope:N.A.	Practically non-toxic	44738201/1996	Not classified
Glyphosate IPA (Roundup Biactive)	Rainbow trout (*Oncorhynchus mykiss*)	36	LC_{50}: >1000 (N.A.) mg formulation/L NOAEC: 800 Slope:N.A.	Practically non-toxic	44738201/1996	Not classified
Glyphosate IPA with Geronol CF/AR	Rainbow trout (*Oncorhynchus mykiss*)	45	LC_{50}: >1000 (N.A.) mg formulation/L NOAEC: 1000 Slope:N.A.	Practically non-toxic	44738201/1996	Not classified

* a.i. = active ingredient; a.e. = acid equivalent; IPA = isopropylamine salt; NR = not reported; NA = not available
[1]Based on LC_{50} (mg/L): < 0.1 very highly toxic; 0.1-1 highly toxic; >1-10 moderately toxic; >10-100 slightly toxic; >100 practically nontoxic
[2] Range is 95% confidence interval for endpoint

Table D-3. Freshwater Fish Acute Toxicity for Surfactants Used with Glyphosate Formulations

Chemical	Species	% a.i.[1]	LC/EC$_{50}$ (mg/L)	Toxicity Category[2]	MRID #/Year; comment	Study Classification
Polyoxy ethylene fatty amine (POEA) (MON 0818)	Fathead minnow (*Pimephales promelas*)	70[4]	96-hr LC$_{50}$: 0.7 (0.84 - 1.19)[3] NOAEC and slope not reported	Highly toxic	00162296/1979; MON 0818 LC$_{50}$: 1 mg/L	Acceptable
Polyoxy ethylene fatty amine (POEA) (MON 0818)	Rainbow trout (*Oncorhynchus mykiss*)	70[4]	96-hr LC$_{50}$: 1.4 (1.05 – 1.89) NOAEC and slope not reported	Moderately toxic	00162296/1979; MON 0818 LC$_{50}$: 2mg/L[5]	Acceptable
Polyoxy ethylene fatty amine (POEA) (MON 0818)	Bluegill sunfish (*Lepomis macrochirus*)	70[4]	96-hr LC$_{50}$: 2.1 (1.75 – 2.59) NOAEC and slope not reported	Moderately toxic	00162296/1979; MON 0818 LC$_{50}$: 3 mg/L	Acceptable
Polyoxy ethylene fatty amine (POEA) (MON 0818)	Channel catfish (*Ictalurus punctatus*)	70[4]	96-hr LC$_{50}$: 9.1 (7.0 – 11.9) NOAEC and slope not reported	Slightly toxic	00162296/1979; MON 0818 LC$_{50}$: 13 mg/L	Acceptable
Surfactant Geronol CF/AR (alkyl polyoxy ethylene phosphoric acid ester)	Zebra fish (*Brachydanio rerio*)	100	96-hr LC$_{50}$: >100 (N.A.) NOAEC and slope not reported	Practically non-toxic	44738201/ Summary from another study	Not Classified

[1] a.i. = active ingredient, assumed 100% for technical material
[2] Based on LC$_{50}$ (mg/L): < 0.1 very highly toxic; 0.1-1 highly toxic; >1-10 moderately toxic; >10-100 slightly toxic; >100 practically nontoxic
[3] Range is 95% confidence interval for endpoint.
[4] Based on information provided by Registrant, the test material, MON 0818, contains 70% POEA; (comment from Monsanto Co. September 21, 2009; http://www.regulations.gov/#!documentDetail:D=EPA-HQ-OPP-2009-0361-0013)
[5] In 00162296 (Folmer 1979), for MON 0818, a reported acute 96-hr LC50 toxicity value of 0.65 mg/L was reported for rainbow trout, however, this study was conducted at a pH of 9.5 and therefore, was not used quantitatively

Table D-4. Freshwater Fish Acute Toxicity for Aminomethyl Phosphonic Acid (AMPA) Degradate of Glyphosate

Chemical	Species	% a.i.[1]	96-hour LC$_{50}$/NOAEC (mg/L)/Slope	Toxicity Category[2]	MRID #/Year	Study Classification
AMPA	Rainbow trout (*Oncorhynchus mykiss*)	94.38	LC$_{50}$: 499 (391 - 647) NOAEC: 174 Slope: 6.42	Practically nontoxic	43334713/1991	Acceptable

[1] a.i. = active ingredient, assumed 100% for technical material
[2] Based on LC$_{50}$ (mg/L): < 0.1 very highly toxic; 0.1-1 highly toxic; >1-10 moderately toxic; >10-100 slightly toxic; >100 practically nontoxic
[3] Range is 95% confidence interval for endpoint.

Table D-5. Estuarine/marine Fish Acute Toxicity for Technical Glyphosate and Its Salts

Species	% Active Ingredient*	96-hour LC$_{50}$ NOAEC (mg a.e./L)*/ Slope	Toxicity Category[2]	MRID #/Year	Study Classification
Sheepshead minnow (*Cyprinodon variegatus*)	96	96-hr. LC$_{50}$: 240 (180-320) NOAEC: 100 Slope: NA	Practically nontoxic	44320632/1996	Acceptable

* a.i. = active ingredient; a.e. = acid equivalent; N.R. = not reported
[1] Range is 95% confidence interval for endpoint
[2]Based on LC$_{50}$ (mg/L): < 0.1 very highly toxic; 0.1-1 highly toxic; >1-10 moderately toxic; >10-100 slightly toxic; >100 practically nontoxic

Table D-6. Estuarine/marine Fish Acute Toxicity for Glyphosate Formulations

Chemical	Species	% Active Ingredient*	96-hour LC$_{50}$ NOAEC (mg a.e./L)*/ Slope[1]	Toxicity Category[2]	MRID #/ Year	Study Classification
Glyphosate (MON 2139)	Sheepshead minnow (*Cyprinodon variegatus*)	30.75	96-hr LC$_{50}$ = 2.7 mg a.e./L 96-hr LC$_{50}$: 8.8 mg formulation/L Slope: NA NOAEC: 6.8	Moderately toxic	48934205/2012	Acceptable
Glyphosate SL formulation	Sheepshead minnow (*Cyprinodon variegatus*)	28.3	96-hr. LC$_{50}$: >50.9 mg a.e./L >180.2 ppm formulation	Practically nontoxic	45374005 /2000	Supplemental

* a.i. = active ingredient; a.e. = acid equivalent; N.R. = not reported
[1] Range is 95% confidence interval for endpoint
[2]Based on LC$_{50}$ (mg/L): < 0.1 very highly toxic; 0.1-1 highly toxic; >1-10 moderately toxic; >10-100 slightly toxic; >100 practically nontoxic

Table D-7. Aquatic-Phase Amphibian Acute Toxicity for Technical Glyphosate and Its Salts

Species	% Active Ingredient*	96-hour LC_{50} NOAEC (mg a.e./L)*/ Slope	Toxicity Category[2]	MRID #/Year	Study Classification
Australian tree frog (*Litoria moorei*) Tadpole	96	LC50: 103.2 (43.2 - 172.8)[1] NOAEL: N.R.* Slope: N.R.	Practically nontoxic	43839601/1995	Supplemental
Australian frog (*Crinia insignifera*) Adult	96	LC50: 75 (60.4-92.7) NOAEL: N.R. Slope: N.R.	Slightly toxic	43839601/1995	Supplemental
Green Frog (*Rana clamitans*) Gosner Stg 25	Tech[3]	LC50: >17.9 (NR) NOAEL: NR Slope: NR	Slightly toxic	46650501/2001	Supplemental

* a.i. = active ingredient; a.e. = acid equivalent; N.R. = not reported
[1] Range is 95% confidence interval for endpoint
[2] Based on LC_{50} (mg/L): < 0.1 very highly toxic; 0.1-1 highly toxic; >1-10 moderately toxic; >10-100 slightly toxic; >100 practically nontoxic
[3] Study conducted with the isopropylamine salt

Table D-8. Aquatic-Phase Amphibian Acute Toxicity for Glyphosate Formulations

Chemical	Species	% a.i.*	96-hour LC_{50}/ NOAEC (mg a.e.*/L)/ Slope	Toxicity Category[1]	MRID #/Year	Study Classification
Glyphosate- IPA (Cosmo Flux Coca mix)	African clawed frog (*Xenopus laevis*) Larvae	18	LC_{50}: 1.1 (0.56 - 2.3) or 10 mg/L formulation NOAEL: 0.14 Slope: 4.92	Moderately toxic	46873601/2006	Supplemental
Glyphosate IPA (Cosmo Flux Poppy mix)	African clawed frog (*Xenopus laevis*) Larvae	0.0205	LC_{50}: 1.3 (0.92 - 1.8) or 16 mg/L formulation NOAEL: 0.43 Slope: NA*	Moderately toxic	46873602/2006	Supplemental
Glyphosate IPA (Roundup Original with 15% POEA)	Green Frog (*Rana clamitans*) Gosner Stg 25	NR	LC_{50}: 2 (1.9-2.2) or 6.5 mg/L formulation NOAEL: NR* Slope: NR	Moderately toxic	46650501/2001	Supplemental

Table D-8. Aquatic-Phase Amphibian Acute Toxicity for Glyphosate Formulations						
Chemical	**Species**	**% a.i.***	**96-hour LC_{50}/ NOAEC (mg a.e.*/L)/ Slope**	**Toxicity Category[1]**	**MRID #/Year**	**Study Classification**
Glyphosate IPA (Roundup Transorb with 15% POEA)	Green Frog (*Rana clamitans*) Gosner Stg 25	NR	LC_{50}: 2.2 (2.1-2.4) or 7.2 mg/L formulation NOAEL: NR Slope: NA	Moderately toxic	46650501/2001	Supplemental
Glyphosate IPA (Roundup Original with 15% POEA)	Leopard Frog (*Rana pipiens*) Gosner Stg 25	NR	LC_{50}: 2.9 (NR) or 9.2 mg/L formulation NOAEL: NR Slope: NR	Moderately toxic	46650501/2000	Supplemental
Glyphosate IPA (Roundup Original with 15% POEA)	American toad (*Bufo americanus*) Gosner Stg 25	NR	LC_{50}: <4.0 (NR) or < 12.9 mg/L formulation NOAEL: NR Slope: NR	Moderately toxic	46650501/1994	Supplemental
Glyphosate IPA (Roundup with 15% POEA)	Wood Frog (*Rana sylvatica*) Gosner Stg 25	NR	LC_{50}: 5.1 (4.9-5.4) or 16.5 mg/L formulation NOAEL: NR Slope: NR	Moderately toxic	46650501/1994	Supplemental
Glyphosate IPA (Roundup 360)	Australian tree frog (*Litoria moorei*) Tadpole	30.3	LC_{50}: 5.6 (4.4 - 7.1) or 18.5 mg/L formulation NOAEL: N.R. Slope: N.R.	Moderately toxic	43839601/1995	Supplemental
Glyphosate IPA (Roundup Original with 15% POEA)	Leopard Frog (*Rana pipiens*) Gosner Stg 20	NR	LC_{50}: 6.5 (6.1-6.8) or 20.9 mg/L formulation NOAEL: NR Slope: NA	Moderately toxic	46650501/1994	Supplemental
Glyphosate IPA (Roundup Original with 15% POEA)	Green frog (*Rana clamitans*) Gosner Stg 20	NR	LC_{50}: 7.1 (6.6-7.6) or 22.8 mg/L formulation NOAEL: NR Slope: NR	Moderately toxic	46650501/1994	Supplemental

Chemical	Species	% a.i.*	96-hour LC$_{50}$/ NOAEC (mg a.e.*/L)/ Slope	Toxicity Category[1]	MRID #/Year	Study Classification
Glyphosate IPA (Roundup Original with 15% POEA)	American toad (*Bufo americanus*) Gosner Stg 20	NR	LC$_{50}$: 8 (NR) or 25.8 mg/L formulation NOAEL: NR Slope: NR	Moderately toxic	46650501/1994	Supplemental
Glyphosate IPA (Roundup Original with 15% POEA)	Wood Frog (*Rana sylvatica*) Gosner Stg 20	NR	LC$_{50}$: > 8 (NR) or > 25.8 mg/L formulation NOAEL: NR Slope: NR	Moderately toxic	46650501/1994	Supplemental
Glyphosate IPA (Glyphos AU with 3-7% POEA)	Green Frog (*Rana clamitans*) Gosner Stg 25	NR	LC$_{50}$: 8.9 (8.6-9.2) or 28.6 mg/L formulation NOAEL: NR Slope: NR	Moderately toxic	46650501/2001	Supplemental
Glyphosate IPA (Roundup Biactive with 10-20% unspecified surfactant)	Green frog (*Rana clamitans*) Gosner Stg 25	NR	LC$_{50}$: >17.9 (NR) or > 57.7 mg/L formulation NOAEL: NR Slope: NR	Slightly toxic	46650501/2001	Supplemental
Glyphosate IPA (Glyphos BIO with 3-7% POEA)	Green Frog (*Rana clamitans*) Gosner Stg 25	NR	LC$_{50}$: >17.9 (NR) or >57.7 mg/L formulation NOAEL: NR Slope: NR	Slightly toxic	46650501/2001	Supplemental
Glyphosate IPA (Roundup 360)	Australian frog (*Crinia insignifera*) Adult	30.3	LC$_{50}$: 30.4 (0-infinity) or 100.2 mg/L formulation NOAEL: N.R. Slope: N.R.	Slightly toxic	43839601/1995	Supplemental
Glyphosate IPA (Roundup 360)	Australian frog (*Crinia insignifera*) Tadpole	30.3	48 hr LC$_{50}$: 38.2 (30.2 - 48.8) or 125.9 mg/L formulation NOAEL: N.R. Slope: N.R.	Slightly toxic	43839601/1995	Supplemental

Table D-8. Aquatic-Phase Amphibian Acute Toxicity for Glyphosate Formulations

Table D-8. Aquatic-Phase Amphibian Acute Toxicity for Glyphosate Formulations

Chemical	Species	% a.i.*	96-hour LC_{50}/ NOAEC (mg a.e.*/L)/ Slope	Toxicity Category[1]	MRID #/Year	Study Classification
Glyphosate IPA (with surfactant Geronol CF/AR	Common froglet (*Ranidella signifera*) Tadpole	45	LC_{50}: >450 (N.A.) or >1000 mg/L formulation NOAEL: 1000 Slope: N.A.	Practically nontoxic	44738201/1996	Supplemental
Glyphosate IPA (Roundup Biactive)	Common froglet (*Ranidella signifera*) Tadpole	36	LC_{50}: >360 (N.A) or >1000 mg/L formulation NOAEL: <800 Slope: N.A.	Practically nontoxic	44738201/1996	Supplemental
Glyphosate IPA (with surfactant Geronol CF/AR)	Common froglet (*Ranidella signifera*) Tadpole	36	LC_{50}: >360 (N.A) or >1000 mg/L formulation NOAEL: 1000 Slope: N.A.	Practically nontoxic	44738201/1996	Supplemental
Glyphosate IPA (with surfactant Geronol CF/AR)	Common froglet (*Ranidella signifera*) Tadpole	10	LC_{50}: >100 (N.A.) or >1000 mg/L formulation NOAEL: 1000 Slope: N.A.	Practically nontoxic	44738201/1996	Supplemental

* a.i. = active ingredient; a.e. = acid equivalent; IPA = isopropylamine salt, N.A. = not available, N.R. = not reported
[1]Based on LC_{50} (mg/L): < 0.1 very highly toxic; 0.1-1 highly toxic; >1-10 moderately toxic; >10-100 slightly toxic; >100 practically nontoxic
[2] Range is 95% confidence interval for endpoint

Table D-9. Aquatic-Phase Amphibian Acute Toxicity for POEA Surfactant Used with Glyphosate Formulations

Chemical	Species	% a.i.[1]	96-hour LC$_{50}$/NOAEC (mg/L)/Slope	Toxicity Category[2]	MRID #/Year	Study Classification
Polyoxy ethylene fatty amine (POEA or MON 0818)	Green Frog (*Rana clamitans*) Gosner Stg 25	69-73	LC50: 2.2 (2.1-2.4) NOAEC: NR* Slope: NR	Moderately toxic	46650501/2001	Supplemental

* NR = not reported
[1] a.i. = active ingredient, assumed 100% for technical material
[2] Based on LC$_{50}$ (mg/L): < 0.1 very highly toxic; 0.1-1 highly toxic; >1-10 moderately toxic; >10-100 slightly toxic; >100 practically nontoxic
[3] Range is 95% confidence interval for endpoint.

Table D-10. Freshwater Fish Chronic Toxicity for Technical Glyphosate and Its Salts

Species	% Active Ingredient	NOAEC/LOAEC (mg acid equivalent/L)	MRID #/Year	Study Classification
Fathead minnow (*Pimephales promelas*)	87.3	25.7/>25.7[1]	00108171/1975	Acceptable

Table D-11. Aquatic Phase Amphibian Chronic Toxicity for Technical Glyphosate IPA Salt and IPA Salt Formulations

Species	% Active Ingredient	NOAEC/LOAEC (mg acid equivalent/L)	MRID #/Year	Study Classification
Leopard Frog (*Rana pipiens*)	Tech (assumed 100%)	NOAEC/LOAEC: 1.8/>1.8	46650501/2004	Supplemental
Leopard Frog (*Rana pipiens*)	Roundup Original & Transorb 15% POEA	NOAEC/LOAEC: <0.6/0.6	46650501/2004	Supplemental

Table D-12. Aquatic-Phase Amphibian Chronic Toxicity for POEA Surfactant Used with Glyphosate Formulations

Chemical	Species	% a.i.[1]	NOAEC/ LOAEC (mg a.i./L)	MRID #/Year	Study Classification
Polyoxy ethylene fatty amine (POEA or MON 0818)	Leopard Frog (*Rana pipiens*) Larvae	Tech	NOAEC/ LOAEC: <0.6/0.6 [reported in units of mg acid equivalents/L]	46650501/2004	Supplemental

[1] a.i. = active ingredient, assumed 100% for technical material

Open Literature Data for Fish and Amphibians (including some submitted studies)

	Table D-13. Fish Effects From Submitted and Open Literature Studies				
Species	**Chemical**	**NOAEC**	**LOAEC:Effects**		**MRID/ ECOTO X Reference No.**
Nile tilapia (*O. niloticus*)	Roundup (48% a.e.)	Not determined	5 ppm: gills: filament cell proliferation, lamellar cell hyperplasia, lamellar fusion, epithelial lifting, and aneurysm. Liver: vacuolation of hepatocytes and nuclear pyknosis. Kidneys: dilation of Bowman's space and accumulation of hyaline droplets in the tubular epithelial cells. Significant increase in aspartate aminotransferase, alanine aminotransferase, and alkaline phosphatase activities. Decreased activity.		E096917
Nile tilapia (*O. niloticus*)	Roundup (48% a.e.)	5 ppm	15 ppm: gills: mucosal cells of laminar epithelium - loss of microridges and appearance of intercellular spaces; thickening of primary epithelium, edema, lifting and fusion of secondary lamellae – may impair respiratory function. Liver: progressive reduction and fragmentation of RER; swollen mitochondria; increases in number and sizes of lysosomes and lipid droplets; infiltration of leukocytes; increased hepatocyte size with pyknotic nuclei and presence of vacuoles. Kidney: degeneration of nuclear membrane; mitochondrial contraction and/or swelling; accumulation of large electron dense particles; increase in number and size of lysosomes and apical vacuoles; some cellular necrosis. Increased plasma aspartate and alanine aminotransferase and alkaline phosphatase activities at 15 ppm.		E096937
Topmouth gudgeon (*pseudorasobora parva*)	Glyphosate IPA salt (41%)	Not determined	1 ppm: Initial possible inhibition of liver esterase activity and then possible induction of enzyme activity. Not dose dependent.		E097111
Rainbow trout (*O. mykiss*)	Vision (356 g/L glyphosate acid with surfactant)	8 ppb	45.75 ppb: increase in wigwag behavior (one of agonistic behaviors). No effects on growth, foraging variables or antagonistic activity; no evidence of neoplasia or melanomacrophages and no increase in gill lesions at 45.75 ppb (highest concentration tested).		E097714
Rainbow trout (*O. mykiss*)	Glyphosate (assumed technical) and combinations	1.25 ppm (glyphosate alone)	Rainbow trout vitellogenin assay. Estrogenic effects. No effects with glyphosate alone. When combined with		E080643

Table D-13. Fish Effects From Submitted and Open Literature Studies

Species	Chemical	NOAEC	LOAEC:Effects	MRID/ ECOTOX Reference No.
	with surfactants R-11 and Target Prospeador Acitvator		surfactants at 1.25 ppm, trends indicated elevated vitellogenin.	
North African catfish (*Clarius gariepinus*)	Roundup (no other identification)	Not determined	3.9 ppm: Increased plasma AST, ALP, ALT levels.	E097133
Rainbow trout (*O. mykiss*)	Technical glyphosate 95.6%	30.6 ppm	53.6 ppm: dark coloration	MRID 44320629
T. rendalli	Roundup® (480g/l) and surfactant	No NOAEL	42 mg/kg. Fish erythrocyte micronucleus assay. Pesticide applied by injection. Roundup induced micronuclei at 42, 85 and 170 mg/kg	E074478
Rainbow trout (*O. mykiss*)	Roundup® 143 g/L	0.01 ppm	0.1 ppm. Olfactory-mediated behavioral and neurophysiological response. Over a concentration range that does not result in acute toxicity, trout detect Roundup but do not avoid it. Above that concentration, they avoid it ($\geq$ 10 ppm). Study found that behavioral responses may be more sensitive toxicological endpoints than neurophysiological responses.	E089625 Tierney 2007
Rainbow trout (*O. mykiss*)	Roundup® 356 g/L glyphosate IPA MON 02139	30 ppm	40 ppm. Fish tend to avoid concentrations that are lethal (40 ppm and above). 96-hr LC_{50} 54.8 in the lab and 52 in the field. No mortality at 2.2 kg a.e./ha, 10x and 100x field dose.	E010471
Rainbow trout (*O. mykiss*)	Vision® 356 g a.e./L with either 10% or 15% surfactant (POEA). 7.5% surfactant tested in acute study	Avoidance: 27 ppm (15%) & 75 ppm (10%) Other behavior 6.75 ppm (15%) & 18.75 ppm (10%)	96 hr LC_{50}: 100 ppm (7.5%); 75 ppm (10%); 27 ppm (15%). Avoidance behavior LOAEC: 150 ppm (10%); 54 ppm (15%) Other behavior LOAEC: Erratic swimming & rapid respiration 13.5 ppm (15%); erratic swimming & labored respiration 37.5 ppm (10%)	E05182
Tilapia (*Oreochromis niloticus*) Lee Koh (*Cyprinus carpio*)	Roundup® 30.5% w/w glyphosate	0.31 ppm for tilapia 1.7 ppm for Lee Koh	Tilapia: 0.55 ppm: erratic swimming. 96-hr LC_{50}: 2.3 ppm. Lee Koh: LC_{50}: 3.1 ppm. LOAEC not provided.	E03296
Piava (*Leporinus obtusidens*)	Roundup (48% glyphosate acid)	NOAEC < 1 mg/L	LOAEC = 1 mg/L Based on reduced body length & weight gain	E161803 / Salbego *et al*. 2010

Table D-13. Fish Effects From Submitted and Open Literature Studies				
Species	**Chemical**	**NOAEC**	**LOAEC:Effects**	**MRID/ ECOTOX Reference No.**
4 species juvenile Pacific salmonids (coho, chum, chinook, and pink) and rainbow trout	Glyphosate (tech); Roundup (41% GLY-IPA); MON 8709 (41% GLY-IPA); MON 0818 (75% POEA)	--	96-hr LC50 range: GLY: 10-211 mg ai/L; Roundup: 11-33 mg form/L; MON 8709: 17-67 mg form/L; MON 0818: 1.4-4.6 mg ai/L	E924/ Wan *et al.* 1989

Table D-14. Aquatic Amphibian Sublethal Effects From Submitted and Open Literature Studies				
Species	**Chemical**	**NOAEC**	**LC_{50} or LOAEC:Effects**	**MRID/ ECOTOX Ref. No.**
Green frog (*Rana pipiens)*	Vision® (contains POEA surfactant)	Not determined for mortality	LOAEC for mortality: 0.75 ppm a.e. at pH 7.5. Note: higher pH (7.5) versus 5.5 increases acute toxicity	E072794
African clawed frog (*Xenopus laevis)*	Rodeo® (480 g a.e./L no surfactant) Roundup® (356 g ae/L with POEA surfactant)	5 ppm a.e. (Roundup®) and 2000 ppm a.e. (Rodeo®)	Frog embryo teratogenesis assay. LC_{50}'s: POEA (6.8 ppm), Roundup® (9.3 ppm a.e.), Rodeo® (7297 ppm a.e.). No significant increases in embryo malformations for either formulation.	E053090
Crinia insignifera, Heleioporus eyrei, Limnodynastes dorsalis,and Litoria moorei	Glyphosate, glyphosate IPA, Roundup®, Touchdown® and Roundup® Biactive	N/A	48-hr acute LC_{50}'s (formulations) for tadpoles, metamorphs and adults between 2.9 and >360 mg a.e./L with Roundup® (MON 2139) as the most toxic formulation to Roundup® Biactive as the least toxic formulation. Glyphosate IPA salt alone (LC_{50}: 466 mg a.e./L) less toxic than glyphosate acid (LC_{50}: 81.2 – 121 mg a.e./L), probably due to acid intolerance. Slight differences in species sensitivity *L moorei* tadpoles more sensitive than other tadpoles; adult and new metamorphs less sensitive than tadpoles.	E071857
Leopard frog (*Rana pipiens*), Green frog, (*Rana clamitans*) American toad, (*Bufo americanus*), African clawed frog	Vision® (contains POEA surfactant)	N/A	96-hr acute studies. Toxicity enhanced by elevated pH with Surfactant POEA (15%) hypothesized as major source of pH interaction. LC_{50}'s (mg a.e./L) pH 6.0 pH 7.5 Leopard frog embryo* 15.1 7.5 Leopard frog larvae* 1.8 1.1 Green frog embryo 5.3 4.1 Green frog larvae 3.5 1.4	E072795

Table D-14. Aquatic Amphibian Sublethal Effects From Submitted and Open Literature Studies					
Species	**Chemical**	**NOAEC**	**LC$_{50}$ or LOAEC:Effects**	**MRID/ ECOTOX Ref. No.**
(*Xenopus laevis*)			American toad embryo 4.8 6.4 American toad larvae 2.9 1.7 African clawed frog embryo 15.6 7.9 African clawed frog larvae 2.1 0.88 *Gosner 8-25 = embryo, Gosner 25 = larvae Growth inhibition in surviving frogs observed with clawed frog, green frog and leopard frog	
Scinax nasicus tadpoles Gosner stages 25-26 (prometamorphic)	Glyfos (48% IPA + 15% POEA)	N/A	96-hr acute LC$_{50}$: 2.64 mg glyphos/L (1.95 mg a.e./L). Malformations (craniofacial and mouth deformities, eye abnormalities and bent curved tails) increase with increased time and mortality.	E071969
Western chorus frog (*Pseudacris triseriata*) and Plains leopard frog (*Rana blairi*) tadpoles Gosner stage 25	Kleeraway Grass and Weed Killer RTU (IPA 0.75%, surfactant – ethoxylated tallowamine).		Concentration levels 750, 75, 7.5 or 0.75 ppm IPA. 24-hr exposure period. No frogs survived 7.5 – 750 ppm. Western chorus frogs slightly more sensitive. No effect on growth or final Gosner stage.	E61464
Rana cascadae larvae	Roundup® 50.2%	Not determined for time to metamorphosis	LOAEL 1 ppm. Concentration levels 0.96 and 1.94 ppm for 43 days. None survived to metamorphosis at 1.94 ppm (mean time 7.5 days). Bent tails and slow swimming ability before death. Metamorphosis occurred more rapidly in treated frogs with decreased size and mass. Unclear from this study if LOAEL is in terms of a.e.	E096423
6 amphibian species endemic to the Pacific Northwest (2 salamanders, 1 toad, 3 frogs)	Roundup Regular (₅0.2% GLY-IPA)	NA	24-h LC$_{50}$ = 0.43 – 2.6 mg ai/L 7-d LC$_{50}$ = 0.32 – 2.08 15-d LC$_{50}$ = 0.30-1.95	E161728 / King and Wagner 2010
American Toad (Bufo americanus)	Roundup WeatherMax (48.8% glyphosate potassium salt)	NOAEC = 0.5 mg a.e./L	LOAEC = 0.572 mg a.e./L based on delayed time to metamorphosis	E153825 / Williams and Semlitsch 2010
Western chorus frog (Pseudoacris triseriata)	Roundup WeatherMax (48.8% glyphosate potassium salt) & Roundup Original (48.7% glyphosate potassium salt)	NOAEC = 0.5 mg a.e./L	LOAEC = 0.572 mg a.e./L based on delayed time to metamorphosis for both formulations and for survival for WeatherMax formulation	E153825 / Williams and Semlitsch 2010

Table D-15. Freshwater Invertebrates Acute Toxicity for Technical Glyphosate*

Species	% a.i.*	48-hour EC_{50} - LC_{50}/ NOAEC (mg a.e./L)*/ Slope	Toxicity Category[1]	MRID #/Year	Study Classification
Midge (*Chironomus plumosus*)	96.7	LC_{50}: **53.2 (30.0 - 93.8)**[2] NOAEC: N.R. Slope: N.R.	Slightly toxic	00162296/1979	Acceptable
Water flea (*Daphnia magna*)	95.6	EC_{50}: 128.1 (95.6 - 172.1) NOAEC: 95.6 Slope: N.R.	Practically nontoxic	44320631/1995	Acceptable
Water flea (*Daphnia magna*)	83	EC_{50}: 647.4 (577.7 - 725.4) NOAEC: 464.8 Slope: N.R.	Practically nontoxic	00108172/1978	Acceptable

* No technical glyphosate salts were tested; a.i. = active ingredient; a.e. = acid equivalent, N.R. = not reported
[1]Based on LC_{50} (mg/L): < 0.1 very highly toxic; 0.1-1 highly toxic; >1-10 moderately toxic; >10-100 slightly toxic; >100 practically nontoxic
[2] Range is 95% confidence interval for endpoint

Table D-16. Freshwater Invertebrates Acute Toxicity for Glyphosate Formulations

Chemical	Species	% a.i.*	48-hour EC_{50} - LC_{50}/ NOAEC (mg a.e./L)*/ Slope	Toxicity Category[1]	MRID #/Year	Study Classification
Glyphosate IPA - Roundup	Water flea (*Daphnia magna*)	41.36	EC_{50}: 1.6 (1.4 - 1.9)[2] NOAEC: 0.6 Slope: 5.4	Moderately toxic	00070893/1980	Acceptable
Glyphosate IPA	Water flea (*Daphnia magna*)	30.3	EC_{50}: 2.2 (1.9 - 2.5) NOAEC: N.R. Slope: N.R.	Moderately toxic	00162296/1979	Acceptable
Glyphosate IPA (MON65005)	Water flea (*Daphnia magna*)	31.32	EC_{50}: 2.7 (2.3 - 3.1) NOAEC: 1.3 Slope: 6.2	Moderately toxic	44538201/1998	Acceptable

Table D-16. Freshwater Invertebrates Acute Toxicity for Glyphosate Formulations						
Chemical	**Species**	**% a.i.***	**48-hour EC_{50} - LC_{50}/ NOAEC (mg a.e./L)*/ Slope**	**Toxicity Category[1]**	**MRID #/Year**	**Study Classification**
Glyphosate IPA (MON 77360)	Waterflea (*Daphnia magna*)	30.0	EC_{50}: 3.2 (2.9 - 3.7) NOAEC: 0.8 Slope: NA	Moderately toxic	45365004/2000	Acceptable
Glyphosate IPA	Crayfish (*Orconectes nais*)	30.3	LC_{50}: 5.2 (4.1 - 6.4) NOAEC: N.R. Slope: N.R.	Moderately toxic	40098001/1986	Supplemental
Glyphosate IPA (Roundup)	Water flea (*Daphnia pulex*)	30.3	EC_{50}: 5.8 (5.3 - 6.4) NOAEC: N.R. Slope: N.R.	Moderately toxic	44125714/1984	Supplemental
Glyphosate IPA (Roundup)	Scud (*Gammarus pseudolimnaeus*)	31	LC_{50}: 13 (9.6 - 19.2) NOAEC: 1.4 Slope: 2.33	Slightly toxic	00124762/1982	Supplemental
Glyphosate IPA	Midge (*Chironomus plumosus*)	30.3	LC_{50}: 13.3 (7.0 - 23.7) NOAEC: N.R. Slope: N.R.	Slightly toxic	00162296/1979	Acceptable
Glyphosate (80WDG formulation)	Water flea (*Daphnia magna*)	80	EC_{50}: >17.6 (N.A.) NOAEC: 17.6 Slope: N.A.	Slightly toxic	44125706/1996	Supplemental
Glyphosate IPA (Roundup with "W" surfactant)	Water flea (*Daphnia magna*)	40.7	EC_{50}: 21.7 (18.7 - 25.0) NOAEC: N.R. Slope: N.R.	Slightly toxic	00078657/1980	Acceptable
Glyphosate monoammonium salt (MON 14420)	Daphnia (*Daphnia magna*)	68.5	EC_{50}: 28.8 (12.3 - 48.5) NOAEC: 12.3 Slope: N.R.	Slightly toxic	45777401/1999	Acceptable

Table D-16. Freshwater Invertebrates Acute Toxicity for Glyphosate Formulations						
Chemical	**Species**	**% a.i.***	**48-hour EC_{50} - LC_{50}/ NOAEC (mg a.e./L)*/ Slope**	**Toxicity Category[1]**	**MRID #/Year**	**Study Classification**
Glyphosate IPA	Scud (*Gammarus pseudolimnaeus*)	30.3	LC_{50}: 31.8 (20.7 - 48.8) NOAEC: N.R. Slope: N.R.	Slightly toxic	00162296/1979	Acceptable
Glyphosate IPA (X-77 surfactant)	Water flea (*Daphnia magna*)	5.27	EC_{50}: >39 (N.R.) NOAEC: 21.8 Slope: N.A.	Slightly toxic	00078666/1980	Supplemental
Glyphosate (360 g/L SL formulation)	Water flea (*Daphnia magna*)	27.25	EC_{50}: 44.8 (38.0 - 52.0) NOAEC: 26 Slope: 7.6	Slightly toxic	45374003/1999	Acceptable
Glyphosate IPA	Water flea (*Daphnia pulex*)	48	EC_{50}: 68.3 (64.3 - 72.8.) NOAEC: <21.3 Slope: 3.9	Slightly toxic	00108109/1973	Supplemental
Glyphosate (Roundup with "AA" surfactant)	Water flea (*Daphnia magna*)	41.2	EC_{50}: 94.5 (76.3 - 122.0) NOAEC: 17.1 Slope: 3.5	Slightly toxic	00078660/1980	Acceptable
Glyphosate IPA (Roundup Biactive)	Water flea (*Daphnia carinata*)	36	EC_{50}: 150 (151 - 179) NOAEC: 45 Slope: N.R.	Practically nontoxic	44738201/1996	Not classified
Trisodium diglyphosate/Urea (Polado formula - MON 8000)	Water flea (*Daphnia magna*)	75	LC_{50}: >315 (N.R.) NOAEC: 315 Slope: N.R.	Practically nontoxic	00079147/1980	Supplemental
Glyphosate IPA with surfactant Geronol CF/AR	Water flea (*Daphnia carinata*)	45	EC_{50}: 365 (315 - 420) NOAEC: 190 Slope: N.R.	Practically nontoxic	44738201/1996	Not classified

Table D-16. Freshwater Invertebrates Acute Toxicity for Glyphosate Formulations

Chemical	Species	% a.i.*	48-hour EC_{50} - LC_{50}/ NOAEC (mg a.e./L)*/ Slope	Toxicity Category[1]	MRID #/Year	Study Classification
Glyphosate IPA (no surfactant)	Water flea (*Daphnia magna*)	62.4	EC_{50}: 401.3 (347.7 - 470.5) NOAEC: 147.8 Slope: 7.6	Practically nontoxic	00078663/1981	Acceptable
Glyphosate IPA with surfactant Geronol CF/AR	Water flea (*Daphnia carinata*)	36	EC_{50}: 610 (540 - 700) NOAEC: 135 Slope: N.R.	Practically nontoxic	44738201/1996	Not classified
Glyphosate IPA with surfactant Geronol CF/AR	Water flea (*Daphnia carinata*)	10	EC_{50}: 810 (700 - 940) NOAEC: 400 Slope: N.R.	Practically nontoxic	44738201/1996	Not classified
Glyphosate IPA (MON77945 Manufacturing concentrate)	Water flea (*Daphnia magna*)	46	EC_{50}: 833 (665 - 1253) NOAEC: 204 Slope: 3.7	Practically nontoxic	44715410/1998	Not classified

* a.i. = active ingredient; a.e. = acid equivalent; IPA = isopropylamine salt
[1]Based on LC_{50} (mg/L): < 0.1 very highly toxic; 0.1-1 highly toxic; >1-10 moderately toxic; >10-100 slightly toxic; >100 practically nontoxic
[2] Range is 95% confidence interval for endpoint

Table D-17. Freshwater Invertebrates Acute Toxicity for Surfactants Used with Glyphosate Formulations

Chemical	Species	% a.i.*	48-hour EC$_{50}$ - LC$_{50}$/ NOAEC (mg/L)/ Slope	Toxicity Category[1]	MRID #/Year	Study Classification
Surfactant Geronol CF/AR (alkyl polyoxy ethylene phosphoric acid ester)	Daphnia (*Daphnia magna*)	Tech.	EC$_{50}$: 48 NOAEC: Slope: N.A.	Slightly toxic	44738201/1996	Not classified
MON 0818 (POEA)	Midge (*Chironomus plumosus*)	70[3]	48-hr LC$_{50}$: 9.1 (4.97-16.8)	Slightly toxic	00162296/1979; MON 0818 LC$_{50}$: 13 mg/L	Acceptable

* a.i. = active ingredient, assumed 100% for technical.
[1]Based on LC$_{50}$ (mg/L): < 0.1 very highly toxic; 0.1-1 highly toxic; >1-10 moderately toxic; >10-100 slightly toxic; >100 practically nontoxic
[2] Range is 95% confidence interval for endpoint
[3] Based on information provided by Registrant, the test material, MON 0818, contains 70% POEA; (comment from Monsanto Co. September 21, 2009; www.regulations.gov , Docket ID EPA-HQ-OPP-2009-0361-0013

Table D-18. Freshwater Invertebrates Acute Toxicity for Aminomethyl Phosphonic Acid (AMPA) Degradate of Glyphosate

Chemical	Species	% a.i.[1]	48-hour LC$_{50}$/NOAEC (mg/L)/Slope	Toxicity Category[2]	MRID #/Year	Study Classification
AMPA	Water flea (*Daphnia magna*)	94.38	EC$_{50}$: 683 (553 - 1010) NOAEC: 320 Slope: N.A.	Practically nontoxic	43334715/1994	Acceptable

[1] a.i. = active ingredient, assumed 100% for technical material
[2]Based on LC$_{50}$ (mg/L): < 0.1 very highly toxic; 0.1-1 highly toxic; >1-10 moderately toxic; >10-100 slightly toxic; >100 practically nontoxic
[3] Range is 95% confidence interval for endpoint, N.A. = not available

Table D-19. Freshwater Invertebrates Chronic Toxicity for Technical Glyphosate IPA Salt

Species	% Active Ingredient	NOAEC/LOAEC (mg acid equivalent/L)	MRID #/Year	Study Classification
Water flea (*Daphnia magna*)	99.7	49.9/95.7	00124763/1982	Acceptable

Table D-20. Estuarine/marine Invertebrates Acute Toxicity for Technical Glyphosate

Species	% a.i.*	48-hour EC$_{50}$ - LC$_{50}$/ NOAEC (mg a.e./L)*/ Slope	Toxicity Category[1]	MRID #/Year	Study Classification
Pacific oyster (*Crassostrea gigas*)	96	48-hr EC$_{50}$: 40 (31-53) NOAEC: 32 Slope: NA	Slightly toxic	44320634 /1996	Acceptable
Mysid shrimp (*Americamysis bahia*)	96	96-hr LC$_{50}$: 79 (63-99) NOAEC: 32 Slope: 8.5	Slightly toxic	44320633 /1996	Acceptable

a.i. = active ingredient; a.e. = acid equivalent, N.R. = not reported
[1]Based on LC$_{50}$ (mg/L): < 0.1 very highly toxic; 0.1-1 highly toxic; >1-10 moderately toxic; >10-100 slightly toxic; >100 practically nontoxic
[2] Range is 95% confidence interval for endpoint

Table D-21. Estuarine/marine Invertebrates Acute Toxicity for Glyphosate Formulations

Chemical	Species	% Active Ingredient *	96-hour LC$_{50}$ NOAEC (mg a.e./L)*/ Slope[1]	Toxicity Category[2]	MRID #/ Year	Study Classification
MON 2139	Eastern oyster (*Crassostrea virginica*)	30.75 a.e.	96-hr IC$_{50}$: 1.06 mg a.e./L (0.846-1.33); 3.45 mg formulation/L (2.75-4.33)[2] NOAEC: 0.51 Slope: NA	Moderately toxic	48934201 / 2012	Acceptable
MON 2139	Mysid shrimp (*Americamysis bahia*)	30.75 a.e.	96-hr LC$_{50}$: 0.765 mg a.e./L (0.601-0.909); 2.45 mg formulation/L (1.95-2.96)[2] NOAEC: 0.51 Slope: 10.4 (5.46-15.3)	Highly toxic	48934202 / 2012	Acceptable
MON 2139	White shrimp (*Litopenaeous vannamei*)	30.87 a.e.	96-hr LC$_{50}$: 54 mg a.e./L (33-134); 175 mg formulation/L (107-434)[2] NOAEC: 5.2 Slope: 1.33	Slightly toxic	48934203/ 2012	Acceptable

MON 2139	Eastern oyster (*Crassostrea virginica*)	30.75 ae	48-hr EC$_{50}$: 0.93 mg a.e./L (0.87-1.0); 3.0 mg formulation/L (2.8-3.3) NOAEC: 0.48	Highly toxic	48934204 / 2012	Acceptable
Glyphosate SL formulation	Pacific oyster (*Crassostrea gigas*)	28.3 a.e.	48-hr LC$_{50}$: 23.2 mg a.e./L; 82 mg formulation/L Slope: NR NOAEC: 28.6 mg formulation/L	Slightly toxic	45374006/2000	Acceptable

* a.i. = active ingredient; a.e. = acid equivalent; N.R. = not reported
[1] Range is 95% confidence interval for endpoint
[2] Based on LC$_{50}$ (mg/L): < 0.1 very highly toxic; 0.1-1 highly toxic; >1-10 moderately toxic; >10-100 slightly toxic; >100 practically nontoxic

Open Literature Data for Aquatic Invertebrates

Table D-22. Open Literature Glyphosate Toxicity Studies on Aquatic Invertebrates

Species	Chemical Form	Endpoint(s)	ECOTOX Ref. No.
Pacific oyster (*Crassostrea gigas*)	Glyphosate acid (97%); Roundup Express (7.2 g ae/L); AMPA (97.5%)	48 hr EC$_{50}$ mollusk abnormality rates, mortality rates, metamorphosis rate (GLY, AMPA, and GLY-express formulation) All values based on nominal GLY = 28.3 mg ae/L (abnorm), >100 mg ae/L (mort, meta) AMPA = 40.6 mg ae/L (abnorm), >100 mg ae/L (mort, meta) GLY-express = 1.13 (abnorm), 8.5 (mort;) 6.37 (meta) mg ae/L	E161544 / Mottier *et al.* 2013
Freshwater snail (*Pomaeca lineatua*)	Roundup (480 g/L glyphosate monoisopropylamine gly-IPA)	Weight gain – two studies ; 1st = 8 day LOEC/NOEC 0.12/<0.12 mg formulation/L ; 2nd = 16 day LOEC/NOEC = 2.4/1.2 mg formulation/L (6 reps w/15/rep)	E107038 / Coler et al 2005
Freshwater snail (*Biomphalaria alexandrina*)	Roundup (120 g ae/L)	3 different studies: 1 – 24-hr LC$_{50}$ = 3.15 mg formulation/L; 2 – At 0.85 mg formulation/L, after 5 weeks 100% mortality, effects on # eggs, hatchability, and Increased abnormal eggs, no eggs after 4 weeks; 3 – after 4 weeks changes in glycogen, AchE, ALP, GOT and others at 0.85 mg formulation/L	E161199 / Barky *et al* 2012
Daphnia magna	Glyphosate monoisopropylamine (GYL-IPA) (40%);	48-h EC$_{50}$ 1.4 – 7.2 mg ai/L (tech); 3.7-10.6 mg ai/L (form) Chronic: technical GYL fecundity NOAEC = 0.45 mg	E161204 / Cuhra *et al.* 2013

	Roundup Weed & Grass Killer concentrate Plus (18% ae; 0.73% diquat-dibromide)	ai/L; Formulation fecundity NOAEC = 0.15 mg a.i./L (<0.05 mg ai/L (F1 growth) (form)	
Sediment-dwelling amphipod (*Hyalella azteca*)	Rodeo (GLY-IPA; % ae NR); Roundup (% ae NR); Roundup Biactive (% ae NR)	Water column 48-hr LC_{50} (mg a.e./L) (95% CI): Rodeo: 225 (151-336); Roundup Biactive: 120 (80.6-180) Roundup: 1.5 (1.0-2.3)	Tsui and Chu 2004
Ceriodaphnia dubia	Rodeo (GLY-IPA; % ae NR); Roundup (% ae NR); Roundup Biactive (% ae NR)	Water column 48-hr LC_{50} (mg a.e./L) (95% CI): Rodeo: 415 (339-508); Roundup Biactive: 81.5 (67.1-99.2) Roundup: 5.7 (could not be calculated)	E74234/ Tsui and Chu 2004
Sediment-dwelling blackworm (*Lumbriculus variegatus*)	Glyphosate acid (98%); Roundup Ultra (GLY-IPA, 360 g/L)	96-hr Water column BCF: worms exposed to 0.05 – 5 mg ae/L for both technical and formulation; Tech BCFs: 1.2 – 2.8 Roundup BCFs: 1.4-5.9	E115572 Contardo-Jara *et al*. 2009
Freshwater mussel (*Lampsilis siliquiodea*)	Glyphosate acid; Glyphosate IPA; IPA; Aqua Star; Roundup	48-hr EC_{50} (mg a.e./L (95% CI) GLY: >200; GLY-IPA: 5.0 (3.3-7.6); IPA: 4.6 (1.9-11.1); Aqua Star: >148 Roundup: 2.9 (2.1-3.9)	E100687 / Bringolf *et al.* 2007
Copepod (*Acartia tonsa*)	Glyphosate acid; Glyphosate IPA; Roundup	48-hr LC_{50} (mg ae/L) (95% CI) GLY acid: 35.3 (30.9-40.3); GLY-IPA: 49.3 (38.4-63.1); Roundup: 1.77 (1.33-2.34)	Tsui and Chu 2003

Aquatic Plants

Table D-23. Aquatic Vascular and Nonvascular Freshwater Plant Toxicity Studies for Technical Glyphosate				
Species	**% Active Ingredient***	**EC$_{50}$ NOAEC (mg a.e./L)*/ Slope**	**MRID #/Year**	**Study Classification**
Vascular Plants				
Duckweed (*Lemna gibba*)	95.6	14-day EC$_{50}$: 11.9 (9.4-14.9) NOAEC: 1.3 Slope: N.R.	44320638/1996	Supplemental
Duckweed (*Lemna gibba*)	96.8	7-day EC$_{50}$: 23.2 (20.3 - 27.1) NOAEC: 7.3 Slope: 2.91	45773101/2002	Acceptable
Duckweed (*Lemna gibba*)	96.6	14-day EC$_{50}$: 20.8 (N.R.) NOAEC: <1.8 Slope: N.R.	40236905/1987	Acceptable
Non-vascular Plants				
Green algae (*Selenastrum capricornutum*)	96.6	4-day EC$_{50}$: 12.1 (11.5 - 12.9) NOAEC: N.R. Slope: 12	40236901/1987	Acceptable
Bluegreen algae (*Anabaena flos-aquae*)	96.6	4-day EC$_{50}$: 11.4 (10.5 - 12.1) NOAEC: N.R. Slope: 3.53	40236904/1987	Acceptable
Green algae (*Selenastrum capricornutum*)	95.6	5-day EC$_{50}$: 13.4 (9.6 - 19.1) NOAEC: 9.6 Slope: N.R.	44320637/1995	Acceptable
Bluegreen algae (*Anabaena flos-aquae*)	95.6	5-day EC$_{50}$: 14.3 (9.3 - 25.8) NOAEC: 11.5 Slope: N.R.	44320639/1996	Acceptable
Freshwater diatom (*Navicula pelliculosa*)	95.6	5-day EC$_{50}$: 16.3 (11.5 - 22.9) NOAEC: 1.7 Slope: N.R.	44320641/1996	Acceptable
Freshwater diatom (*Navicula pelliculosa*)	96.6	7-day EC$_{50}$: 37.3 (34.8 - 41.5) NOAEC: 18.5 Slope: 5.87	40236902/1987	Acceptable
* a.i. = active ingredient; a.e. = acid equivalent; N.R. = Not reported [1] Range is 95% confidence interval for endpoint				

Table D-24 Aquatic Vascular and Nonvascular Freshwater Plant Toxicity Studies for Glyphosate Formulations

Chemical	Species	% a.i.*	EC$_{50}$/ NOAEC (mg a.e.*/L)/ Slope	MRID #/Year	Study Classification
Vascular Plants					
Glyphosate IPA salt* (glyphos (glyphosate product))	Duckweed (*Lemna gibba*)	31.0	7-Day EC$_{50}$: 7.7 (7.1 - 8.3) [1] NOAEC: 0.29 Slope: 4.76	45666704/2001	Acceptable
Glyphosate IPA salt (Roundup 41%)	Duckweed (*Lemna minor*)	30.3	14-day EC$_{50}$: 1.5 (N.R.) NOAEC: N.R. Slope: N.R.	44125714/1984	Supplemental
Glyphosate IPA salt (TEP Roundup)	Duckweed (*Lemna minor*)	NR	48 hr. EC$_{50}$: >16.91 (N.A.) NOAEC: 16.91 Slope: N.A.	44125713/1989	Supplemental
Glyphosate IPA salt	Duckweed (*Lemna minor*)	N.R.	14-day EC$_{50}$: 2.0 (N.R.) NOAEC: N.R. Slope: N.R.	44125714/1984	Supplemental
Nonvascular Plants					
Glyphosate monoammonium salt (MON 14420)	Green algae (*Selenastrum capricornutum*)	68.5	72-hr EC$_{50}$: 1.85 (1.3 - 2.3) NOAEC: 0.61 Slope: N.R.	45777403/1999	Supplemental
Glyphosate monoammonium salt (MON78568)	Green algae (*Selenastrum capricornutum*)	64.9	72-hr EC$_{50}$: 11.2 (10 - 12.6) NOAEC: 1.58 Slope: N.R.	45767102/2002	Supplemental
Glyphosate IPA salt with surfactant Geronol CF/AR	Green algae (*Selenastrum capricornutum*)	36	72-hr EC$_{50}$: 97 (85 - 111) NOAEC: 73 Slope: N.A.	44738201/1996	Supplemental
Glyphosate IPA salt with surfactant Geronol CF/AR	Green algae (*Selenastrum capricornutum*)	36	72-hr EC$_{50}$: 39 (33 - 45) NOAEC: 16 Slope: N.A.	44738201/1996	Supplemental
Glyphosate (glyphos)	Freshwater diatom (*Navicula pelliculosa*)	31.0	96-hr EC$_{50}$: 0.12 (0.11 – 0.13) NOAEC: 0.082 Slope: 8.78	45666701/2001	Acceptable
Glyphosate IPA salt (glyphos (glyphosate product))	Green algae (*Selenastrum capricornutum*)	31.0	96-hr EC$_{50}$: 0.68 (0.57 - 0.81) NOAEC: 0.43 Slope: 4.47	45666702/2001	Acceptable

* a.i. = active ingredient; a.e. = acid equivalent; IPA = isopropylamine salt; NR = not reported; NA = not available
[1] Range is 95% confidence interval for endpoint

Table D-25. Aquatic Nonvascular Freshwater Plant Toxicity Studies on Glyphosate Mixtures

Chemical	Species	% a.i.*	EC$_{50}$/ NOAEC (mg a.e.*/L)/ Slope	MRID #/Year	Study Classification
Nonvascular Plants					
Glyphosate acid-equivalent (IPA)/Oxyfluorfen mix	Green algae (*Selenastrum capricornutum*)	32	96-hr EC$_{50}$: 0.0026 (0.0021 - 0.0033)[1] NOAEC: 0.00045 Slope: 3.96	45906008/2001	Acceptable

* a.i. = active ingredient; a.e. = acid equivalent; IPA = isopropylamine salt;
[1]Range is 95% confidence interval for endpoint

Open Literature Data for Aquatic Plants

Table D-26. Open literature glyphosate toxicity studies on aquatic plants

Species	Chemical Form	Endpoint(s)	ECOTOX Ref. No.
Chlorella pyrenoidosa	Tech Glyphosate (95%, unsure if acid or IPA)	96-hr EC$_{50}$: 3.530 mg/L	E61983/ Ma *et.al* 2001,
Chlorella vulgaris	Tech Glyphosate (95%, assumed to be acid)	96 hr. EC$_{50}$: 4.70 mg/L	E65938/ Ma *et al.*, 2002
Raphidocelis subcapitata (Selenastrum capricornutum)	Tech Glyphosate (95%, assumed to be acid)	96 hr. EC$_{50}$: 5.56 mg/L	E83543/ Ma *et al.*, 2006
8 non-vascular species	Roundup 360 SL (% ai NR); Glyphosate acid (% ae NR); Glyphosate isopropylamine (40%)	21-d EC$_{50}$ (growth rate) Roundup = 2.9-118 mg formulation/L Glyphosate acid = 246 ->169,000 mg ae/L GLY-IPA = 7.1-233 mg ai/L	E161695 / Lipok *et al.* 2010
Lemna minor	Sting Pro 2 (400 g a.i/L; glyphosate acid)	96-hr Growth rate inhibition compared to control significant ≥ 20 uL ae/L, inhibition did not exceed 25%; photosynthetic parameters inhibited at ≥20 uL ae/L, inhibition did not exceed 10%, no NOAEC	E156171 / Dosnon-Olette *et al.* 2011
Rooted vascular plant *Myriophyllum aquaticum*	Glyphosate (35.6% emulsifiable concentrate)	14-d EC$_{50}$ Most sensitive endpoint = 0.221 mg/L (area under growth curve); fresh wt, shoot length and root length EC$_{50}$ all about 2 mg/L	E150059 / Turgut *et al.* 2002

Birds

Chemical	Species	% a.i.[1]	LD$_{50}$/ LC$_{50}$ NOAEL/ NOAEC (mg a.e./kg bw or ppm a.e.)[1]	Toxicity Category[2]	MRID #/ Year	Study Classification

Table D-27. Avian Acute Toxicity for Technical Glyphosate

Chemical	Species	% a.i.[1]	LD$_{50}$/ LC$_{50}$ NOAEL/ NOAEC (mg a.e./kg bw or ppm a.e.)[1]	Toxicity Category[2]	MRID #/ Year	Study Classification
Glyphosate	Bobwhite quail (*Colinus virginianus*)	83	LD$_{50}$: >3196.3 mg a.e./kg bw	Practically nontoxic	00108204	Acceptable
Glyphosate	Mallard duck (*Anas platyrhynchos*)	98.5	LC$_{50}$: >4570.4 (N.A.) PPM NOAEC: 4570.4	Slightly toxic	108107/37765/1973	Acceptable
Glyphosate	Bobwhite quail (*Colinus virginianus*)	98.5	LC$_{50}$: >4570 (N.R.) PPM NOAEC: 4570	Slightly toxic	00076492/1973	Acceptable
Glyphosate	Bobwhite quail (*Colinus virginianus*)	95.6	LD$_{50}$: **>1912** (N.A.) mg/kg bw NOAEL: 1912	Slightly toxic	44320626/1997	Acceptable
Glyphosate	Mallard duck (*Anas platyrhynchos*)	95.6	LC$_{50}$: >4971.2 (N.A.) PPM NOAEC: 4971.2	Slightly toxic	44320627/1998	Acceptable
Glyphosate	Bobwhite quail (*Colinus virginianus*)	95.6	LC$_{50}$: **>4971.2** (N.A.) PPM NOAEC: 4971.2	Slightly toxic	44320628/1997	Acceptable
Glyphosate	Canary (*Serinus canaria*)	96	LD$_{50}$: >2,000 ED$_{50}$ (based on regurgitation): 2819 NOAEL: 2000 (visually observed)	Practically nontoxic	4893406 / 2012	Acceptable

[1] a.i. = active ingredient; a.e. = acid equivalent
[2] Based on LC$_{50}$ (ppm): < 50 very highly toxic; 50 - 500 highly toxic; 501 - 1000 moderately toxic; 1001-5000 slightly toxic; >5000 practically non-toxic; based on LD$_{50}$ (mg/kg bw): < 10 very highly toxic; 10 - 50 highly toxic; 51 - 500 moderately toxic; 501-2000 slightly toxic; >2000 practically non-toxic
[3] Range is 95% confidence interval for endpoint, N.A. = not available, N.R. = not reported

Table D-28. Avian Acute Toxicity for Glyphosate Formulations

Chemical	Species	% a.i.[1]	LD$_{50}$/ LC$_{50}$ NOAEL/ NOAEC (mg a.e./kg bw or ppm a.e.)[1]	Toxicity Category[2]	MRID #/Year	Study Classification
Trisodium diglyphosate/Urea (Polado formula; MON 8000)	Bobwhite quail (*Colinus virginianus*)	75	LD$_{50}$: >780 (N.R.) PPM NOAEC: 780	Slightly toxic	00085638/1980	Supplemental
Trisodium diglyphosate/Urea (Polado formula; MON 8000)	Bobwhite quail (*Colinus virginianus*)	75	LC$_{50}$: >1770 (N.R.) PPM NOAEC: 1770	Slightly toxic	00085639/1981	Supplemental
Trisodium diglyphosate/Urea (Polado formula; MON 8000)	Mallard duck (*Anas platyrhynchos*)	75	LC$_{50}$: >1770 (N.R.) PPM NOAEC: 315	Slightly toxic	00085640/1980	Supplemental
Glyphosate monoammonium salt (MON 14420)	Bobwhite quail (*Colinus virginianus*)	68.5	LD$_{50}$: 1131 (925 - 1541) mg/kg bw NOAEL: 333 (decreases in bw and food consumption at 555 mg/kg bw)	Slightly toxic	45777402/1999	Acceptable
Glyphosate isopropylamine salt (MON65005)	Mallard duck (*Anas platyrhynchos*)	31.32	LC$_{50}$> 1760 (N.A.) PPM NOAEC: 1760	Slightly toxic	44465701/1997	Acceptable
Glyphosate isopropylamine salt (MON65005)	Bobwhite quail (*Colinus virginianus*)	31.32	LC$_{50}$> 1760 (N.A.) PPM NOAEC: 1760	Slightly toxic	44465702/1997	Acceptable

[1] a.i. = active ingredient; a.e. = acid equivalent
[2] Based on LC$_{50}$ (ppm): < 50 very highly toxic; 50 - 500 highly toxic; 501 - 1000 moderately toxic; 1001-5000 slightly toxic; >5000 practically non-toxic; based on LD$_{50}$ (mg/kg bw): < 10 very highly toxic; 10 - 50 highly toxic; 51 - 500 moderately toxic; 501-2000 slightly toxic; >2000 practically non-toxic
[3] Range is 95% confidence interval for endpoint, N.A. = not available, N.R. = not reported

Table D-29. Avian Acute Toxicity for Aminomethyl Phosphonic Acid (AMPA) Degradate of Glyphosate

Chemical	Species	% a.i.[1]	LD$_{50}$/ LC$_{50}$ NOAEL/ NOAEC (mg a.e./kg bw or ppm a.e.)/ Slope[1]	Toxicity Category[2]	MRID #/Year	Study Classification
AMPA	Bobwhite quail (*Colinus virginianus*)	87.8	LD50: >1976 (N.A.) mg/kg NOAEL: 1185 Slope: N.A.	Slightly toxic	43334709/1991	Acceptable
AMPA	Bobwhite quail (*Colinus virginianus*)	87.8	LC50: >4934 (N.A.) PPM NOAEC: 4934 Slope: N.A.	Slightly toxic	43334710/1994	Acceptable
AMPA	Mallard duck (*Anas platyrhynchos*)	87.8	LC50: >4934 (N.A.) PPM NOAEC: 4934 Slope: N.A.	Slightly toxic	43334711/1994	Acceptable

[1] a.i. = active ingredient; a.e. = acid equivalent
[2] Based on LC$_{50}$ (ppm): < 50 very highly toxic; 50 - 500 highly toxic; 501 - 1000 moderately toxic; 1001-5000 slightly toxic; >5000 practically non-toxic; based on LD$_{50}$ (mg/kg bw): < 10 very highly toxic; 10 - 50 highly toxic; 51 - 500 moderately toxic; 501-2000 slightly toxic; >2000 practically non-toxic
[4] Range is 95% confidence interval for endpoint, N.A. = not available

Table D-30. Avian Chronic Toxicity for Technical Glyphosate

Chemical	Species	% a.i.[1]	LD$_{50}$/ LC$_{50}$ NOAEL/ NOAEC (mg a.e./kg bw or ppm a.e.)[1]	Toxicity Category[2]	MRID #/Year	Study Classification
Glyphosate	Mallard duck (*Anas platyrhynchos*)	90.4	LOAEC: >27 (N.A.) PPM NOAEC: 27	N.A	00036328/ 113457/ 1975	Supplemental
Glyphosate	Mallard duck (*Anas platyrhynchos*)	83	LOAEC: >830 (N.A.) PPM NOAEC: 830	N.A.	111953/1978	Acceptable
Glyphosate	Bobwhite quail (*Colinus virginianus*)	83	LOAEC: >830 (N.A.) PPM NOAEC: 830	N.A.	108207/1978	Acceptable

Table D-30. Avian Chronic Toxicity for Technical Glyphosate

Chemical	Species	% a.i.[1]	LD$_{50}$/ LC$_{50}$ NOAEL/ NOAEC (mg a.e./kg bw or ppm a.e.)[1]	Toxicity Category[2]	MRID #/Year	Study Classification
Glyphosate	Mallard duck (*Anas platyrhynchos*)	96	NOAEC: <501; LOAEC: 501 mg a.e./kg diet (lowest concentration tested), based on effects to male weight gain and offspring weight.	NA	48876602 / 1999	Supplemental

[1] a.i. = active ingredient; a.e. = acid equivalent
[2] Range is 95% confidence interval for endpoint, N.A. = not applicable

Open Literature Data for Birds and Terrestrial-phase Amphibians

Table D-31. Open literature studies for glyphosate for birds and terrestrial-phase amphibians

Species	Chemical Form	Endpoint(s)	ECOTOX Ref. No.
Rough-skinned newt (*Taricha granulosa*)	Glyphosate isopropylamine (45.5% solution)	96-h LD$_{50}$ > 2,600 mg/kg-bw	E162011 / McComb *et al.* 2008
8 species frogs in Columbia – juvenile phase	Mixture Glyphos and Cosmo-Flux	96-h LC$_{50}$: 4.5-22.8 kg ae/ha (direct spray on frogs)	E11766 / Bernal *et al* 2009
Chicken (*Gallus gallus domesticus*)	Glyphosate isopropylamine (purity not reported)	Significant 50% reduction in male and female body wt by day 7 at 6080 mg/kg-diet, no effect at 608 mg/kg-diet; 21-d exposure; did not evaluate reproductive parameters	E162010 / Kubena *et al.* 1981
Mallard duck drakes (*Anas platyrhynchos*)	Roundup360 g/l of glyphosate, 480 g/l of IPA salt	significant reduction (90%, p≤ 0.05) in plasma testosterone at 5 & 100 mg/kg-bw; no NOAEC; alterations in structure of testis and epididymal region	Oliveira et. al. 2007

Mammals

Table D-32. Mammalian Acute Toxicity for Technical Glyphosate						
Chemical	**Species**	**% a.i.[1]**	**LD$_{50}$ (mg a.e./kg bw)[1]**	**Toxicity Category[2]**	**MRID No.**	**Study Classification**
Glyphosate	Rat (*rattus norvegicus*)	96	>4800 limit test. No mortalities.	Practically non-toxic	43728003	Acceptable
Glyphosate	Rat (*rattus norvegicus*)	95	>4750 – limit test. No mortalities	Practically non-toxic	45058306	Acceptable
Glyphosate	Rat (*rattus norvegicus*)	97.2	>4860 up and down – no mortalities	Practically non-toxic	46760505	Acceptable
Glyphosate	Rat (*rattus norvegicus*)	88	>4400. No mortalities	Practically non-toxic	44320604	Acceptable
Glyphosate	Rat (*rattus norvegicus*)	95	>4750 up and down – no mortalities	Practically non-toxic	46998805	Acceptable
Glyphosate	Rat (*rattus norvegicus*)	76	>3800 – no mortalities	Practically non-toxic	41400601	Acceptable
Glyphosate (IPA 62%)	Rat (*rattus norvegicus*)	96	>1920 – no mortalities	Slightly toxic (when expressed as a.e.)	44142104	Acceptable
Glyphosate	Rat (*rattus norvegicus*)	95.4	>4770 up and down – no mortalities	Practically non-toxic	46816107	Acceptable
[1] a.i. = active ingredient; a.e. = acid equivalent [2]Based on LD$_{50}$ (mg/kg bw): < 10 very highly toxic; 10 - 50 highly toxic; 51 - 500 moderately toxic; 501-2000 slightly toxic; >2000 practically non-toxic.						

Table D-33. Mammalian Acute Toxicity for Glyphosate Formulations

Chemical	Species	% a.i.[1]	LD$_{50}$ (mg a.e./ kg bw a.e.)[1]	Toxicity Category[2]	MRID No.	Study Classification
ClearOut 41 (41% glyphosate IPA)	Rat (*rattus norvegicus*)	30.3	>606	Slightly toxic	44883104	Acceptable
ClearOut 41 Plus (41% glyphosate IPA)	Rat (*rattus norvegicus*)	30.3	>606	Slightly toxic	44883113	Acceptable
Clearout 62 (62% glyphosate IPA)	Rat (*rattus norvegicus*)	62	>1240	Slightly toxic	45657801	Acceptable
Dual Salt Fully Loaded (glyphosate IPA and NH4 Salt)	Rat (*rattus norvegicus*)	36	>1800	Slightly toxic	45615104	Acceptable
Glyphosate Acid 7.10 g/kg SL Formulation	Rat (*rattus norvegicus*)	0.71	>35.5	Highly toxic when reported as a.e. due to low percentage of a.i.	43746804	Acceptable
EH-1384 (6.75% glyphosate IPA)	Rat (*rattus norvegicus*)	5	>100	Slightly toxic	45328903	Acceptable
EH-1386 (50.0% glyphosate IPA	Rat (*rattus norvegicus*)	37	>740	Slightly toxic	45387703	Acceptable
GF-1280 (50.8% glyphosate dimethylammonium	Rat (*rattus norvegicus*)	40.1	>2005	Practically nontoxic	46775603	Acceptable
GF-1667 (62.1% glyphosate dimethylammonium salt)	Rat (*rattus norvegicus*)	49	>2450	Practically nontoxic	46730705	Acceptable
GF-772 (40.2% IPA salt)	Rat (*rattus norvegicus*)	29.8	>1490	Slightly toxic	45871303	Acceptable
GF-887 (54.2% glyphosate IPA)	Rat (*rattus norvegicus*)	40.1	>2005	Practically nontoxic	45819303	Acceptable
Glyfos (41% IPA)	Rat (*rattus norvegicus*)	30.3	>1515	Slightly toxic	43530002	Acceptable
Glygran WDG glyphosate 80 WDG	Rat (*rattus norvegicus*)	80	>1600	Slightly toxic	44125603	Acceptable
Glyphosate	Rat (*rattus norvegicus*)	62	>3100	Practically nontoxic	45101503	Acceptable
Glyphosate Unloaded (52.9% IPA)	Rat (*rattus norvegicus*)	39.2	>1960	Slightly toxic	46783403	Acceptable
Glyphosate 360g/l SL	Rat (*rattus norvegicus*)	27.25	>1363	Slightly toxic	44953503	Acceptable

Table D-33. Mammalian Acute Toxicity for Glyphosate Formulations

Chemical	Species	% a.i.[1]	LD$_{50}$ (mg a.e./ kg bw a.e.)[1]	Toxicity Category[2]	MRID No.	Study Classification
Glyphosate 500 SL-M (36.7% Glyphosate Potassium)	Rat (*rattus norvegicus*)	36.7	>1835	Slightly toxic	45830201	Acceptable
Glyphosate Acid 7.10 g/kg SL Formulation	Rat (*rattus norvegicus*)	0.73	>36.5	Highly toxic when reported as a.e. due to low percentage of a.i.	44497001	Acceptable
Glyphosate acid formulation 500 g/kg WP	Rat (*rattus norvegicus*)	49.3	>2465	Practically nontoxic	44317201	Acceptable
Glyphosate IPA	Rat (*rattus norvegicus*)	22.9	724	Slightly toxic	44918601	Acceptable
Glyphosate IPA salt (NAF 545)	Rat (*rattus norvegicus*)	30.9	>1545	Slightly toxic	44863801	Acceptable
Glyphosate premix (62.2%)	Rat (*rattus norvegicus*)	62.2	>3110	Practically nontoxic	44949802	Acceptable
Glyphosate SL (600)	Rat (*rattus norvegicus*)	42.6	>2130	Practically nontoxic	46006803	Acceptable
HM-0548 5905-LTE Mixture of ammonium salt (19.68%) and IPA (13.36%)	Rat (*rattus norvegicus*)	25	>1250	Slightly toxic	47236803	Acceptable
HM-2028 (Glyphosate: 11.4%)	Rat (*rattus norvegicus*)	11.4	357	Moderately toxic when reported as a.e. due to low percentage of a.i.	46714802	Acceptable
LI6130 (13 41% Glyphosate Full Load: 40.6% IPA)	Rat (*rattus norvegicus*)	4	>215	Moderately toxic when reported as a.e. due to low percentage of a.i.	46862303	Acceptable
LI6167-11 (40.5% IPA ("Half load"))	Rat (*rattus norvegicus*)	30	>1500	Slightly toxic	46862103	Acceptable
MON 20033	Rat (*rattus norvegicus*)	63	3150	Practically nontoxic	41142304	Acceptable
MON 20047	Rat (*rattus norvegicus*)	18.4	460 - 690	Moderately toxic when reported as a.e. due to low percentage of a.i.	41305404	Acceptable
MON 60696 (70.1% monoammonium salt)	Rat (*rattus norvegicus*)	54	>2700	Practically nontoxic	43049302	Acceptable

Table D-33. Mammalian Acute Toxicity for Glyphosate Formulations

Chemical	Species	% a.i.[1]	LD$_{50}$ (mg a.e./ kg bw a.e.)[1]	Toxicity Category[2]	MRID No.	Study Classification
MON 65005 (41% IPA)	Rat (*rattus norvegicus*)	30.3	>1515	Slightly toxic	43020902	Acceptable
MON 77063	Rat (*rattus norvegicus*)	65.4	2599	Practically nontoxic	44615502	Acceptable
MON 77945	Rat (*rattus norvegicus*)	46.6	>2330	Practically nontoxic	44715402	Acceptable
MON 78063	Rat (*rattus norvegicus*)	37.7	>1885	Slightly toxic	44872702	Acceptable
MON 78293	Rat (*rattus norvegicus*)	39.3	>1965	Slightly toxic	44809002	Acceptable
MON 78634 (71.8% ammonium salt)	Rat (*rattus norvegicus*)	65.2	>1304	Slightly toxic	46087001	Acceptable
Mon 79186 (2.02% glyphosate IPA)	Rat (*rattus norvegicus*)	1.5	>75	Moderately toxic when reported as a.e. due to low percentage of a.i.	46473802	Acceptable
MON 79188	Rat (*rattus norvegicus*)	4.42	>221	Moderately toxic when reported as a.e. due to low percentage of a.i.	46078502	Acceptable
Nufarm NUP 3G 02 (450 g/L glyphosate as IPA salt)	Rat (*rattus norvegicus*)	45	>2250	Practically nontoxic	46009104	Acceptable
Nufarm RUP0532 (41% Glyphosate as IPA and ammonium salts)	Rat (*rattus norvegicus*)	30.3	>1515	Slightly toxic	45386802	Acceptable
NUP-07010 (Glyphosate, 41.72%)	Rat (*rattus norvegicus*)	41.72	>2086	Practically nontoxic	47298403	Acceptable
NUP3a99 (41% glyphosate IPA)	Rat (*rattus norvegicus*)	30.3	>1515	Slightly toxic	44872602	Acceptable
NUP3b99 (53.8% glyphosate IPA)	Rat (*rattus norvegicus*)	39.8	>1990	Slightly toxic	44873302	Acceptable
NUP5a99 (62% glyphosate MUP)	Rat (*rattus norvegicus*)	62	>3100	Practically nontoxic	45293503	Acceptable
56077-LL - Phoss-8	Rat (*rattus norvegicus*)	80	>4000	Practically nontoxic	45044402	Acceptable

Table D-33. Mammalian Acute Toxicity for Glyphosate Formulations

Chemical	Species	% a.i.[1]	LD$_{50}$ (mg a.e./ kg bw a.e.)[1]	Toxicity Category[2]	MRID No.	Study Classification
Roundup L&G Ready to Use (glyphosate IPA)	Rat (*rattus norvegicus*)	0.85	>40	Highly toxic when reported as a.e. due to low percentage of a.i.	41395601	Acceptable
Spray–Charlie (44% GLY-41 (524-475 with 41% IPA)	Rat (*rattus norvegicus*)	15.2	>760	Slightly toxic	45929403	Acceptable

[1] a.i. = active ingredient; a.e. = acid equivalent
[2] Based on LD$_{50}$ (mg/kg bw): < 10 very highly toxic; 10 - 50 highly toxic; 51 - 500 moderately toxic; 501-2000 slightly toxic; >2000 practically non-toxic.

Table D-34. Mammalian Chronic Toxicity for Technical Glyphosate

Chemical	Species	% a.i.[1]	NOAEL/ NOAEC (mg a.e./kg bw or ppm a.e.)[1]	MRID #/Year	Study Classification
Glyphosate	Rat (*rattus norvegicus*)	97.67	2-generation reproduction study Parental/Systemic NOAEL: 500 mg/kg/day (10,000 ppm) LOAEL: 1500 mg/kg/day (30,000 ppm) Reproductive NOAEL: 1500 mg/kg/day (HDT) Offspring NOAEL: 500 mg/kg/day (10,000 ppm) LOAEL: 1500 mg/kg/day	41621501/1990	Acceptable
Glyphosate	Rat (*rattus norvegicus*)	100%	3-generation reproduction study Parental/Systemic, Offspring and Reproductive NOAELs: 30 mg/kg/day (highest dose tested).	00081674; 00105995 1981; 1982	Acceptable
Glyphosate	Rabbit (*Oryctolagus cuniculus*)	98.7	Developmental toxicity study Maternal NOAEL = 175 mg/kg/day LOAEL = 350 mg/kg/day based on mortality, diarrhea, soft stools, and nasal discharge. Developmental NOAEL = 350 mg/kg/day (HDT) LOAEL = not established.	00046363/1980	Acceptable

Table D-34. Mammalian Chronic Toxicity for Technical Glyphosate

Chemical	Species	% a.i.[1]	NOAEL/ NOAEC (mg a.e./kg bw or ppm a.e.)[1]	MRID #/Year	Study Classification
Glyphosate	Rat (*rattus norvegicus*)		NOAEL: 408/422 mg/kg bw/day (males/females); NOAEC: 5000 mg/kg-diet Reproduction study Offspring toxicity LOAEL: 1234/1273 (males/female) mg/kg bw/day; LOAEC: 15000 ppm (delayed age and increased weight at male sexual development). No observed effects on parental or reproductive toxicity (LOAEL >15000 ppm)	48865101-48865105 /2007 & 2012	Acceptable

[1] a.i. = active ingredient; a.e. = acid equivalent
[2] Range is 95% confidence interval for endpoint, N.A. = not applicable

Table D-35. Mammalian Chronic Toxicity for Surfactants

Chemical	Species	% a.i.[1]	NOAEL/ NOAEC (mg a.e./kg bw or ppm a.e.)[1]	MRID #/Year	Study Classification
POEA	Rat (*rattus norvegicus*)	100%	Reproduction/developmental screening study temporary endpoints: Parental/Systemic NOAEL: 1000 ppm (52.8 – 56.1 mg/kg bw/day (M) and 64.9 – 66.6 mg/kg bw/day (F) Reproductive NOAEL: 300 ppm (14.9 - 16.6 mg/kg bw/day (M) and 18.9 - 19.5 mg/kg bw/day (F) LOAEL: 1000 ppm (52.8 – 56.1 mg/kg bw/day (M) and 64.9 – 66.6 mg/kg bw/day (F) Based on increased mean number of unaccounted-for sites. Offspring NOAEL: 300 ppm (14.9 - 16.6 mg/kg bw/day (M) and 18.9 - 19.5 mg/kg bw/day (F) LOAEL: 1000 ppm (52.8 – 56.1 mg/kg bw/day (M) and 64.9 – 66.6 mg/kg bw/day (F) Based on litter loss, decreased mean number of pups born live, litter size and postnatal survival from birth to PND 4. Effects not reproducible in second generation; however, this is a definitive NOAEL/LOAEL.	47097401/2006	Acceptable

[1] a.i. = active ingredient; a.e. = acid equivalent
[2] Range is 95% confidence interval for endpoint, N.A. = not applicable

Open Literature Data for Mammals

Table D-36. Open Literature Studies for Glyphosate on Mammals			
Species	Chemical Form	Endpoint(s)	ECOTOX Ref. No.
Deer Mouse (*Peromyscus maniculatus*)	Glyphosate isopropylamine (45.5% solution)	96-h LD_{50} > 6000 mg/kg-bw	E162011 / McComb *et al.* 2008
Rat (male Wistar)	Roundup Transorb (480 g glyphosate acid/L)	Significant sexual development effects at 50 mg ai/kg-bw (NOAEL = 5 mg ae/kg-bw) increase in age of sexual development, hormone changes Newly weaned male rats oral gavage from post natal day (PND) 23 to PND53	E155939 / Romano *et al.* 2010
Rat (Wistar)	Roundup Transorb (480 g glyphosate acid/L)	Significant sexual development effects at 50 mg ai/kg-bw for male offspring (decrease in age of sexual development, changes in hormone and sexual behavior Parental females oral gavage and then offspring observed, females dosed from gestational day 18 to PND 5	E161810 / Romano *et al.* 2012

Terrestrial Invertebrates

Table D-37. Acute Toxicity Studies on Terrestrial Invertebrates for Technical Glyphosate					
Chemical	Species	% a.i.[1]	LD_{50}/ LC_{50} NOAEL/ NOAEC	MRID #/Year	Study Classification
Glyphosate	Honey bee (*Apis mellifera*)	98.5	48 hr LD_{50} (O): **>100** (N.R.)[2] μg/bee NOAEL: N.R. Slope: N.R.	00026489/1972	Acceptable
Glyphosate	Honey bee (*Apis mellifera*)	98.5	48 hr LD_{50} (C): >100 (N.R.) μg/bee NOAEL: N.R. Slope: N.R.	00026489/1972	Acceptable
Glyphosate	Honey bee (*Apis mellifera*)	97.6	48 hr LD_{50} (C): >103 (N.R.) μg/bee NOAEL: 103 48 hr LD_{50} (O): >182 (N.R.) μg/bee NOAEL: 182	48876603	Acceptable
[1] a.i. = active ingredient; a.e. = acid equivalent [2] Range is 95% confidence interval for endpoint, N.R. = not reported; O = oral study; C = contact study					

Table D-38. Acute Toxicity Studies on Terrestrial Invertebrates for Glyphosate Formulations

Chemical	Species	% a.i.[1]	LD$_{50}$/ LC$_{50}$ NOAEL/ NOAEC	MRID #/Year	Study Classification
Glyphosate monoammonium salt (MON78568)	Honey bee (*Apis mellifera*)	65.6	48 hr LD$_{50}$ (C): >100 (N.A.)[2] µg/bee NOAEL: 100 Slope: N.R.	45767104/2001	Not classified
Glyphosate monoammonium salt (MON78568)	Honey bee (*Apis mellifera*)	65.6	48 hr LD$_{50}$ (O): >76.23 (N.A.) µg a.e./bee NOAEL: <76.23 µg a.e./bee Slope: N.R.	45767104/2001	Not classified
Glyphosate monoammonium salt (MON78568)	Predatory mite (*Typhlodromus pyri*)	64.9	7 D LD$_{50}$ (C): 1200 (839-1786) g a.e./ha NOAEL: 216 Slope: N.R.	45767105/2002	Not classified
Glyphosate monoammonium salt (MON78568)	Predatory mite (*Typhlodromus pyri*)	64.9	7 D LD$_{50}$ (C): >4320 (N.R.) g/ha NOAEL: 216 Slope: N.R.	45767106/2002	Not classified
Glyphosate monoammonium salt (MON78568)	Predatory mite (*Typhlodromus pyri*)	64.9	14 - 21 D LD$_{50}$ (C): N.A. (N.A.) g/ha NOAEL: 216 or <119 (no dose-response) Slope: N.A.	45767106/2002	Not classified
Glyphosate monoammonium salt (MON78568)	Earthworm (*Eisenia fetida*)	64.9	14 D LD$_{50}$ (C): >6560 (N.A.) mg/kg soil NOAEL: 6560 Slope: N.R.	45767109/2001	Not classified
Glyphosate monoammonium salt (MON78568)	Parasitic wasp (*Aphidius rhopalosiphi*)	64.9	48 hr - 13 days LD$_{50}$ (C): >108 (N.R.) g a.e./ha NOAEL: Not established Slope: N.R.	45767107/2002	Not classified
Glyphosate monoammonium salt (MON78568)	Parasitic wasp (*Aphidius rhopalosiphi*)	64.9	48 hr - 13 days LD$_{50}$ (C): >4320 (N.R.) g/ha NOAEL: 4320 Slope: N.R.	45767107/2002	Not classified
Glyphosate monoammonium salt (MON78568)	Parasitic wasp (*Aphidius rhopalosiphi*)	64.9	48 hr - 13 days LD$_{50}$ (C): >4320 (N.R.) g a.e./ha NOAEL: 4320 Slope: N.R.	45767108/2002	Not classified

Table D-38. Acute Toxicity Studies on Terrestrial Invertebrates for Glyphosate Formulations

Chemical	Species	% a.i.[1]	LD$_{50}$/ LC$_{50}$ NOAEL/ NOAEC	MRID #/Year	Study Classification
Glyphosate monoammonium salt (MON78568)	Lacewing (*Chrysoperla carnia*)	64.9	Up to 10 days LD$_{50}$ (C): >4320 (N.R.) g/ha NOAEC: 4320 Slope: N.R.	45767110/2002	Not classified
Glyphosate IPA salt (MON 2139)	Honey bee (*Apis mellifera*)	36	48 hr LD$_{50}$ (O): >100 (N.R.) µg/bee NOAEL: N.R. Slope: N.R.	00026489/1972	Acceptable
Glyphosate IPA salt (MON 2139)	Honey bee (*Apis mellifera*)	36	48 hr LD$_{50}$ (C): >100 (N.R.) µg/bee NOAEL: N.R. Slope: N.R.	00026489/1972	Acceptable
Glyphosate IPA salt (MON65005)	Honey bee (*Apis mellifera*)	31.32	48 hr LD$_{50}$ (C): >31.3 (N.A.) µg a.e./bee NOAEL: 319 Slope: N.A.	44465703/1997	Acceptable
Glyphosate IPA salt (MON 77360)	Honey bee (*Apis mellifera*)	30.0	48 hr LD$_{50}$ (C): >30 (NA) µg/bee NOAEL: 30 Slope: NA	45370301/2001	Acceptable
Glyphosate IPA salt (MON 77360)	Honey bee (*Apis mellifera*)	30.0	48 hr LD$_{50}$ (O): >30 (NA) µg/bee NOAEL: 15 Slope: NA	45370302/2001	Supplemental

[1] a.i. = active ingredient; a.e. = acid equivalent/ IPA = isopropylamine; N.R. = not reported; O = oral study; C = contact study
[2] Range is 95% confidence interval for endpoint,

Open Literature Data for Terrestrial Invertebrates

Table D-39. Open literature studies for glyphosate for terrestrial invertebrates

Species	Chemical Form	Endpoint(s)	ECOTOX Ref. No.
Earthworm (*Eisenia fetida andrei*)	Roundup Ready	56-d sign decrease at 1440 g ai/ha (Roundup applied to soybean field and soil samples collected) in % hatchability of cocoons, # of juveniles, # juv/hatched cocoons Earthworms also sign avoided GLY treated soil in avoidance test; had reduced feeding activity	E160273 / Casabe *et al.* 2007
Parasitoid Wasp (*Trichogramma pretiosum*)	Roundup Ready (972 g glyphosate /ha); Roundup Original (960 g glyphosate/ha)	Roundup Ready at 972 mg a.e./ha - 100% decrease egg viability; Roundup original at 960 mg ae/ha decreased egg (37%) and larvae viability (32%); No effects using Roundup Transorb or Gliz; No effect on pupae stage for all 4 formulations; based on categories of effect (% effect) Only one concentration tested	E110225 / De Freitas Bueno *et al.* 2008

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Terrestrial Plants

Studies on Technical Material

Table D-40. Vegetative Vigor Study on Terrestrial Plants with Technical Glyphosate					
Chemical	**Species**	**% a.i.[1]**	**EC$_{25}$/ NOAEC (EC$_{05}$) (lb a.e./Acre[1]**	**MRID #/Year**	**Study Classification**
Monocots					
Glyphosate	Oat (*Avena sativa*)	96.6	21 D EC$_{25}$: 0.4 (N.R.) lb/A NOAEC/EC$_{05}$: 0.14 Slope: 2.3	43088701/1994	Acceptable
Glyphosate	Corn (*Zea mays*)	96.6	21 D EC$_{25}$: 0.43 (N.R.) lb /A NOAEC/EC$_{05}$: 0.07 Slope: 3.7	43088701/1994	Acceptable
Glyphosate	Onion (*Allium cepa*)	96.6	21 D EC$_{25}$: 0.83 (N.R.) lb /A NOAEC/EC$_{05}$: 0.56 Slope: 2.4	43088701/1994	Acceptable
Glyphosate	Ryegrass (*Lolium perenne*)	96.6	21 D EC$_{25}$: 0.98 (N.R.) lb /A NOAEC/EC$_{05}$: 0.56 Slope: 4.9	43088701/1994	Acceptable
Dicots					
Glyphosate	Tomato (*Lycopersicon esculentum*)	96.6	21 D EC$_{25}$: 0.11 (N.R.) lb /A NOAEC/EC$_{05}$: 0.035 Slope: 3.4	43088701/1994	Acceptable
Glyphosate	Cucumber (*Cucumis sativus*)	96.6	21 D EC$_{25}$: 0.46 (N.R.) lb /A NOAEC/EC$_{05}$: 0.14 Slope: 2.6	43088701/1994	Acceptable
Glyphosate	Lettuce (*Lactuca sativa*)	96.6	21 D EC$_{25}$: 0.4 (N.R.) lb /A NOAEC/EC$_{05}$: 0.28 Slope: N.R.	43088701/1994	Acceptable
Glyphosate	Cabbage (*Brassica oleracea*)	96.6	21 D EC$_{25}$: 0.3 (N.R.) lb /A NOAEC/EC$_{05}$: 0.14 Slope: N.R.	43088701/1994	Acceptable
Glyphosate	Soybean (*Glycine max*)	96.6	21 D EC$_{25}$: 0.42 (N.R.) lb /A NOAEC/EC$_{05}$: 0.28 Slope: N.R.	43088701/1994	Acceptable
Glyphosate	Radish (*Rhaphanus sativus*)	96.6	21 D EC$_{25}$: 0.14 (N.R.) LB/A NOAEC/EC$_{05}$: 0.035 Slope: N.R.	43088701/1994	Acceptable
[1] a.i. = active ingredient; a.e. = acid equivalent; N.R. = Not reported					

Studies on Formulations

Table D-41. Terrestrial Plant Studies with Glyphosate Formulations					
Chemical	**Species**	**% a.i.[1]**	**EC$_{25}$/ NOAEC (EC$_{05}$) (lb a.e./Acre[1]**	**MRID #/Year**	**Study Classification**
Seedling Emergence Studies					
Monocots					
Glyphosate (80 WDG formulation)	Veg.Crops (10 Sp.) (Monocots & Dicots)	75	29 D EC$_{25}$: >4.5 (N.R.) NOAEC/EC$_{05}$: 3.6 Slope: N.R.	44125712/1996	Acceptable
Glyphosate IPA salt CP-70139	Oat (*Avena sativa*)	50	14 D EC$_{25}$: >5 (N.R.) NOAEC/EC$_{05}$: N.R. Slope: N.R.	40159301/1987	Acceptable
Glyphosate IPA salt CP-70139	Rice (*Oryza sativa*)	50	14 D EC$_{25}$: >5 (N.R.) NOAEC/EC$_{05}$: N.R. Slope: N.R.	40159301/1987	Acceptable
Glyphosate IPA salt CP-70139	Sorghum (*Sorghum bicolor*)	50	14 D EC$_{25}$: >5 (N.R.) NOAEC/EC$_{05}$: N.R. Slope: N.R.	40159301/1987	Acceptable
Glyphosate IPA salt CP-70139	Barnyard grass (*Echinochloa crusgalli*)	50	14 D EC$_{25}$: >5 (N.R.) NOAEC/EC$_{05}$: N.R. Slope: N.R.	40159301/1987	Acceptable
Glyphosate (80 WDG formulation)	Veg.Crops (10 Sp.) (Monocots & Dicots)	48.3	4WKS EC$_{25}$: >4 (N.A.) NOAEC/EC$_{05}$: 4 Slope: N.A.	44320635/1996	Acceptable
Dicots					
Glyphosate (80 WDG formulation)	Veg.Crops (10 Sp.) (Monocots & Dicots)	75	29 D EC$_{25}$: >4.5 (N.R.) NOAEC/EC$_{05}$: 3.6 Slope: N.R.	44125712/1996	Acceptable
Glyphosate IPA salt CP-70139	Soybean (*Glycine max*)	50	14 D EC$_{25}$: >5 (N.R.) NOAEC/EC$_{05}$: N.R. Slope: N.R.	40159301/1987	Acceptable
Glyphosate IPA salt CP-70139	Sugarbeet (*Beta vulgaris*)	50	14 D E$_{C2}$5: >5 (N.R.) NOAEC/EC$_{05}$: N.R. Slope: N.R.	40159301/1987	Acceptable
Glyphosate IPA salt CP-70139	Buckwheat (*Polygonum convolvulus*)	50	14 D EC$_{25}$: >5 (N.R.) NOAEC/EC$_{05}$: N.R. Slope: N.R.	40159301/1987	Acceptable
Glyphosate IPA salt CP-70139	Cocklebur (*Xanthium pensylvanicum*)	50	14 D EC$_{25}$: >5 (N.R.) NOAEC/EC$_{05}$: N.R. Slope: N.R.	40159301/1987	Acceptable
Glyphosate IPA salt CP-70139	Crabgrass (*Digitaria sanguinalis*)	50	14 D EC$_{25}$: >5 (N.R.) NOAEC/EC$_{05}$: N.R. Slope: N.R.	40159301/1987	Acceptable

Table D-41. Terrestrial Plant Studies with Glyphosate Formulations

Chemical	Species	% a.i.[1]	EC$_{25}$/ NOAEC (EC$_{05}$) (lb a.e./Acre[1]	MRID #/Year	Study Classification
Glyphosate IPA salt CP-70139	Panicum grass (*Panicum sp.*)	50	14 D EC$_{25}$: >5 (N.R.) NOAEC/EC$_{05}$: N.R. Slope: N.R.	40159301/1987	Acceptable
Glyphosate IPA salt CP-70139	Downy brome (*Bromus tectorum*)	50	14 D EC$_{25}$: >5 (N.R.) NOAEC/EC$_{05}$: N.R. Slope: N.R.	40159301/1987	Acceptable
Glyphosate IPA salt CP-70139	Velvetleaf (*Abutilon theophrasti*)	50	14 D EC$_{25}$: >5 (N.R.) NOAEC/EC$_{05}$: N.R. Slope: N.R.	40159301/1987	Acceptable
Glyphosate IPA salt CP-70139	Smartweed (*Polygonum pensylvanicum*)	50	14 D EC$_{25}$: >5 (N.R.) NOAEC/EC$_{05}$: N.R. Slope: N.R.	40159301/1987	Acceptable
Glyphosate IPA salt CP-70139	Morning glory (*Ipomoea sp.*)	50	14 D EC$_{25}$: >5 (N.R.) NOAEC/EC$_{05}$: N.R. Slope: N.R.	40159301/1987	Acceptable
Glyphosate IPA salt CP-70139	Lambsquarter (*Chenopodium album*)	50	14 D EC$_{25}$: >5 (N.R.) NOAEC/EC$_{05}$: N.R. Slope: N.R.	40159301/1987	Acceptable
Glyphosate IPA salt CP-70139	Hemp (*Sesbania exaltata*)	50	14 D EC$_{25}$: >5 (N.R.) NOAEC/EC$_{05}$: N.R. Slope: N.R.	40159301/1987	Acceptable
Glyphosate (80 WDG formulation)	Veg.Crops (10 Sp.) (Monocots & Dicots)	48.3	4WKS EC$_{25}$: >4 (N.A.) NOAEC/EC$_{05}$: 4 Slope: N.A.	44320635/1996	Acceptable
Vegetative Vigor Studies					
Monocots					
Glyphosate (80 WDG formulation)	Onion (*Allium cepa*)	75	27 D EC$_{25}$: 0.28 (N.R.) NOAEC/EC$_{05}$: 0.14 Slope: N.R.	44125715/45045101/1995	Acceptable
Glyphosate (80 WDG formulation)	Sorghum (*Sorghum bicolor*)	75	27 D EC$_{25}$: 0.16 (N.R.) NOAEC/EC$_{05}$: 0.07 Slope: N.R.	44125715/45045101/1995	Acceptable
Glyphosate (80 WDG formulation)	Wheat (*Triticum aestivum*)	75	27 D EC$_{25}$: 0.22 (N.R.) NOAEC/EC$_{05}$: 0.1 Slope: N.R.	44125715/45045101/1995	Acceptable
Glyphosate (80 WDG formulation)	Corn (*Zea mays*)	75	27 D EC$_{25}$: 0.35 (N.R.) NOAEC/EC$_{05}$: 0.18 Slope: N.R.	44125715/45045101/1996	Acceptable
Glyphosate (80 WDG formulation)	Corn (*Zea mays*)	48.3	48WKS EC$_{25}$: 0.227 (N.R.) NOAEC/EC$_{05}$: 0.148 Slope: N.R.	44320636/1996	Acceptable

Table D-41. Terrestrial Plant Studies with Glyphosate Formulations

Chemical	Species	% a.i.[1]	EC$_{25}$/ NOAEC (EC$_{05}$) (lb a.e./Acre[1]	MRID #/Year	Study Classification
Glyphosate(80 WDG formulation)	Purple nutsedge (*Cyperus rotundus*)	48.3	4WKS EC$_{25}$: 0.805 (N.R.) NOAEC/EC$_{05}$: 0.445 Slope: N.R.	44320636/1996	Acceptable
Glyphosate(80 WDG formulation)	Wheat (*Triticum aestivum*)	48.3	4WKS EC$_{25}$: 0.176 (0.138-0.183 a.e.) NOAEC/EC$_{05}$: 0.049 Slope: N.R.	44320636/1996	Acceptable
Glyphosate(80 WDG formulation)	Oat (*Avena sativa*)	48.3	4WKS EC$_{25}$: 0.201 (N.R.) NOAEC/EC$_{05}$: 0.148 Slope: N.R.	44320636/1996	Acceptable
Dicots					
Glyphosate(80 WDG formulation)	Garden pea (*Pisum sativum*)	75	27 D EC$_{25}$: 0.89 (N.R.) NOAEC/EC$_{05}$: 0.45 Slope: N.R.	44125715/ 45045101/ 1995	Acceptable
Glyphosate(80 WDG formulation)	Sugarbeet (*Beta vulgaris*)	75	27 D EC$_{25}$: 0.21 (B.R.) NOAEC/EC$_{05}$: 0.12 Slope: N.R.	44125715/ 45045101/ 1995	Acceptable
Glyphosate(80 WDG formulation)	Sunflower (*Helianthus annus*)	75	27 D EC$_{25}$: 0.16 (N.R.) NOAEC/EC$_{05}$: 0.08 Slope: N.R.	44125715/ 45045101 /1995	Acceptable
Glyphosate(80 WDG formulation)	Radish (*Rhaphanus sativus*)	75	27 D EC$_{25}$: 0.09 (N.R.) NOAEC/EC$_{05}$: 0.02 Slope: N.R.	44125715/ 45045101/ 1995	Acceptable
Glyphosate(80 WDG formulation)	Soybean (*Glycine max*)	75	27 D EC$_{25}$: 0.32 (N.R.) NOAEC/EC$_{05}$: 0.12 Slope: N.R.	44125715/ 45045101/ 1995	Acceptable
Glyphosate (80 WDG formulation)	Cucumber (*Cucumis sativus*)	75	27 D EC$_{25}$: 0.45 (N.R.) NOAEC/EC$_{05}$: 0.16 Slope: N.R.	44125715/ 45045101/ 1995	Acceptable
Glyphosate (80 WDG formulation)	Sugarbeet (*Beta vulgaris*)	48.3	4WKS EC$_{25}$: 0.277 (N.R.) NOAEC/EC$_{05}$: 0.148 Slope: N.R.	44320636/1996	Acceptable
Glyphosate (80 WDG formulation)	Radish (*Rhaphanus sativus*)	48.3	4WKS EC$_{25}$: 0.235 (N.R.) NOAEC/EC$_{05}$: 0.148 Slope: N.R.	44320636/1996	Acceptable
Glyphosate (80 WDG formulation)	Soybean (*Glycine max*)	48.3	4WKS EC$_{25}$: 0.126 (N.R.) NOAEC/EC$_{05}$: 0.049 Slope: N.R.	44320636/1996	Acceptable
Glyphosate (80WDG formulation)	Lettuce (*Lactuca sativa*)	48.3	4WKS EC$_{25}$: 0.217 (N.R.) NOAEC/EC$_{05}$: 0.148 Slope: N.R.	44320636/1996	Acceptable

Table D-41. Terrestrial Plant Studies with Glyphosate Formulations

Chemical	Species	% a.i.[1]	EC25/ NOAEC (EC05) (lb a.e./Acre[1]	MRID #/Year	Study Classification
Glyphosate (80WDG formulation)	Cucumber (*Cucumis sativus*)	48.3	4WKS EC25: 0.074 (N.R.) NOAEC/EC05: 0.049 Slope: N.R.	44320636/1996	Acceptable
Glyphosate (80WDG formulation)	Rape (*Brassica compestris*)	48.3	4WKS EC25: 0.098 (0.065-0.084) NOAEC/EC05: 0.049 Slope: N.A.	44320636/1996	Acceptable
Glyphosate (80WDG formulation)	Okra (*Hibiscus esculentus*)	48.3	4WKS EC25: 0.172 (N.R.) NOAEC/EC05: 0.049 Slope: N.R.	44320636/1996	Acceptable

[1] a.i. = active ingredient; a.e. = acid equivalent; N.R. = Not reported; IPA = isopropylamine

Open Literature for Terrestrial Plants

Table D-42. Open literature studies for glyphosate for terrestrial plants

Species	Chemical Form	Endpoint(s)	ECOTOX Ref. No.
Bellis perennis (most sensitive species; multiple species tested)	Roundup Original or Vision (both containing 356 g glyphosate acid/L)	Biomass (dry wt) 28-d IC_{25} = 0.053 lb a.i./A	E152615 / Boutin *et al* 2010
Bellis perennis (most sensitive species; multiple species tested)	Roundup Bio (360 g/l glyphosate with 480 g glyphosate-isopropylamine salt)	Biomass (dry wt) 28-d EC_{50} = 0.013 lb a.i./A	E87923 / Boutin *et al* 2004
Brassica oleracea (most sensitive species; multiple species tested)	Roundup Original (356 g glyphosate acid/L)	Biomass (dry wt) (assumed to be 28-d) IC_{25} = 0.038 lb a.i./A	E159072 / Boutin *et al.* 2012
Pisum sativum (Garden pea)	Roundup Original	Seed wt EC_{25} = 0.0074 lb ai/A [0.0096 x 833 g ai/ha], NOEC [0.01 x 833]	Rec#8500 / Olszyk *et al.* 2009
Solanum Tuberosum L (Potatoes)	Roundup	Most endpoints (growth and reproductive) affected at 0.1 x 832 g/ha, most sensitive endpoint was above biomass with EC25 of 0.004 x 832 [0.003 lb/A]	Rec# 5780 / Pfleeger et al. 2011
Triticum aestivum (most sensitive species; multiple species tested)	Roundup Original	Biomass (dry wt) (assumed to be 28-d) IC_{25} = 0.0178 lb a.i./A	White and Boutin 2007

Appendix E.

Ecotoxicity Bibliography

Chemical Name	Genus	Species	Common Name	Effect Group	Effect	Meas	Endpt1	Endpt2	Dur Preferred Mean	Dur Unit Preferred	Conc #1 Purity Adjusted in Preferred Unit Mean	Conc #2 Purity Adjusted in Preferred Unit Mean	Conc Units Preferred	% Purity	Ref #
Glyphosate isopropylamine salt	Quercus	nigra	Water Oak	POP	POP	ABND	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	NR	Magnoliopsida	Dicot Class	POP	POP	DVRS	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	NR	Magnoliopsida	Dicot Class	POP	POP	DVRS	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	Galium	bermudense	Coastal Bedstraw	POP	POP	ABND	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	Eupatorium	sp.	Thoroughwort	POP	POP	ABND	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	Lespedeza	sp.	Clover	POP	POP	ABND	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	Quercus	sp.	Oak Spp.	POP	POP	ABND	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	Andropogon	sp.	Bluestem	POP	POP	ABND	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	NR	Plantae	Plant Kingdom	POP	POP	DVRS	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	NR	Magnoliopsida	Dicot Class	POP	POP	DVRS	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	NR	Magnoliopsida	Dicot Class	POP	POP	DVRS	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	NR	Poaceae	Grass Family	POP	POP	DVRS	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	NR	Magnoliopsida	Dicot Class	POP	POP	DVRS	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	Liquidambar	styraciflua	Sweetgum	POP	POP	ABND	NOAEL		2555	d	1.7		ae kg/ha	100	160829

Glyphosate isopropylamine salt	Cornus	florida	Flowering Dogwood	POP	POP	ABND	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	Quercus	falcata	Southern Red Oak	POP	POP	ABND	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	Prunus	serotina	Black Cherry	POP	POP	ABND	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	NR	Magnoliopsida	Dicot Class	POP	POP	ABND	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	NR	Magnoliopsida	Dicot Class	POP	POP	ABND	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	Vaccinium	stamineum	Deerberry	POP	POP	ABND	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	Vaccinium	sp.	Blueberry	POP	POP	ABND	LOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	Rhus	copallina	Dwarf Sumac	POP	POP	ABND	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	Diospyros	virginiana	Common Persimmon	POP	POP	ABND	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	Pinus	taeda	Loblolly Pine	POP	POP	ABND	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	Panicum	sp.	Panic Grass	POP	POP	ABND	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	Dichanthelium	commutatum	Variable Panicgrass	POP	POP	ABND	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	Rubus	argutus	Prickly Florida Blackberry	POP	POP	ABND	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	Vitis	rotundifolia	Muscadine Grape	POP	POP	ABND	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	Gelsemium	sempervirens	Carolina Jessamine	POP	POP	ABND	NOAEL		2555	d	1.7		ae kg/ha	100	160829

Glyphosate isopropylamine salt	Smilax	sp.	Greenbrier	POP	POP	ABND	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	Smilax	glauca	Cat Greenbrier	POP	POP	ABND	NOAEL		2555	d	1.7		ae kg/ha	100	160829
Glyphosate isopropylamine salt	Empetrum	nigrum	Black Crowberry	POP	POP	COVR	NOAEL		730	d	1.2488		lb/acre	100	162002
Glyphosate isopropylamine salt	Vaccinium	sp.	Blueberry	POP	POP	COVR	NOAEL		730	d	1.2488		lb/acre	100	162002
Glyphosate isopropylamine salt	Erica	tetralix	Crossleaf Heath	POP	POP	COVR	NOAEL		730	d	1.2488		lb/acre	100	162002
Glyphosate isopropylamine salt	Calluna	vulgaris	Heather	POP	POP	COVR	LOAEL		730	d	1.2488		lb/acre	100	162002
Glyphosate	Rattus	norvegicus	Norway Rat	GRO	MPH	SMIX	NOAEL	LOAEL	91	d	12375	24750	ppm	99	161806
Glyphosate	Rattus	norvegicus	Norway Rat	BCM	BCM	HMCT	NOAEL	LOAEL	90	d	6187.5	12375	ppm	99	161806
Glyphosate	Rattus	norvegicus	Norway Rat	BCM	ENZ	AATT	LOAEL		90	d	3093.75		ppm	99	161806
Glyphosate	Rattus	norvegicus	Norway Rat	REP	REP	ETRS	NOAEL	LOAEL	91	d	24750	49500	ppm	99	161806
Glyphosate	Rattus	norvegicus	Norway Rat	GRO	MPH	SMIX	LOAEL		91	d	3093.75		ppm	99	161806
Glyphosate	Rattus	norvegicus	Norway Rat	CEL	CEL	RBCE	NOAEL	LOAEL	90	d	6187.5	12375	ppm	99	161806
Glyphosate	Rattus	norvegicus	Norway Rat	CEL	CEL	LMPH	LOAEL		90	d	3093.75		ppm	99	161806
Glyphosate	Rattus	norvegicus	Norway Rat	BCM	BCM	HMGL	NOAEL	LOAEL	5	d	24750	49500	ppm	99	161806
Glyphosate	Rattus	norvegicus	Norway Rat	BCM	ENZ	AATT	LOAEL		5	d	3093.75		ppm	99	161806
Glyphosate	Rattus	norvegicus	Norway Rat	GRO	GRO	WGHT	NOAEL	LOAEL	91	d	12375	24750	ppm	99	161806
Glyphosate	Rattus	norvegicus	Norway Rat	REP	REP	SPCL	NOAEL	LOAEL	91	d	12375	24750	ppm	99	161806
Glyphosate	Mus	musculus	House Mouse	REP	REP	SPCL	NOAEL		91	d	49500		ppm	99	161806
Glyphosate	Mus	musculus	House Mouse	GRO	MPH	WGHT	NOAEL	LOAEL	91	d	12375	24750	ppm	99	161806
Glyphosate	Mus	musculus	House Mouse	GRO	GRO	WGHT	NOAEL	LOAEL	91	d	12375	24750	ppm	99	161806
Glyphosate	Mus	musculus	House Mouse	REP	REP	ETRS	NOAEL		91	d	49500		ppm	99	161806
Glyphosate	Mus	musculus	House Mouse	GRO	MPH	SMIX	NOAEL	LOAEL	91	d	3093.75	6187.5	ppm	99	161806
Glyphosate isopropylamine salt	Labeo	rohita	Rohu	MOR	MOR	MORT	NR-LETH		4	d	14		AI ug/L	41	161848
Glyphosate isopropylamine salt	Labeo	rohita	Rohu	MOR	MOR	MORT	NR-LETH		1	d	14		AI ug/L	41	161848
Glyphosate isopropylamine salt	Labeo	rohita	Rohu	MOR	MOR	MORT	NR-LETH		4	d	14		AI ug/L	41	161848
Glyphosate isopropylamine salt	Desmanthus	virgatus	Wild Tantan	POP	POP	WGHT	LOAEL		35	d	0.32112		lb/acre	100	157094

Compound	Genus	Species	Common Name				Effect		Dur		Conc		Units	%	Ref
Glyphosate isopropylamine salt	Desmanthus	virgatus	Wild Tantan	GRO	GRO	VGOR	LOAEL		7	d	1.6056		lb/acre	100	157094
Glyphosate isopropylamine salt	Desmanthus	virgatus	Wild Tantan	POP	POP	ABND	LOAEL		39	d	1.6056		lb/acre	100	157094
Glyphosate isopropylamine salt	Sida	rhombifolia	Arrowleaf Sida	GRO	GRO	VGOR	LOAEL		7	d	1.6056		lb/acre	100	157094
Glyphosate isopropylamine salt	Ipomoea	biflora	Bellvine	GRO	GRO	VGOR	LOAEL		7	d	1.6056		lb/acre	100	157094
Glyphosate, Monopotassium salt	Spea	multiplicata	Mexican Spadefoot	MOR	MOR	SURV	NOAEL		2	d	29.8		ppm	48.8	152560
Glyphosate isopropylamine salt	Spea	multiplicata	Mexican Spadefoot	MOR	MOR	SURV	NOAEL		2	d	628		ppm	50.2	152560
Glyphosate isopropylamine salt	Spea	multiplicata	Mexican Spadefoot	MOR	MOR	SURV	NOAEL		2	d	628		ppm	50.2	152560
Glyphosate isopropylamine salt	Spea	multiplicata	Mexican Spadefoot	MOR	MOR	MORT	NR-ZERO		2	d	628		ppm	50.2	152560
Glyphosate isopropylamine salt	Spea	multiplicata	Mexican Spadefoot	MOR	MOR	MORT	NR-LETH		2	d	1092		ppm	2	152560
Glyphosate isopropylamine salt	Spea	multiplicata	Mexican Spadefoot	MOR	MOR	SURV	LOAEL		2	d	1092		ppm	2	152560
Glyphosate isopropylamine salt	Spea	multiplicata	Mexican Spadefoot	MOR	MOR	SURV	LOAEL		2	d	1092		ppm	2	152560
Glyphosate isopropylamine salt	Spea	multiplicata	Mexican Spadefoot	MOR	MOR	MORT	NR-LETH		2	d	1092		ppm	2	152560
Glyphosate, Monopotassium salt	Bufo	cognatus	Great Plains Toad	MOR	MOR	SURV	NOAEL		2	d	29.8		ppm	48.8	152560
Glyphosate, Monopotassium salt	Bufo	cognatus	Great Plains Toad	MOR	MOR	MORT	NR-ZERO		2	d	29.8		ppm	48.8	152560
Glyphosate isopropylamine salt	Bufo	cognatus	Great Plains Toad	MOR	MOR	SURV	LOAEL		2	d	628		ppm	50.2	152560

Glyphosate isopropylamine salt	Bufo	cognatus	Great Plains Toad	MOR	MOR	SURV	LOAEL		2	d	1092		ppm	2	152560
Glyphosate isopropylamine salt	Bufo	cognatus	Great Plains Toad	MOR	MOR	MORT	NR-LETH		2	d	1092		ppm	2	152560
Glyphosate, Monopotassium salt	Spea	multiplicata	Mexican Spadefoot	MOR	MOR	SURV	NOAEL		2	d	29.8		ppm	48.8	152560
Glyphosate, Monopotassium salt	Spea	multiplicata	Mexican Spadefoot	MOR	MOR	MORT	NR-ZERO		2	d	29.8		ppm	48.8	152560
Glyphosate isopropylamine salt	Bufo	cognatus	Great Plains Toad	MOR	MOR	SURV	NOAEL		2	d	628		ppm	50.2	152560
Glyphosate isopropylamine salt	Bufo	cognatus	Great Plains Toad	MOR	MOR	MORT	NR-ZERO		2	d	628		ppm	50.2	152560
Glyphosate isopropylamine salt	Bufo	cognatus	Great Plains Toad	MOR	MOR	SURV	LOAEL		2	d	1092		ppm	2	152560
Glyphosate, Monopotassium salt	Bufo	cognatus	Great Plains Toad	MOR	MOR	SURV	NOAEL		2	d	29.8		ppm	48.8	152560
Glyphosate isopropylamine salt	Deschampsia	flexuosa	Wavy Hairgrass	PHY	INJ	DAMG	LOAEL		15	d	0.32112		lb/acre	100	160843
Glyphosate isopropylamine salt	Deschampsia	flexuosa	Wavy Hairgrass	POP	POP	WGHT	LOAEL		375	d	0.32112		lb/acre	100	160843
Glyphosate isopropylamine salt	Deschampsia	flexuosa	Wavy Hairgrass	PHY	INJ	DAMG	LOAEL		15	d	0.32112		lb/acre	100	160843
Glyphosate isopropylamine salt	Deschampsia	flexuosa	Wavy Hairgrass	POP	POP	WGHT	LOAEL		375	d	0.32112		lb/acre	100	160843
Glyphosate isopropylamine salt	Deschampsia	flexuosa	Wavy Hairgrass	PHY	INJ	DAMG	LOAEL		14	d	0.8028		lb/acre	100	160843
Glyphosate isopropylamine salt	Deschampsia	flexuosa	Wavy Hairgrass	PHY	INJ	DAMG	LOAEL		15	d	0.32112		lb/acre	100	160843
Glyphosate isopropylamine salt	Deschampsia	flexuosa	Wavy Hairgrass	POP	POP	WGHT	LOAEL		375	d	0.32112		lb/acre	100	160843

Chemical	Genus	Species	Common Name												
Glyphosate isopropylamine salt	Deschampsia	flexuosa	Wavy Hairgrass	PHY	INJ	DAMG	LOAEL		13	d	0.64224		lb/acre	100	160843
Glyphosate isopropylamine salt	Deschampsia	flexuosa	Wavy Hairgrass	POP	POP	WGHT	LOAEL		308	d	0.64224		lb/acre	100	160843
Glyphosate isopropylamine salt	Deschampsia	flexuosa	Wavy Hairgrass	PHY	INJ	DAMG	NOAEL	LOAEL	21	d	0.8028	1.6056	lb/acre	100	160843
Glyphosate	Lecane	quadridentata	Rotifer	MOR	MOR	MORT	NOEC	LOEC	2	d	120	140	mg/L	100	161360
Glyphosate	Lecane	quadridentata	Rotifer	MOR	MOR	MORT	LC50		2	d	150		mg/L	100	161360
Glyphosate	Lecane	quadridentata	Rotifer	BCM	ENZ	ESTE	NOEC	LOEC	0.0313	d	0.017	0.033	mg/L	100	161360
Glyphosate	Lecane	quadridentata	Rotifer	BCM	ENZ	ESTE	EC50		0.0313	d	0.15		mg/L	100	161360
Glyphosate	Lecane	quadridentata	Rotifer	BCM	ENZ	PLA2	NOEC	LOEC	0.0313	d	0.22	0.73	mg/L	100	161360
Glyphosate	Lecane	quadridentata	Rotifer	BCM	ENZ	PLA2	EC50		0.0313	d	0.26		mg/L	100	161360
Glyphosate	Lecane	quadridentata	Rotifer	MOR	MOR	MORT	NOEC	LOEC	2	d	5.2	13	mg/L	100	161360
Glyphosate	Lecane	quadridentata	Rotifer	MOR	MOR	MORT	LC50		2	d	13.1		mg/L	100	161360
Glyphosate	Daphnia	magna	Water Flea	MOR	MOR	MORT	NOEC	LOEC	2	d	120	140	mg/L	100	161360
Glyphosate	Daphnia	magna	Water Flea	MOR	MOR	MORT	LC50		2	d	146		mg/L	100	161360
Glyphosate	Daphnia	magna	Water Flea	MOR	MOR	MORT	NOEC	LOEC	2	d	1.7	3.4	mg/L	100	161360
Glyphosate	Daphnia	magna	Water Flea	MOR	MOR	MORT	LC50		2	d	4.1		mg/L	100	161360
Glyphosate	Lecane	quadridentata	Rotifer	BCM	ENZ	ESTE	NOEC	LOEC	0.0313	d	0.01	0.05	mg/L	100	161360
Glyphosate	Lecane	quadridentata	Rotifer	BCM	ENZ	ESTE	EC50		0.0313	d	0.1		mg/L	100	161360
Glyphosate	Lecane	quadridentata	Rotifer	BCM	ENZ	PLA2	NOEC	LOEC	0.0313	d	5	10	mg/L	100	161360
Glyphosate	Lecane	quadridentata	Rotifer	BCM	ENZ	PLA2	EC50		0.0313	d	17.6		mg/L	100	161360
Glyphosate isopropylamine salt	Scenedesmus	quadricauda	Green Algae	POP	POP	PGRT	EC50		3	d	10.17		mg/dm3	100	161189
Glyphosate isopropylamine salt	Pseudokirchneriella	subcapitata	Green Algae	POP	POP	PGRT	EC50		3	d	2.55		mg/dm3	100	161189
Glyphosate isopropylamine salt	Scenedesmus	acutus var. acutus	Green Algae	POP	POP	PGRT	EC50		4	d	80		mg/L	100	152180

Glyphosate isopropylamine salt	Algae	NR	Algae	POP	POP	CHAP	NOAEL		1	d			mg/L	100	161504
Glyphosate isopropylamine salt	Algae	NR	Algae	POP	POP	CHAP	NOAEL		6	d			mg/L	100	161504
Glyphosate isopropylamine salt	Algae	NR	Algae	POP	POP	CHAP	NOAEL		20	d			mg/L	100	161504
Glyphosate isopropylamine salt	Algae	NR	Algae	POP	POP	CHAP	NOAEL		37	d			mg/L	100	161504
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	ENZ	CTLS	LOAEL		4	d	1.21		mg/L	100	151710
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	ENZ	GSTR	LOAEL		4	d	1.21		mg/L	100	151710
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	MOR	MOR	MORT	NR-ZERO		4	d	1.21		mg/L	100	151710
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	BCM	TBAR	NOAEL		4	d	1.21		mg/L	100	151710
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	BCM	PCAR	NOAEL		4	d	1.21		mg/L	100	151710
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	BCM	NPSH	NOAEL		4	d	1.21		mg/L	100	151710
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	ENZ	AATT	NOAEL		4	d	1.21		mg/L	100	151710
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	ENZ	ASAT	NOAEL		4	d	1.21		mg/L	100	151710
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	BCM	ASCA	LOAEL		4	d	1.21		mg/L	100	151710
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	BCM	GLTH	LOAEL		4	d	1.21		mg/L	100	151710
Glyphosate isopropylamine salt	Huso	huso	Beluga	MOR	MOR	MORT	LC50		4	d	8.2		mg/L	41	161365

Chemical	Genus	Species	Common						Duration		Value		Units		
Glyphosate isopropylamine salt	Huso	huso	Beluga	MOR	MOR	MORT	LC50		0.25	d	30.75		mg/L	41	161365
Glyphosate isopropylamine salt	Huso	huso	Beluga	MOR	MOR	MORT	LC50		0.5	d	24.6		mg/L	41	161365
Glyphosate isopropylamine salt	Huso	huso	Beluga	MOR	MOR	MORT	LC50		1	d	18.45		mg/L	41	161365
Glyphosate isopropylamine salt	Huso	huso	Beluga	MOR	MOR	MORT	LC50		2	d	12.3		mg/L	41	161365
Glyphosate isopropylamine salt	Huso	huso	Beluga	MOR	MOR	MORT	LC50		7	d	6.15		mg/L	41	161365
Glyphosate isopropylamine salt	Acipenser	persicus	Persian Sturgeon	MOR	MOR	MORT	LC50		0.25	d	41		mg/L	41	161365
Glyphosate isopropylamine salt	Acipenser	persicus	Persian Sturgeon	MOR	MOR	MORT	LC50		0.5	d	34.85		mg/L	41	161365
Glyphosate isopropylamine salt	Acipenser	persicus	Persian Sturgeon	MOR	MOR	MORT	LC50		1	d	28.7		mg/L	41	161365
Glyphosate isopropylamine salt	Acipenser	persicus	Persian Sturgeon	MOR	MOR	MORT	LC50		2	d	16.4		mg/L	41	161365
Glyphosate isopropylamine salt	Acipenser	persicus	Persian Sturgeon	MOR	MOR	MORT	LC50		4	d	16.4		mg/L	41	161365
Glyphosate isopropylamine salt	Acipenser	persicus	Persian Sturgeon	MOR	MOR	MORT	LC50		7	d	8.2		mg/L	41	161365
Glyphosate isopropylamine salt	Acipenser	stellatus	Sevruga, Stellate Sturgeon	MOR	MOR	MORT	LC50		0.25	d	38.95		mg/L	41	161365
Glyphosate isopropylamine salt	Acipenser	stellatus	Sevruga, Stellate Sturgeon	MOR	MOR	MORT	LC50		0.5	d	32.8		mg/L	41	161365
Glyphosate isopropylamine salt	Acipenser	stellatus	Sevruga, Stellate Sturgeon	MOR	MOR	MORT	LC50		1	d	26.65		mg/L	41	161365
Glyphosate isopropylamine salt	Acipenser	stellatus	Sevruga, Stellate Sturgeon	MOR	MOR	MORT	LC50		2	d	22.55		mg/L	41	161365

Glyphosate isopropylamine salt	Acipenser	stellatus	Sevruga, Stellate Sturgeon	MOR	MOR	MORT	LC50		4	d	14.35		mg/L	41	161365
Glyphosate isopropylamine salt	Acipenser	stellatus	Sevruga, Stellate Sturgeon	MOR	MOR	MORT	LC50		7	d	8.2		mg/L	41	161365
Glyphosate isopropylamine salt	Algae	NR	Algae	POP	POP	PSYN	NOAEL		0.1667	d	640.8		mg/L	35.6	161202
Glyphosate isopropylamine salt	Algae	NR	Algae	POP	POP	PSYN	EC50		0.1667	d			mg/L	35.6	161202
Glyphosate isopropylamine salt	Algae	NR	Algae	POP	POP	PSYN	EC50		0.1667	d	24.8132		mg/L	35.6	161202
Glyphosate isopropylamine salt	Algae	NR	Algae	POP	POP	PSYN	EC50		0.1667	d			mg/L	35.6	161202
Glyphosate isopropylamine salt	Algae	NR	Algae	POP	POP	PSYN	EC50		0.1667	d			mg/L	35.6	161202
Glyphosate isopropylamine salt	Algae	NR	Algae	POP	POP	PSYN	EC50		0.1667	d	15.8064		mg/L	35.6	161202
Glyphosate isopropylamine salt	Algae	NR	Algae	POP	POP	PSYN	EC50		0.1667	d	12.6024		mg/L	35.6	161202
Glyphosate isopropylamine salt	Pinus	radiata	Insignis Pine	GRO	GRO	DMTR	NOAEL		639.24	d	1.78		lb/acre	100	160718
Glyphosate isopropylamine salt	Phaeosphaeria	nodorum	Fungi	REP	REP	SEPD	LOAEL		7	d	80		ppm	100	162023
Glyphosate isopropylamine salt	Phaeosphaeria	nodorum	Fungi	REP	REP	GERM	LOAEL		0.5	d	160		ppm	100	162023
Glyphosate isopropylamine salt	Phaeosphaeria	nodorum	Fungi	REP	REP	SEPD	LOAEL		7	d	80		ppm	100	162023
Glyphosate isopropylamine salt	Phaeosphaeria	nodorum	Fungi	REP	REP	GERM	LOAEL		0.5	d	160		ppm	100	162023
Glyphosate isopropylamine salt	Phaeosphaeria	nodorum	Fungi	POP	POP	ABND	LOAEL		0.5	d	160		ppm	100	162023

Chemical	Genus	Species	Common Name										Unit		ID
Glyphosate isopropylamine salt	Comptonia	peregrina	Sweet Fern	POP	POP	ABND	LOAEL		730	d	0.5		lb/acre	100	159938
Glyphosate isopropylamine salt	Comptonia	peregrina	Sweet Fern	POP	POP	ABND	LOAEL		1095	d	0.5		lb/acre	100	159938
Glyphosate isopropylamine salt	Comptonia	peregrina	Sweet Fern	POP	POP	ABND	LOAEL		365	d	0.5		lb/acre	100	159938
Glyphosate	Poa	pratensis	Kentucky Bluegrass	POP	POP	ABND	NOAEL			d	3		AI lb/acre	100	161677
Glyphosate	Medicago	sativa	Alfalfa	POP	POP	BMAS	LOAEL			hv	1.784		lb/acre	100	161678
Glyphosate	Agrostis	capillaris	Colonial Bentgrass	POP	POP	ABND	NOAEL		584	d	1.784		lb/acre	100	161678
Glyphosate	Conium	maculatum	Hemlock	GRO	GRO	VGOR	LOAEL		1	gs	0.4		ae kg/ha	100	160719
Glyphosate	Conium	maculatum	Hemlock	POP	POP	CNTL	NOAEL	LOAEL	1	gs	0.4	0.6	ae kg/ha	100	160719
Glyphosate	Conium	maculatum	Hemlock	GRO	GRO	VGOR	LOAEL		1	gs	0.4		ae kg/ha	100	160719
Glyphosate	Conium	maculatum	Hemlock	POP	POP	CNTL	NOAEL	LOAEL	1	gs	0.4	0.6	ae kg/ha	100	160719
Glyphosate	Conium	maculatum	Hemlock	GRO	GRO	VGOR	LOAEL		1	gs	0.4		ae kg/ha	100	160719
Glyphosate	Conium	maculatum	Hemlock	POP	POP	CNTL	LOAEL		1	gs	0.4		ae kg/ha	100	160719
Glyphosate	Cynodon	sp.	Bermudagrass	POP	POP	COVR	NOAEL		90	d	0.15164		lb/acre	100	157310
Glyphosate	NR	Poaceae	Grass Family	PHY	INJ	GINJ	LOAEL		13	d	0.09812		lb/acre	100	157310
Glyphosate	NR	Poaceae	Grass Family	PHY	INJ	GINJ	LOAEL		14	d	0.09812		lb/acre	100	157310
Glyphosate	Lolium	perenne	Perennial Ryegrass	POP	POP	COVR	NOAEL		90	d	0.15164		lb/acre	100	157310
Glyphosate	Cynodon	sp.	Bermudagrass	POP	POP	COVR	NOAEL		78	d	0.15164		lb/acre	100	157310
Glyphosate	Lolium	perenne	Perennial Ryegrass	POP	POP	COVR	NOAEL		78	d	0.15164		lb/acre	100	157310
Glyphosate isopropylamine salt	Paspalum	notatum	Bahiagrass	GRO	GRO	HGHT	LOAEL		14	d	0.1784		lb/acre	100	156191
Glyphosate, Sesquisodium salt	Paspalum	notatum	Bahiagrass	GRO	GRO	HGHT	LOAEL		14	d	0.1784		lb/acre	100	156191
Glyphosate isopropylamine salt	Paspalum	notatum	Bahiagrass	GRO	GRO	HGHT	LOAEL		42	d	0.1784		lb/acre	100	156191
Glyphosate, Sesquisodium salt	Paspalum	notatum	Bahiagrass	GRO	GRO	HGHT	LOAEL		42	d	0.1784		lb/acre	100	156191
Glyphosate	Daphnia	magna	Water Flea	MOR	MOR	MORT	NR-LETH		1	d	350		mg/L	100	161956
Glyphosate	Daphnia	magna	Water Flea	MOR	MOR	MORT	LC05		1	d	190		mg/L	100	161956
Glyphosate	Daphnia	magna	Water Flea	MOR	MOR	MORT	LC10		1	d	202		mg/L	100	161956

Glyphosate	Daphnia	magna	Water Flea	MOR	MOR	MORT	LC20		1	d	214		mg/L	100	161956
Glyphosate	Daphnia	magna	Water Flea	MOR	MOR	MORT	LC50		1	d	234		mg/L	100	161956
Glyphosate isopropylamine salt	Typha	sp.	Cattail	POP	POP	ABND	LOAEL		365	d	4.7		L/ha	100	162001
Glyphosate isopropylamine salt	Typha	sp.	Cattail	POP	POP	ABND	LOAEL		730	d			L/ha	100	162001
Glyphosate isopropylamine salt	Carassius	auratus	Goldfish	BCM	ENZ	CTLS	LOAEL		4	d	2.5		mg/L	100	150118
Glyphosate isopropylamine salt	Carassius	auratus	Goldfish	BCM	ENZ	GSTR	NOAEL		4	d	20		mg/L	100	150118
Glyphosate isopropylamine salt	Carassius	auratus	Goldfish	BCM	ENZ	GLRE	LOAEL		4	d	2.5		mg/L	100	150118
Glyphosate isopropylamine salt	Carassius	auratus	Goldfish	BCM	BCM	NPSH	NOAEL		4	d	20		mg/L	100	150118
Glyphosate isopropylamine salt	Carassius	auratus	Goldfish	BCM	BCM	PRSH	NOAEL		4	d	20		mg/L	100	150118
Glyphosate isopropylamine salt	Carassius	auratus	Goldfish	BCM	BCM	PRSH	NOAEL		4	d	20		mg/L	100	150118
Glyphosate isopropylamine salt	Carassius	auratus	Goldfish	BCM	BCM	PRSH	NOAEL		4	d	20		mg/L	100	150118
Glyphosate isopropylamine salt	Carassius	auratus	Goldfish	BCM	ENZ	SODA	LOAEL		4	d	2.5		mg/L	100	150118
Glyphosate isopropylamine salt	Carassius	auratus	Goldfish	BCM	ENZ	SODA	LOAEL		4	d	2.5		mg/L	100	150118
Glyphosate isopropylamine salt	Carassius	auratus	Goldfish	BCM	ENZ	SODA	LOAEL		4	d	2.5		mg/L	100	150118
Glyphosate isopropylamine salt	Carassius	auratus	Goldfish	BCM	ENZ	CTLS	NOAEL		4	d	20		mg/L	100	150118
Glyphosate isopropylamine salt	Carassius	auratus	Goldfish	BCM	ENZ	GSTR	NOAEL		4	d	20		mg/L	100	150118
Glyphosate isopropylamine salt	Carassius	auratus	Goldfish	BCM	ENZ	GSTR	LOAEL		4	d	2.5		mg/L	100	150118

Glyphosate isopropylamine salt	Carassius	auratus	Goldfish	BCM	ENZ	GLRE	LOAEL		4	d	2.5		mg/L	100	150118
Glyphosate isopropylamine salt	Carassius	auratus	Goldfish	BCM	ENZ	G6PD	LOAEL		4	d	2.5		mg/L	100	150118
Glyphosate isopropylamine salt	Carassius	auratus	Goldfish	BCM	BCM	LDPO	NOAEL		4	d	20		mg/L	100	150118
Glyphosate isopropylamine salt	Carassius	auratus	Goldfish	BCM	BCM	LDPO	NOAEL		4	d	20		mg/L	100	150118
Glyphosate	Chlorella	pyrenoidosa	Green Algae	POP	POP	PGRT	EC50		4	d	3.514		mg/L	95	158793
Glyphosate isopropylamine salt	Ligustrum	lucidum	Glossy Privet	POP	POP	CNTL	LOAEL	182.64	d	2.4		AI %	100	160875
Glyphosate isopropylamine salt	Ligustrum	lucidum	Glossy Privet	POP	POP	CNTL	LOAEL	426.16	d	2.4		AI %	100	160875
Glyphosate isopropylamine salt	Rattus	norvegicus	Norway Rat	MOR	MOR	MORT	NR-ZERO		1	d	1		ml	100	162013
Glyphosate isopropylamine salt	Rattus	norvegicus	Norway Rat	MOR	MOR	MORT	NR-LETH		1	d	5		ml	100	162013
Glyphosate isopropylamine salt	Rattus	norvegicus	Norway Rat	MOR	MOR	MORT	NR-ZERO		1	d	5		ml	100	162013
Glyphosate isopropylamine salt	Peromyscus	maniculatus	Deer Mouse	MOR	MOR	MORT	LD50		4	d	6000		mg/kg bdwt	100	162011
Glyphosate isopropylamine salt	Taricha	granulosa	Rough Skinned Newt	MOR	MOR	MORT	LD50		4	d	2600		mg/kg bdwt	100	162011
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	ENZ	SODA	LOAEL		1	d	4.1		mg/L	41	155953
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	ENZ	CTLS	NOAEL		4	d	4.1		mg/L	41	155953
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	ENZ	GLPX	LOAEL	0.25	d	4.1		mg/L	41	155953
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	ENZ	SODA	NOAEL	0.25	d	4.1		mg/L	41	155953

Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	ENZ	CTLS	NOAEL		1	d		4.1		mg/L	41	155953
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	ENZ	CTLS	NOAEL		0.25	d		4.1		mg/L	41	155953
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	ENZ	GLPX	LOAEL		1	d		4.1		mg/L	41	155953
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	ENZ	GSTR	LOAEL		1	d		4.1		mg/L	41	155953
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	ENZ	GSTR	NOAEL		0.25	d		4.1		mg/L	41	155953
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	BCM	GLTH	LOAEL		0.25	d		4.1		mg/L	41	155953
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	BCM	GLTH	LOAEL		1	d		4.1		mg/L	41	155953
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	BCM	GLTH	NOAEL		4	d		4.1		mg/L	41	155953
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	ENZ	ACHE	LOAEL		4	d		4.1		mg/L	41	155953
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	ENZ	ACHE	LOAEL		1	d		4.1		mg/L	41	155953
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	BCM	MLDH	NOAEL		4	d		4.1		mg/L	41	155953
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	BCM	MLDH	NOAEL		1	d		4.1		mg/L	41	155953
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	BCM	MLDH	NOAEL		0.25	d		4.1		mg/L	41	155953
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	MOR	MOR	MORT	NR-ZERO		4	d		4.1		mg/L	41	155953
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	ENZ	GLPX	NOAEL		4	d		4.1		mg/L	41	155953

Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	ENZ	GSTR	LOAEL		4	d	4.1		mg/L	41	155953
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	ENZ	ACHE	NOAEL		0.25	d	4.1		mg/L	41	155953
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	ENZ	ACHE	LOAEL		4	d	4.1		mg/L	41	155953
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	ENZ	ACHE	NOAEL		0.25	d	4.1		mg/L	41	155953
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	ENZ	ACHE	NOAEL		1	d	4.1		mg/L	41	155953
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	ENZ	SODA	NOAEL		4	d	4.1		mg/L	41	155953
Glyphosate isopropylamine salt	NR	Plantae	Plant Kingdom	REP	REP	GERM	NOAEL	LOAEL	29	d	1000	5000	ppm	100	160882
Glyphosate isopropylamine salt	Rubus	sp.	Brambles	REP	REP	GERM	NOAEL	LOAEL	29	d	1000	5000	ppm	100	160882
Glyphosate isopropylamine salt	NR	Magnoliopsi da	Dicot Class	REP	REP	GERM	NOAEL	LOAEL	29	d	1000	5000	ppm	100	160882
Glyphosate isopropylamine salt	NR	Liliopsida	Monocot Class	REP	REP	GERM	NOAEL	LOAEL	29	d	1000	5000	ppm	100	160882
Glyphosate isopropylamine salt	Salix	sp.	Willow Species	MOR	MOR	SURV	LOAEL		365	d	1.8732		lb/acre	100	160748
Glyphosate isopropylamine salt	Salix	sp.	Willow Species	PHY	INJ	DAMG	LOAEL		365	d	1.8732		lb/acre	100	160748
Glyphosate isopropylamine salt	Salix	sp.	Willow Species	GRO	GRO	HGHT	LOAEL		365	d	1.8732		lb/acre	100	160748
Glyphosate isopropylamine salt	Pinus	taeda	Loblolly Pine	MOR	MOR	MORT	NOAEL		2	gs	1.125		ae lb/ac	100	160835
Glyphosate isopropylamine salt	Pinus	taeda	Loblolly Pine	PHY	INJ	DAMG	LOAEL		1	gs	1.125		ae lb/ac	100	160835

Chemical	Genus	Species	Common Name												
Glyphosate isopropylamine salt	Pinus	taeda	Loblolly Pine	GRO	GRO	HGHT	NOAEL		2	gs	1.125		ae lb/ac	100	160835
Glyphosate isopropylamine salt	Pinus	taeda	Loblolly Pine	POP	POP	BMAS	NOAEL		2	gs	1.125		ae lb/ac	100	160835
Glyphosate isopropylamine salt	NR	Plantae	Plant Kingdom	POP	POP	BMAS	LOAEL		2	gs	1.125		ae lb/ac	100	160835
Glyphosate, Monopotassium salt	Lithobates	sylvaticus	Wood Frog	MOR	MOR	MORT	LC10		4	d	1.3		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Lithobates	sylvaticus	Wood Frog	MOR	MOR	MORT	LC50		4	d	1.9		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Lithobates	sylvaticus	Wood Frog	MOR	MOR	MORT	LC90		4	d	2.8		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Lithobates	sylvaticus	Wood Frog	MOR	MOR	MORT	NOAEL	LOAEL	4	d	1.12	2.11	ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Lithobates	pipiens	Leopard Frog	MOR	MOR	MORT	LC10		4	d	1.2		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Lithobates	pipiens	Leopard Frog	MOR	MOR	MORT	LC50		4	d	1.5		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Lithobates	pipiens	Leopard Frog	MOR	MOR	MORT	LC90		4	d	1.8		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Lithobates	pipiens	Leopard Frog	MOR	MOR	MORT	NOAEL	LOAEL	4	d	1.12	2.11	ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Rana	cascadae	Cascades Frog	MOR	MOR	MORT	LC10		4	d	1.2		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Rana	cascadae	Cascades Frog	MOR	MOR	MORT	LC50		4	d	1.7		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Rana	cascadae	Cascades Frog	MOR	MOR	MORT	LC90		4	d	2.1		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Rana	cascadae	Cascades Frog	MOR	MOR	MORT	NOAEL	LOAEL	4	d	1.12	2.11	ae mg/L	48.7	153679

Glyphosate, Monopotassium salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	LC10		4	d	1		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	LC50		4	d	1.4		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	LC90		4	d	1.8		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	LOAEL		4	d	1.12		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Rana	catesbeiana	Bullfrog	MOR	MOR	MORT	LC10		4	d	0.5		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Rana	catesbeiana	Bullfrog	MOR	MOR	MORT	LC50		4	d	0.8		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Rana	catesbeiana	Bullfrog	MOR	MOR	MORT	LC90		4	d	1.2		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Rana	catesbeiana	Bullfrog	MOR	MOR	MORT	LOAEL		4	d	1.12		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Bufo	americanus	American Toad	MOR	MOR	MORT	LC10		4	d	1.2		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Bufo	americanus	American Toad	MOR	MOR	MORT	LC50		4	d	1.6		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Bufo	americanus	American Toad	MOR	MOR	MORT	LC90		4	d	2.1		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Bufo	americanus	American Toad	MOR	MOR	MORT	NOAEL	LOAEL	4	d	1.12	2.11	ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Anaxyrus	boreas	Western Toad	MOR	MOR	MORT	LC10		4	d	1.7		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Anaxyrus	boreas	Western Toad	MOR	MOR	MORT	LC50		4	d	2		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Anaxyrus	boreas	Western Toad	MOR	MOR	MORT	LC90		4	d	2.4		ae mg/L	48.7	153679

Chemical	Genus	Species	Common Name								Conc 1	Conc 2	Unit		Ref
Glyphosate, Monopotassium salt	Anaxyrus	boreas	Western Toad	MOR	MOR	MORT	NOAEL	LOAEL	4	d	1.12	2.11	ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Hyla	versicolor	Gray Tree Frog	MOR	MOR	MORT	LC10		4	d	1.4		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Hyla	versicolor	Gray Tree Frog	MOR	MOR	MORT	LC50		4	d	1.7		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Hyla	versicolor	Gray Tree Frog	MOR	MOR	MORT	LC90		4	d	2		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Hyla	versicolor	Gray Tree Frog	MOR	MOR	MORT	NOAEL	LOAEL	4	d	1.12	2.11	ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Pseudacris	crucifer	Spring Peeper	MOR	MOR	MORT	LC10		4	d	0.1		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Pseudacris	crucifer	Spring Peeper	MOR	MOR	MORT	LC50		4	d	0.8		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Pseudacris	crucifer	Spring Peeper	MOR	MOR	MORT	LC90		4	d	1.6		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Pseudacris	crucifer	Spring Peeper	MOR	MOR	MORT	LOAEL		4	d	1.12		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Ambystoma	gracile	Northwestern Salamander	MOR	MOR	MORT	LC10		4	d	2.4		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Ambystoma	gracile	Northwestern Salamander	MOR	MOR	MORT	LC50		4	d	2.8		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Ambystoma	gracile	Northwestern Salamander	MOR	MOR	MORT	LC90		4	d	3.3		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Ambystoma	maculatum	Spotted Salamander	MOR	MOR	MORT	LC10		4	d	2.4		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Ambystoma	maculatum	Spotted Salamander	MOR	MOR	MORT	LC50		4	d	2.8		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Ambystoma	maculatum	Spotted Salamander	MOR	MOR	MORT	LC90		4	d	3.3		ae mg/L	48.7	153679

Chemical	Genus	Species	Common name				Endpoint		Dur	Unit	Val1	Val2	Units		ID
Glyphosate, Monopotassium salt	Ambystoma	laterale	Blue-spotted Salamander	MOR	MOR	MORT	LC10		4	d	2.7		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Ambystoma	laterale	Blue-spotted Salamander	MOR	MOR	MORT	LC50		4	d	3.2		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Ambystoma	laterale	Blue-spotted Salamander	MOR	MOR	MORT	LC90		4	d	3.7		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Notophthalmus	viridescens	Salamander	MOR	MOR	MORT	LC10		4	d	2.3		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Notophthalmus	viridescens	Salamander	MOR	MOR	MORT	LC50		4	d	2.7		ae mg/L	48.7	153679
Glyphosate, Monopotassium salt	Notophthalmus	viridescens	Salamander	MOR	MOR	MORT	LC90		4	d	3.1		ae mg/L	48.7	153679
Glyphosate isopropylamine salt	Rattus	norvegicus	Norway Rat	GRO	GRO	WGHT	NOAEL		30	d	250		mg/kg bdwt	100	155939
Glyphosate isopropylamine salt	Rattus	norvegicus	Norway Rat	GRO	MPH	SMIX	NOAEL	LOAEL	30	d	5	50	mg/kg bdwt	100	155939
Glyphosate isopropylamine salt	Rattus	norvegicus	Norway Rat	BCM	HRM	TSTR	LOAEL		30	d	5		mg/kg bdwt	100	155939
Glyphosate isopropylamine salt	Rattus	norvegicus	Norway Rat	CEL	CEL	HGHT	LOAEL		30	d	5		mg/kg bdwt	100	155939
Glyphosate isopropylamine salt	Rattus	norvegicus	Norway Rat	GRO	DVP	SXDP	NOAEL	LOAEL	30	d	5	50	mg/kg bdwt	100	155939
Glyphosate	NR	Fungi	Fungi Kingdom	PHY	PHY	RESP	LOAEL		214	d	1000		ppm	100	162021
Glyphosate	NR	Fungi	Fungi Kingdom	POP	POP	ABND	NOAEL		214	d	1000		ppm	100	162021
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	MOR	MOR	MORT	NR-ZERO		90	d	2.4		mg/L	48	161803
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	GRO	GRO	COND	NOAEL		90	d	2.4		mg/L	48	161803
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	GRO	GRO	LGTH	NOAEL		60	d	2.4		mg/L	48	161803
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	GRO	GRO	LGTH	LOAEL		90	d	2.4		mg/L	48	161803

Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	GRO	GRO	GAIN	LOAEL		30	d	0.48		mg/L	48	161803
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	GRO	GRO	GAIN	LOAEL		60	d	0.48		mg/L	48	161803
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	GLYC	LOAEL		90	d	0.48		mg/L	48	161803
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	GLUC	NOAEL	LOAEL	90	d	0.48	2.4	mg/L	48	161803
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	LACT	LOAEL		90	d	0.48		mg/L	48	161803
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	HMCT	LOAEL		90	d	0.48		mg/L	48	161803
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	HMGL	LOAEL		90	d	0.48		mg/L	48	161803
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	CEL	CEL	LEUK	NOAEL		90	d	2.4		mg/L	48	161803
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BEH	FDB	FCNS	NOAEL		90	d	2.4		mg/L	48	161803
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	GRO	GRO	LGTH	LOAEL		30	d	0.48		mg/L	48	161803
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	GRO	GRO	GAIN	LOAEL		90	d	0.48		mg/L	48	161803
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	ENZ	ACHE	NOAEL	LOAEL	90	d	0.48	2.4	mg/L	48	161803
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	PRTL	NOAEL	LOAEL	90	d	0.48	2.4	mg/L	48	161803
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	GLYC	NOAEL		90	d	2.4		mg/L	48	161803
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	GLUC	NOAEL		90	d	2.4		mg/L	48	161803

Glyphosate isopropylamine salt	Leporinu s	obtusidens	Characin	BCM	BCM	LACT	LOAEL		90	d	0.48		mg/L	48	161803
Glyphosate isopropylamine salt	Leporinu s	obtusidens	Characin	BCM	BCM	PRTL	LOAEL		90	d	0.48		mg/L	48	161803
Glyphosate isopropylamine salt	Leporinu s	obtusidens	Characin	BCM	BCM	PRTL	LOAEL		90	d	0.48		mg/L	48	161803
Glyphosate isopropylamine salt	Leporinu s	obtusidens	Characin	CEL	CEL	RBCE	LOAEL		90	d	0.48		mg/L	48	161803
Glyphosate	Danio	rerio	Zebra Danio	GRO	DVP	NORM	NOAEL		5	dpf	9.9		mg/L	99	161316
Glyphosate	Danio	rerio	Zebra Danio	GRO	GRO	LGTH	NOAEL		5	dpf	9.9		mg/L	99	161316
Glyphosate	Myrioph yllum	aquaticum	Parrot Feather Watermilfoil	BCM	BCM	CHLA	EC50		14	d	0.222		AI mg/L	35.6	150059
Glyphosate	Myrioph yllum	aquaticum	Parrot Feather Watermilfoil	BCM	BCM	CHLB	EC50		14	d	0.222		AI mg/L	35.6	150059
Glyphosate	Myrioph yllum	aquaticum	Parrot Feather Watermilfoil	BCM	BCM	CARC	EC50		14	d	0.222		AI mg/L	35.6	150059
Glyphosate	Myrioph yllum	aquaticum	Parrot Feather Watermilfoil	GRO	GRO	GRRT	EC50		14	d	0.221		AI mg/L	35.6	150059
Glyphosate	Myrioph yllum	aquaticum	Parrot Feather Watermilfoil	GRO	GRO	WGHT	EC50		14	d	1.999		AI mg/L	35.6	150059
Glyphosate	Myrioph yllum	aquaticum	Parrot Feather Watermilfoil	GRO	GRO	LGTH	EC50		14	d	2.04		AI mg/L	35.6	150059
Glyphosate	Myrioph yllum	aquaticum	Parrot Feather Watermilfoil	GRO	GRO	LGTH	EC50		14	d	1.998		AI mg/L	35.6	150059
Glyphosate	Chlorella	saccharophil a	Green Algae	POP	POP	PGRT	EC10		3	d	2.925		mg/L	97.5	150096
Glyphosate	Chlorella	saccharophil a	Green Algae	POP	POP	PGRT	NOAEL	LOAEL	3	d	0.38025	1.521	mg/L	97.5	150096
Glyphosate	Chlorella	saccharophil a	Green Algae	POP	POP	PGRT	EC50		3	d	39.585		mg/L	97.5	150096
Glyphosate	Chlorella	saccharophil a	Green Algae	POP	POP	PGRT	EC90		3	d	76.1475		mg/L	97.5	150096
Glyphosate	Chlorella	vulgaris	Green Algae	POP	POP	PGRT	LOAEL		3	d	0.0975		mg/L	97.5	150096
Glyphosate	Chlorella	vulgaris	Green Algae	POP	POP	ABND	LOAEL		3	d	0.0975		mg/L	97.5	150096
Glyphosate	Chlorella	vulgaris	Green Algae	POP	POP	PGRT	EC50		3	d	40.6575		mg/L	97.5	150096
Glyphosate	Chlorella	vulgaris	Green Algae	POP	POP	PGRT	EC90		3	d	84.7275		mg/L	97.5	150096
Glyphosate	Scenede smus	acutus	Green Algae	POP	POP	PGRT	LOAEL		3	d	0.0975		mg/L	97.5	150096

Glyphosate	Scenedesmus	acutus	Green Algae	POP	POP	ABND	LOAEL			3	d	0.0975		mg/L	97.5	150096
Glyphosate	Scenedesmus	acutus	Green Algae	POP	POP	PGRT	EC50			3	d	23.8875		mg/L	97.5	150096
Glyphosate	Scenedesmus	acutus	Green Algae	POP	POP	PGRT	EC90			3	d	52.26		mg/L	97.5	150096
Glyphosate	Scenedesmus	subspicatus	Green Algae	POP	POP	PGRT	NOAEL	LOAEL		3	d	0.0975	0.38025	mg/L	97.5	150096
Glyphosate	Scenedesmus	subspicatus	Green Algae	POP	POP	ABND	NOAEL	LOAEL		3	d	0.0975	0.38025	mg/L	97.5	150096
Glyphosate	Scenedesmus	subspicatus	Green Algae	POP	POP	PGRT	EC10			3	d	1.56		mg/L	97.5	150096
Glyphosate	Scenedesmus	subspicatus	Green Algae	POP	POP	PGRT	EC50			3	d	25.35		mg/L	97.5	150096
Glyphosate	Scenedesmus	subspicatus	Green Algae	POP	POP	PGRT	EC90			3	d	49.0425		mg/L	97.5	150096
Glyphosate	Bromus	tectorum	Downy Brome	POP	POP	CNTL	LOAEL				d	0.2676		lb/acre	100	159489
Glyphosate	Pascopyrum	smithii	Western Wheatgrass	POP	POP	BMAS	NOAEL			91.32	d	0.2676		lb/acre	100	159489
Glyphosate	Elymus	trachycaulus	Slender Wheatgrass	POP	POP	BMAS	NOAEL			91.32	d	0.2676		lb/acre	100	159489
Glyphosate	Leymus	triticoides	Beardless Wildrye	POP	POP	BMAS	NOAEL			91.32	d	0.2676		lb/acre	100	159489
Glyphosate	Elymus	lanceolatus	Streambank Wheatgrass	POP	POP	BMAS	LOAEL			91.32	d	0.2676		lb/acre	100	159489
Glyphosate	Bromus	biebersteinii	Meadow Brome	POP	POP	BMAS	LOAEL			91.32	d	0.2676		lb/acre	100	159489
Glyphosate	NR	Poaceae	Grass Family	POP	POP	BMAS	NOAEL			91.32	d	0.2676		lb/acre	100	159489
Glyphosate, Monopotassium salt	Hyla	versicolor	Gray Tree Frog	GRO	DVP	MMPH	NOAEL			42	go	572		ae ppb	48.8	153825
Glyphosate isopropylamine salt	Pseudacris	triseriata	Striped, Northern Chorus Frog	GRO	GRO	WGHT	NOAEL			29	d	572		ae ppb	48.7	153825
Glyphosate isopropylamine salt	Pseudacris	triseriata	Striped, Northern Chorus Frog	GRO	DVP	MMPH	NOAEL			29	d	572		ae ppb	48.7	153825
Glyphosate, Monopotassium salt	Hyla	versicolor	Gray Tree Frog	GRO	GRO	WGHT	NOAEL			42	go	572		ae ppb	48.8	153825
Glyphosate isopropylamine salt	Bufo	americanus	American Toad	GRO	GRO	WGHT	NOAEL			26.2	d	572		ae ppb	48.7	153825
Glyphosate, Monopotassium salt	Pseudacris	triseriata	Striped, Northern Chorus Frog	GRO	GRO	WGHT	NOAEL			32	d	572		ae ppb	48.8	153825

Chemical	Genus	Species	Common Name						Duration		Conc	Conc	Units		ID
Glyphosate isopropylamine salt	Hyla	versicolor	Gray Tree Frog	MOR	MOR	SURV	NOAEL		42	go	572		ae ppb	48.7	153825
Glyphosate, Monopotassium salt	Hyla	versicolor	Gray Tree Frog	MOR	MOR	SURV	NOAEL		42	go	572		ae ppb	48.8	153825
Glyphosate isopropylamine salt	Hyla	versicolor	Gray Tree Frog	GRO	GRO	WGHT	NOAEL		42	go	572		ae ppb	48.7	153825
Glyphosate, Monopotassium salt	Bufo	americanus	American Toad	GRO	GRO	WGHT	NOAEL		27.8	d	572		ae ppb	48.8	153825
Glyphosate isopropylamine salt	Pseudacris	triseriata	Striped, Northern Chorus Frog	MOR	MOR	SURV	NOAEL		42	go	572		ae ppb	48.7	153825
Glyphosate isopropylamine salt	Hyla	versicolor	Gray Tree Frog	GRO	DVP	MMPH	NOAEL		42	go	572		ae ppb	48.7	153825
Glyphosate, Monopotassium salt	Bufo	americanus	American Toad	GRO	DVP	MMPH	NOAEL	LOAEL		d	0.5	572	ae ppb	48.8	153825
Glyphosate, Monopotassium salt	Pseudacris	triseriata	Striped, Northern Chorus Frog	MOR	MOR	SURV	NOAEL	LOAEL	42	go	0.5	572	ae ppb	48.8	153825
Glyphosate, Monopotassium salt	Bufo	americanus	American Toad	MOR	MOR	SURV	NOAEL		42	go	572		ae ppb	48.8	153825
Glyphosate isopropylamine salt	Bufo	americanus	American Toad	GRO	DVP	MMPH	NOAEL	LOAEL		d	0.5	572	ae ppb	48.7	153825
Glyphosate, Monopotassium salt	Pseudacris	triseriata	Striped, Northern Chorus Frog	GRO	DVP	MMPH	NOAEL		32	d	572		ae ppb	48.8	153825
Glyphosate isopropylamine salt	Bufo	americanus	American Toad	MOR	MOR	SURV	NOAEL		42	go	572		ae ppb	48.7	153825
Glyphosate isopropylamine salt	Zizaniopsis	miliaceae	Giant Cutgrass	POP	POP	ABND	LOAEL		365	d	4.66		L/ha	100	161190
Glyphosate isopropylamine salt	Zizaniopsis	miliaceae	Giant Cutgrass	POP	POP	ABND	LOAEL		730	d	4.66		L/ha	100	161190
Glyphosate isopropylamine salt	Polygonum	hydropiperoides	Swamp Smartweed	POP	POP	ABND	NOAEL		365	d	4.66		L/ha	100	161190

Glyphosate isopropylamine salt	Polygonum	hydropiperoides	Swamp Smartweed	POP	POP	ABND	NOAEL		730	d	4.66		L/ha	100	161190
Glyphosate isopropylamine salt	Cyperus	sp.	Flatsedge	POP	POP	ABND	NOAEL		365	d	4.66		L/ha	100	161190
Glyphosate isopropylamine salt	Cyperus	sp.	Flatsedge	POP	POP	ABND	NOAEL		730	d	4.66		L/ha	100	161190
Glyphosate isopropylamine salt	Panicum	sp.	Panic Grass	POP	POP	ABND	LOAEL		365	d	4.66		L/ha	100	161190
Glyphosate isopropylamine salt	Panicum	sp.	Panic Grass	POP	POP	ABND	NOAEL		730	d	4.66		L/ha	100	161190
Glyphosate isopropylamine salt	Alternanthera	philoxeroides	Alligator-Weed	POP	POP	ABND	NOAEL		365	d	4.66		L/ha	100	161190
Glyphosate isopropylamine salt	Alternanthera	philoxeroides	Alligator-Weed	POP	POP	ABND	NOAEL		730	d	4.66		L/ha	100	161190
Glyphosate isopropylamine salt	Sesbania	herbacea	Colorado Riverhemp	POP	POP	ABND	NOAEL		365	d	4.66		L/ha	100	161190
Glyphosate isopropylamine salt	Sesbania	herbacea	Colorado Riverhemp	POP	POP	ABND	NOAEL		730	d	4.66		L/ha	100	161190
Glyphosate isopropylamine salt	Echinochloa	walteri	Coast Cockspur	POP	POP	ABND	NOAEL		730	d	4.66		L/ha	100	161190
Glyphosate isopropylamine salt	Eleocharis	parvula	Dwarf Spikesedge	POP	POP	ABND	NOAEL		730	d	4.66		L/ha	100	161190
Glyphosate isopropylamine salt	Sagittaria	latifolia	Arrowhead	POP	POP	ABND	NOAEL		365	d	4.66		L/ha	100	161190
Glyphosate isopropylamine salt	Sagittaria	latifolia	Arrowhead	POP	POP	ABND	NOAEL		730	d	4.66		L/ha	100	161190
Glyphosate isopropylamine salt	Luziola	fluitans	Southern Watergrass	POP	POP	ABND	NOAEL		365	d	4.66		L/ha	100	161190
Glyphosate isopropylamine salt	Luziola	fluitans	Southern Watergrass	POP	POP	ABND	NOAEL		730	d	4.66		L/ha	100	161190

Chemical	Genus	Species	Common	Grp1	Grp2	Endpoint	Level1	Level2	Dur	Unit	Value1	Value2	Units	%	ID
Glyphosate isopropylamine salt	Rhopalosiphum	padi	Aphid	MOR	MOR	MORT	NOAEL		0.7083	d	800		AI g/ha	100	150565
Glyphosate	Chlamydomonas	eugametos	Green Algae	POP	POP	ABND	NOAEL	LOAEL	2	d	0.0001	0.001	M	100	6513
Glyphosate	Lithobates	pipiens	Leopard Frog	GRO	DVP	MMPH	NOAEL			d	0.0069		mg/L	98	114296
Glyphosate	Hyla	versicolor	Gray Tree Frog	GRO	DVP	WGHT	NOAEL		26	d	0.0069		mg/L	98	114296
Glyphosate	Lithobates	pipiens	Leopard Frog	MOR	MOR	SURV	NOAEL			d	0.0069		mg/L	98	114296
Glyphosate	NR	Plantae	Plant Kingdom	POP	POP	CHLA	NOAEL		16	d	0.0069		mg/L	98	114296
Glyphosate	Leptodiaptomus	minutus	Copepod	POP	POP	ABND	NOAEL			d	0.0069		mg/L	98	114296
Glyphosate	Hyla	versicolor	Gray Tree Frog	GRO	DVP	MMPH	NOAEL		26	d	0.0069		mg/L	98	114296
Glyphosate	Hyla	versicolor	Gray Tree Frog	MOR	MOR	SURV	NOAEL		26	d	0.0069		mg/L	98	114296
Glyphosate	NR	Plantae	Plant Kingdom	POP	POP	CHLA	NOAEL		35	d	0.0069		mg/L	98	114296
Glyphosate	Ceriodaphnia	sp.	Water Flea	POP	POP	ABND	NOAEL			d	0.0069		mg/L	98	114296
Glyphosate	NR	Plantae	Plant Kingdom	POP	POP	BMAS	NOAEL		36	d	0.0069		mg/L	98	114296
Glyphosate	NR	Plantae	Plant Kingdom	POP	POP	BMAS	NOAEL		25	d	0.0069		mg/L	98	114296
Glyphosate	Skistodiaptomus	oregonensis	Calanoid Copepod	POP	POP	ABND	NOAEL			d	0.0069		mg/L	98	114296
Glyphosate	Lithobates	pipiens	Leopard Frog	GRO	DVP	WGHT	NOAEL			d	0.0069		mg/L	98	114296
Glyphosate	Daphnia	pulex	Water Flea	POP	POP	ABND	NOAEL			d	0.0069		mg/L	98	114296
AMPA	Glomus	intraradices	Mycorrhizal Fungi	REP	REP	SEPD	IC50		14	d	5.335		ppm	97	55367
AMPA	Glomus	intraradices	Mycorrhizal Fungi	GRO	GRO	LGTH	IC50		14	d	4.947		ppm	97	55367
Glyphosate	Glomus	intraradices	Mycorrhizal Fungi	REP	REP	SEPD	IC50		14	d	0.3996		ppm	99.9	55367
Glyphosate	Glomus	intraradices	Mycorrhizal Fungi	GRO	GRO	LGTH	IC50		14	d	0.4995		ppm	99.9	55367
Glyphosate	Kochia	scoparia	Kochia	GRO	GRO	WGHT	LOAEL		28	d	0.74928		lb/acre	100	116117
Glyphosate	Kochia	scoparia	Kochia	GRO	GRO	WGHT	LOAEL		28	d	0.74928		lb/acre	100	116117
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	ENZ	ACHE	LOAEL		4	d	0.096		mg/L	48	111451
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	BCM	TBAR	LOAEL		4	d	0.096		mg/L	48	111451
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	BCM	TBAR	NOAEL		4	d	0.192		mg/L	48	111451

Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	BCM	TBAR	LOAEL		4	d	0.096		mg/L	48	111451
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	BCM	GLUC	LOAEL		4	d	0.096		mg/L	48	111451
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	BCM	GLYC	LOAEL		4	d	0.096		mg/L	48	111451
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	BCM	LACT	LOAEL		4	d	0.096		mg/L	48	111451
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	BCM	PRCO	LOAEL		4	d	0.096		mg/L	48	111451
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	BCM	AMMO	LOAEL		4	d	0.096		mg/L	48	111451
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	BCM	GLUC	LOAEL		4	d	0.096		mg/L	48	111451
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	BCM	GLYC	LOAEL		4	d	0.096		mg/L	48	111451
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	BCM	LACT	LOAEL		4	d	0.096		mg/L	48	111451
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	BCM	PRCO	LOAEL		4	d	0.096		mg/L	48	111451
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	BCM	AMMO	LOAEL		4	d	0.096		mg/L	48	111451
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	ENZ	ACHE	NOAEL		4	d	0.192		mg/L	48	111451
Glyphosate isopropylamine salt	Piaractus	brachypomus	Pirapatinga	MOR	MOR	MORT	LC50		4	d	46.7856		mg/L	48	120635
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	MOR	MOR	MORT	LC50		4	d	7.3		mg/L	100	111938
Glyphosate isopropylamine salt	Prosopis	glandulosa var. glandulosa	Honey Mesquite	MOR	MOR	MORT	LOAEL		2	gs	30		ae g/L	100	44096

Glyphosate isopropylamine salt	Prosopis	glandulosa var. glandulosa	Honey Mesquite	MOR	MOR	MORT	NOAEL		2	gs	30		ae g/L	100	44096
Glyphosate isopropylamine salt	Prosopis	glandulosa var. glandulosa	Honey Mesquite	MOR	MOR	MORT	LOAEL		2	gs	120		ae g/L	100	44096
Glyphosate isopropylamine salt	Prosopis	glandulosa var. glandulosa	Honey Mesquite	POP	POP	COVR	LOAEL		1	gs	30		ae g/L	100	44096
Glyphosate isopropylamine salt	Prosopis	glandulosa var. glandulosa	Honey Mesquite	MOR	MOR	MORT	LOAEL		1	gs	30		ae g/L	100	44096
Glyphosate isopropylamine salt	Prosopis	glandulosa var. glandulosa	Honey Mesquite	MOR	MOR	MORT	LOAEL		1	gs	120		ae g/L	100	44096
Glyphosate isopropylamine salt	Prosopis	glandulosa var. glandulosa	Honey Mesquite	MOR	MOR	MORT	NOAEL		1	gs	30		ae g/L	100	44096
Glyphosate isopropylamine salt	Prosopis	glandulosa var. glandulosa	Honey Mesquite	POP	POP	COVR	LOAEL		1	gs	30		ae g/L	100	44096
Glyphosate isopropylamine salt	Prosopis	glandulosa var. glandulosa	Honey Mesquite	POP	POP	COVR	LOAEL		2	gs	30		ae g/L	100	44096
Glyphosate isopropylamine salt	Prosopis	glandulosa var. glandulosa	Honey Mesquite	MOR	MOR	MORT	LOAEL		2	gs	120		ae g/L	100	44096
Glyphosate isopropylamine salt	Prosopis	glandulosa var. glandulosa	Honey Mesquite	MOR	MOR	MORT	NOAEL		2	gs	30		ae g/L	100	44096
Glyphosate isopropylamine salt	Prosopis	glandulosa var. glandulosa	Honey Mesquite	MOR	MOR	MORT	NOAEL		2	gs	120		ae g/L	100	44096
Glyphosate isopropylamine salt	Prosopis	glandulosa var. glandulosa	Honey Mesquite	POP	POP	COVR	LOAEL		2	gs	30		ae g/L	100	44096
Glyphosate isopropylamine salt	Prosopis	glandulosa var. glandulosa	Honey Mesquite	POP	POP	COVR	LOAEL		1	gs	30		ae g/L	100	44096
Glyphosate isopropylamine salt	Prosopis	glandulosa var. glandulosa	Honey Mesquite	MOR	MOR	MORT	LOAEL		1	gs	30		ae g/L	100	44096
Glyphosate isopropylamine salt	Prosopis	glandulosa var. glandulosa	Honey Mesquite	MOR	MOR	MORT	NOAEL		1	gs	30		ae g/L	100	44096

Glyphosate isopropylamine salt	Prosopis	glandulosa var. glandulosa	Honey Mesquite	MOR	MOR	MORT	LOAEL		1	gs	120		ae g/L	100	44096
Glyphosate isopropylamine salt	Prosopis	glandulosa var. glandulosa	Honey Mesquite	POP	POP	COVR	LOAEL		1	gs	30		ae g/L	100	44096
Glyphosate isopropylamine salt	Prosopis	glandulosa var. glandulosa	Honey Mesquite	POP	POP	COVR	LOAEL		2	gs	30		ae g/L	100	44096
Glyphosate isopropylamine salt	Prosopis	glandulosa var. glandulosa	Honey Mesquite	MOR	MOR	MORT	LOAEL		2	gs	30		ae g/L	100	44096
Glyphosate isopropylamine salt	Prosopis	glandulosa var. glandulosa	Honey Mesquite	MOR	MOR	MORT	LOAEL		2	gs	120		ae g/L	100	44096
Glyphosate isopropylamine salt	Prosopis	glandulosa var. glandulosa	Honey Mesquite	MOR	MOR	MORT	NOAEL		2	gs	30		ae g/L	100	44096
Glyphosate isopropylamine salt	Prosopis	glandulosa var. glandulosa	Honey Mesquite	POP	POP	COVR	LOAEL		2	gs	30		ae g/L	100	44096
Glyphosate	Glycine	max	Soybean	POP	POP	ABND	NOAEL			hv	3.0328		lb/acre	100	116445
Glyphosate	Sorghum	bicolor	Broomcorn	POP	POP	ABND	NOAEL			hv	3.0328		lb/acre	100	116445
Glyphosate	Brunnichia	ovata	Buckwheat Vine	POP	POP	ABND	LOAEL		304.4	d	3.0328		lb/acre	100	116445
Glyphosate isopropylamine salt	Pomacea	lineata	Golden Apple Snail	GRO	GRO	GAIN	NOEC		8	d	0.12		mg/L	100	107038
Glyphosate isopropylamine salt	Pomacea	lineata	Golden Apple Snail	GRO	GRO	GAIN	NOEC	LOEC	4	d	0.25	0.5	mg/L	100	107038
Glyphosate isopropylamine salt	Pomacea	lineata	Golden Apple Snail	GRO	GRO	GAIN	NOEC	LOEC	4	d	2.4	4.8	mg/L	100	107038
Glyphosate isopropylamine salt	Lumbriculus	variegatus	Oligochaete, Worm	BCM	ENZ	GSTR	LOAEL		4	d	0.05		mg/L	100	115572
Glyphosate isopropylamine salt	Lumbriculus	variegatus	Oligochaete, Worm	BCM	ENZ	GSTR	NOAEL		4	d	5		mg/L	100	115572
Glyphosate isopropylamine salt	Lumbriculus	variegatus	Oligochaete, Worm	BCM	ENZ	CTLS	NOAEL		4	d	5		mg/L	100	115572
Glyphosate isopropylamine salt	Lumbriculus	variegatus	Oligochaete, Worm	BCM	ENZ	SODA	NOAEL	LOAEL	4	d	0.05	0.1	mg/L	100	115572

Chemical	Genus	Species	Common	C1	C2	C3	Effect	Effect2	Val	Dur	Unit	Conc1	Conc2	Units	Purity	Ref
Glyphosate isopropylamine salt	Lumbric ulus	variegatus	Oligochaete, Worm	ACC	ACC	RSDE	BCF			4	d	0.05		mg/L	100	115572
Glyphosate isopropylamine salt	Lumbric ulus	variegatus	Oligochaete, Worm	ACC	ACC	RSDE	BCF			4	d	0.1		mg/L	100	115572
Glyphosate isopropylamine salt	Lumbric ulus	variegatus	Oligochaete, Worm	ACC	ACC	RSDE	BCF			4	d	0.5		mg/L	100	115572
Glyphosate isopropylamine salt	Lumbric ulus	variegatus	Oligochaete, Worm	ACC	ACC	RSDE	BCF			4	d	1		mg/L	100	115572
Glyphosate isopropylamine salt	Lumbric ulus	variegatus	Oligochaete, Worm	ACC	ACC	RSDE	BCF			4	d	5		mg/L	100	115572
Glyphosate	Lumbric ulus	variegatus	Oligochaete, Worm	ACC	ACC	RSDE	BCF			4	d	1		mg/L	98	115572
Glyphosate	Lumbric ulus	variegatus	Oligochaete, Worm	ACC	ACC	RSDE	BCF			4	d	5		mg/L	98	115572
Glyphosate	Lumbric ulus	variegatus	Oligochaete, Worm	ACC	ACC	RSDE	BCF			4	d	0.05		mg/L	98	115572
Glyphosate	Lumbric ulus	variegatus	Oligochaete, Worm	ACC	ACC	RSDE	BCF			4	d	0.1		mg/L	98	115572
Glyphosate	Lumbric ulus	variegatus	Oligochaete, Worm	ACC	ACC	RSDE	BCF			4	d	0.5		mg/L	98	115572
Glyphosate isopropylamine salt	Thalassio sira	weissflogii	Diatom	POP	POP	PGRT	NOAEL			2	d	1.96		mg/L	>=98	105925
Glyphosate	Oncorhy nchus	kisutch	Silver Salmon	PHY	PHY	EPYR	NOAEL	LOAEL	0.0139	d		0.099	0.99	mg/L	99	89637
Glyphosate	Oncorhy nchus	kisutch	Silver Salmon	PHY	PHY	EPYR	NOAEL	LOAEL	0.0174	d		0.099	0.99	mg/L	99	89637
Glyphosate	Oncorhy nchus	kisutch	Silver Salmon	PHY	PHY	EPYR	NOAEL	LOAEL	0.0014	d		9.9	99	mg/L	99	89637
Glyphosate	Oncorhy nchus	kisutch	Silver Salmon	PHY	PHY	EPYR	NOAEL	LOAEL	0.0035	d		0.99	9.9	mg/L	99	89637
Glyphosate	Oncorhy nchus	kisutch	Silver Salmon	PHY	PHY	EPYR	NOAEL	LOAEL	0.0069	d		0.099	0.99	mg/L	99	89637
Glyphosate	Oncorhy nchus	kisutch	Silver Salmon	PHY	PHY	EPYR	NOAEL	LOAEL	0.0104	d		0.099	0.99	mg/L	99	89637
Glyphosate	Oncorhy nchus	kisutch	Silver Salmon	PHY	PHY	EPYR	NOAEL	LOAEL	0.0208	d		0.099	0.99	mg/L	99	89637
Glyphosate isopropylamine salt	Lithobat es	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	NOAEL			4	d	0.03		ae mg/L	100	72797

Glyphosate isopropylamine salt	Lithobat es	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	NOAEL		4	d	0.18		ae mg/L	100	72797
Glyphosate isopropylamine salt	Lithobat es	pipiens	Leopard Frog	MOR	MOR	MORT	NOAEL		4	d	0.18		ae mg/L	100	72797
Glyphosate isopropylamine salt	Lithobat es	pipiens	Leopard Frog	MOR	MOR	MORT	NOAEL		4	d	0.03		ae mg/L	100	72797
Glyphosate	Prosopis	farcta	Syrian Mesquite	POP	POP	BMAS	LOAEL		19	d	3.84		AI l/ha	100	99679
Glyphosate	Prosopis	farcta	Syrian Mesquite	POP	POP	BMAS	LOAEL		72	d	3.84		AI l/ha	100	99679
Glyphosate	Rubus	fruticosus	Bramble Blackberry	REP	REP	VEGR	LOAEL			d	3.8356		lb/acre	100	116507
Glyphosate	Rubus	fruticosus	Bramble Blackberry	REP	REP	VEGR	LOAEL			d	3.8356		lb/acre	100	116507
Glyphosate	Rubus	fruticosus	Bramble Blackberry	POP	POP	ABND	LOAEL			d	3.8356		lb/acre	100	116507
Glyphosate	Rubus	fruticosus	Bramble Blackberry	POP	POP	ABND	LOAEL			d	3.8356		lb/acre	100	116507
Glyphosate	Xanthos oma	sagittifolium	Cocoyam	POP	POP	BMAS	LOAEL		370	d	2.34		L/ha	100	116434
Glyphosate	Phragmit es	australis	Grass	POP	POP	WGHT	LOAEL		30.44	d	1.99808		lb/acre	100	110337
Glyphosate	Phragmit es	australis	Grass	POP	POP	WGHT	LOAEL		30.44	d	1.99808		lb/acre	100	110337
Glyphosate	Steinern ema	feltiae	Nematode	REP	REP	PROG	NOAEL		10	d	21600		ppm	100	109598
Glyphosate	Steinern ema	feltiae	Nematode	BEH	FDB	PRBE	NOAEL			d	21600		ppm	100	109598
Glyphosate	Steinern ema	feltiae	Nematode	REP	REP	PROG	NOAEL		10	d	21600		ppm	100	109598
Glyphosate	Steinern ema	feltiae	Nematode	BEH	FDB	PRBE	NOAEL		5	d	21600		ppm	100	109598
Glyphosate	Pinus	taeda	Loblolly Pine	BCM	BCM	MGCO	LOAEL		1	gs	4.46		lb/acre	100	120301
Glyphosate	Pinus	taeda	Loblolly Pine	GRO	GRO	HGHT	NOAEL		2	gs	4.46		lb/acre	100	120301
Glyphosate	NR	Plantae	Plant Kingdom	POP	POP	ABND	LOAEL		1	gs	4.46		lb/acre	100	120301
Glyphosate	Rhyacion ia	frustrana	Nantucket Pinetip Moth	GRO	GRO	WGHT	LOAEL		730	d	5		AI kg/ha	100	120301
Glyphosate	Rhyacion ia	frustrana	Nantucket Pinetip Moth	POP	POP	ABND	LOAEL		730	d	5		AI kg/ha	100	120301
Glyphosate isopropylamine salt	Cornus	canadensis	Bunchberry Dogwood	POP	POP	COVR	NOAEL		3650	d	2.676		lb/acre	100	118733

Glyphosate isopropylamine salt	Picea	glauca	White Spruce	GRO	GRO	HGHT	NOAEL		3650	d	2.676		lb/acre	100	118733
Glyphosate isopropylamine salt	NR	Plantae	Plant Kingdom	POP	POP	DVRS	LOAEL		3650	d	2.676		lb/acre	100	118733
Glyphosate isopropylamine salt	Alnus	viridis	Green Alder	POP	POP	COVR	NOAEL		3650	d	2.676		lb/acre	100	118733
Glyphosate isopropylamine salt	Betula	papyrifera	Paper Birch	POP	POP	COVR	NOAEL		3650	d	2.676		lb/acre	100	118733
Glyphosate isopropylamine salt	Calamagrostis	canadensis	Bluejoint Reedgrass	POP	POP	COVR	NOAEL		3650	d	2.676		lb/acre	100	118733
Glyphosate isopropylamine salt	Chamerion	angustifolium ssp. angustifolium	Fireweed	POP	POP	COVR	NOAEL		3650	d	2.676		lb/acre	100	118733
Glyphosate isopropylamine salt	Equisetum	arvense	Field Horsetail	POP	POP	COVR	NOAEL		3650	d	2.676		lb/acre	100	118733
Glyphosate isopropylamine salt	Equisetum	sylvaticum	Woodland Horsetail	POP	POP	COVR	NOAEL		3650	d	2.676		lb/acre	100	118733
Glyphosate isopropylamine salt	Heracleum	sphondylium ssp. montanum	Common Cowparsnip	POP	POP	COVR	NOAEL		3650	d	2.676		lb/acre	100	118733
Glyphosate isopropylamine salt	Lonicera	involucrata	Bearberry Honeysuckle	POP	POP	COVR	NOAEL		3650	d	2.676		lb/acre	100	118733
Glyphosate isopropylamine salt	Picea	glauca	White Spruce	POP	POP	COVR	NOAEL		3650	d	2.676		lb/acre	100	118733
Glyphosate isopropylamine salt	Populus	balsamifera	Balsam Poplar	POP	POP	COVR	LOAEL		3650	d	2.676		lb/acre	100	118733
Glyphosate isopropylamine salt	Rosa	acicularis	Prickly Rose	POP	POP	COVR	NOAEL		3650	d	2.676		lb/acre	100	118733
Glyphosate isopropylamine salt	Rubus	idaeus	European Red Raspberry	POP	POP	COVR	NOAEL		3650	d	2.676		lb/acre	100	118733
Glyphosate isopropylamine salt	Rubus	pubescens	Dwarf Red Raspberry	POP	POP	COVR	NOAEL		3650	d	2.676		lb/acre	100	118733

Glyphosate isopropylamine salt	Salix	sp.	Willow Species	POP	POP	COVR	NOAEL		3650	d		2.676		lb/acre	100	118733
Glyphosate isopropylamine salt	Viburnum	edule	Squashberry	POP	POP	COVR	NOAEL		3650	d		2.676		lb/acre	100	118733
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	HRM	CRTS	LOAEL		4	d		1.2		mg/L	100	112293
Glyphosate isopropylamine salt	Sclerotinia	sclerotiorum	Fungus	POP	POP	ABND	NOAEL		26	d		840		ae g/ha	100	70920
Glyphosate isopropylamine salt	Glycine	max	Soybean	BCM	BCM	PYAX	NOAEL		26	d		840		ae g/ha	100	70920
Glyphosate isopropylamine salt	Glycine	max	Soybean	POP	POP	BMAS	NOAEL			hv		840		ae g/ha	100	70920
Glyphosate isopropylamine salt	Glycine	max	Soybean	POP	POP	BMAS	NOAEL			hv		840		ae g/ha	100	70920
Glyphosate isopropylamine salt	Glycine	max	Soybean	POP	POP	BMAS	NOAEL			hv		840		ae g/ha	100	70920
Glyphosate isopropylamine salt	Glycine	max	Soybean	POP	POP	BMAS	NOAEL			hv		840		ae g/ha	100	70920
Glyphosate isopropylamine salt	Glycine	max	Soybean	POP	POP	BMAS	NOAEL			hv		840		ae g/ha	100	70920
Glyphosate isopropylamine salt	Glycine	max	Soybean	PHY	INJ	SYMP	NOAEL		7	d		840		ae g/ha	100	70920
Glyphosate isopropylamine salt	Glycine	max	Soybean	PHY	INJ	SYMP	NOAEL		7	d		840		ae g/ha	100	70920
Glyphosate isopropylamine salt	Glycine	max	Soybean	PHY	INJ	SYMP	NOAEL		7	d		840		ae g/ha	100	70920
Glyphosate isopropylamine salt	Sclerotinia	sclerotiorum	Fungus	POP	POP	ABND	NOAEL			hv		840		ae g/ha	100	70920
Glyphosate isopropylamine salt	Sclerotinia	sclerotiorum	Fungus	POP	POP	ABND	NOAEL			hv		840		ae g/ha	100	70920

Chemical	Genus	Species	Common Name										Units		
Glyphosate isopropylamine salt	Sclerotinia	sclerotiorum	Fungus	POP	POP	ABND	LOAEL			hv	840		ae g/ha	100	70920
Glyphosate isopropylamine salt	Sclerotinia	sclerotiorum	Fungus	POP	POP	ABND	NOAEL			hv	840		ae g/ha	100	70920
Glyphosate isopropylamine salt	Peromyscus	maniculatus	Deer Mouse	MOR	MOR	LFSP	NOAEL		1217.6	d	3		AI kg/ha	100	69229
Glyphosate isopropylamine salt	Peromyscus	maniculatus	Deer Mouse	REP	REP	RPRD	NOAEL		1217.6	d	3		AI kg/ha	100	69229
Glyphosate isopropylamine salt	Peromyscus	maniculatus	Deer Mouse	REP	REP	RPRD	NOAEL		1217.6	d	3		AI kg/ha	100	69229
Glyphosate isopropylamine salt	Microtus	oregoni	Creeping Vole	REP	REP	RPRD	NOAEL		1217.6	d	3		AI kg/ha	100	69229
Glyphosate isopropylamine salt	Peromyscus	maniculatus	Deer Mouse	REP	REP	RPRD	NOAEL		365	d	3		AI kg/ha	100	69229
Glyphosate isopropylamine salt	Peromyscus	maniculatus	Deer Mouse	REP	REP	RPRD	NOAEL		365	d	3		AI kg/ha	100	69229
Glyphosate isopropylamine salt	Microtus	oregoni	Creeping Vole	MOR	MOR	LFSP	LOAEL		365.28	d	3		AI kg/ha	100	69229
Glyphosate isopropylamine salt	Microtus	oregoni	Creeping Vole	REP	REP	RPRD	NOAEL		1217.6	d	3		AI kg/ha	100	69229
Glyphosate isopropylamine salt	Carassius	auratus	Goldfish	CEL	GEN	NABN	NOAEL	LOAEL	2	d	5	10	mg/L	100	97710
Glyphosate isopropylamine salt	Carassius	auratus	Goldfish	CEL	GEN	MNUC	NOAEL	LOAEL	2	d	10	15	mg/L	100	97710
Glyphosate isopropylamine salt	Carassius	auratus	Goldfish	CEL	GEN	NABN	NOAEL	LOAEL	4	d	5	10	mg/L	100	97710
Glyphosate isopropylamine salt	Carassius	auratus	Goldfish	CEL	GEN	DAMG	LOAEL		2	d	5		mg/L	100	97710
Glyphosate isopropylamine salt	Carassius	auratus	Goldfish	CEL	GEN	NABN	LOAEL		6	d	5		mg/L	100	97710

Glyphosate isopropylamine salt	Carassius	auratus	Goldfish	CEL	GEN	MNUC	LOAEL		6	d	5		mg/L	100	97710
Glyphosate isopropylamine salt	Carassius	auratus	Goldfish	CEL	GEN	DAMG	LOAEL		6	d	5		mg/L	100	97710
Glyphosate isopropylamine salt	Carassius	auratus	Goldfish	CEL	GEN	DAMG	LOAEL		4	d	5		mg/L	100	97710
Glyphosate	Algae	NR	Algae	POP	POP	PSYN	NOAEL		0.1667	d	10		uM	100	109342
Glyphosate	Algae	NR	Algae	POP	POP	PSYN	NOAEL		0.1667	d	10		uM	100	109342
Glyphosate	Algae	NR	Algae	POP	POP	PSYN	NOAEL		0.1667	d	10		uM	100	109342
Glyphosate	Zostera	marina	Eelgrass	GRO	GRO	RLGR	NOAEL		3	d	100		uM	100	109342
Glyphosate	Zostera	marina	Eelgrass	BCM	BCM	CHAB	NOAEL		3	d	100		uM	100	109342
Glyphosate	Algae	NR	Algae	POP	POP	PSYN	NOAEL		0.1667	d	10		uM	100	109342
Glyphosate	Algae	NR	Algae	POP	POP	PSYN	NOAEL		0.1667	d	10		uM	100	109342
Glyphosate	Algae	NR	Algae	POP	POP	PSYN	NOAEL		0.1667	d	10		uM	100	109342
Glyphosate	Cassinia	arcuata	Drooping Cassinia	MOR	MOR	MORT	LOAEL		111	d	0.4014		lb/acre	100	70755
Glyphosate	Cassinia	arcuata	Drooping Cassinia	MOR	MOR	MORT	NR-LETH		111	d	0.4014		lb/acre	100	70755
Glyphosate	Cassinia	arcuata	Drooping Cassinia	MOR	MOR	MORT	LOAEL		111	d	0.4014		lb/acre	100	70755
Glyphosate	Cassinia	arcuata	Drooping Cassinia	MOR	MOR	MORT	NR-LETH		111	d	0.8028		lb/acre	100	70755
Glyphosate	Cassinia	arcuata	Drooping Cassinia	MOR	MOR	MORT	LOAEL		111	d	0.4014		lb/acre	100	70755
Glyphosate	Cassinia	arcuata	Drooping Cassinia	MOR	MOR	MORT	NR-LETH		111	d	0.4014		lb/acre	100	70755
Glyphosate	Aphis	fabae	Black Bean Aphid	BEH	AVO	CHEM	LOAEL		0.0104	d	1.5		mM	100	118858
Glyphosate	Aphis	fabae	Black Bean Aphid	POP	POP	ABND	LOAEL		8	d	0.015		mM	100	118858
Glyphosate	Vicia	faba	Broadbean	GRO	GRO	HGHT	NOAEL	LOAEL	8	d	15	150	mM	100	118858
Glyphosate	Aphis	fabae	Black Bean Aphid	POP	POP	ABND	NOAEL	LOAEL	8	d	15	150	mM	100	118858
Glyphosate	Vicia	faba	Broadbean	GRO	GRO	HGHT	NOAEL		8	d	150		mM	100	118858
Glyphosate	Vicia	faba	Broadbean	GRO	GRO	HGHT	NOAEL	LOAEL	8	d	15	150	mM	100	118858
Glyphosate	Aphis	fabae	Black Bean Aphid	POP	POP	ABND	LOAEL		2	d	1.5		mM	100	118858
Glyphosate	Vicia	faba	Broadbean	GRO	GRO	HGHT	LOAEL		8	d	0.015		mM	100	118858
Glyphosate	Poa	annua	Annual Bluegrass	POP	POP	CNTL	LOAEL		7	d	0.2676		lb/acre	100	121125
Glyphosate isopropylamine salt	Tetrahymena	pyriformis	Ciliate	BEH	AVO	STIM	EC50		0.2083	d	0.83712		mg/L	0.96	60864

Glyphosate isopropylamine salt	Aphytis	melinus	Red Scale Parasite	MOR	MOR	MORT	NR-ZERO		0.3333	d	0.48		%	48	90421
Glyphosate isopropylamine salt	Aphytis	lignanensis	Parasitic Wasp	MOR	MOR	MORT	NR-ZERO		0.3333	d	0.48		%	48	90421
Glyphosate isopropylamine salt	Aphytis	melinus	Red Scale Parasite	MOR	MOR	MORT	NR-ZERO		0.3333	d	0.48		%	48	90421
Glyphosate isopropylamine salt	Aphytis	lignanensis	Parasitic Wasp	MOR	MOR	MORT	NR-ZERO		0.3333	d	0.48		%	48	90421
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	ENZ	ACHE	NOAEL		4	d	9.6		mg/L	48	108093
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	GLYC	LOAEL		4	d	1.44		mg/L	48	108093
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	AMMO	LOAEL		4	d	1.44		mg/L	48	108093
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	AMMO	LOAEL		4	d	1.44		mg/L	48	108093
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	ENZ	ACHE	LOAEL		4	d	1.44		mg/L	48	108093
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	LACT	LOAEL		4	d	1.44		mg/L	48	108093
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	GLYC	LOAEL		4	d	1.44		mg/L	48	108093
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	PRCO	LOAEL		4	d	1.44		mg/L	48	108093
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	PRCO	LOAEL		4	d	1.44		mg/L	48	108093
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	GLUC	LOAEL		4	d	1.44		mg/L	48	108093
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	GLUC	LOAEL		4	d	1.44		mg/L	48	108093

Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	HMCT	LOAEL		4	d	1.44		mg/L	48	108093
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	PRCO	LOAEL		4	d	1.44		mg/L	48	108093
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	HMGL	LOAEL		4	d	1.44		mg/L	48	108093
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	CEL	CEL	RBCE	LOAEL		4	d	1.44		mg/L	48	108093
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	CEL	CEL	LEUK	NOAEL		4	d	9.6		mg/L	48	108093
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	LACT	LOAEL		4	d	1.44		mg/L	48	108093
Glyphosate	Lemna	minor	Duckweed	PHY	PHY	PERM	LOAEL		1	d	1.69		mg/L	100	6963
Glyphosate	Lemna	minor	Duckweed	PHY	PHY	PERM	LOAEL		2	d	1.69		mg/L	100	6963
Glyphosate	Lemna	minor	Duckweed	PHY	PHY	PERM	NOAEL	LOAEL	3	d	1.69	16.9	mg/L	100	6963
Glyphosate	Lemna	minor	Duckweed	PHY	PHY	PERM	LOAEL		4	d	1.69		mg/L	100	6963
Glyphosate	Lemna	minor	Duckweed	PHY	PHY	PERM	NOAEL		0.5	d	16.9		mg/L	100	6963
Glyphosate isopropylamine salt	NR	Fungi	Fungi Kingdom	POP	POP	ABND	NOAEL		3	d	3600		ppm	100	71212
Glyphosate isopropylamine salt	NR	Fungi	Fungi Kingdom	POP	POP	ABND	NOAEL		7	d	3600		ppm	100	71212
Glyphosate isopropylamine salt	Picea	glauca	White Spruce	MOR	MOR	MORT	NR-ZERO		182.64	d	10		AI ul/L	35.9	92279
Glyphosate isopropylamine salt	Picea	glauca	White Spruce	MOR	MOR	MORT	NR-LETH		182.64	d	100		AI ul/L	35.9	92279
Glyphosate isopropylamine salt	Picea	glauca	White Spruce	GRO	GRO	HGHT	LOAEL		182.64	d	1		AI ul/L	35.9	92279
Glyphosate isopropylamine salt	Picea	glauca	White Spruce	GRO	GRO	HGHT	NOAEL		182.64	d	0.1		AI ul/L	35.9	92279
Glyphosate isopropylamine salt	Picea	glauca	White Spruce	GRO	GRO	LGTH	NOAEL		182.64	d	1		AI ul/L	35.9	92279
Glyphosate isopropylamine salt	Picea	glauca	White Spruce	GRO	GRO	LGTH	LOAEL		182.64	d	10		AI ul/L	35.9	92279

Glyphosate isopropylamine salt	Picea	glauca	White Spruce	GRO	GRO	WGHT	NOAEL		182.64	d		1		AI ul/L	35.9	92279
Glyphosate isopropylamine salt	Picea	glauca	White Spruce	GRO	GRO	WGHT	LOAEL		182.64	d		10		AI ul/L	35.9	92279
Glyphosate isopropylamine salt	Picea	glauca	White Spruce	GRO	GRO	NROT	NOAEL		182.64	d		0.1		AI ul/L	35.9	92279
Glyphosate isopropylamine salt	Picea	glauca	White Spruce	GRO	GRO	NROT	LOAEL		182.64	d		1		AI ul/L	35.9	92279
Glyphosate isopropylamine salt	Pinus	contorta var. latifolia	Lodgepole Pine	MOR	MOR	MORT	NR-ZERO		182.64	d		10		AI ul/L	35.9	92279
Glyphosate isopropylamine salt	Pinus	contorta var. latifolia	Lodgepole Pine	MOR	MOR	MORT	NR-LETH		182.64	d		50		AI ul/L	35.9	92279
Glyphosate isopropylamine salt	Pinus	contorta var. latifolia	Lodgepole Pine	GRO	GRO	HGHT	LOAEL		182.64	d		0.1		AI ul/L	35.9	92279
Glyphosate isopropylamine salt	Pinus	contorta var. latifolia	Lodgepole Pine	GRO	GRO	LGTH	LOAEL		182.64	d		1		AI ul/L	35.9	92279
Glyphosate isopropylamine salt	Pinus	contorta var. latifolia	Lodgepole Pine	GRO	GRO	LGTH	NOAEL		182.64	d		0.1		AI ul/L	35.9	92279
Glyphosate isopropylamine salt	Pinus	contorta var. latifolia	Lodgepole Pine	GRO	GRO	WGHT	LOAEL		182.64	d		10		AI ul/L	35.9	92279
Glyphosate isopropylamine salt	Pinus	contorta var. latifolia	Lodgepole Pine	GRO	GRO	WGHT	NOAEL		182.64	d		1		AI ul/L	35.9	92279
Glyphosate isopropylamine salt	Pinus	contorta var. latifolia	Lodgepole Pine	GRO	GRO	NROT	NOAEL		182.64	d		0.1		AI ul/L	35.9	92279
Glyphosate isopropylamine salt	Pinus	contorta var. latifolia	Lodgepole Pine	GRO	GRO	NROT	LOAEL		182.64	d		1		AI ul/L	35.9	92279
Glyphosate isopropylamine salt	Perkinsus	olseni	Protozoan	POP	POP	ABND	IC50		3	d		0.2788		mM	68	111736
Glyphosate	Perkinsus	olseni	Protozoan	POP	POP	ABND	IC50		3	d		3.4		mM	100	111736
Glyphosate isopropylamine salt	Ruditapes	decussatus	Clam	MOR	MOR	MORT	NR-ZERO		4	d		6.8		mg/L	68	111736

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Chemical	Genus	Species	Common Name												
Glyphosate	Ruditapes	decussatus	Clam	MOR	MOR	MORT	NR-ZERO		4	d	10		mg/L	100	111736
Glyphosate isopropylamine salt	NR	Plantae	Plant Kingdom	POP	POP	COVR	LOAEL		1	gs	50		AI %	100	120311
Glyphosate isopropylamine salt	Pinus	sylvestris	Scots Pine	MOR	MOR	MORT	NOAEL		6	gs	50		AI %	100	120311
Glyphosate isopropylamine salt	Pinus	sylvestris	Scots Pine	GRO	GRO	HGHT	NOAEL		11	gs	50		AI %	100	120311
Glyphosate isopropylamine salt	Pinus	sylvestris	Scots Pine	POP	POP	ABND	NOAEL		4015	d	50		AI %	100	120311
Glyphosate isopropylamine salt	Picea	abies	Norway Spruce	MOR	MOR	MORT	NOAEL		6	gs	50		AI %	100	120311
Glyphosate isopropylamine salt	Picea	abies	Norway Spruce	GRO	GRO	HGHT	NOAEL		11	gs	50		AI %	100	120311
Glyphosate isopropylamine salt	Picea	abies	Norway Spruce	POP	POP	ABND	NOAEL		4015	d	50		AI %	100	120311
Glyphosate isopropylamine salt	Picea	abies	Norway Spruce	MOR	MOR	MORT	NOAEL		6	gs	100		AI %	100	120311
Glyphosate isopropylamine salt	Picea	abies	Norway Spruce	GRO	GRO	HGHT	NOAEL		4	gs	100		AI %	100	120311
Glyphosate isopropylamine salt	NR	Plantae	Plant Kingdom	POP	POP	COVR	LOAEL		1	gs	100		AI %	100	120311
Glyphosate isopropylamine salt	Pinus	sylvestris	Scots Pine	MOR	MOR	MORT	NOAEL		6	gs	100		AI %	100	120311
Glyphosate isopropylamine salt	Pinus	sylvestris	Scots Pine	GRO	GRO	HGHT	NOAEL		6	gs	100		AI %	100	120311
Glyphosate isopropylamine salt	Trechus	apicalis	Ground Beetle	POP	POP	ABND	NOAEL		770	d	1.5		ae kg/ha	100	97441
Glyphosate isopropylamine salt	Invertebrates	NR	Invertebrates	POP	POP	ABND	NOAEL		730	d	2.8		L/ha	100	96964
Glyphosate	Danthonia	sp.	Oatgrass	POP	POP	BMAS	NOAEL	LOAEL	96	d	0.1602	0.3204	lb/acre	100	44275

Glyphosate	Trichogr amma	pretiosum	Parasitic Wasp	GRO	DVP	EMRG	NOAEL			em	960		AI g/ha	100	110225
Glyphosate	Trichogr amma	pretiosum	Parasitic Wasp	GRO	DVP	EMRG	NOAEL			em	960		AI g/ha	100	110225
Glyphosate	Trichogr amma	pretiosum	Parasitic Wasp	GRO	DVP	EMRG	LOAEL			em	960		AI g/ha	100	110225
Glyphosate isopropylamine salt	Trichogr amma	pretiosum	Parasitic Wasp	GRO	DVP	EMRG	LOAEL			em	960		AI g/ha	100	110225
Glyphosate isopropylamine salt	Trichogr amma	pretiosum	Parasitic Wasp	GRO	DVP	EMRG	NOAEL			em	960		AI g/ha	100	110225
Glyphosate isopropylamine salt	Trichogr amma	pretiosum	Parasitic Wasp	GRO	DVP	EMRG	LOAEL			em	960		AI g/ha	100	110225
Glyphosate isopropylamine salt	Trichogr amma	pretiosum	Parasitic Wasp	GRO	DVP	EMRG	NOAEL			em	960		AI g/ha	100	110225
Glyphosate isopropylamine salt	Trichogr amma	pretiosum	Parasitic Wasp	GRO	DVP	EMRG	NOAEL			em	960		AI g/ha	100	110225
Glyphosate isopropylamine salt	Trichogr amma	pretiosum	Parasitic Wasp	GRO	DVP	EMRG	NOAEL			em	960		AI g/ha	100	110225
Glyphosate isopropylamine salt	Trichogr amma	pretiosum	Parasitic Wasp	GRO	DVP	EMRG	NOAEL			em	972		AI g/ha	100	110225
Glyphosate isopropylamine salt	Trichogr amma	pretiosum	Parasitic Wasp	GRO	DVP	EMRG	NOAEL			em	972		AI g/ha	100	110225
Glyphosate isopropylamine salt	Trichogr amma	pretiosum	Parasitic Wasp	GRO	DVP	EMRG	LOAEL			em	972		AI g/ha	100	110225
Glyphosate isopropylamine salt	Fragilaria	sp.	Diatom	POP	POP	ABND	NOAEL		5	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Fragilaria	sp.	Diatom	POP	POP	ABND	NOAEL		5	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Meridion	sp.	Diatom	POP	POP	ABND	NOAEL		5	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Fragilaria	sp.	Diatom	POP	POP	ABND	NOAEL		47	d	2.2		AI kg/ha	100	6383

Glyphosate isopropylamine salt	Amphora	sp.	Diatom	POP	POP	ABND	NOAEL		1	d		2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	NR	Tabellariales	Diatom Order	POP	POP	ABND	LOAEL		5	d		2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	NR	Tabellariales	Diatom Order	POP	POP	ABND	NOAEL		29	d		22		AI kg/ha	100	6383
Glyphosate isopropylamine salt	NR	Cymbellaceae	Diatom Family	POP	POP	ABND	NOAEL		5	d		2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Frustilia	sp.	Diatom	POP	POP	ABND	NOAEL		5	d		2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Achnanthes	sp.	Diatom	POP	POP	ABND	NOAEL		5	d		2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	NR	Cymbellaceae	Diatom Family	POP	POP	ABND	NOAEL		1	d		2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Amphora	sp.	Diatom	POP	POP	ABND	NOAEL		29	d		2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Achnanthes	sp.	Diatom	POP	POP	ABND	NOAEL		1	d		2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Navicula	sp.	Diatom	POP	POP	ABND	NOAEL		5	d		2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Meridion	sp.	Diatom	POP	POP	ABND	NOAEL		29	d		2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Achnanthes	sp.	Diatom	POP	POP	ABND	NOAEL		5	d		22		AI kg/ha	100	6383
Glyphosate isopropylamine salt	NR	Tabellariales	Diatom Order	POP	POP	ABND	NOAEL		5	d		22		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Frustilia	sp.	Diatom	POP	POP	ABND	NOAEL		47	d		2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Fragilaria	sp.	Diatom	POP	POP	ABND	NOAEL		1	d		2.2		AI kg/ha	100	6383

Glyphosate isopropylamine salt	Amphora	sp.	Diatom	POP	POP	ABND	NOAEL		5	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Hannaea	sp.	Diatom	POP	POP	ABND	NOAEL		5	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Fragilaria	sp.	Diatom	POP	POP	ABND	NOAEL		29	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	NR	Cymbellaceae	Diatom Family	POP	POP	ABND	NOAEL		29	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Navicula	sp.	Diatom	POP	POP	ABND	NOAEL		29	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Achnanthes	sp.	Diatom	POP	POP	ABND	NOAEL		47	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Achnanthes	sp.	Diatom	POP	POP	ABND	NOAEL		29	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Hannaea	sp.	Diatom	POP	POP	ABND	NOAEL		47	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Meridion	sp.	Diatom	POP	POP	ABND	NOAEL		1	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	NR	Tabellariales	Diatom Order	POP	POP	ABND	NOAEL		29	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	NR	Tabellariales	Diatom Order	POP	POP	ABND	NOAEL		1	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Frustilia	sp.	Diatom	POP	POP	ABND	NOAEL		1	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Frustilia	sp.	Diatom	POP	POP	ABND	NOAEL		29	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Fragilaria	sp.	Diatom	POP	POP	ABND	NOAEL		5	d	22		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Amphora	sp.	Diatom	POP	POP	ABND	NOAEL		47	d	2.2		AI kg/ha	100	6383

Glyphosate isopropylamine salt	Achnanthes	sp.	Diatom	POP	POP	ABND	NOAEL		29	d	22		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Fragilaria	sp.	Diatom	POP	POP	ABND	NOAEL		29	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Frustilia	sp.	Diatom	POP	POP	ABND	NOAEL		29	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Meridion	sp.	Diatom	POP	POP	ABND	NOAEL		47	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Meridion	sp.	Diatom	POP	POP	ABND	NOAEL		29	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Gomphonema	sp.	Diatom	POP	POP	ABND	LOAEL		29	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Gomphonema	sp.	Diatom	POP	POP	ABND	LOAEL		5	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Fragilaria	sp.	Diatom	POP	POP	ABND	NOAEL		47	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Frustilia	sp.	Diatom	POP	POP	ABND	NOAEL		47	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Meridion	sp.	Diatom	POP	POP	ABND	NOAEL		5	d	22		AI kg/ha	100	6383
Glyphosate isopropylamine salt	NR	Tabellariales	Diatom Order	POP	POP	ABND	NOAEL		5	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Navicula	sp.	Diatom	POP	POP	ABND	NOAEL		1	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Meridion	sp.	Diatom	POP	POP	ABND	NOAEL		5	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	NR	Tabellariales	Diatom Order	POP	POP	ABND	LOAEL		29	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Hannaea	sp.	Diatom	POP	POP	ABND	NOAEL		29	d	2.2		AI kg/ha	100	6383

Chemical	Genus	Species	Common Name						Value		Conc		Unit	%	ID
Glyphosate isopropylamine salt	Frustilia	sp.	Diatom	POP	POP	ABND	NOAEL		5	d	2.2		AI kg/ha	100	6383
Glyphosate isopropylamine salt	Triticum	sp.	Wheat	GRO	GRO	NROT	NOAEL		50	d	360000		ppm	100	96992
Glyphosate isopropylamine salt	Triticum	sp.	Wheat	GRO	GRO	NROT	NOAEL		50	d	360000		ppm	100	96992
Glyphosate isopropylamine salt	Gaeumannomyces	graminis var. tritici	Fungus	POP	POP	CNTL	LOAEL		4	d	360000		ppm	100	96992
Glyphosate isopropylamine salt	Alnus	sp.	Alder	PHY	INJ	SYMP	NOAEL		182.64	d	0.9812		lb/acre	100	70518
Glyphosate isopropylamine salt	Alnus	sp.	Alder	GRO	GRO	HGHT	LOAEL		30.44	d	0.9812		lb/acre	100	70518
Glyphosate isopropylamine salt	NR	Plantae	Plant Kingdom	POP	POP	CNTL	LOAEL		60.88	d	0.9812		lb/acre	100	70518
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	NOEC	LOEC	10	d	7.5		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC50		7	d	25		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC25		7	d	16.2		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC10		7	d			mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC10		10	d	8.5		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC25		10	d	11.9		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC50		10	d	22.1		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	GRO	GRRT	IC25		5	d	11.4		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	GRO	GRRT	IC25		2	d	15.1		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	GRO	GRRT	IC50		2	d	33.1		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	GRO	GRRT	IC50		5	d	22.6		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	GRO	GRRT	IC50		10	d	20.5		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC50		10	d	25		mg/L	95	114615

Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC10		10	d	10.2		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC10		7	d	14.1		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC25		7	d	25		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC25		10	d	15.8		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC50		7	d	25		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC50		7	d	25		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC25		7	d	16		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC10		7	d	11.2		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	GRO	GRRT	IC10		2	d			mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	GRO	GRRT	IC10		5	d			mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	GRO	GRRT	IC10		10	d	4.6		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	GRO	GRRT	IC25		10	d	10.7		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC10		10	d	10.1		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC25		10	d	14.5		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC50		10	d	25		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC50		10	d	18.3		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC25		10	d	10.2		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC10		10	d	6.3		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC10		7	d			mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC25		7	d	7.3		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC50		7	d	25		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	NOEC	LOEC	10	d		7.5	mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	NOEC	LOEC	10	d	7.5		mg/L	95	114615

Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	NOEC	LOEC	10	d	7.5		mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	NOEC		10	d			mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	NOEC		10	d			mg/L	95	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC10		7	d	2.8		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC50		7	d	13.6		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	NOEC	LOEC	10	d	1	7.5	mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	LOEC		10	d	1		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	NOEC		10	d	25		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	GRO	GRRT	IC25		5	d	6.5		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC25		10	d	10.1		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC25		7	d	25		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC50		7	d	25		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC50		7	d	25		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC25		7	d	25		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	GRO	GRRT	IC10		10	d	2.5		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC10		7	d	5.3		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC10		10	d	3.4		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC25		10	d	7		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC50		10	d	8.8		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC25		10	d	2.6		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC10		10	d			mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC25		7	d	6		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC50		7	d	25		mg/L	100	114615

Chemical	Genus	Species	Common Name						Dur	Unit	Conc	Val2	Units		ID
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC25		7	d	6.2		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC10		7	d	2.7		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC10		10	d			mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	GRO	GRRT	IC10		2	d			mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	GRO	GRRT	IC10		5	d	2.1		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	GRO	GRRT	IC25		10	d	5		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	GRO	GRRT	IC25		2	d			mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	GRO	GRRT	IC50		2	d	9.2		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	GRO	GRRT	IC50		5	d	15.9		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	GRO	GRRT	IC50		10	d	11.6		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC50		10	d	25		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC10		10	d	2.8		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC10		7	d	9.7		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC25		10	d	3.8		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC50		10	d	12.7		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	NOEC	LOEC	10	d	1	7.5	mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	LOEC		10	d	1		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	IC50		10	d	25		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	MPH	SIZE	NOEC		10	d	25		mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	POP	POP	ABND	NOEC	LOEC	10	d	0.5	1	mg/L	100	114615
Glyphosate	Lemna	gibba	Inflated Duckweed	POP	POP	ABND	NOEC	LOEC	7	d	0.5	1	mg/L	100	114615
Glyphosate isopropylamine salt	Cyprinus	carpio	Common Carp	MOR	MOR	MORT	LOAEL		0.0208	d	410		mg/L	100	56640

Glyphosate isopropylamine salt	Cyprinus	carpio	Common Carp	MOR	MOR	MORT	LOAEL		0.0417	d	205		mg/L	100	56640
Glyphosate isopropylamine salt	Myriophyllum	sibiricum	Water Milfoil	BCM	BCM	CARC	NOAEL		14	d	25.6		ae mg/L	100	111592
Glyphosate isopropylamine salt	Myriophyllum	sibiricum	Water Milfoil	BCM	BCM	CHLA	NOAEL		14	d	25.6		ae mg/L	100	111592
Glyphosate isopropylamine salt	Myriophyllum	sibiricum	Water Milfoil	BCM	BCM	CHLB	NOAEL		14	d	25.6		ae mg/L	100	111592
Glyphosate isopropylamine salt	Myriophyllum	sibiricum	Water Milfoil	GRO	GRO	WGHT	IC50		14	d	3.81		ae mg/L	100	111592
Glyphosate isopropylamine salt	Myriophyllum	sibiricum	Water Milfoil	GRO	GRO	WGHT	IC50		14	d	1.65		ae mg/L	100	111592
Glyphosate isopropylamine salt	Myriophyllum	sibiricum	Water Milfoil	PHY	PHY	PERM	NOAEL		14	d	25.6		ae mg/L	100	111592
Glyphosate isopropylamine salt	Myriophyllum	sibiricum	Water Milfoil	GRO	GRO	LGTH	IC50		14	d	0.84		ae mg/L	100	111592
Glyphosate isopropylamine salt	Myriophyllum	sibiricum	Water Milfoil	GRO	GRO	NROT	IC50		14	d	1.77		ae mg/L	100	111592
Glyphosate isopropylamine salt	Myriophyllum	sibiricum	Water Milfoil	GRO	GRO	LGTH	IC50		14	d	31.16		ae mg/L	100	111592
Glyphosate isopropylamine salt	Myriophyllum	sibiricum	Water Milfoil	GRO	GRO	AREA	IC50		14	d	3.22		ae mg/L	100	111592
Glyphosate isopropylamine salt	Myriophyllum	sibiricum	Water Milfoil	BCM	BCM	CARC	NOAEL		14	d	25.6		ae mg/L	100	111592
Glyphosate isopropylamine salt	Myriophyllum	sibiricum	Water Milfoil	BCM	BCM	CHLA	NOAEL		14	d	25.6		ae mg/L	100	111592
Glyphosate isopropylamine salt	Myriophyllum	sibiricum	Water Milfoil	BCM	BCM	CHLB	NOAEL		14	d	25.6		ae mg/L	100	111592
Glyphosate isopropylamine salt	Myriophyllum	sibiricum	Water Milfoil	GRO	GRO	WGHT	IC50		14	d	24.14		ae mg/L	100	111592

Glyphosate isopropylamine salt	Myriophyllum	sibiricum	Water Milfoil	GRO	GRO	WGHT	IC50		14	d	2.98		ae mg/L	100	111592
Glyphosate isopropylamine salt	Myriophyllum	sibiricum	Water Milfoil	PHY	PHY	PERM	NOAEL		14	d	25.6		ae mg/L	100	111592
Glyphosate isopropylamine salt	Myriophyllum	sibiricum	Water Milfoil	GRO	GRO	LGTH	IC50		14	d	1.22		ae mg/L	100	111592
Glyphosate isopropylamine salt	Myriophyllum	sibiricum	Water Milfoil	GRO	GRO	NROT	IC50		14	d	3.35		ae mg/L	100	111592
Glyphosate isopropylamine salt	Myriophyllum	sibiricum	Water Milfoil	GRO	GRO	LGTH	IC50		14	d	28.79		ae mg/L	100	111592
Glyphosate isopropylamine salt	Myriophyllum	sibiricum	Water Milfoil	GRO	GRO	AREA	IC50		14	d	14.76		ae mg/L	100	111592
Glyphosate	Lemna	gibba	Inflated Duckweed	BCM	BCM	CARC	IC50		7	d	20.92		ae mg/L	97	111592
Glyphosate	Lemna	gibba	Inflated Duckweed	BCM	BCM	CHLA	IC50		7	d	24.97		ae mg/L	97	111592
Glyphosate	Lemna	gibba	Inflated Duckweed	BCM	BCM	CHLB	NOAEL		7	d	26		ae mg/L	97	111592
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	GRO	WGHT	NOAEL		7	d	26		ae mg/L	97	111592
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	GRO	WGHT	IC50		7	d	9.98		ae mg/L	97	111592
Glyphosate	Lemna	gibba	Inflated Duckweed	GRO	GRO	NLEF	IC50		7	d	11.74		ae mg/L	97	111592
Glyphosate isopropylamine salt	Lemna	gibba	Inflated Duckweed	BCM	BCM	CARC	IC50		7	d	11.54		ae mg/L	100	111592
Glyphosate isopropylamine salt	Lemna	gibba	Inflated Duckweed	BCM	BCM	CHLA	IC50		7	d	7.85		ae mg/L	100	111592
Glyphosate isopropylamine salt	Lemna	gibba	Inflated Duckweed	BCM	BCM	CHLB	IC50		7	d	7.69		ae mg/L	100	111592
Glyphosate isopropylamine salt	Lemna	gibba	Inflated Duckweed	GRO	GRO	WGHT	NOAEL		7	d	26		ae mg/L	100	111592
Glyphosate isopropylamine salt	Lemna	gibba	Inflated Duckweed	GRO	GRO	WGHT	IC50		7	d	8.57		ae mg/L	100	111592

Glyphosate isopropylamine salt	Lemna	gibba	Inflated Duckweed	GRO	GRO	NLEF	IC50		7	d	5.37		ae mg/L	100	111592
Glyphosate isopropylamine salt	Lemna	gibba	Inflated Duckweed	POP	POP	ABND	IC50		7	d	4.58		ae mg/L	100	111592
Glyphosate isopropylamine salt	Lemna	gibba	Inflated Duckweed	BCM	BCM	CARC	IC50		7	d	32.24		ae mg/L	100	111592
Glyphosate isopropylamine salt	Lemna	gibba	Inflated Duckweed	BCM	BCM	CHLA	IC50		7	d	22.76		ae mg/L	100	111592
Glyphosate isopropylamine salt	Lemna	gibba	Inflated Duckweed	BCM	BCM	CHLB	IC50		7	d	16.27		ae mg/L	100	111592
Glyphosate isopropylamine salt	Lemna	gibba	Inflated Duckweed	GRO	GRO	WGHT	NOAEL		7	d	26		ae mg/L	100	111592
Glyphosate isopropylamine salt	Lemna	gibba	Inflated Duckweed	GRO	GRO	WGHT	IC50		7	d	14.44		ae mg/L	100	111592
Glyphosate isopropylamine salt	Lemna	gibba	Inflated Duckweed	GRO	GRO	NLEF	IC50		7	d	12.46		ae mg/L	100	111592
Glyphosate isopropylamine salt	Lemna	gibba	Inflated Duckweed	POP	POP	ABND	IC50		7	d	7.6		ae mg/L	100	111592
Glyphosate isopropylamine salt	Tubifex	tubifex	Tubificid Worm	MOR	MOR	SURV	NOAEL		28	d	106.4		ae mg/L	100	111592
Glyphosate isopropylamine salt	Tubifex	tubifex	Tubificid Worm	REP	REP	PROG	NOAEL		28	d	106.4		ae mg/L	100	111592
Glyphosate isopropylamine salt	Tubifex	tubifex	Tubificid Worm	REP	REP	PROG	NOAEL		28	d	106.4		ae mg/L	100	111592
Glyphosate isopropylamine salt	Tubifex	tubifex	Tubificid Worm	REP	REP	PROG	NOAEL		28	d	106.4		ae mg/L	100	111592
Glyphosate isopropylamine salt	Tubifex	tubifex	Tubificid Worm	REP	REP	PROG	NOAEL		28	d	106.4		ae mg/L	100	111592
Glyphosate isopropylamine salt	Tubifex	tubifex	Tubificid Worm	REP	REP	PROG	NOAEL		28	d	106.4		ae mg/L	100	111592

Glyphosate isopropylamine salt	Tubifex	tubifex	Tubificid Worm	MOR	MOR	SURV	NOAEL		28	d	106.4		ae mg/L	100	111592
Glyphosate isopropylamine salt	Tubifex	tubifex	Tubificid Worm	REP	REP	PROG	NOAEL		28	d	106.4		ae mg/L	100	111592
Glyphosate isopropylamine salt	Tubifex	tubifex	Tubificid Worm	REP	REP	PROG	NOAEL		28	d	106.4		ae mg/L	100	111592
Glyphosate isopropylamine salt	Tubifex	tubifex	Tubificid Worm	REP	REP	PROG	NOAEL		28	d	106.4		ae mg/L	100	111592
Glyphosate isopropylamine salt	Tubifex	tubifex	Tubificid Worm	REP	REP	PROG	NOAEL		28	d	106.4		ae mg/L	100	111592
Glyphosate isopropylamine salt	Tubifex	tubifex	Tubificid Worm	REP	REP	PROG	NOAEL		28	d	106.4		ae mg/L	100	111592
Glyphosate isopropylamine salt	Tubifex	tubifex	Tubificid Worm	MOR	MOR	SURV	NOAEL		28	d	53.2		ae mg/L	100	111592
Glyphosate isopropylamine salt	Tubifex	tubifex	Tubificid Worm	REP	REP	PROG	NOAEL		28	d	53.2		ae mg/L	100	111592
Glyphosate isopropylamine salt	Tubifex	tubifex	Tubificid Worm	REP	REP	PROG	NOAEL		28	d	53.2		ae mg/L	100	111592
Glyphosate isopropylamine salt	Tubifex	tubifex	Tubificid Worm	REP	REP	PROG	NOAEL		28	d	53.2		ae mg/L	100	111592
Glyphosate isopropylamine salt	Tubifex	tubifex	Tubificid Worm	REP	REP	PROG	NOAEL		28	d	53.2		ae mg/L	100	111592
Glyphosate isopropylamine salt	Tubifex	tubifex	Tubificid Worm	MOR	MOR	MORT	NR-ZERO		28	d	53.2		ae mg/L	100	111592
Glyphosate isopropylamine salt	Tubifex	tubifex	Tubificid Worm	MOR	MOR	SURV	NOAEL		28	d	53.2		ae mg/L	100	111592
Glyphosate isopropylamine salt	Tubifex	tubifex	Tubificid Worm	REP	REP	PROG	NOAEL		28	d	53.2		ae mg/L	100	111592

Glyphosate isopropylamine salt	Tubifex	tubifex	Tubificid Worm	REP	REP	PROG	NOAEL		28	d	53.2		ae mg/L	100	111592
Glyphosate isopropylamine salt	Tubifex	tubifex	Tubificid Worm	REP	REP	PROG	NOAEL		28	d	53.2		ae mg/L	100	111592
Glyphosate isopropylamine salt	Tubifex	tubifex	Tubificid Worm	REP	REP	PROG	NOAEL		28	d	53.2		ae mg/L	100	111592
Glyphosate isopropylamine salt	Tubifex	tubifex	Tubificid Worm	REP	REP	PROG	NOAEL		28	d	53.2		ae mg/L	100	111592
Glyphosate	Myriophyllum	sibiricum	Water Milfoil	GRO	GRO	LGTH	IC50		14	d	34.53		ae mg/L	97	111592
Glyphosate	Myriophyllum	sibiricum	Water Milfoil	BCM	BCM	CARC	NOAEL		14	d	25.6		ae mg/L	97	111592
Glyphosate	Myriophyllum	sibiricum	Water Milfoil	BCM	BCM	CHLA	NOAEL		14	d	25.6		ae mg/L	97	111592
Glyphosate	Myriophyllum	sibiricum	Water Milfoil	BCM	BCM	CHLB	NOAEL		14	d	25.6		ae mg/L	97	111592
Glyphosate	Myriophyllum	sibiricum	Water Milfoil	GRO	GRO	WGHT	IC50		14	d	6.79		ae mg/L	97	111592
Glyphosate	Myriophyllum	sibiricum	Water Milfoil	GRO	GRO	WGHT	IC50		14	d	3.3		ae mg/L	97	111592
Glyphosate	Myriophyllum	sibiricum	Water Milfoil	PHY	PHY	PERM	NOAEL		14	d	25.6		ae mg/L	97	111592
Glyphosate	Myriophyllum	sibiricum	Water Milfoil	GRO	GRO	LGTH	IC50		14	d	1.56		ae mg/L	97	111592
Glyphosate	Myriophyllum	sibiricum	Water Milfoil	GRO	GRO	NROT	IC50		14	d	4.57		ae mg/L	97	111592
Glyphosate	Myriophyllum	sibiricum	Water Milfoil	GRO	GRO	AREA	IC50		14	d	4.82		ae mg/L	97	111592
Glyphosate isopropylamine salt	Pinus	contorta	Tamarack Pine	PHY	IMM	PRNF	LOAEL		35	d	360000		ppm	100	96963
Glyphosate isopropylamine salt	Pinus	contorta	Tamarack Pine	PHY	IMM	PRNF	LOAEL		49	d	360000		ppm	100	96963
Glyphosate isopropylamine salt	Xylothamia	palmeri	Texas Desert Goldenrod	POP	POP	COVR	LOAEL		730	d	0.9812		lb/acre	100	44033
Glyphosate isopropylamine salt	Xylothamia	palmeri	Texas Desert Goldenrod	POP	POP	COVR	LOAEL		182.64	d	0.9812		lb/acre	100	44033
Glyphosate isopropylamine salt	Xylothamia	palmeri	Texas Desert Goldenrod	POP	POP	COVR	LOAEL			d	0.9812		lb/acre	100	44033

Chemical	Genus	Species	Common Name										Unit		Study
Glyphosate isopropylamine salt	NR	Poaceae	Grass Family	POP	POP	COVR	NOAEL		730.56	d	1.9624		lb/acre	100	44033
Glyphosate isopropylamine salt	NR	Poaceae	Grass Family	POP	POP	COVR	NOAEL	LOAEL	182.64	d	0.9812	1.9624	lb/acre	100	44033
Glyphosate isopropylamine salt	NR	Plantae	Plant Kingdom	POP	POP	BMAS	NOAEL			d	1.9624		lb/acre	100	44033
Glyphosate	Anacardium	occidentale	Cashew	POP	POP	BMAS	NOAEL			hv	2.676		lb/acre	100	48148
Glyphosate	Anacardium	occidentale	Cashew	BCM	BCM	NCON	NOAEL			hv	2.676		lb/acre	100	48148
Glyphosate	NR	Cyperales	Grass/Sedge Order	POP	POP	BMAS	NOAEL	LOAEL	121.76	d	1.784	2.676	lb/acre	100	48148
Glyphosate	NR	Cyperales	Grass/Sedge Order	BCM	BCM	KCON	NOAEL	LOAEL	121.76	d	1.784	2.676	lb/acre	100	48148
Glyphosate	NR	Plantae	Plant Kingdom	POP	POP	BMAS	LOAEL		121.76	d	1.784		lb/acre	100	48148
Glyphosate	NR	Plantae	Plant Kingdom	BCM	BCM	NCON	NOAEL		121.76	d	2.676		lb/acre	100	48148
Glyphosate	NR	Plantae	Plant Kingdom	POP	POP	BMAS	NOAEL	LOAEL	121.76	d	1.784	2.676	lb/acre	100	48148
Glyphosate	NR	Plantae	Plant Kingdom	BCM	BCM	NCON	NOAEL	LOAEL	121.76	d	1.784	2.676	lb/acre	100	48148
Glyphosate	NR	Cyperales	Grass/Sedge Order	POP	POP	BMAS	NOAEL		121.76	d	2.676		lb/acre	100	48148
Glyphosate	NR	Cyperales	Grass/Sedge Order	BCM	BCM	NCON	NOAEL	LOAEL	121.76	d	1.784	2.676	lb/acre	100	48148
Glyphosate	Anacardium	occidentale	Cashew	BCM	BCM	NCON	NOAEL			hv	2.676		lb/acre	100	48148
Glyphosate	NR	Plantae	Plant Kingdom	POP	POP	BMAS	LOAEL		121.76	d	1.784		lb/acre	100	48148
Glyphosate	NR	Plantae	Plant Kingdom	POP	POP	BMAS	LOAEL		121.76	d	1.784		lb/acre	100	48148
Glyphosate	Gladiolus	sp.	Gladiolus	REP	REP	VEGR	LOAEL			gm	0.892		lb/acre	100	113903
Glyphosate	Gladiolus	sp.	Gladiolus	GRO	MPH	WGHT	LOAEL			hv	0.892		lb/acre	100	113903
Glyphosate	Gladiolus	sp.	Gladiolus	GRO	GRO	DMTR	NOAEL			hv	0.892		lb/acre	100	113903
Glyphosate	NR	Plantae	Plant Kingdom	POP	POP	ABND	LOAEL		90	d	0.892		lb/acre	100	113903
Glyphosate isopropylamine salt	Plankton	sp.	Plankton	POP	POP	PSYN	NOAEL		1	d	0.43		AI kg/ha	100	53095
Glyphosate	Nicotiana	tabacum	Tobacco	POP	POP	BMAS	LOAEL			hv	1.99808		lb/acre	100	48141
Glyphosate	Nicotiana	tabacum	Tobacco	GRO	GRO	VGOR	NOAEL			d	1.99808		lb/acre	100	48141
Glyphosate	Nicotiana	tabacum	Tobacco	POP	POP	ABND	LOAEL		27	d	1.99808		lb/acre	100	48141
Glyphosate	Nicotiana	tabacum	Tobacco	GRO	GRO	VGOR	LOAEL			d	1.99808		lb/acre	100	48141

Glyphosate	Dactylis	glomerata	Orchardgrass	PHY	INJ	DAMG	NOAEL		42	d	1.99808		lb/acre	100	48141
Glyphosate	Secale	cereale	Common Rye	PHY	INJ	DAMG	NOAEL		42	d	1.99808		lb/acre	100	48141
Glyphosate	Caenorhabditis	elegans	Nematode	BEH	BEH	NMVM	LOAEL		1	d	7		ppm	100	117675
Glyphosate	Caenorhabditis	elegans	Nematode	BEH	BEH	BOWW	NOAEL		1	d	0.7		ppm	100	117675
Glyphosate	Caenorhabditis	elegans	Nematode	BEH	BEH	BOWW	LOAEL		1	d	7		ppm	100	117675
Glyphosate	Caenorhabditis	elegans	Nematode	BEH	BEH	NMVM	NOAEL		3	d	0.7		ppm	100	117675
Glyphosate	Caenorhabditis	elegans	Nematode	BEH	BEH	NMVM	LOAEL		3	d	7		ppm	100	117675
Glyphosate	Caenorhabditis	elegans	Nematode	REP	REP	PROG	NOAEL		3	d	0.7		ppm	100	117675
Glyphosate	Caenorhabditis	elegans	Nematode	REP	REP	PROG	LOAEL		3	d	7		ppm	100	117675
Glyphosate isopropylamine salt	Anas	platyrhynchos	Mallard Duck	NOC	NOC	MULT	NOAEL		15	d	178		AI lb/100gal/ac	100	35249
Glyphosate isopropylamine salt	Anas	platyrhynchos	Mallard Duck	GRO	DVP	ABNM	NOAEL		15	d	178		AI lb/100gal/ac	100	35249
Glyphosate isopropylamine salt	Anas	platyrhynchos	Mallard Duck	MOR	MOR	MORT	LC50		15	d	178		AI lb/100gal/ac	100	35249
Glyphosate isopropylamine salt	Zea	mays	Corn	POP	POP	ABND	NOAEL		28	d	3		fl oz mat/cwt	100	88098
Glyphosate isopropylamine salt	Melanotus	depressus	Wireworm	POP	POP	ABND	LOAEL		28	d	3		fl oz mat/cwt	100	88098
Glyphosate isopropylamine salt	Melanotus	depressus	Wireworm	POP	POP	ABND	LOAEL		28	d	3		fl oz mat/cwt	100	88098
Glyphosate isopropylamine salt	Ageratum	houstonianum	Ageratum	PHY	INJ	DAMG	NOAEL		56	d	0.74036		lb/acre	100	70759
Glyphosate isopropylamine salt	Lobularia	maritima	Sweet Alyssum	PHY	INJ	DAMG	LOAEL		14	d	0.74036		lb/acre	100	70759
Glyphosate isopropylamine salt	Callistephus	chinensis	China Aster	PHY	INJ	DAMG	LOAEL		14	d	0.74036		lb/acre	100	70759
Glyphosate isopropylamine salt	Celosia	cristata	Crested Cock's Comb	PHY	INJ	DAMG	LOAEL		56	d	0.74036		lb/acre	100	70759

Glyphosate isopropylamine salt	Coreopsis	lanceolata	Lanceleaf Tickseed	PHY	INJ	DAMG	LOAEL		14	d	0.74036		lb/acre	100	70759
Glyphosate isopropylamine salt	Dahlia	sp.	Dahlia	PHY	INJ	DAMG	LOAEL		14	d	0.74036		lb/acre	100	70759
Glyphosate isopropylamine salt	Dianthus	barbatus	Sweet-William	PHY	INJ	DAMG	LOAEL		14	d	0.74036		lb/acre	100	70759
Glyphosate isopropylamine salt	Pelargonium	x hortorum	Zonal Geranium	PHY	INJ	DAMG	NOAEL		56	d	0.74036		lb/acre	100	70759
Glyphosate isopropylamine salt	Hibiscus	moscheutos	Crimsoneyed Rosemallow	PHY	INJ	DAMG	NOAEL		56	d	0.74036		lb/acre	100	70759
Glyphosate isopropylamine salt	Impatiens	walleriana	Busy Lizzy	PHY	INJ	DAMG	NOAEL		56	d	0.74036		lb/acre	100	70759
Glyphosate isopropylamine salt	Tagetes	patula	French Marigold	PHY	INJ	DAMG	NOAEL		56	d	0.74036		lb/acre	100	70759
Glyphosate isopropylamine salt	Tagetes	patula	French Marigold	PHY	INJ	DAMG	NOAEL		56	d	0.74036		lb/acre	100	70759
Glyphosate isopropylamine salt	Nicotiana	alata	Jasmine Tobacco	PHY	INJ	DAMG	NOAEL		56	d	0.74036		lb/acre	100	70759
Glyphosate isopropylamine salt	Capsicum	annuum	Bell Pepper	PHY	INJ	DAMG	NOAEL		56	d	0.74036		lb/acre	100	70759
Glyphosate isopropylamine salt	Petunia	hybrida	Petunia	PHY	INJ	DAMG	LOAEL		14	d	0.74036		lb/acre	100	70759
Glyphosate isopropylamine salt	Petunia	hybrida	Petunia	PHY	INJ	DAMG	NOAEL		56	d	0.74036		lb/acre	100	70759
Glyphosate isopropylamine salt	Salvia	farinacea	Mealycup Sage	PHY	INJ	DAMG	NOAEL		56	d	0.74036		lb/acre	100	70759
Glyphosate isopropylamine salt	Salvia	splendens	Scarlet Sage	PHY	INJ	DAMG	NOAEL		56	d	0.74036		lb/acre	100	70759
Glyphosate isopropylamine salt	Antirrhinum	majus	Snapdragon	PHY	INJ	DAMG	LOAEL		14	d	0.74036		lb/acre	100	70759

Glyphosate isopropylamine salt	Catharanthus	roseus	Bright-Eyes	PHY	INJ	DAMG	NOAEL		56	d	0.74036		lb/acre	100	70759
Glyphosate isopropylamine salt	Zinnia	violacea	Zinnia	PHY	INJ	DAMG	NOAEL		56	d	0.74036		lb/acre	100	70759
Glyphosate isopropylamine salt	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	CNTL	LOAEL		14	d	0.74036		lb/acre	100	70759
Glyphosate isopropylamine salt	Amaranthus	sp.	Amaranth	POP	POP	CNTL	LOAEL		14	d	0.74036		lb/acre	100	70759
Glyphosate	Toxicodendron	radicans	Poison-Ivy	POP	POP	CNTL	LOAEL		35	d	0.74928		lb/acre	100	73745
Glyphosate	Vitis	labrusca	American Grape	POP	POP	BMAS	NOAEL		126	d	0.74928		lb/acre	100	73745
Glyphosate	Conyza	canadensis	Butterweed	POP	POP	CNTL	LOAEL		35	d	0.74928		lb/acre	100	73745
Glyphosate	Bromus	catharticus	Rescuegrass	POP	POP	CNTL	LOAEL		35	d	0.74928		lb/acre	100	73745
Glyphosate	Lolium	multiflorum	Annual Ryegrass	POP	POP	CNTL	LOAEL		35	d	0.74928		lb/acre	100	73745
Glyphosate	Taraxacum	officinale	Common Dandelion	POP	POP	CNTL	LOAEL		35	d	0.74928		lb/acre	100	73745
Glyphosate isopropylamine salt	Triticum	sp.	Wheat	POP	POP	CNTL	LOAEL		14	d	0.5352		lb/acre	100	73916
Glyphosate isopropylamine salt	Vicia	villosa	Hairy Vetch	POP	POP	CNTL	LOAEL		14	d	0.5352		lb/acre	100	73916
Glyphosate isopropylamine salt	Glycine	max	Soybean	PHY	INJ	GINJ	NOAEL		7	d	840		ae g/ha	100	114121
Glyphosate isopropylamine salt	Glycine	max	Soybean	POP	POP	BMAS	NOAEL			hv	840		ae g/ha	100	114121
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	CEL	GEN	DAMG	LOAEL		0.25	d	4.1		mg/L	41	117389
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	CEL	GEN	DAMG	NOAEL		1	d	4.1		mg/L	41	117389
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	CEL	GEN	DAMG	NOAEL		4	d	4.1		mg/L	41	117389
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	CEL	GEN	DAMG	LOAEL		0.25	d	4.1		mg/L	41	117389

Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	CEL	GEN	DAMG	LOAEL		1	d		4.1		mg/L	41	117389
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	CEL	GEN	DAMG	NOAEL		4	d		4.1		mg/L	41	117389
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	CEL	GEN	MNUC	NOAEL		0.25	d		4.1		mg/L	41	117389
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	CEL	GEN	MNUC	NOAEL		1	d		4.1		mg/L	41	117389
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	CEL	GEN	MNUC	NOAEL		4	d		4.1		mg/L	41	117389
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	CEL	GEN	NABN	NOAEL		0.25	d		4.1		mg/L	41	117389
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	CEL	GEN	NABN	NOAEL		1	d		4.1		mg/L	41	117389
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	CEL	GEN	NABN	NOAEL		4	d		4.1		mg/L	41	117389
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	CEL	GEN	DAMG	LOAEL		0.25	d		4.1		mg/L	41	117389
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	CEL	GEN	DAMG	NOAEL		1	d		4.1		mg/L	41	117389
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	CEL	GEN	DAMG	LOAEL		4	d		4.1		mg/L	41	117389
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	CEL	GEN	DAMG	LOAEL		0.25	d		4.1		mg/L	41	117389
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	CEL	GEN	DAMG	LOAEL		1	d		4.1		mg/L	41	117389
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	CEL	GEN	DAMG	NOAEL		4	d		4.1		mg/L	41	117389
Glyphosate isopropylamine salt	Phakops ora	pachyrhizi	Fungi	POP	POP	ABND	LOAEL		14	d		1.26		ae kg/ha	100	109341

Glyphosate isopropylamine salt	Phakopsora	pachyrhizi	Fungi	POP	POP	ABND	NOAEL		21	d	1.26			ae kg/ha	100	109341
Glyphosate isopropylamine salt	Phakopsora	pachyrhizi	Fungi	POP	POP	ABND	LOAEL		14	d	1.26			ae kg/ha	100	109341
Glyphosate isopropylamine salt	Phakopsora	pachyrhizi	Fungi	POP	POP	ABND	NOAEL	LOAEL	14	d	1.26		2.52	ae kg/ha	100	109341
Glyphosate isopropylamine salt	Phakopsora	pachyrhizi	Fungi	POP	POP	ABND	LOAEL		14	d	1.26			ae kg/ha	100	109341
Glyphosate isopropylamine salt	Phakopsora	pachyrhizi	Fungi	POP	POP	ABND	LOAEL		14	d	1.26			ae kg/ha	100	109341
Glyphosate	Echinochloa	phyllopogon	Rice Barnyardgrass	POP	POP	BMAS	EC50			d	0.26			ae kg/ha	100	59421
Glyphosate	Echinochloa	phyllopogon	Rice Barnyardgrass	POP	POP	BMAS	EC50			d	0.16			ae kg/ha	100	59421
Glyphosate isopropylamine salt	Chenopodium	album	Lamb's-Quarters	POP	POP	COVR	LOAEL		56	d	0.9812			lb/acre	100	117340
Glyphosate isopropylamine salt	Glycine	max	Soybean	GRO	GRO	HGHT	NOAEL		56	d	1.9624			lb/acre	100	117340
Glyphosate isopropylamine salt	Glycine	max	Soybean	POP	POP	BMAS	NOAEL		56	d	1.9624			lb/acre	100	117340
Glyphosate isopropylamine salt	Sida	spinosa	Prickly Mallow	POP	POP	COVR	NOAEL		56	d	1.9624			lb/acre	100	117340
Glyphosate isopropylamine salt	Sorghum	halepense	Johnson Grass	POP	POP	COVR	NOAEL		56	d	1.9624			lb/acre	100	117340
Glyphosate isopropylamine salt	Amaranthus	sp.	Amaranth	POP	POP	COVR	LOAEL		56	d	0.9812			lb/acre	100	117340
Glyphosate isopropylamine salt	Chenopodium	album	Lamb's-Quarters	POP	POP	COVR	LOAEL		56	d	0.9812			lb/acre	100	117340
Glyphosate isopropylamine salt	Glycine	max	Soybean	GRO	GRO	HGHT	NOAEL		56	d	1.9624			lb/acre	100	117340
Glyphosate isopropylamine salt	Glycine	max	Soybean	POP	POP	BMAS	NOAEL		56	d	1.9624			lb/acre	100	117340

Glyphosate isopropylamine salt	Sida	spinosa	Prickly Mallow	POP	POP	COVR	NOAEL		56	d	1.9624		lb/acre	100	117340
Glyphosate isopropylamine salt	Sorghum	halepense	Johnson Grass	POP	POP	COVR	NOAEL		56	d	1.9624		lb/acre	100	117340
Glyphosate isopropylamine salt	Amaranthus	sp.	Amaranth	POP	POP	COVR	LOAEL		56	d	0.9812		lb/acre	100	117340
Glyphosate isopropylamine salt	Glycine	max	Soybean	POP	POP	COVR	NOAEL		56	d	1.9624		lb/acre	100	117340
Glyphosate isopropylamine salt	Glycine	max	Soybean	PHY	INJ	GINJ	NOAEL		56	d	1.9624		lb/acre	100	117340
Glyphosate isopropylamine salt	Glycine	max	Soybean	POP	POP	COVR	NOAEL		56	d	1.9624		lb/acre	100	117340
Glyphosate isopropylamine salt	Glycine	max	Soybean	PHY	INJ	GINJ	NOAEL		56	d	1.9624		lb/acre	100	117340
Glyphosate isopropylamine salt	Ipomoea	lacunosa	White Morninglory	PHY	PHY	WLSS	LOAEL		7	d	0.9812		lb/acre	100	63873
Glyphosate isopropylamine salt	Ipomoea	lacunosa	White Morninglory	PHY	PHY	WLSS	LOAEL		7	d	0.9812		lb/acre	100	63873
Glyphosate isopropylamine salt	Euphorbia	maculata	Spotted Spurge	PHY	PHY	WLSS	LOAEL		7	d	0.9812		lb/acre	100	63873
Glyphosate isopropylamine salt	Sesbania	herbacea	Colorado Riverhemp	PHY	PHY	WLSS	LOAEL		7	d	0.9812		lb/acre	100	63873
Glyphosate isopropylamine salt	Senna	obtusifolia	Sicklepod	PHY	PHY	WLSS	LOAEL		7	d	0.9812		lb/acre	100	63873
Glyphosate isopropylamine salt	Ipomoea	lacunosa	White Morninglory	PHY	PHY	WLSS	LOAEL		7	d	0.9812		lb/acre	100	63873
Glyphosate isopropylamine salt	Xanthium	strumarium	Common Cocklebur	PHY	PHY	WLSS	LOAEL		7	d	0.9812		lb/acre	100	63873
Glyphosate isopropylamine salt	Glycine	max	Soybean	BCM	BCM	WTCO	NOAEL		1	gs	1.9624		lb/acre	100	63873

Glyphosate isopropylamine salt	Glycine	max	Soybean	BCM	BCM	WTCO	NOAEL		1	gs	1.9624		lb/acre	100	63873
Glyphosate isopropylamine salt	Salvinia	molesta	Water Fern	POP	POP	CNTL	LOAEL		42	d	8.97		ae kg/ha	100	71381
Glyphosate isopropylamine salt	Salvinia	molesta	Water Fern	POP	POP	CNTL	LOAEL		21	d	8.97		ae kg/ha	100	71381
Glyphosate isopropylamine salt	Salvinia	molesta	Water Fern	POP	POP	CNTL	LOAEL		14	d	8.97		ae kg/ha	100	71381
Glyphosate isopropylamine salt	Salvinia	molesta	Water Fern	POP	POP	CNTL	LOAEL		28	d	8.97		ae kg/ha	100	71381
Glyphosate isopropylamine salt	Salvinia	molesta	Water Fern	POP	POP	CNTL	LOAEL		7	d	56.7		ae kg/ha	100	71381
Glyphosate isopropylamine salt	Salvinia	molesta	Water Fern	POP	POP	CNTL	LOAEL		3	d	8.97		ae kg/ha	100	71381
Glyphosate	Epilobium	nummulariifolium	Creeping Willow Herb	POP	POP	INDX	NOAEL		49	d	0.64224		lb/acre	100	120532
Glyphosate	Veronica	filiformis	Whetzel Weed	POP	POP	INDX	LOAEL		49	d	0.48168		lb/acre	100	120532
Glyphosate	Ranunculus	repens	Creeping Buttercup	POP	POP	INDX	LOAEL		49	d	0.48168		lb/acre	100	120532
Glyphosate isopropylamine salt	Dichondra	micrantha	Dichondra	POP	POP	ABND	LOAEL		4.9	d	0.48168		lb/acre	100	120479
Glyphosate isopropylamine salt	Dichondra	micrantha	Dichondra	POP	POP	ABND	NOAEL		126	d	0.48168		lb/acre	100	120479
Glyphosate	Brassica	napus	Colza	POP	POP	PGRT	IC50		8	d	0.0005		M	100	78497
Glyphosate	Zea	mays	Corn	POP	POP	PGRT	IC50		8	d	0.0003		M	100	78497
Glyphosate monosodium salt	Chlorella	sp.	Green Algae	POP	POP	CHLO	IC10		0.0833	d	450		mg/L	100	118972
Glyphosate monosodium salt	NR	Trebouxiophyceae	Algae Class	POP	POP	CHLO	IC10		0.0833	d	4700		mg/L	100	118972
Glyphosate monosodium salt	Neochloris	sp.	Green Algae	POP	POP	CHLO	IC10		0.0833	d	3600		mg/L	100	118972
Glyphosate monosodium salt	NR	Trebouxiophyceae	Algae Class	POP	POP	CHLO	IC10		0.0833	d	4000		mg/L	100	118972

Glyphosate isopropylamine salt	Neochetina	eichhorniae	Weevil	POP	POP	ABND	NOAEL		60	d	0.11		AI g/m2	100	115186
Glyphosate isopropylamine salt	Neochetina	eichhorniae	Weevil	BEH	FDB	FDNG	LOAEL		60	d	0.11		AI g/m2	100	115186
Glyphosate isopropylamine salt	Neochetina	eichhorniae	Weevil	POP	POP	ABND	NOAEL		60	d	0.11		AI g/m2	100	115186
Glyphosate isopropylamine salt	Neochetina	eichhorniae	Weevil	POP	POP	ABND	NOAEL		60	d	0.11		AI g/m2	100	115186
Glyphosate isopropylamine salt	Eichhornia	crassipes	Water-Hyacinth	REP	REP	VEGR	NOAEL	LOAEL	56	d	0.07	0.11	AI g/m2	100	115186
Glyphosate isopropylamine salt	Eichhornia	crassipes	Water-Hyacinth	GRO	DVP	STGE	NOAEL	LOAEL	56	d	0.04	0.07	AI g/m2	100	115186
Glyphosate isopropylamine salt	Eichhornia	crassipes	Water-Hyacinth	GRO	GRO	NLEF	NOAEL	LOAEL	56	d	0.04	0.07	AI g/m2	100	115186
Glyphosate isopropylamine salt	Neochetina	bruchi	Water Hyacinth Weevil	POP	POP	ABND	NOAEL		60	d	0.11		AI g/m2	100	115186
Glyphosate isopropylamine salt	Neochetina	bruchi	Water Hyacinth Weevil	BEH	FDB	FDNG	LOAEL		60	d	0.11		AI g/m2	100	115186
Glyphosate isopropylamine salt	Neochetina	bruchi	Water Hyacinth Weevil	POP	POP	ABND	NOAEL		60	d	0.11		AI g/m2	100	115186
Glyphosate isopropylamine salt	Neochetina	bruchi	Water Hyacinth Weevil	POP	POP	ABND	NOAEL		60	d	0.11		AI g/m2	100	115186
Glyphosate isopropylamine salt	Eichhornia	crassipes	Water-Hyacinth	MOR	MOR	MORT	NR-LETH		60	d	0.21		AI g/m2	100	115186
Glyphosate isopropylamine salt	Eichhornia	crassipes	Water-Hyacinth	MOR	MOR	MORT	NR-ZERO		60	d	0.11		AI g/m2	100	115186
Glyphosate	NR	Annelida	Segmented Worm Phylum	POP	POP	ABND	NOAEL		730	d	900		AI g/ha	100	52153
Glyphosate isopropylamine salt	Aedes	aegypti	Yellow Fever Mosquito	BCM	ENZ	P450	NOAEL		3	d	0.1691		mg/L	100	117853
Glyphosate isopropylamine salt	Aedes	aegypti	Yellow Fever Mosquito	BCM	ENZ	GSTR	NOAEL		3	d	0.1691		mg/L	100	117853

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Chemical	Genus	Species	Common						Dur		Value		Unit		ID
Glyphosate isopropylamine salt	Aedes	aegypti	Yellow Fever Mosquito	CEL	GEN	GEXP	NOAEL		3	d	0.1691		mg/L	100	117853
Glyphosate isopropylamine salt	Aedes	aegypti	Yellow Fever Mosquito	CEL	GEN	GEXP	LOAEL		3	d	0.1691		mg/L	100	117853
Glyphosate isopropylamine salt	Aedes	aegypti	Yellow Fever Mosquito	BCM	ENZ	ESTE	LOAEL		3	d	0.1691		mg/L	100	117853
Glyphosate isopropylamine salt	Aedes	aegypti	Yellow Fever Mosquito	BCM	ENZ	ESTE	NOAEL		3	d	0.1691		mg/L	100	117853
Glyphosate isopropylamine salt	Juniperus	pinchotii	Juniper, Redb	MOR	MOR	MORT	LOAEL		365.28	d	0.5		AI %	100	41265
Glyphosate isopropylamine salt	Juniperus	pinchotii	Juniper, Redb	MOR	MOR	MORT	LOAEL		487.04	d	0.5		AI %	100	41265
Glyphosate isopropylamine salt	Juniperus	pinchotii	Juniper, Redb	MOR	MOR	MORT	LOAEL		761	d	0.5		AI %	100	41265
Glyphosate isopropylamine salt	Juniperus	pinchotii	Juniper, Redb	MOR	MOR	MORT	LOAEL		91.32	d	0.5		AI %	100	41265
Glyphosate, Monopotassium salt	Beta	vulgaris ssp. vulgaris	Beet	BCM	BCM	GBCM	LOAEL		3	d	0.84		ae kg/ha	100	97121
Glyphosate, Monopotassium salt	Beta	vulgaris ssp. vulgaris	Beet	BCM	BCM	GBCM	LOAEL		3	d	0.84		ae kg/ha	100	97121
Glyphosate, Monopotassium salt	Beta	vulgaris ssp. vulgaris	Beet	BCM	BCM	GBCM	LOAEL		7	d	0.84		ae kg/ha	100	97121
Glyphosate, Monopotassium salt	Fusarium	oxysporum	Fungi	POP	POP	CNTL	LOAEL		1	d	0.84		ae kg/ha	100	97121
Glyphosate, Monopotassium salt	Thanatephorus	cucumeris	Fungi	POP	POP	CNTL	NOAEL		9	d	0.84		ae kg/ha	100	97121
Glyphosate, Monopotassium salt	Thanatephorus	cucumeris	Fungi	POP	POP	CNTL	LOAEL		1	d	0.84		ae kg/ha	100	97121
Glyphosate, Monopotassium salt	Fusarium	oxysporum	Fungi	POP	POP	CNTL	LOAEL		1	d	0.84		ae kg/ha	100	97121

Glyphosate, Monopotassium salt	Thanate phorus	cucumeris	Fungi	POP	POP	CNTL	NOAEL		9	d	0.84		ae kg/ha	100	97121
Glyphosate, Monopotassium salt	Thanate phorus	cucumeris	Fungi	POP	POP	CNTL	NOAEL		9	d	0.84		ae kg/ha	100	97121
Glyphosate, Monopotassium salt	Beta	vulgaris ssp. vulgaris	Beet	PHY	INJ	GINJ	NOAEL		42	d	0.84		ae kg/ha	100	97121
Glyphosate, Monopotassium salt	Beta	vulgaris ssp. vulgaris	Beet	PHY	INJ	GINJ	NOAEL		42	d	0.84		ae kg/ha	100	97121
Glyphosate, Monopotassium salt	Beta	vulgaris ssp. vulgaris	Beet	PHY	INJ	GINJ	NOAEL		42	d	0.84		ae kg/ha	100	97121
Glyphosate isopropylamine salt	Ceriodap hnia	dubia	Water Flea	MOR	MOR	MORT	LC50		1	d	6000		ae ug/L	41	87704
Glyphosate	Thanate phorus	cucumeris	Fungi	POP	POP	ABND	NOAEL		28	d	1.49856		lb/acre	100	59458
Glyphosate	Thanate phorus	cucumeris	Fungi	REP	REP	GERM	NOAEL	LOAEL	28	d	0.74928	1.49856	lb/acre	100	59458
Glyphosate	Thanate phorus	cucumeris	Fungi	POP	POP	ABND	LOAEL		42	d	0.37464		lb/acre	100	59458
Glyphosate	Thanate phorus	cucumeris	Fungi	REP	REP	GERM	NOAEL		42	d	1.49856		lb/acre	100	59458
Glyphosate	Thanate phorus	cucumeris	Fungi	POP	POP	ABND	NOAEL		28	d	0.74928		lb/acre	100	59458
Glyphosate	Thanate phorus	cucumeris	Fungi	REP	REP	GERM	NOAEL		28	d	0.74928		lb/acre	100	59458
Glyphosate	Thanate phorus	cucumeris	Fungi	POP	POP	ABND	NOAEL		42	d	1.49856		lb/acre	100	59458
Glyphosate	Thanate phorus	cucumeris	Fungi	REP	REP	GERM	NOAEL		42	d	1.49856		lb/acre	100	59458
Glyphosate	Thanate phorus	cucumeris	Fungi	POP	POP	ABND	NOAEL		42	d	1.49856		lb/acre	100	59458
Glyphosate	Thanate phorus	cucumeris	Fungi	REP	REP	GERM	NOAEL		42	d	1.49856		lb/acre	100	59458
Glyphosate isopropylamine salt	Sclerotin ia	sclerotioru m	Fungus	REP	REP	GERM	NOAEL		28	d	0.89		lb/acre	100	70745
Glyphosate isopropylamine salt	Sclerotin ia	sclerotioru m	Fungus	REP	REP	GERM	NOAEL		28	d	0.89		lb/acre	100	70745
Glyphosate	Kalmia	angustifolia	Sheep Laurel	POP	POP	ABND	NOAEL		273.96	d	2.99712		lb/acre	100	116216

Glyphosate	Kalmia	angustifolia	Sheep Laurel	GRO	MPH	LGTH	NOAEL		273.96 d		2.99712		lb/acre	100	116216
Glyphosate	Kalmia	angustifolia	Sheep Laurel	POP	POP	ABND	LOAEL		273.96 d		2.56896		lb/acre	100	116216
Glyphosate	Kalmia	angustifolia	Sheep Laurel	GRO	MPH	LGTH	NOAEL		273.96 d		2.56896		lb/acre	100	116216
Glyphosate	Kalmia	angustifolia	Sheep Laurel	POP	POP	ABND	NOAEL		273.96 d		2.56896		lb/acre	100	116216
Glyphosate	Kalmia	angustifolia	Sheep Laurel	GRO	MPH	LGTH	NOAEL		273.96 d		2.56896		lb/acre	100	116216
Glyphosate isopropylamine salt	Calocoris	norvegicus	Strawberry Bug	MOR	MOR	MORT	NOAEL		0.5 d		1.8		AI ug/org	100	91087
Glyphosate isopropylamine salt	Adenostoma	fasciculatum	Chamise	POP	POP	ABND	LOAEL		2920 d		2.2		ae kg/ha	100	44103
Glyphosate isopropylamine salt	Adenostoma	fasciculatum	Chamise	REP	REP	SEED	NOAEL		2920 d		4.5		ae kg/ha	100	44103
Glyphosate isopropylamine salt	Quercus	dumosa	Coastal Sage Scrub Oak	POP	POP	COVR	NOAEL		730 d		4.5		ae kg/ha	100	44103
Glyphosate isopropylamine salt	Quercus	dumosa	Coastal Sage Scrub Oak	POP	POP	ABND	NOAEL		730 d		4.5		ae kg/ha	100	44103
Glyphosate isopropylamine salt	Quercus	dumosa	Coastal Sage Scrub Oak	POP	POP	ABND	LOAEL		2920 d		4.5		ae kg/ha	100	44103
Glyphosate isopropylamine salt	Quercus	dumosa	Coastal Sage Scrub Oak	POP	POP	ABND	NOAEL		2920 d		2.2		ae kg/ha	100	44103
Glyphosate isopropylamine salt	Quercus	dumosa	Coastal Sage Scrub Oak	POP	POP	COVR	NOAEL		2920 d		2.2		ae kg/ha	100	44103
Glyphosate isopropylamine salt	Quercus	dumosa	Coastal Sage Scrub Oak	POP	POP	COVR	LOAEL		2920 d		4.5		ae kg/ha	100	44103
Glyphosate isopropylamine salt	Adenostoma	fasciculatum	Chamise	POP	POP	ABND	LOAEL		730 d		2.2		ae kg/ha	100	44103
Glyphosate isopropylamine salt	Adenostoma	fasciculatum	Chamise	POP	POP	COVR	LOAEL		730 d		2.2		ae kg/ha	100	44103
Glyphosate isopropylamine salt	Adenostoma	fasciculatum	Chamise	POP	POP	COVR	LOAEL		2920 d		2.2		ae kg/ha	100	44103
Glyphosate	Mus	musculus	House Mouse	CEL	CEL	NCCM	NOAEL		90 d		5		%	100	116496

Chemical	Genus	Species	Common Name						Dur	Unit	Val1	Val2	Units	%	Ref
Glyphosate isopropylamine salt	Simocephalus	vetulus	Water Flea	MOR	MOR	MORT	NR-LETH		21	d	1.5		ae mg/L	100	72794
Glyphosate isopropylamine salt	NR	Fungi	Fungi Kingdom	POP	POP	ABND	NOAEL		426.16	d	2.88116		lb/acre	100	48089
Glyphosate isopropylamine salt	NR	Fungi	Fungi Kingdom	POP	POP	ABND	NOAEL		365.28	d	2.88116		lb/acre	100	48089
Glyphosate isopropylamine salt	NR	Fungi	Fungi Kingdom	POP	POP	ABND	NOAEL		304.4	d	2.88116		lb/acre	100	48089
Glyphosate	Pinus	banksiana	Jack Pine	GRO	GRO	HGHT	NOAEL	LOAEL	1460	d	1.784	3.568	lb/acre	100	31942
Glyphosate	Pinus	banksiana	Jack Pine	GRO	GRO	HGHT	NOAEL	LOAEL	1095	d	0.892	1.784	lb/acre	100	31942
Glyphosate	Acacia	farnesiana	Cassie	POP	POP	COVR	NOAEL	LOAEL		d	0.12488	0.24976	lb/acre	100	115987
Glyphosate	Prosopis	juliflora	Mesquite	POP	POP	COVR	NOAEL	LOAEL		d	0.12488	0.24976	lb/acre	100	115987
Glyphosate	Aloysia	gratissima	Whitebrush	POP	POP	COVR	LOAEL			d	0.49952		lb/acre	100	115987
Glyphosate	Quercus	virginiana	Live Oak	POP	POP	COVR	NOAEL			d	1.99808		lb/acre	100	115987
Glyphosate isopropylamine salt	Rattus	norvegicus	Norway Rat	GRO	MPH	SMIX	NOAEL			d	450		mg/kg bdwt	100	106280
Glyphosate isopropylamine salt	Rattus	norvegicus	Norway Rat	GRO	GRO	GAIN	NOAEL		21	d	450		mg/kg bdwt	100	106280
Glyphosate isopropylamine salt	Rattus	norvegicus	Norway Rat	POP	POP	SEXR	NOAEL		21	d	450		mg/kg bdwt	100	106280
Glyphosate isopropylamine salt	Rattus	norvegicus	Norway Rat	GRO	DVP	SXDP	LOAEL		58.6	d	50		mg/kg bdwt	100	106280
Glyphosate isopropylamine salt	Rattus	norvegicus	Norway Rat	BCM	HRM	TSTR	NOAEL	LOAEL		d	150	450	mg/kg bdwt	100	106280
Glyphosate isopropylamine salt	Rattus	norvegicus	Norway Rat	REP	REP	SPCL	NOAEL			d	450		mg/kg bdwt	100	106280
Glyphosate isopropylamine salt	Rattus	norvegicus	Norway Rat	MOR	MOR	MORT	NR-ZERO			d	450		mg/kg bdwt	100	106280
Glyphosate isopropylamine salt	Rattus	norvegicus	Norway Rat	GRO	DVP	SXDP	NOAEL	LOAEL		d	150	450	mg/kg bdwt	100	106280
Glyphosate	Oryza	sativa	Rice	POP	POP	ABND	LOAEL		1	gs	1.8		AI kg/ha	100	95840
Glyphosate	Oryza	sativa	Rice	POP	POP	BMAS	NOAEL		1	hv	1.8		AI kg/ha	100	95840
Glyphosate	Rosa	bracteata	Macartney Rose	PHY	INJ	DAMG	NOAEL		365	d	4.014		lb/acre	100	44158

Glyphosate	Rosa	bracteata	Macartney Rose	POP	POP	COVR	LOAEL		365	d	4.014		lb/acre	100	44158
Glyphosate	Rosa	bracteata	Macartney Rose	PHY	INJ	DAMG	NOAEL		730	d	4.014		lb/acre	100	44158
Glyphosate	Rosa	bracteata	Macartney Rose	POP	POP	COVR	LOAEL		730	d	4.014		lb/acre	100	44158
Glyphosate	Rosa	bracteata	Macartney Rose	PHY	INJ	DAMG	NOAEL		1095	d	4.014		lb/acre	100	44158
Glyphosate	Rosa	bracteata	Macartney Rose	POP	POP	COVR	NOAEL		1095	d	4.014		lb/acre	100	44158
Glyphosate	Rosa	bracteata	Macartney Rose	PHY	INJ	DAMG	NOAEL			d	4.014		lb/acre	100	44158
Glyphosate	Rosa	bracteata	Macartney Rose	POP	POP	COVR	NOAEL			d	4.014		lb/acre	100	44158
Glyphosate	NR	Poaceae	Grass Family	POP	POP	COVR	NOAEL		365	d	4.014		lb/acre	100	44158
Glyphosate	NR	Poaceae	Grass Family	POP	POP	COVR	NOAEL		730	d	4.014		lb/acre	100	44158
Glyphosate	NR	Poaceae	Grass Family	POP	POP	COVR	LOAEL		91.32	d	1.9624		lb/acre	100	44158
Glyphosate	NR	Plantae	Plant Kingdom	POP	POP	COVR	LOAEL		91.32	d	1.9624		lb/acre	100	44158
Glyphosate isopropylamine salt	Adenostoma	fasciculatum	Chamise	PHY	INJ	GINJ	LOAEL		700.12	d	2.99712		lb/acre	100	41472
Glyphosate isopropylamine salt	Adenostoma	fasciculatum	Chamise	PHY	INJ	GINJ	LOAEL		852.32	d	2.99712		lb/acre	100	41472
Glyphosate isopropylamine salt	Adenostoma	fasciculatum	Chamise	POP	POP	CNTL	LOAEL		1339.36	d	2.99712		lb/acre	100	41472
Glyphosate isopropylamine salt	Adenostoma	fasciculatum	Chamise	POP	POP	COVR	LOAEL		1339.36	d	2.99712		lb/acre	100	41472
Glyphosate isopropylamine salt	Adenostoma	fasciculatum	Chamise	POP	POP	CNTL	LOAEL		1491.56	d	2.99712		lb/acre	100	41472
Glyphosate isopropylamine salt	Adenostoma	fasciculatum	Chamise	POP	POP	COVR	LOAEL		1491.56	d	2.99712		lb/acre	100	41472
Glyphosate isopropylamine salt	Adenostoma	sparsifolium	Redshank	POP	POP	COVR	NOAEL		456.6	d	3.99616		lb/acre	100	41472
Glyphosate isopropylamine salt	Adenostoma	sparsifolium	Redshank	PHY	INJ	GINJ	LOAEL		365.28	d	1.99808		lb/acre	100	41472
Glyphosate isopropylamine salt	Adenostoma	sparsifolium	Redshank	POP	POP	CNTL	NOAEL		639.24	d	1.99808		lb/acre	100	41472

Glyphosate isopropylamine salt	Adenostoma	sparsifolium	Redshank	POP	POP	CNTL	LOAEL		639.24	d	3.99616		lb/acre	100	41472
Glyphosate isopropylamine salt	Adenostoma	sparsifolium	Redshank	POP	POP	COVR	LOAEL		639.24	d	3.99616		lb/acre	100	41472
Glyphosate isopropylamine salt	Adenostoma	sparsifolium	Redshank	POP	POP	COVR	NOAEL		639.24	d	1.99808		lb/acre	100	41472
Glyphosate isopropylamine salt	Adenostoma	fasciculatum	Chamise	PHY	INJ	GINJ	LOAEL		365.28	d	1.99808		lb/acre	100	41472
Glyphosate isopropylamine salt	Adenostoma	fasciculatum	Chamise	POP	POP	CNTL	LOAEL		639.24	d	1.99808		lb/acre	100	41472
Glyphosate isopropylamine salt	Adenostoma	fasciculatum	Chamise	POP	POP	COVR	LOAEL		639.24	d	1.99808		lb/acre	100	41472
Glyphosate isopropylamine salt	Adenostoma	fasciculatum	Chamise	PHY	INJ	GINJ	LOAEL		365.28	d	1.99808		lb/acre	100	41472
Glyphosate isopropylamine salt	Adenostoma	fasciculatum	Chamise	PHY	INJ	GINJ	LOAEL		426.16	d	1.99808		lb/acre	100	41472
Glyphosate isopropylamine salt	Adenostoma	fasciculatum	Chamise	POP	POP	COVR	LOAEL		456.6	d	1.99808		lb/acre	100	41472
Glyphosate isopropylamine salt	Adenostoma	fasciculatum	Chamise	POP	POP	CNTL	LOAEL		456.6	d	1.99808		lb/acre	100	41472
Glyphosate isopropylamine salt	Adenostoma	fasciculatum	Chamise	POP	POP	CNTL	LOAEL		608.8	d	1.99808		lb/acre	100	41472
Glyphosate isopropylamine salt	Adenostoma	fasciculatum	Chamise	POP	POP	COVR	LOAEL		608.8	d	1.99808		lb/acre	100	41472
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	HRM	CRTS	NOAEL		4	d	1.2118		mg/L	100	112903
Glyphosate	Gossypium	sp.	Cotton	PHY	INJ	DAMG	NOAEL		14	d	870		ae g/ha	100	110909
Glyphosate	Gossypium	sp.	Cotton	PHY	INJ	DAMG	NOAEL		7	d	870		ae g/ha	100	110909
Glyphosate	Gossypium	sp.	Cotton	POP	POP	BMAS	NOAEL			hv	870		ae g/ha	100	110909
Glyphosate	Gossypium	sp.	Cotton	POP	POP	BMAS	NOAEL			hv	870		ae g/ha	100	110909

Glyphosate isopropylamine salt	Beauveria	bassiana	Fungus	GRO	GRO	WGHT	LOAEL		7	d	12000		ppm	100	70790
Glyphosate isopropylamine salt	Beauveria	bassiana	Fungus	GRO	GRO	WGHT	NOAEL		7	d	6000		ppm	100	70790
Glyphosate isopropylamine salt	Beauveria	bassiana	Fungus	REP	REP	GERM	NOAEL		1	d	30000		ppm	100	70790
Glyphosate	Vicia	faba	Broadbean	POP	POP	BMAS	NOAEL		2	gs	12.6		ml/100 L	36	95836
Glyphosate	Vicia	faba	Broadbean	BCM	BCM	DRYM	NOAEL			hv	12.6		ml/100 L	36	95836
Glyphosate	Vicia	faba	Broadbean	GRO	GRO	HGHT	NOAEL			hv	12.6		ml/100 L	36	95836
Glyphosate	Vicia	faba	Broadbean	GRO	MPH	LGTH	LOAEL			hv	12.6		ml/100 L	36	95836
Glyphosate	Botrytis	fabae	Fungus	POP	POP	ABND	LOAEL			hv	12.6		ml/100 L	36	95836
Glyphosate isopropylamine salt	Cyperus	esculentus	Yellow Nutsedge	GRO	GRO	WGHT	LOAEL		28	d	0.84		ae kg/ha	100	120063
Glyphosate isopropylamine salt	Rana	cascadae	Cascades Frog	GRO	DVP	EMRG	LOAEL		34	d	0.96		mg/L	50.2	96423
Glyphosate isopropylamine salt	Rana	cascadae	Cascades Frog	GRO	DVP	MMPH	LOAEL		33	d	0.96		mg/L	50.2	96423
Glyphosate isopropylamine salt	Rana	cascadae	Cascades Frog	GRO	DVP	MMPH	LOAEL		30	d	0.96		mg/L	50.2	96423
Glyphosate isopropylamine salt	Rana	cascadae	Cascades Frog	GRO	GRO	BMAS	LOAEL		43	d	0.96		mg/L	50.2	96423
Glyphosate isopropylamine salt	Rana	cascadae	Cascades Frog	MOR	MOR	MORT	NR-LETH		43	d	1.94		mg/L	50.2	96423
Glyphosate	Citrus	sp.	Citrus	PHY	INJ	DAMG	NOAEL		28	d	4.014		lb/acre	100	43582
Glyphosate	Citrus	sp.	Citrus	PHY	INJ	DAMG	NOAEL		189	d	4.014		lb/acre	100	43582
Glyphosate	Derocceras	reticulatum	Grey Field Slug	MOR	MOR	MORT	NOAEL		10	d	1.4		AI %	100	79821
Glyphosate	Derocceras	panormitanum	Longneck Fieldslug	MOR	MOR	MORT	NOAEL		10	d	1.4		AI %	100	79821
Glyphosate	Derocceras	reticulatum	Grey Field Slug	MOR	MOR	MORT	NOAEL		10	d	2.2		kg/ha	100	79821
Glyphosate	Derocceras	panormitanum	Longneck Fieldslug	MOR	MOR	MORT	NOAEL		10	d	2.2		kg/ha	100	79821
Glyphosate isopropylamine salt	NR	Plantae	Plant Kingdom	PHY	INJ	DAMG	LOAEL		60.88	d	1.6056		lb/acre	36	116055

Glyphosate isopropylamine salt	Rumex	acetosella	Field Sorrel	POP	POP	ABND	LOAEL		60.88	d	1.6056		lb/acre	36	116055
Glyphosate isopropylamine salt	Oryctolagus	cuniculus	European Rabbit	POP	POP	INDX	NOAEL		943.64	d	1.8		AI kg/ha	36	116055
Glyphosate isopropylamine salt	Calluna	vulgaris	Heather	PHY	INJ	DAMG	LOAEL		60.88	d	1.6056		lb/acre	36	116055
Glyphosate	Myriophyllum	aquaticum	Parrot Feather Watermilfoil	BCM	BCM	CHLA	LOAEL		14	d	0.168744		mg/L	35.6	105140
Glyphosate	Myriophyllum	aquaticum	Parrot Feather Watermilfoil	BCM	BCM	CHLB	LOAEL		14	d	0.168744		mg/L	35.6	105140
Glyphosate	Myriophyllum	aquaticum	Parrot Feather Watermilfoil	BCM	BCM	CARC	LOAEL		14	d	0.168744		mg/L	35.6	105140
Glyphosate	Myriophyllum	aquaticum	Parrot Feather Watermilfoil	GRO	GRO	LGTH	NOAEL		14	d	0.168744		mg/L	35.6	105140
Glyphosate isopropylamine salt	Fragaria	sp.	Strawberry	GRO	GRO	WGHT	LOAEL		60.88	d	0.16056		lb/acre	36	40855
Glyphosate	Lotus	pedunculatus	Big Trefoil	PHY	INJ	DAMG	LOAEL		49	d	0.64224		lb/acre	100	70295
Glyphosate	Trifolium	repens	Dutch Clover	PHY	INJ	DAMG	NOAEL	LOAEL	49	d	0.32112	0.64224	lb/acre	100	70295
Glyphosate	Hydrocotyle	heteromeria	Waxweed	PHY	INJ	DAMG	NOAEL		49	d	0.48168		lb/acre	100	70295
Glyphosate	Dichondra	micrantha	Dichondra	PHY	INJ	DAMG	NOAEL		56	d	0.48168		lb/acre	100	70295
Glyphosate	Agrostis	castellana	Bentgrass	PHY	INJ	DAMG	LOAEL		49	d	0.48168		lb/acre	100	70295
Glyphosate	Centella	asiatica	Asiatic Pennywort	PHY	INJ	DAMG	NOAEL		49	d	0.48168		lb/acre	100	70295
Glyphosate	Dichondra	micrantha	Dichondra	PHY	INJ	DAMG	NOAEL		49	d	0.48168		lb/acre	100	70295
Glyphosate	Festuca	rubra	Ravine Fescue	PHY	INJ	DAMG	LOAEL		49	d	0.48168		lb/acre	100	70295
Glyphosate	Festuca	trachyphylla	Hard Fescue	PHY	INJ	DAMG	NOAEL		49	d	0.48168		lb/acre	100	70295
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	MOR	MOR	MORT	LC50		4	d			mg/L	100	111445
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	MOR	MOR	MORT	LC50		1	d			mg/L	100	111445
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	MOR	MOR	MORT	LC50		0.25	d	20		mg/L	100	111445

Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	CEL	HIS	GHIS	NOAEL	LOAEL	4	d	7.5	10	mg/L	100	111445
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	BCM	GLUC	NOAEL	LOAEL	4	d	7.5	10	mg/L	100	111445
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	BCM	GLUC	NOAEL	LOAEL	1	d	7.5	10	mg/L	100	111445
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	BCM	NACO	NOAEL		4	d	10		mg/L	100	111445
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	BCM	CLCO	NOAEL		4	d	10		mg/L	100	111445
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	PHY	PHY	OSML	NOAEL	LOAEL	1	d	7.5	10	mg/L	100	111445
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	PHY	PHY	OSML	NOAEL		0.25	d	10		mg/L	100	111445
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	PHY	PHY	OSML	NOAEL		4	d	10		mg/L	100	111445
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	ENZ	GSTR	NOAEL		1	d	10		mg/L	100	111445
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	BCM	NACO	NOAEL		0.25	d	10		mg/L	100	111445
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	BCM	NACO	NOAEL		1	d	10		mg/L	100	111445
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	ENZ	GSTR	NOAEL		4	d	10		mg/L	100	111445
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	HRM	CRTS	NOAEL		4	d	10		mg/L	100	111445
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	ENZ	GSTR	NOAEL		0.25	d	10		mg/L	100	111445
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	ENZ	CTLS	NOAEL		0.25	d	10		mg/L	100	111445

Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	ENZ	CTLS	NOAEL		4	d	10		mg/L	100	111445
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	ENZ	CTLS	NOAEL	LOAEL	4	d	7.5	10	mg/L	100	111445
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	CEL	HIS	GHIS	LOAEL		1	d	7.5		mg/L	100	111445
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	CEL	HIS	GHIS	NOAEL	LOAEL	0.25	d	7.5	10	mg/L	100	111445
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	HRM	CRTS	NOAEL		0.25	d	10		mg/L	100	111445
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	BCM	GLUC	NOAEL		0.25	d	10		mg/L	100	111445
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	HRM	CRTS	NOAEL		1	d	10		mg/L	100	111445
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	BCM	CLCO	NOAEL		0.25	d	10		mg/L	100	111445
Glyphosate isopropylamine salt	Prochilo dus	lineatus	Curimbata	BCM	BCM	CLCO	NOAEL	LOAEL	1	d	7.5	10	mg/L	100	111445
Glyphosate isopropylamine salt	Procamb arus	sp.	Crayfish	MOR	MOR	MORT	LC50		2	d	32650		mg/L	35.6	46779
Glyphosate isopropylamine salt	Lepomis	macrochirus	Bluegill	MOR	MOR	MORT	LC50		2	d	4.5		mg/L	35.6	46779
Glyphosate isopropylamine salt	Ictalurus	punctatus	Channel Catfish	MOR	MOR	MORT	LC50		2	d	5.5		mg/L	35.6	46779
Glyphosate isopropylamine salt	Pseudoki rchneriel la	subcapitata	Green Algae	POP	POP	PGRT	EC50		4	d	71		mg/L	100	118717
Glyphosate isopropylamine salt	Daphnia	magna	Water Flea	PHY	ITX	IMBL	EC50		2	d	307		mg/L	100	118717
Glyphosate	Pseudoki rchneriel la	subcapitata	Green Algae	POP	POP	PGRT	EC50		4	d	129		mg/L	95	118717
Glyphosate	Daphnia	magna	Water Flea	PHY	ITX	IMBL	EC50		2	d	2000		mg/L	95	118717
Glyphosate	Eisenia	andrei	Earthworm	BEH	AVO	CHEM	NOAEL		2	d	8.49		AI kg/ha	95	118717

Glyphosate isopropylamine salt	Eisenia	andrei	Earthworm	BEH	AVO	CHEM	NOAEL		2	d	14.7		AI kg/ha	100	118717
Glyphosate isopropylamine salt	Rhinella	sp.	South American Toads	MOR	MOR	MORT	LC50		4	d	1500		ae ug/L	100	117668
Glyphosate isopropylamine salt	Rhinella	marina	Cane Toad	MOR	MOR	MORT	LC01		4	d	1578		ae ug/L	100	117668
Glyphosate isopropylamine salt	Rhinella	marina	Cane Toad	MOR	MOR	MORT	LC50		4	d	2733		ae ug/L	100	117668
Glyphosate isopropylamine salt	Dendrop sophus	microcephal us	Tree Frog	MOR	MOR	MORT	LC50		4	d	1200		ae ug/L	100	117668
Glyphosate isopropylamine salt	Scinax	ruber	Red Snouted Treefrog	MOR	MOR	MORT	LC01		4	d	1103		ae ug/L	100	117668
Glyphosate isopropylamine salt	Scinax	ruber	Red Snouted Treefrog	MOR	MOR	MORT	LC50		4	d	1642		ae ug/L	100	117668
Glyphosate isopropylamine salt	Hypsiboa s	crepitans	Emerald-Eyed Tree Frog	MOR	MOR	MORT	LC01		4	d	984		ae ug/L	100	117668
Glyphosate isopropylamine salt	Hypsiboa s	crepitans	Emerald-Eyed Tree Frog	MOR	MOR	MORT	LC50		4	d	2064		ae ug/L	100	117668
Glyphosate isopropylamine salt	Rhinella	granulosa	Toad	MOR	MOR	MORT	LC01		4	d	1300		ae ug/L	100	117668
Glyphosate isopropylamine salt	Rhinella	granulosa	Toad	MOR	MOR	MORT	LC50		4	d	2348		ae ug/L	100	117668
Glyphosate isopropylamine salt	Centrole ne	prosoblepo n	Glass Frog	MOR	MOR	MORT	LC01		4	d	1145		ae ug/L	100	117668
Glyphosate isopropylamine salt	Centrole ne	prosoblepo n	Glass Frog	MOR	MOR	MORT	LC50		4	d	2414		ae ug/L	100	117668
Glyphosate isopropylamine salt	Engysto mops	pustulosus	Tungara Frog	MOR	MOR	MORT	LC01		4	d	1514		ae ug/L	100	117668
Glyphosate isopropylamine salt	Engysto mops	pustulosus	Tungara Frog	MOR	MOR	MORT	LC50		4	d	2787		ae ug/L	100	117668

Glyphosate isopropylamine salt	Rhinella	marina	Cane Toad	MOR	MOR	MORT	NR-LETH		4	d	29.52		ae kg/ha	100	117666
Glyphosate isopropylamine salt	Rhinella	marina	Cane Toad	MOR	MOR	MORT	LC01		4	d	2.4		ae kg/ha	100	117666
Glyphosate isopropylamine salt	Rhinella	marina	Cane Toad	MOR	MOR	MORT	LC50		4	d	5963		ae ug/L	100	117666
Glyphosate isopropylamine salt	Scinax	ruber	Red Snouted Treefrog	MOR	MOR	MORT	NR-LETH		4	d	14.76		ae kg/ha	100	117666
Glyphosate isopropylamine salt	Scinax	ruber	Red Snouted Treefrog	MOR	MOR	MORT	LC50		4	d	6900		ae ug/L	100	117666
Glyphosate isopropylamine salt	Rhinella	granulosa	Toad	MOR	MOR	MORT	LC01		4	d	6.4		ae kg/ha	100	117666
Glyphosate isopropylamine salt	Rhinella	granulosa	Toad	MOR	MOR	MORT	LC50		4	d	7169		ae ug/L	100	117666
Glyphosate isopropylamine salt	Hypsiboas	crepitans	Emerald-Eyed Tree Frog	MOR	MOR	MORT	NR-LETH		4	d	29.52		ae kg/ha	100	117666
Glyphosate isopropylamine salt	Hypsiboas	crepitans	Emerald-Eyed Tree Frog	MOR	MOR	MORT	LC01		4	d	4.8		ae kg/ha	100	117666
Glyphosate isopropylamine salt	Hypsiboas	crepitans	Emerald-Eyed Tree Frog	MOR	MOR	MORT	LC50		4	d	7303		ae ug/L	100	117666
Glyphosate isopropylamine salt	Hypsiboas	crepitans	Emerald-Eyed Tree Frog	MOR	MOR	MORT	NR-ZERO		4	d	1.85		ae kg/ha	100	117666
Glyphosate isopropylamine salt	Centrolene	prosoblepon	Glass Frog	MOR	MOR	MORT	NR-ZERO		4	d	1.85		ae kg/ha	100	117666
Glyphosate isopropylamine salt	Centrolene	prosoblepon	Glass Frog	MOR	MOR	MORT	NR-LETH		4	d	14.76		ae kg/ha	100	117666
Glyphosate isopropylamine salt	Centrolene	prosoblepon	Glass Frog	MOR	MOR	MORT	LC01		4	d	1.97		ae kg/ha	100	117666
Glyphosate isopropylamine salt	Centrolene	prosoblepon	Glass Frog	MOR	MOR	MORT	LC50		4	d	4.5		ae kg/ha	100	117666

Glyphosate isopropylamine salt	Pristimantis	taeniatus	Frog	MOR	MOR	MORT	NR-ZERO			4	d	1.85		ae kg/ha	100	117666
Glyphosate isopropylamine salt	Pristimantis	taeniatus	Frog	MOR	MOR	MORT	LC01			4	d	1.93		ae kg/ha	100	117666
Glyphosate isopropylamine salt	Pristimantis	taeniatus	Frog	MOR	MOR	MORT	LC50			4	d	5.6		ae kg/ha	100	117666
Glyphosate isopropylamine salt	Rhinella	granulosa	Toad	MOR	MOR	MORT	NR-LETH			4	d	29.52		ae kg/ha	100	117666
Glyphosate isopropylamine salt	Rhinella	granulosa	Toad	MOR	MOR	MORT	LC50			4	d	6.5		ae kg/ha	100	117666
Glyphosate isopropylamine salt	Scinax	ruber	Red Snouted Treefrog	MOR	MOR	MORT	LC01			4	d	0.32		ae kg/ha	100	117666
Glyphosate isopropylamine salt	Scinax	ruber	Red Snouted Treefrog	MOR	MOR	MORT	LC50			4	d	7.3		ae kg/ha	100	117666
Glyphosate isopropylamine salt	Rhinella	sp.	South American Toads	MOR	MOR	MORT	LC01			4	d	1.56		ae kg/ha	100	117666
Glyphosate isopropylamine salt	Rhinella	sp.	South American Toads	MOR	MOR	MORT	LC50			4	d	14.8		ae kg/ha	100	117666
Glyphosate isopropylamine salt	Engystomops	pustulosus	Tungara Frog	MOR	MOR	MORT	NR-ZERO			4	d	7.38		ae kg/ha	100	117666
Glyphosate isopropylamine salt	Engystomops	pustulosus	Tungara Frog	MOR	MOR	MORT	LC01			4	d	7.02		ae kg/ha	100	117666
Glyphosate isopropylamine salt	Engystomops	pustulosus	Tungara Frog	MOR	MOR	MORT	LC50			4	d	19.6		ae kg/ha	100	117666
Glyphosate isopropylamine salt	Rhinella	marina	Cane Toad	MOR	MOR	MORT	LC01			4	d	5.08		ae kg/ha	100	117666
Glyphosate isopropylamine salt	Rhinella	marina	Cane Toad	MOR	MOR	MORT	LC50			4	d	22.8		ae kg/ha	100	117666
Glyphosate isopropylamine salt	Dendrobates	truncatus	Poison Dart Frog	MOR	MOR	MORT	NR-ZERO			4	d	7.38		ae kg/ha	100	117666

Glyphosate isopropylamine salt	Dendrobates	truncatus	Poison Dart Frog	MOR	MOR	MORT	LC01		4	d	7.38		ae kg/ha	100	117666
Glyphosate isopropylamine salt	Dendrobates	truncatus	Poison Dart Frog	MOR	MOR	MORT	LC50		4	d	7.38		ae kg/ha	100	117666
Glyphosate isopropylamine salt	Chordodes	nobilii	Horsehair Worm	POP	~POP	ABND	LOAEL			d	0.07		ae mg/L	35.2	111033
Glyphosate isopropylamine salt	Chordodes	nobilii	Horsehair Worm	POP	~POP	ABND	LOAEL		5	d	0.07		ae mg/L	35.2	111033
Glyphosate	Chordodes	nobilii	Horsehair Worm	POP	~POP	ABND	LOAEL			d	0.1		ae mg/L	95	111033
Glyphosate	Chordodes	nobilii	Horsehair Worm	POP	~POP	ABND	LOAEL		5	d	0.1		ae mg/L	95	111033
Glyphosate isopropylamine salt	Chordodes	nobilii	Horsehair Worm	MOR	MOR	MORT	LOAEL		4	d	1.76		ae mg/L	35.2	111033
Glyphosate isopropylamine salt	Bellis	perennis	English Daisy	GRO	MPH	WGHT	EC50		21	d	0.0126914		lb/acre	100	87923
Glyphosate isopropylamine salt	Centaurea	cyanus	Bachelor's-Button	GRO	MPH	WGHT	EC50		21	d	0.0259702		lb/acre	100	87923
Glyphosate isopropylamine salt	Inula	helenium	Elecampane Inula	GRO	MPH	WGHT	EC50		21	d	0.0386794		lb/acre	100	87923
Glyphosate isopropylamine salt	Rudbeckia	hirta	Blackeyed Susan	GRO	MPH	WGHT	EC50		21	d	0.021983		lb/acre	100	87923
Glyphosate isopropylamine salt	Solidago	canadensis	Canada Goldenrod	GRO	MPH	WGHT	EC50		21	d	0.0214134		lb/acre	100	87923
Glyphosate isopropylamine salt	Leonurus	cardiaca	Motherwort	GRO	MPH	WGHT	EC50		21	d	0.0318798		lb/acre	100	87923
Glyphosate isopropylamine salt	Mentha	spicata	Spearmint	GRO	MPH	WGHT	EC50		21	d	0.0159666		lb/acre	100	87923
Glyphosate isopropylamine salt	Nepeta	cataria	Catmint	GRO	MPH	WGHT	EC50		21	d	0.0353686		lb/acre	100	87923
Glyphosate isopropylamine salt	Prunella	vulgaris	Heal All	GRO	MPH	WGHT	EC50		21	d	0.02492		lb/acre	100	87923

Glyphosate isopropylamine salt	Fallopia	convolvulus	Black Bindweed	GRO	MPH	WGHT	EC50		21	d	0.0140264		lb/acre	100	87923
Glyphosate isopropylamine salt	Rumex	crispus	Curley Dock	GRO	MPH	WGHT	EC50		21	d	0.024475		lb/acre	100	87923
Glyphosate isopropylamine salt	Anagallis	arvensis	Pimpernel	GRO	MPH	WGHT	EC50		21	d	0.0155928		lb/acre	100	87923
Glyphosate isopropylamine salt	Digitalis	purpurea	Common Foxglove	GRO	MPH	WGHT	EC50		21	d	0.0575474		lb/acre	100	87923
Glyphosate isopropylamine salt	Sinapis	arvensis	California Rape	GRO	MPH	WGHT	EC50		21	d	0.0171592		lb/acre	100	87923
Glyphosate isopropylamine salt	Papaver	rhoeas	Corn Poppy	GRO	MPH	WGHT	EC50		21	d	0.0164828		lb/acre	100	87923
Glyphosate isopropylamine salt	Leonurus	cardiaca	Motherwort	GRO	GRO	GGRO, VGOR	LOEL		14	d	0.012816		lb/acre	100	87923
Glyphosate isopropylamine salt	Solidago	canadensis	Canada Goldenrod	GRO	GRO	GGRO, VGOR	LOEL		14	d	0.012816		lb/acre	100	87923
Glyphosate isopropylamine salt	Rudbeckia	hirta	Blackeyed Susan	GRO	GRO	GGRO, VGOR	LOEL		14	d	0.012816		lb/acre	100	87923
Glyphosate isopropylamine salt	Inula	helenium	Elecampane Inula	GRO	GRO	GGRO, VGOR	NOAEL	LOAEL	14	d	0.012816	0.12816	lb/acre	100	87923
Glyphosate isopropylamine salt	Centaurea	cyanus	Bachelor's-Button	GRO	GRO	GGRO, VGOR	NOAEL	LOAEL	14	d	0.012816	0.12816	lb/acre	100	87923
Glyphosate isopropylamine salt	Bellis	perennis	English Daisy	GRO	GRO	GGRO, VGOR	LOEL		14	d	0.012816		lb/acre	100	87923
Glyphosate isopropylamine salt	Sinapis	arvensis	California Rape	GRO	GRO	GGRO, VGOR	NOAEL	LOAEL	14	d	0.012816	0.12816	lb/acre	100	87923
Glyphosate isopropylamine salt	Papaver	rhoeas	Corn Poppy	GRO	GRO	GGRO, VGOR	LOEL		14	d	0.012816		lb/acre	100	87923
Glyphosate isopropylamine salt	Digitalis	purpurea	Common Foxglove	GRO	GRO	GGRO, VGOR	NOAEL	LOAEL	14	d	0.012816	0.12816	lb/acre	100	87923

Glyphosate isopropylamine salt	Anagallis	arvensis	Pimpernel	GRO	GRO	GGRO, VGOR	LOEL		14	d	0.012816		lb/acre	100	87923
Glyphosate isopropylamine salt	Rumex	crispus	Curley Dock	GRO	GRO	GGRO, VGOR	NOAEL	LOAEL	14	d	0.012816	0.12816	lb/acre	100	87923
Glyphosate isopropylamine salt	Fallopia	convolvulus	Black Bindweed	GRO	GRO	GGRO, VGOR	LOEL		14	d	0.012816		lb/acre	100	87923
Glyphosate isopropylamine salt	Prunella	vulgaris	Heal All	GRO	GRO	GGRO, VGOR	LOEL		14	d	0.012816		lb/acre	100	87923
Glyphosate isopropylamine salt	Nepeta	cataria	Catmint	GRO	GRO	GGRO, VGOR	LOEL		14	d	0.012816		lb/acre	100	87923
Glyphosate isopropylamine salt	Mentha	spicata	Spearmint	GRO	GRO	GGRO, VGOR	NOAEL	LOAEL	14	d	0.012816	0.12816	lb/acre	100	87923
Glyphosate	Planorbella	trivolvis	Snail, Marsh Rams-Horn	BEH	BEH	MIGR	NOAEL		28	d	3.7		mg/L	>98	112912
Glyphosate	Lithobates	clamitans ssp. clamitans	Bronze Frog	PHY	IMM	PRNF	LOAEL		15	d	3.7		mg/L	>98	112912
Glyphosate	Echinostoma	trivolvis	Trematode	BEH	BEH	PNPY	NOAEL		0.1667	d	3.7		mg/L	>98	112912
Glyphosate	Echinostoma	trivolvis	Trematode	MOR	MOR	LFSP	NOAEL		1.0833	d	3.7		mg/L	>98	112912
Glyphosate	Planorbella	trivolvis	Snail, Marsh Rams-Horn	REP	REP	PROG	NOAEL		28	d	3.7		mg/L	>98	112912
Glyphosate	Planorbella	trivolvis	Snail, Marsh Rams-Horn	GRO	GRO	GAIN	NOAEL		28	d	3.7		mg/L	>98	112912
Glyphosate	Lithobates	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	NOAEL		14	d	3.7		mg/L	>98	112912
Glyphosate	Lithobates	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	NOAEL		7	d	3.7		mg/L	>98	112912
Glyphosate	Planorbella	trivolvis	Snail, Marsh Rams-Horn	MOR	MOR	SURV	NOAEL		28	d	3.7		mg/L	>98	112912
Glyphosate isopropylamine salt	Abies	fraseri	Fraser Balsam Fir	GRO	MPH	LGTH	NOAEL		395.72	d	0.9968		lb/acre	100	118596
Glyphosate	Daucus	carota	Wild Carrot	PHY	INJ	GINJ	LOAEL		7	d	840		ae g/ha	100	117333
Glyphosate	Daucus	carota	Wild Carrot	GRO	GRO	BMAS	NOAEL		28	d	840		ae g/ha	100	117333
Glyphosate	Daucus	carota	Wild Carrot	POP	POP	CNTL	LOAEL		198	d	0.21		ae kg/ha	100	117333
Glyphosate	Daucus	carota	Wild Carrot	POP	POP	CNTL	LOAEL		198	d	0.21		ae kg/ha	100	117333
Glyphosate	Daucus	carota	Wild Carrot	POP	POP	CNTL	LOAEL		74	d	420		ae g/ha	100	117333

Chemical	Genus	Species	Common Name												
Glyphosate	Daucus	carota	Wild Carrot	POP	POP	CNTL	LOAEL		64	d	420		ae g/ha	100	117333
Glyphosate	Daucus	carota	Wild Carrot	POP	POP	CNTL	LOAEL		67	d	420		ae g/ha	100	117333
Glyphosate	Daucus	carota	Wild Carrot	POP	POP	CNTL	LOAEL		54	d	420		ae g/ha	100	117333
Glyphosate	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	NOEC		20	d	1000		ppm	100	150358
Glyphosate	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	EC50		20	d	1324		ppm	100	150358
Glyphosate	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	EC10		20	d	854		ppm	100	150358
Glyphosate	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	NOEC	LOEC	20	d	1782	3564	ppm	99	150358
Glyphosate	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	EC10		20	d	1249.38		ppm	99	150358
Glyphosate	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	EC50		20	d	1821.6		ppm	99	150358
Glyphosate	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	EC50		20	d	1178.1		ppm	99	150358
Glyphosate	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	EC10		20	d	724.68		ppm	99	150358
Glyphosate	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	NOEC		20	d	1386		ppm	99	150358
Glyphosate	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	NOEC		20	d	1782		ppm	99	150358
Glyphosate	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	EC10		20	d	1436.49		ppm	99	150358
Glyphosate	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	EC50		20	d	1564.2		ppm	99	150358
Glyphosate isopropylamine salt	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	EC50		20	d	18		ppm	100	150358
Glyphosate isopropylamine salt	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	EC10		20	d	1		ppm	100	150358
Glyphosate isopropylamine salt	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	NOEC	LOEC	20	d	45	225	ppm	100	150358
Glyphosate isopropylamine salt	Galaxias	anomalus	Roundhead Galaxias	PHY	IMM	PARA	NOAEL		26	d	0.36		AI mg/L	100	161707
Glyphosate isopropylamine salt	Galaxias	anomalus	Roundhead Galaxias	GRO	DVP	DFRM	NOAEL		26	d	0.36		AI mg/L	100	161707
Glyphosate isopropylamine salt	Galaxias	anomalus	Roundhead Galaxias	MOR	MOR	SURV	LOAEL		26	d	0.36		AI mg/L	100	161707

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Glyphosate isopropylamine salt	Potamop yrgus	antipodaru m	Snail	MOR	MOR	MORT	NR-ZERO		21	d	0.36		AI mg/L	100	161707
Glyphosate isopropylamine salt	Potamop yrgus	antipodaru m	Snail	MOR	MOR	MORT	NR-LETH		21	d	36		AI mg/L	100	161707
Glyphosate isopropylamine salt	Potamop yrgus	antipodaru m	Snail	PHY	IMM	PARA	NOAEL	LOAEL	21	d	0.36	3.6	AI mg/L	100	161707
Glyphosate isopropylamine salt	Galaxias	anomalus	Roundhead Galaxias	GRO	DVP	DFRM	NOAEL		26	d	0.36		AI mg/L	100	161707
Glyphosate isopropylamine salt	Galaxias	anomalus	Roundhead Galaxias	MOR	MOR	SURV	NOAEL		26	d	0.36		AI mg/L	100	161707
Glyphosate	Asclepias	syriaca	Common Milkweed	GRO	GRO	HGHT	LOAEL		65.8	d	1.1		ae kg/ha	100	150896
Glyphosate	Asclepias	syriaca	Common Milkweed	GRO	GRO	HGHT	NOAEL		49	d	1.1		ae kg/ha	100	150896
Glyphosate	Asclepias	syriaca	Common Milkweed	GRO	GRO	HGHT	LOAEL		65.8	d	1.1		ae kg/ha	100	150896
Glyphosate	Asclepias	syriaca	Common Milkweed	ACC	ACC	RSDE	NOAEL		6	d	1.1		ae kg/ha	100	150896
Glyphosate, Monopotassium salt	Spea	bombifrons	Plains Spadefoot	MOR	MOR	MORT	NR-LETH		11	d	2		ae mg/L	48.8	155517
Glyphosate, Monopotassium salt	Spea	bombifrons	Plains Spadefoot	MOR	MOR	MORT	NR-LETH		12	d	2		ae mg/L	48.8	155517
Glyphosate, Monopotassium salt	Spea	multiplicata	Mexican Spadefoot	MOR	MOR	MORT	NR-LETH		18	d	2		ae mg/L	48.8	155517
Glyphosate, Monopotassium salt	Spea	multiplicata	Mexican Spadefoot	MOR	MOR	MORT	NR-LETH		5	d	2.8		ae mg/L	48.8	155517
Glyphosate, Monopotassium salt	Spea	bombifrons	Plains Spadefoot	MOR	MOR	MORT	NR-ZERO		2	d	0.75		ae mg/L	48.8	155517
Glyphosate, Monopotassium salt	Spea	bombifrons	Plains Spadefoot	MOR	MOR	MORT	LC50		2	d	1.85		ae mg/L	48.8	155517
Glyphosate, Monopotassium salt	Spea	bombifrons	Plains Spadefoot	MOR	MOR	MORT	LC01		2	d	0.97		ae mg/L	48.8	155517
Glyphosate, Monopotassium salt	Spea	bombifrons	Plains Spadefoot	MOR	MOR	MORT	LC01		2	d	1.09		ae mg/L	48.8	155517

Glyphosate, Monopotassium salt	Spea	bombifrons	Plains Spadefoot	MOR	MOR	MORT	LC50		2	d	2.03		ae mg/L	48.8	155517
Glyphosate, Monopotassium salt	Spea	bombifrons	Plains Spadefoot	MOR	MOR	MORT	NR-ZERO		2	d	0.75		ae mg/L	48.8	155517
Glyphosate, Monopotassium salt	Spea	multiplicata	Mexican Spadefoot	MOR	MOR	MORT	LC50		2	d	2.3		ae mg/L	48.8	155517
Glyphosate, Monopotassium salt	Spea	multiplicata	Mexican Spadefoot	MOR	MOR	MORT	LC01		2	d	1.32		ae mg/L	48.8	155517
Glyphosate, Monopotassium salt	Spea	multiplicata	Mexican Spadefoot	MOR	MOR	MORT	NR-ZERO		2	d	0.75		ae mg/L	48.8	155517
Glyphosate, Monopotassium salt	Spea	multiplicata	Mexican Spadefoot	MOR	MOR	MORT	LC50		2	d	2.11		ae mg/L	48.8	155517
Glyphosate, Monopotassium salt	Spea	multiplicata	Mexican Spadefoot	MOR	MOR	MORT	LC01		2	d	1.01		ae mg/L	48.8	155517
Glyphosate, Monopotassium salt	Spea	multiplicata	Mexican Spadefoot	MOR	MOR	MORT	NR-ZERO		2	d	0.75		ae mg/L	48.8	155517
Glyphosate	Vicia	faba	Broadbean	CEL	GEN	MNUC	NOAEL		4	d	1400		ppm	21	153794
Glyphosate	Vicia	faba	Broadbean	CEL	GEN	MNUC	NOAEL		4	d	1400		ppm	21	153794
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	NABN	NOAEL		1	d	0.036		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		1	d	0.018		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	NABN	NOAEL		1	d	0.036		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	NABN	LOAEL		3	d	0.018		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		1	d	0.036		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		1	d	0.018		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		3	d	0.018		mg/L	30.8	161797

Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	NABN	NOAEL		1	d	0.036		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	NABN	LOAEL		3	d	0.018		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	MNUC	NOAEL		3	d	0.036		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	NABN	NOAEL		1	d	0.036		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	NABN	LOAEL		3	d	0.036		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	CTLS	NOAEL		1	d	0.036		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	CTLS	NOAEL		3	d	0.036		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	GSTR	NOAEL		3	d	0.036		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	GLPX	NOAEL		1	d	0.036		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	GLRE	NOAEL		3	d	0.036		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	GLRE	NOAEL		3	d	0.036		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	BCM	GLTH	NOAEL		1	d	0.036		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		3	d	0.018		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		1	d	0.018		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL	LOAEL	1	d	0.018	0.036	mg/L	30.8	161797

Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL	LOAEL	1	d	0.018	0.036	mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		3	d	0.036		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		3	d	0.018		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		3	d	0.018		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		3	d	0.036		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	NABN	NOAEL		1	d	0.036		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	NABN	NOAEL		1	d	0.036		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	MNUC	NOAEL		1	d	0.036		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	NABN	LOAEL		3	d	0.018		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	NABN	NOAEL		3	d	0.036		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	NABN	NOAEL		3	d	0.036		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	GSTR	NOAEL		1	d	0.036		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	GLPX	NOAEL		3	d	0.036		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	GLRE	NOAEL		1	d	0.036		mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	BCM	GLTH	NOAEL		3	d	0.036		mg/L	30.8	161797

Chemical	Genus	Species	Common Name												
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	BCM	TBAR	NOAEL	LOAEL	1	d	0.018	0.036	mg/L	30.8	161797
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	BCM	TBAR	NOAEL		3	d	0.036		mg/L	30.8	161797
Glyphosate	Rhamdia	quelen	Catfish	PHY	IMM	PHAG	LOAEL		1	d	0.73		mg/L	100	153795
Glyphosate isopropylamine salt	Gallus	domesticus	Domestic Chicken	GRO	GRO	WGHT	NOAEL	LOAEL	7	d	608	6080	ppm	100	162010
Glyphosate isopropylamine salt	Gallus	domesticus	Domestic Chicken	GRO	MPH	WGHT	NOAEL	LOAEL	7	d	608	6080	ppm	100	162010
Glyphosate isopropylamine salt	Gallus	domesticus	Domestic Chicken	BCM	BCM	CAPR	LOAEL		21	d	60.8		ppm	100	162010
Glyphosate isopropylamine salt	Gallus	domesticus	Domestic Chicken	GRO	MPH	WGHT	NOAEL	LOAEL	14	d	60.8	608	ppm	100	162010
Glyphosate isopropylamine salt	Gallus	domesticus	Domestic Chicken	GRO	GRO	WGHT	NOAEL	LOAEL	7	d	608	6080	ppm	100	162010
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	ENZ	CTLS	LOAEL		1	d	1		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	BCM	GLTH	NOAEL		0.25	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	BCM	GLTH	NOAEL	LOAEL	4	d	1	5	mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	ENZ	GLPX	NOAEL		0.25	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	BCM	LDPO	LOAEL		0.25	d	1		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	MOR	MOR	MORT	NR-ZERO		4	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	BCM	HMGL	NOAEL		0.25	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	BCM	HMGL	NOAEL		1	d	5		mg/L	100	161813

Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	CEL	CEL	MONO	NOAEL		1	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	CEL	CEL	BASO	NOAEL		0.25	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	ENZ	SODA	NOAEL		4	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	ENZ	GSTR	NOAEL		4	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	BCM	HMGL	NOAEL		4	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	BCM	HMCT	NOAEL		0.25	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	CEL	CEL	NEUT	NOAEL		1	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	CEL	CEL	NEUT	NOAEL	LOAEL	4	d	1	5	mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	CEL	CEL	MONO	NOAEL		0.25	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	CEL	CEL	MONO	NOAEL		4	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	CEL	CEL	EOSN	NOAEL		4	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	CEL	CEL	BASO	NOAEL		1	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	CEL	CEL	BASO	NOAEL		4	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	ENZ	SODA	NOAEL	LOAEL	0.25	d	1	5	mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	ENZ	SODA	NOAEL		1	d	5		mg/L	100	161813

Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	BCM	HMCT	NOAEL	LOAEL	4	d	1	5	mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	CEL	CEL	RBCE	NOAEL		0.25	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	CEL	CEL	TWBC	NOAEL		0.25	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	CEL	CEL	TWBC	NOAEL		1	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	CEL	CEL	TWBC	NOAEL	LOAEL	4	d	1	5	mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	CEL	CEL	LMPH	NOAEL		0.25	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	CEL	CEL	LMPH	NOAEL		1	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	CEL	CEL	LMPH	NOAEL	LOAEL	4	d	1	5	mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	CEL	CEL	NEUT	NOAEL		0.25	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	ENZ	GSTR	LOAEL		0.25	d	1		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	ENZ	GSTR	NOAEL	LOAEL	1	d	1	5	mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	ENZ	GLPX	NOAEL	LOAEL	1	d	1	5	mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	ENZ	GLPX	NOAEL	LOAEL	4	d	1	5	mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	BCM	LDPO	NOAEL		1	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	ENZ	ACHE	NOAEL		0.25	d	5		mg/L	100	161813

Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	ENZ	ACHE	NOAEL		1	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	ENZ	ACHE	NOAEL		1	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	ENZ	ACHE	NOAEL	LOAEL	4	d	1	5	mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	ENZ	CTLS	NOAEL		4	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	BCM	GLTH	LOAEL		1	d	1		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	BCM	LDPO	NOAEL		4	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	ENZ	ACHE	NOAEL		0.25	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	ENZ	ACHE	LOAEL		4	d	1		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	BCM	HMCT	NOAEL	LOAEL	1	d	1	5	mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	CEL	CEL	RBCE	NOAEL	LOAEL	1	d	1	5	mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	CEL	CEL	RBCE	NOAEL	LOAEL	4	d	1	5	mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	CEL	CEL	EOSN	NOAEL		0.25	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	CEL	CEL	EOSN	NOAEL		1	d	5		mg/L	100	161813
Glyphosate isopropylamine salt	Prochilodus	lineatus	Curimbata	BCM	ENZ	CTLS	NOAEL	LOAEL	0.25	d	1	5	mg/L	100	161813
Glyphosate	Eisenia	fetida	Earthworm	REP	REP	PROG	LOAEL		56	d	9.97		mg/kg d soil	99.7	161791
Glyphosate	Eisenia	fetida	Earthworm	MOR	MOR	MORT	NR-ZERO		56	d	997		mg/kg d soil	99.7	161791

Glyphosate	Eisenia	fetida	Earthworm	REP	REP	PROG	LOAEL		56	d	9.97		mg/kg d soil	99.7	161791
Glyphosate isopropylamine salt	Chlorella	vulgaris	Green Algae	POP	POP	PGRT	EC50		21	d	118.1		mg/L	100	161695
Glyphosate isopropylamine salt	Spirulina	platensis	Blue-Green Algae	POP	POP	PGRT	EC50		21	d	134.9		mg/L	100	161695
Glyphosate isopropylamine salt	Arthrospira	fusiformis	Blue-Green Algae	POP	POP	PGRT	EC50		21	d	82.4		mg/L	100	161695
Glyphosate isopropylamine salt	Chlorella	vulgaris	Green Algae	POP	POP	PGRT	EC50		21	d	83.1		mg/L	100	161695
Glyphosate isopropylamine salt	Spirulina	platensis	Blue-Green Algae	POP	POP	DBLT	NOAEL	LOAEL	21	d	5.2	51.99	mg/L	100	161695
Glyphosate isopropylamine salt	Synechocystis	aquatilis	Blue-Green Algae	POP	POP	PGRT	EC50		21	d	89.8		mg/L	100	161695
Glyphosate isopropylamine salt	Arthrospira	fusiformis	Blue-Green Algae	POP	POP	DBLT	NOAEL	LOAEL	21	d	5.2	51.99	mg/L	100	161695
Glyphosate isopropylamine salt	Nostoc	commune	Blue-Green Algae	POP	POP	DBLT	NOAEL		21	d	51.99		mg/L	100	161695
Glyphosate isopropylamine salt	Synechocystis	aquatilis	Blue-Green Algae	POP	POP	DBLT	NOAEL	LOAEL	21	d	5.2	51.99	mg/L	100	161695
Glyphosate isopropylamine salt	Microcystis	aeruginosa	Blue-Green Algae	POP	POP	DBLT	LOAEL		21	d	5.2		mg/L	100	161695
Glyphosate isopropylamine salt	Leptolyngbya	boryana	Blue-Green Algae	POP	POP	DBLT	LOAEL		21	d	5.2		mg/L	100	161695
Glyphosate	Chlorella	vulgaris	Green Algae	POP	POP	PGRT	EC50		21	d	292.3		mg/L	100	161695
Glyphosate	Arthrospira	fusiformis	Blue-Green Algae	POP	POP	PGRT	EC50		21	d	169		mg/L	100	161695
Glyphosate	Anabaena	catenula	Blue-Green Algae	POP	POP	PGRT	EC50		21	d	256.5		mg/L	100	161695
Glyphosate	Synechocystis	aquatilis	Blue-Green Algae	POP	POP	PGRT	EC50		21	d	164.9		mg/L	100	161695
Glyphosate	Microcystis	aeruginosa	Blue-Green Algae	POP	POP	PGRT	EC50		21	d	251.4		mg/L	100	161695
Glyphosate	Leptolyngbya	boryana	Blue-Green Algae	POP	POP	PGRT	EC50		21	d	246.6		mg/L	100	161695

Glyphosate isopropylamine salt	Nostoc	commune	Blue-Green Algae	POP	POP	PGRT	EC50		21	d	59.3		mg/L	100	161695
Glyphosate isopropylamine salt	Anabaena	catenula	Blue-Green Algae	POP	POP	PGRT	EC50		21	d	7.1		mg/L	100	161695
Glyphosate isopropylamine salt	Synechocystis	aquatilis	Blue-Green Algae	POP	POP	PGRT	EC50		21	d	233		mg/L	100	161695
Glyphosate isopropylamine salt	Microcystis	aeruginosa	Blue-Green Algae	POP	POP	PGRT	EC50		21	d	10.7		mg/L	100	161695
Glyphosate isopropylamine salt	Leptolyngbya	boryana	Blue-Green Algae	POP	POP	PGRT	EC50		21	d	8.9		mg/L	100	161695
Glyphosate	Chlorella	vulgaris	Green Algae	POP	POP	DBLT	NOAEL		21	d	11.83		mg/L	100	161695
Glyphosate	Spirulina	platensis	Blue-Green Algae	POP	POP	DBLT	NOAEL		21	d	11.83		mg/L	100	161695
Glyphosate	Arthrospira	fusiformis	Blue-Green Algae	POP	POP	DBLT	NOAEL		21	d	11.83		mg/L	100	161695
Glyphosate	Nostoc	commune	Blue-Green Algae	POP	POP	DBLT	NOAEL		21	d	11.83		mg/L	100	161695
Glyphosate	Anabaena	catenula	Blue-Green Algae	POP	POP	DBLT	NOAEL		21	d	11.83		mg/L	100	161695
Glyphosate	Synechocystis	aquatilis	Blue-Green Algae	POP	POP	DBLT	NOAEL		21	d	11.83		mg/L	100	161695
Glyphosate	Microcystis	aeruginosa	Blue-Green Algae	POP	POP	DBLT	NOAEL		21	d	11.83		mg/L	100	161695
Glyphosate isopropylamine salt	Chlorella	vulgaris	Green Algae	POP	POP	DBLT	NOAEL		21	d	51.99		mg/L	100	161695
Glyphosate isopropylamine salt	Spirulina	platensis	Blue-Green Algae	POP	POP	DBLT	NOAEL		21	d	51.99		mg/L	100	161695
Glyphosate isopropylamine salt	Arthrospira	fusiformis	Blue-Green Algae	POP	POP	DBLT	NOAEL		21	d	51.99		mg/L	100	161695
Glyphosate isopropylamine salt	Nostoc	commune	Blue-Green Algae	POP	POP	DBLT	NOAEL		21	d	51.99		mg/L	100	161695
Glyphosate isopropylamine salt	Anabaena	catenula	Blue-Green Algae	POP	POP	DBLT	LOAEL		21	d	51.99		mg/L	100	161695
Glyphosate isopropylamine salt	Microcystis	aeruginosa	Blue-Green Algae	POP	POP	DBLT	LOAEL		21	d	51.99		mg/L	100	161695

Glyphosate isopropylamine salt	Leptolyngbya	boryana	Blue-Green Algae	POP	POP	DBLT	LOAEL		21	d	51.99		mg/L	100	161695
Glyphosate isopropylamine salt	Microcystis	aeruginosa	Blue-Green Algae	POP	POP	PGRT	EC50		21	d	6.7		mg/L	100	161695
Glyphosate	Leptolyngbya	boryana	Blue-Green Algae	POP	POP	DBLT	NOAEL		21	d	11.83		mg/L	100	161695
Glyphosate isopropylamine salt	Synechocystis	aquatilis	Blue-Green Algae	POP	POP	DBLT	NOAEL		21	d	51.99		mg/L	100	161695
Glyphosate isopropylamine salt	Spirulina	platensis	Blue-Green Algae	POP	POP	PGRT	EC50		21	d	33.1		mg/L	100	161695
Glyphosate isopropylamine salt	Arthrospira	fusiformis	Blue-Green Algae	POP	POP	PGRT	EC50		21	d	28.2		mg/L	100	161695
Glyphosate isopropylamine salt	Nostoc	commune	Blue-Green Algae	POP	POP	PGRT	EC50		21	d	42.3		mg/L	100	161695
Glyphosate isopropylamine salt	Anabaena	catenula	Blue-Green Algae	POP	POP	PGRT	EC50		21	d	2.9		mg/L	100	161695
Glyphosate isopropylamine salt	Leptolyngbya	boryana	Blue-Green Algae	POP	POP	PGRT	EC50		21	d	4.1		mg/L	100	161695
Glyphosate	Spirulina	platensis	Blue-Green Algae	POP	POP	PGRT	EC50		21	d	169		mg/L	100	161695
Glyphosate isopropylamine salt	Chlorella	vulgaris	Green Algae	POP	POP	DBLT	NOAEL	LOAEL	21	d	5.2	51.99	mg/L	100	161695
Glyphosate	Nostoc	commune	Blue-Green Algae	POP	POP	PGRT	EC50		21	d	598.4		mg/L	100	161695
Glyphosate	Polypedates	cruciger	Common Hourglass Tree Frog	MOR	MOR	MORT	LC50		2	d	14.99		ppm	100	159829
Glyphosate	Polypedates	cruciger	Common Hourglass Tree Frog	MOR	MOR	MORT	NOAEL	LOAEL	5	d	0.75	1	mg/L	100	159829
Glyphosate	Polypedates	cruciger	Common Hourglass Tree Frog	MOR	MOR	MORT	NOAEL	LOAEL	25	d	0.75	1	mg/L	100	159829
Glyphosate	Polypedates	cruciger	Common Hourglass Tree Frog	MOR	MOR	MORT	NOAEL	LOAEL		mmph	0.5	0.75	mg/L	100	159829

Glyphosate	Polypeda tes	cruciger	Common Hourglass Tree Frog	GRO	GRO	LGTH	LOAEL			mmph	0.25		mg/L	100	159829
Glyphosate	Polypeda tes	cruciger	Common Hourglass Tree Frog	GRO	GRO	WGHT	LOAEL			mmph	0.25		mg/L	100	159829
Glyphosate	Polypeda tes	cruciger	Common Hourglass Tree Frog	GRO	DVP	DVLP	ET50			d	0.25		mg/L	100	159829
Glyphosate	Polypeda tes	cruciger	Common Hourglass Tree Frog	GRO	DVP	DVLP	ET50			d	0.5		mg/L	100	159829
Glyphosate	Polypeda tes	cruciger	Common Hourglass Tree Frog	GRO	DVP	DVLP	ET50			d	0.75		mg/L	100	159829
Glyphosate	Polypeda tes	cruciger	Common Hourglass Tree Frog	GRO	DVP	DVLP	ET50			d	1		mg/L	100	159829
Glyphosate	Polypeda tes	cruciger	Common Hourglass Tree Frog	GRO	DVP	DVLP	NOAEL	LOAEL		d	0.25	0.5	mg/L	100	159829
Glyphosate	Channa	punctata	Snake-Head Catfish	MOR	MOR	MORT	LC90		4	d	14.37214		mg/L	41	153834
Glyphosate	Channa	punctata	Snake-Head Catfish	MOR	MOR	MORT	LC90		1	d	18.8149		mg/L	41	153834
Glyphosate	Channa	punctata	Snake-Head Catfish	MOR	MOR	MORT	LC10		2	d	14.23069		mg/L	41	153834
Glyphosate	Channa	punctata	Snake-Head Catfish	MOR	MOR	MORT	LC90		3	d	15.3832		mg/L	41	153834
Glyphosate	Channa	punctata	Snake-Head Catfish	MOR	MOR	MORT	LC50		2	d	15.3053		mg/L	41	153834
Glyphosate	Channa	punctata	Snake-Head Catfish	MOR	MOR	MORT	LC10		1	d	14.8625		mg/L	41	153834
Glyphosate	Channa	punctata	Snake-Head Catfish	MOR	MOR	MORT	LC10		4	d	11.14339		mg/L	41	153834
Glyphosate	Channa	punctata	Snake-Head Catfish	MOR	MOR	MORT	LC50		4	d	13.3414		mg/L	41	153834
Glyphosate	Channa	punctata	Snake-Head Catfish	MOR	MOR	MORT	LC10		3	d	11.47631		mg/L	41	153834
Glyphosate	Channa	punctata	Snake-Head Catfish	MOR	MOR	MORT	LC90		2	d	16.4574		mg/L	41	153834
Glyphosate	Channa	punctata	Snake-Head Catfish	MOR	MOR	MORT	LC50		1	d	16.72308		mg/L	41	153834
Glyphosate	Channa	punctata	Snake-Head Catfish	MOR	MOR	MORT	LC50		3	d	13.93631		mg/L	41	153834

Glyphosate isopropylamine salt	Callinectes	sapidus	Blue Crab	MOR	MOR	MORT	LC50		1	d	6.279		mg/L	50.2	152973
Glyphosate isopropylamine salt	Callinectes	sapidus	Blue Crab	GRO	DVP	MMPH	LOAEL	2.6408		d	5.5		mg/L	50.2	152973
Glyphosate isopropylamine salt	Callinectes	sapidus	Blue Crab	BCM	BCM	GLTH	NOAEL		1	d	5.5		mg/L	50.2	152973
Glyphosate isopropylamine salt	Callinectes	sapidus	Blue Crab	BCM	BCM	MLDH	NOAEL		1	d	5.5		mg/L	50.2	152973
Glyphosate isopropylamine salt	Callinectes	sapidus	Blue Crab	MOR	MOR	MORT	LC50		1	d	316		mg/L	50.2	152973
Glyphosate isopropylamine salt	Callinectes	sapidus	Blue Crab	GRO	DVP	MOLT	NOAEL			it	5.5		mg/L	50.2	152973
Glyphosate isopropylamine salt	Callinectes	sapidus	Blue Crab	MOR	MOR	MORT	LOAEL			it	5.5		mg/L	50.2	152973
Glyphosate isopropylamine salt	Callinectes	sapidus	Blue Crab	GRO	DVP	MMPH	ET50	2.1692		d	5.5		mg/L	50.2	152973
Glyphosate isopropylamine salt	Hyalella	castroi	Scud	BCM	BCM	PRTL	LOAEL		7	d	0.36		mg/L	100	152145
Glyphosate isopropylamine salt	Hyalella	castroi	Scud	BCM	BCM	TBAR	LOAEL		7	d	0.36		mg/L	100	152145
Glyphosate isopropylamine salt	Phalloceros	caudimaculatus	Spotted Livebearer	MOR	MOR	MORT	LC50		4	d	975		mg/L	100	156213
Glyphosate, Monopotassium salt	Rana	catesbeiana	Bullfrog	MOR	MOR	MORT	LC10			d	1.38		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Rana	catesbeiana	Bullfrog	MOR	MOR	MORT	LC50			d	2.18		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Rana	catesbeiana	Bullfrog	MOR	MOR	MORT	LC90			d	3.46		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Rana	catesbeiana	Bullfrog	GRO	GRO	WGHT	NOAEL			d	2.04		ae mg/L	48.7	156497

Glyphosate, Monopotassium salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	LC10			d	1.84		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	LC50			d	2.35		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	LC90			d	3		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	GRO	GRO	WGHT	NOAEL			d	2.04		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Hyla	versicolor	Gray Tree Frog	MOR	MOR	MORT	LC90			d	2.96		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Hyla	versicolor	Gray Tree Frog	MOR	MOR	MORT	LC10			d	1		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Hyla	versicolor	Gray Tree Frog	MOR	MOR	MORT	LC50			d	1.71		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Hyla	versicolor	Gray Tree Frog	GRO	GRO	WGHT	NOAEL			d	2.04		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	LC10			d	1.58		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	GRO	GRO	WGHT	NOAEL			d	2.04		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	LC50			d	2.18		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	LC90			d	3		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Hyla	versicolor	Gray Tree Frog	MOR	MOR	MORT	LC10			d	1.41		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Hyla	versicolor	Gray Tree Frog	MOR	MOR	MORT	LC50			d	2.04		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Hyla	versicolor	Gray Tree Frog	MOR	MOR	MORT	LC90			d	2.96		ae mg/L	48.7	156497

Glyphosate, Monopotassium salt	Hyla	versicolor	Gray Tree Frog	GRO	GRO	WGHT	NOAEL			d	2.04		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	LC50			d	2.58		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	LC90			d	5.28		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	LC10			d	1.26		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	GRO	GRO	WGHT	NOAEL			d	2.04		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Hyla	versicolor	Gray Tree Frog	MOR	MOR	MORT	LC10			d	1.85		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Hyla	versicolor	Gray Tree Frog	MOR	MOR	MORT	LC50			d	2.29		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Hyla	versicolor	Gray Tree Frog	MOR	MOR	MORT	LC90			d	2.83		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Hyla	versicolor	Gray Tree Frog	GRO	GRO	WGHT	NOAEL			d	2.04		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Rana	catesbeiana	Bullfrog	MOR	MOR	MORT	LC10			d	1.63		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Rana	catesbeiana	Bullfrog	MOR	MOR	MORT	LC50			d	2.12		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Rana	catesbeiana	Bullfrog	MOR	MOR	MORT	LC90			d	2.76		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Rana	catesbeiana	Bullfrog	GRO	GRO	WGHT	NOAEL			d	2.04		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Rana	catesbeiana	Bullfrog	MOR	MOR	MORT	LC50			d	1.61		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Rana	catesbeiana	Bullfrog	MOR	MOR	MORT	LC90			d	2.21		ae mg/L	48.7	156497

Chemical	Genus	Species	Common						Dur	Unit	Conc		Units	Num	Ref
Glyphosate, Monopotassium salt	Rana	catesbeiana	Bullfrog	GRO	GRO	WGHT	NOAEL			d	2.04		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Rana	catesbeiana	Bullfrog	MOR	MOR	MORT	LC10			d	1.18		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Algae	NR	Algae	POP	POP	BMAS	NOAEL		8	d	2.04		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Algae	NR	Algae	POP	POP	BMAS	NOAEL		8	d	2.04		ae mg/L	48.7	156497
Glyphosate, Monopotassium salt	Algae	NR	Algae	POP	POP	BMAS	NOAEL		8	d	2.04		ae mg/L	48.7	156497
Glyphosate isopropylamine salt	Eichhornia	crassipes	Water-Hyacinth	PHY	INJ	GINJ	LOAEL		7	d	0.4		ae kg/ha	100	159025
Glyphosate isopropylamine salt	Eichhornia	crassipes	Water-Hyacinth	PHY	INJ	GINJ	LOAEL		21	d	0.4		ae kg/ha	100	159025
Glyphosate isopropylamine salt	Eichhornia	crassipes	Water-Hyacinth	PHY	INJ	GINJ	LOAEL		42	d	0.4		ae kg/ha	100	159025
Glyphosate isopropylamine salt	Eichhornia	crassipes	Water-Hyacinth	PHY	INJ	GINJ	LOAEL		42	d	0.4		ae kg/ha	100	159025
Glyphosate isopropylamine salt	Eichhornia	crassipes	Water-Hyacinth	PHY	INJ	GINJ	LOAEL		7	d	0.4		ae kg/ha	100	159025
Glyphosate isopropylamine salt	Eichhornia	crassipes	Water-Hyacinth	PHY	INJ	GINJ	LOAEL		21	d	0.4		ae kg/ha	100	159025
Glyphosate	Rhamdia	quelen	Catfish	CEL	CEL	RBCE	LOAEL		4	d	0.73		mg/L	100	155345
Glyphosate	Rhamdia	quelen	Catfish	CEL	CEL	NEUT	NOAEL		4	d	0.73		mg/L	100	155345
Glyphosate	Rhamdia	quelen	Catfish	CEL	CEL	MONO	NOAEL		4	d	0.73		mg/L	100	155345
Glyphosate	Rhamdia	quelen	Catfish	CEL	CEL	LMPH	LOAEL		4	d	0.73		mg/L	100	155345
Glyphosate	Rhamdia	quelen	Catfish	CEL	CEL	LEUK	LOAEL		4	d	0.73		mg/L	100	155345
Glyphosate	Rhamdia	quelen	Catfish	BCM	BCM	HMCT	NOAEL		4	d	0.73		mg/L	100	155345
Glyphosate	Rhamdia	quelen	Catfish	CEL	CEL	NCEL	LOAEL		4	d	0.73		mg/L	100	155345

Glyphosate	Rhamdia	quelen	Catfish	CEL	CEL	THRM	LOAEL		4	d	0.73		mg/L	100	155345
Glyphosate	Rhamdia	quelen	Catfish	PHY	IMM	PHAG	LOAEL		1	d	0.73		mg/L	100	155345
Glyphosate	Rhamdia	quelen	Catfish	PHY	IMM	PHAG	NOAEL		10	d	0.73		mg/L	100	155345
Glyphosate	Rhamdia	quelen	Catfish	PHY	IMM	NKCA	NOAEL		1	d	0.73		mg/L	100	155345
Glyphosate	Rhamdia	quelen	Catfish	PHY	IMM	NKCA	NOAEL		10	d	0.73		mg/L	100	155345
Glyphosate	Rhamdia	quelen	Catfish	PHY	IMM	GIMM	LOAEL		10	d	0.73		mg/L	100	155345
Glyphosate	Rhamdia	quelen	Catfish	BCM	ENZ	PODA	NOAEL		10	d	0.73		mg/L	100	155345
Glyphosate	Rhamdia	quelen	Catfish	PHY	IMM	GIMM	LOAEL		1	d	0.73		mg/L	100	155345
Glyphosate	Rhamdia	quelen	Catfish	BCM	ENZ	LYZM	NOAEL		1	d	0.73		mg/L	100	155345
Glyphosate	Rhamdia	quelen	Catfish	BCM	ENZ	LYZM	LOAEL		10	d	0.73		mg/L	100	155345
Glyphosate	Rhamdia	quelen	Catfish	BCM	ENZ	PODA	LOAEL		1	d	0.73		mg/L	100	155345
Glyphosate	Rhamdia	quelen	Catfish	PHY	IMM	ABDT	NOAEL		1	d	0.73		mg/L	100	155345
Glyphosate	Rhamdia	quelen	Catfish	PHY	IMM	ABDT	NOAEL		10	d	0.73		mg/L	100	155345
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC50		28	d	0.10852072		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC80		28	d	0.17445736		lb/acre	100	152884
Glyphosate	Sorghum	bicolor	Broomcorn	POP	POP	DBMS	EC50		28	d	0.01098944		lb/acre	100	152884
Glyphosate	Sorghum	bicolor	Broomcorn	POP	POP	DBMS	EC80		28	d	0.01923152		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC50		28	d	0.08379448		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC80		28	d	0.13324696		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	MOR	MOR	MORT	NR-LETH		28	d	1.37368		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC50		28	d	0.12637856		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC50		28	d	0.02884728		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	MOR	MOR	MORT	NR-LETH		28	d	0.042816		lb/acre	100	152884

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Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC50			28	d	0.0412104		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC50			28	d	0.0274736		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC80			28	d	0.04395776		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	MOR	MOR	MORT	NR-LETH			28	d	0.68684		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC50			28	d	0.07692608		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC80			28	d	0.1236312		lb/acre	100	152884
Glyphosate	Sorghum	bicolor	Broomcorn	POP	POP	DBMS	EC50			28	d	0.0206052		lb/acre	100	152884
Glyphosate	Sorghum	bicolor	Broomcorn	POP	POP	DBMS	EC80			28	d	0.03159464		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC50			28	d	0.0412104		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC80			28	d	0.06731032		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	MOR	MOR	MORT	NR-LETH			28	d	1.37368		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC50			28	d	0.0961576		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC50			28	d	0.02335256		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	MOR	MOR	MORT	NR-LETH			28	d	0.042816		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC50			28	d	0.03022096		lb/acre	100	152884
Glyphosate	Sorghum	arundinaceum	Shattercane	POP	POP	DBMS	EC50			28	d	0.03708936		lb/acre	100	152884
Glyphosate	Sorghum	arundinaceum	Shattercane	MOR	MOR	MORT	NR-LETH			28	d	0.042816		lb/acre	100	152884
Glyphosate	Sorghum	arundinaceum	Shattercane	MOR	MOR	MORT	NR-LETH			28	d	0.042816		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC50			28	d	0.16758896		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC80			28	d	0.26924128		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC50			28	d	0.17033632		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC80			28	d	0.27198864		lb/acre	100	152884
Glyphosate	Sorghum	bicolor	Broomcorn	POP	POP	DBMS	EC50			28	d	0.03022096		lb/acre	100	152884

Glyphosate	Sorghum	bicolor	Broomcorn	POP	POP	DBMS	EC80		28	d	0.04945248		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC50		28	d	0.17033632		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC80		28	d	0.27336232		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	MOR	MOR	MORT	NR-LETH		28	d	1.37368		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC50		28	d	0.1236312		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC50		28	d	0.03296832		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	MOR	MOR	MORT	NR-LETH		28	d	0.042816		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC50		28	d	0.0274736		lb/acre	100	152884
Glyphosate	Sorghum	arundinaceum	Shattercane	POP	POP	DBMS	EC50		28	d	0.03159464		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC50		28	d	0.08791552		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC80		28	d	0.14148904		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	MOR	MOR	MORT	NR-LETH		28	d	1.37368		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC50		28	d	0.1236312		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC50		28	d	0.03846304		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	MOR	MOR	MORT	NR-LETH		28	d	0.042816		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC50		28	d	0.0480788		lb/acre	100	152884
Glyphosate	Sorghum	arundinaceum	Shattercane	POP	POP	DBMS	EC50		28	d	0.01236312		lb/acre	100	152884
Glyphosate	Sorghum	arundinaceum	Shattercane	MOR	MOR	MORT	NR-LETH		28	d	0.042816		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC50		28	d	0.09753128		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC80		28	d	0.15659952		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC50		28	d	0.0892892		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC80		28	d	0.14148904		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC50		28	d	0.05906824		lb/acre	100	152884

Glyphosate	Sorghum	arundinaceum	Shattercane	POP	POP	DBMS	EC50		28	d	0.02472624		lb/acre	100	152884
Glyphosate	Sorghum	arundinaceum	Shattercane	MOR	MOR	MORT	NR-LETH		28	d	0.042816		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC50		28	d	0.03296832		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC80		28	d	0.05219984		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC50		28	d	0.11813648		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC80		28	d	0.18819416		lb/acre	100	152884
Glyphosate	Sorghum	bicolor	Broomcorn	POP	POP	DBMS	EC50		28	d	0.00549472		lb/acre	100	152884
Glyphosate	Sorghum	bicolor	Broomcorn	POP	POP	DBMS	EC80		28	d	0.00961576		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC50		28	d	0.05219984		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC80		28	d	0.08379448		lb/acre	100	152884
Glyphosate	Sorghum	bicolor	Broomcorn	POP	POP	DBMS	EC50		28	d	0.01648416		lb/acre	100	152884
Glyphosate	Sorghum	bicolor	Broomcorn	POP	POP	DBMS	EC80		28	d	0.0274736		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC50		28	d	0.0618156		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC80		28	d	0.09890496		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	MOR	MOR	MORT	NR-LETH		28	d	1.37368		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC50		28	d	0.10577336		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC50		28	d	0.03983672		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	MOR	MOR	MORT	NR-LETH		28	d	0.042816		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC50		28	d	0.04670512		lb/acre	100	152884
Glyphosate	Sorghum	arundinaceum	Shattercane	POP	POP	DBMS	EC50		28	d	0.02335256		lb/acre	100	152884
Glyphosate	Sorghum	arundinaceum	Shattercane	MOR	MOR	MORT	NR-LETH		28	d	0.042816		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC50		28	d	0.05632088		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC80		28	d	0.09066288		lb/acre	100	152884

Glyphosate	Abutilon	theophrasti	Butter Print	MOR	MOR	MORT	NR-LETH			28	d	0.68684		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC50			28	d	0.1923152		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC80			28	d	0.30633064		lb/acre	100	152884
Glyphosate	Sorghum	bicolor	Broomcorn	POP	POP	DBMS	EC50			28	d	0.0137368		lb/acre	100	152884
Glyphosate	Sorghum	bicolor	Broomcorn	POP	POP	DBMS	EC80			28	d	0.0206052		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC50			28	d	0.02472624		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC80			28	d	0.03983672		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	MOR	MOR	MORT	NR-LETH			28	d	1.37368		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC50			28	d	0.14286272		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC50			28	d	0.02197888		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	MOR	MOR	MORT	NR-LETH			28	d	0.042816		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC50			28	d	0.02335256		lb/acre	100	152884
Glyphosate	Sorghum	arundinaceum	Shattercane	POP	POP	DBMS	EC50			28	d	0.01648416		lb/acre	100	152884
Glyphosate	Sorghum	arundinaceum	Shattercane	MOR	MOR	MORT	NR-LETH			28	d	0.042816		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC50			28	d	0.0274736		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC80			28	d	0.04395776		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	MOR	MOR	MORT	NR-LETH			28	d	0.68684		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC50			28	d	0.1167628		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC80			28	d	0.18819416		lb/acre	100	152884
Glyphosate	Sorghum	bicolor	Broomcorn	POP	POP	DBMS	EC50			28	d	0.01785784		lb/acre	100	152884
Glyphosate	Sorghum	bicolor	Broomcorn	POP	POP	DBMS	EC80			28	d	0.02884728		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC50			28	d	0.0824208		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC80			28	d	0.13187328		lb/acre	100	152884

Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	MOR	MOR	MORT	NR-LETH			28	d	1.37368		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC50			28	d	0.0206052		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC50			28	d	0.01785784		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	MOR	MOR	MORT	NR-LETH			28	d	0.042816		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC50			28	d	0.01923152		lb/acre	100	152884
Glyphosate	Sorghum	arundinaceum	Shattercane	POP	POP	DBMS	EC50			28	d	0.03022096		lb/acre	100	152884
Glyphosate	Sorghum	arundinaceum	Shattercane	MOR	MOR	MORT	NR-LETH			28	d	0.042816		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC50			28	d	0.08104712		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC80			28	d	0.12912592		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC50			28	d	0.10714704		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC80			28	d	0.17171		lb/acre	100	152884
Glyphosate	Sorghum	bicolor	Broomcorn	POP	POP	DBMS	EC50			28	d	0.03159464		lb/acre	100	152884
Glyphosate	Sorghum	bicolor	Broomcorn	POP	POP	DBMS	EC80			28	d	0.05082616		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC50			28	d	0.09753128		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC80			28	d	0.15659952		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	MOR	MOR	MORT	NR-LETH			28	d	1.37368		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC50			28	d	0.17583104		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC50			28	d	0.0206052		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	MOR	MOR	MORT	NR-LETH			28	d	0.042816		lb/acre	100	152884
Glyphosate	Sorghum	arundinaceum	Shattercane	POP	POP	DBMS	EC50			28	d	0.034342		lb/acre	100	152884
Glyphosate	Sorghum	arundinaceum	Shattercane	MOR	MOR	MORT	NR-LETH			28	d	0.042816		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC50			28	d	0.03571568		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC80			28	d	0.05769456		lb/acre	100	152884

Glyphosate	Abutilon	theophrasti	Butter Print	MOR	MOR	MORT	NR-LETH		28	d	0.68684		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC50		28	d	0.10577336		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC80		28	d	0.16896264		lb/acre	100	152884
Glyphosate	Sorghum	bicolor	Broomcorn	POP	POP	DBMS	EC50		28	d	0.00961576		lb/acre	100	152884
Glyphosate	Sorghum	bicolor	Broomcorn	POP	POP	DBMS	EC80		28	d	0.01511048		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC50		28	d	0.07967344		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC80		28	d	0.12775224		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	MOR	MOR	MORT	NR-LETH		28	d	1.37368		lb/acre	100	152884
Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	DBMS	EC50		28	d	0.11951016		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	POP	POP	DBMS	EC50		28	d	0.03159464		lb/acre	100	152884
Glyphosate	Digitaria	sanguinalis	Purple Crabgrass	MOR	MOR	MORT	NR-LETH		28	d	0.042816		lb/acre	100	152884
Glyphosate	Amaranthus	palmeri	Palmer's Amaranth	POP	POP	DBMS	EC50		28	d	0.03708936		lb/acre	100	152884
Glyphosate	Sorghum	arundinaceum	Shattercane	POP	POP	DBMS	EC50		28	d	0.0206052		lb/acre	100	152884
Glyphosate	Sorghum	arundinaceum	Shattercane	MOR	MOR	MORT	NR-LETH		28	d	0.042816		lb/acre	100	152884
Glyphosate	Apis	mellifera	Honey Bee	CEL	GEN	APOP	LOAEL		4	d	400		ppm	100	156418
Glyphosate	Apis	mellifera	Honey Bee	CEL	GEN	APOP	LOAEL		4	d	400		ppm	100	156418
Glyphosate isopropylamine salt	Lemna	minor	Duckweed	BCM	ENZ	ASCP	LOAEL		2	d	1.58		AI mmol/dm3	100	161958
Glyphosate isopropylamine salt	Lemna	minor	Duckweed	BCM	BCM	PUTR	LOAEL		2	d	1.58		AI mmol/dm3	100	161958
Glyphosate isopropylamine salt	Lemna	minor	Duckweed	GRO	GRO	BMAS	LOAEL		21	d	1.58		AI mmol/dm3	100	161958
Glyphosate isopropylamine salt	Lithobates	pipiens	Leopard Frog	CEL	CEL	MONO	NOAEL		94	d			ae ug/L	100	153789
Glyphosate isopropylamine salt	Lithobates	pipiens	Leopard Frog	CEL	HIS	MELM	NOAEL		94	d			ae ug/L	100	153789

Glyphosate isopropylamine salt	Lithobates	pipiens	Leopard Frog	GRO	MPH	SMIX	NOAEL		21	d			ae ug/L	100	153789
Glyphosate isopropylamine salt	Lithobates	pipiens	Leopard Frog	CEL	CEL	RATO	NOAEL		94	d			ae ug/L	100	153789
Glyphosate isopropylamine salt	Lithobates	pipiens	Leopard Frog	GRO	DVP	MOLT	NOAEL		54	d			ae ug/L	100	153789
Glyphosate isopropylamine salt	Lithobates	pipiens	Leopard Frog	CEL	CEL	NEUT	NOAEL		94	d			ae ug/L	100	153789
Glyphosate isopropylamine salt	Lithobates	pipiens	Leopard Frog	CEL	HIS	MELM	NOAEL		94	d			ae ug/L	100	153789
Glyphosate isopropylamine salt	Lithobates	pipiens	Leopard Frog	CEL	HIS	GRNM	NOAEL		94	d			ae ug/L	100	153789
Glyphosate isopropylamine salt	Lithobates	pipiens	Leopard Frog	GRO	MPH	SMIX	NOAEL		21	d			ae ug/L	100	153789
Glyphosate isopropylamine salt	Lithobates	pipiens	Leopard Frog	CEL	HIS	MELM	NOAEL		94	d			ae ug/L	100	153789
Glyphosate isopropylamine salt	Lithobates	pipiens	Leopard Frog	CEL	CEL	RATO	NOAEL		94	d			ae ug/L	100	153789
Glyphosate isopropylamine salt	Lithobates	pipiens	Leopard Frog	CEL	HIS	MELM	NOAEL		94	d			ae ug/L	100	153789
Glyphosate isopropylamine salt	Lithobates	pipiens	Leopard Frog	CEL	CEL	LMPH	NOAEL		94	d			ae ug/L	100	153789
Glyphosate isopropylamine salt	Lithobates	pipiens	Leopard Frog	MOR	MOR	SURV	NOAEL		21	d			ae ug/L	100	153789
Glyphosate isopropylamine salt	Lithobates	pipiens	Leopard Frog	CEL	CEL	BASO	NOAEL		94	d			ae ug/L	100	153789
Glyphosate isopropylamine salt	Lithobates	pipiens	Leopard Frog	GRO	GRO	GAIN	NOAEL		21	d			ae ug/L	100	153789
Glyphosate isopropylamine salt	Lithobates	pipiens	Leopard Frog	CEL	HIS	GRNM	NOAEL		94	d			ae ug/L	100	153789

Chemical	Genus	Species	Common Name				Endpoint	Endpoint2	Duration	Unit	Value	Value2	Conc Unit	%	ID
Glyphosate isopropylamine salt	Lithobates	pipiens	Leopard Frog	CEL	CEL	EOSN	NOAEL		94	d			ae ug/L	100	153789
Glyphosate isopropylamine salt	Lithobates	pipiens	Leopard Frog	GRO	GRO	LGTH	LOAEL		21	d			ae ug/L	100	153789
Sulfosate	Caenorhabditis	elegans	Nematode	MOR	MOR	MORT	LC50		1	d	8		AI %	52.3	156398
Sulfosate	Caenorhabditis	elegans	Nematode	CEL	HIS	DEGN	LOAEL		1	d	3		AI %	52.3	156398
Sulfosate	Caenorhabditis	elegans	Nematode	MOR	MOR	MORT	LC50		1	d	5.7		AI %	52.3	156398
Sulfosate	Caenorhabditis	elegans	Nematode	CEL	HIS	DEGN	NOAEL	LOAEL	1	d	5.5	9.8	AI %	52.3	156398
Glyphosate isopropylamine salt	Lemna	minor	Duckweed	BCM	BCM	FLRS	LOAEL		1	d	20		AI ug/L	100	156171
Glyphosate isopropylamine salt	Lemna	minor	Duckweed	BCM	BCM	FLRS	LOAEL		4	d	20		AI ug/L	100	156171
Glyphosate isopropylamine salt	Lemna	minor	Duckweed	BCM	BCM	FLRS	LOAEL		4	d	20		AI ug/L	100	156171
Glyphosate isopropylamine salt	Lemna	minor	Duckweed	BCM	BCM	FLRS	LOAEL		3	d	20		AI ug/L	100	156171
Glyphosate isopropylamine salt	Lemna	minor	Duckweed	BCM	BCM	FLRS	LOAEL		2	d	20		AI ug/L	100	156171
Glyphosate isopropylamine salt	Lemna	minor	Duckweed	BCM	BCM	FLRS	LOAEL		1	d	20		AI ug/L	100	156171
Glyphosate isopropylamine salt	Lemna	minor	Duckweed	POP	POP	PGRT	LOAEL		1	d	20		AI ug/L	100	156171
Glyphosate isopropylamine salt	Lemna	minor	Duckweed	POP	POP	PGRT	LOAEL		2	d	20		AI ug/L	100	156171
Glyphosate isopropylamine salt	Lemna	minor	Duckweed	POP	POP	PGRT	LOAEL		3	d	20		AI ug/L	100	156171
Glyphosate isopropylamine salt	Lemna	minor	Duckweed	POP	POP	PGRT	LOAEL		4	d	20		AI ug/L	100	156171
Glyphosate isopropylamine salt	Lemna	minor	Duckweed	PHY	PHY	PSII	NOAEL	LOAEL	4	d	40	80	AI ug/L	100	156171

Glyphosate isopropylamine salt	Lemna	minor	Duckweed	PHY	PHY	PSII	NOAEL	LOAEL	3	d	40	80	AI ug/L	100	156171
Glyphosate isopropylamine salt	Lemna	minor	Duckweed	PHY	PHY	PSII	NOAEL	LOAEL	2	d	40	80	AI ug/L	100	156171
Glyphosate isopropylamine salt	Lemna	minor	Duckweed	PHY	PHY	PSII	NOAEL	LOAEL	1	d	40	80	AI ug/L	100	156171
Glyphosate isopropylamine salt	Lemna	minor	Duckweed	BCM	BCM	FLRS	LOAEL		2	d	20		AI ug/L	100	156171
Glyphosate isopropylamine salt	Lemna	minor	Duckweed	BCM	BCM	FLRS	LOAEL		3	d	20		AI ug/L	100	156171
Glyphosate	Echinostoma	trivolvis	Trematode	GRO	DVP	GDVP	NOAEL		26	d	3.6853		mg/L	>98	153845
Glyphosate	Echinostoma	trivolvis	Trematode	MOR	MOR	HTCH	NOAEL		26	d	3.6853		mg/L	>98	153845
Glyphosate	Echinostoma	trivolvis	Trematode	MOR	MOR	SURV	NOAEL		0.5	d	3.6853		mg/L	>98	153845
Glyphosate isopropylamine salt	Lilium	sp.	Lily	GRO	GRO	WGHT	LOAEL		209	d	0.6408		lb/acre	100	153931
Glyphosate isopropylamine salt	Lilium	longiflorum	Easter Lily	GRO	GRO	WGHT	NOAEL		209	d	0.6408		lb/acre	100	153931
Glyphosate isopropylamine salt	Lilium	sp.	Lily	GRO	GRO	WGHT	LOAEL		212	d	0.3204		lb/acre	100	153931
Glyphosate isopropylamine salt	Lilium	longiflorum	Easter Lily	GRO	GRO	WGHT	NOAEL		66	d	0.6408		lb/acre	100	153931
Glyphosate isopropylamine salt	Lilium	sp.	Lily	GRO	GRO	WGHT	NOAEL		161	d	0.3204		lb/acre	100	153931
Glyphosate isopropylamine salt	Lilium	sp.	Lily	GRO	GRO	WGHT	NOAEL		66	d	0.6408		lb/acre	100	153931
Glyphosate isopropylamine salt	Lilium	sp.	Lily	GRO	GRO	WGHT	NOAEL		66	d	0.6408		lb/acre	100	153931
Glyphosate isopropylamine salt	Lilium	sp.	Lily	GRO	GRO	WGHT	NOAEL		66	d	0.6408		lb/acre	100	153931

Chemical	Genus	Species	Common name						Dur		Val1	Val2	Unit		ID
Glyphosate isopropylamine salt	Xenopus	laevis	African Clawed Frog	CEL	HIS	EDMA	NOAEL		2	d	5		mg/L	100	153876
Glyphosate isopropylamine salt	Xenopus	laevis	African Clawed Frog	MOR	MOR	MORT	NR-ZERO		2	d	5		mg/L	100	153876
Glyphosate isopropylamine salt	Xenopus	laevis	African Clawed Frog	GRO	DVP	DFRM	NOAEL	LOAEL	2	d	1	5	mg/L	100	153876
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	BCM	NPSH	NOAEL	LOAEL	8	d			mg/L	48	161790
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	BCM	MLDH	NOAEL	LOAEL	8	d			mg/L	48	161790
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	BCM	MLDH	LOAEL		8	d			mg/L	48	161790
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	BCM	MLDH	NOAEL	LOAEL	8	d			mg/L	48	161790
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	BCM	PCAR	LOAEL		8	d			mg/L	48	161790
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	ENZ	CTLS	NOAEL		8	d			mg/L	48	161790
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	ENZ	SODA	NOAEL		8	d			mg/L	48	161790
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	ENZ	GSTR	LOAEL		8	d			mg/L	48	161790
Glyphosate isopropylamine salt	Rhamdia	quelen	Catfish	BCM	BCM	ASCA	NOAEL		8	d			mg/L	48	161790
Glyphosate ammonium salt	Rhinella	arenarum	Toad	MOR	MOR	MORT	LC50		0.5	d	3.26		ae mg/L	74.7	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	BCM	ENZ	ACHE	LOAEL		2	d	1.85		ae mg/L	74.7	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	BCM	ENZ	BCHE	LOAEL		2	d	1.85		ae mg/L	74.7	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	MOR	MOR	MORT	LC50		0.25	d	5.62		ae mg/L	74.7	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	MOR	MOR	MORT	LC50		1	d	2.42		ae mg/L	74.7	161996

Glyphosate ammonium salt	Rhinella	arenarum	Toad	MOR	MOR	MORT	LC50		2	d	2.42		ae mg/L	74.7	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	BCM	ENZ	ALIE	LOAEL		2	d	1.85		ae mg/L	74.7	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	BCM	ENZ	GSTR	LOAEL		2	d	1.85		ae mg/L	74.7	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	MOR	MOR	MORT	LC50		0.25	d	104.33		ae mg/L	48	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	MOR	MOR	MORT	LC50		0.5	d	84.06		ae mg/L	48	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	MOR	MOR	MORT	LC50		1	d	77.52		ae mg/L	48	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	MOR	MOR	MORT	LC50		2	d	77.52		ae mg/L	48	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	BCM	ENZ	ACHE	LOAEL		2	d	1.85		ae mg/L	48	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	BCM	ENZ	BCHE	LOAEL		2	d	1.85		ae mg/L	48	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	BCM	ENZ	ALIE	LOAEL		2	d	1.85		ae mg/L	48	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	BCM	ENZ	GSTR	LOAEL		2	d	1.85		ae mg/L	48	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	MOR	MOR	MORT	LC50		0.25	d	49.65		ae mg/L	48	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	MOR	MOR	MORT	LC50		0.5	d	47.25		ae mg/L	48	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	MOR	MOR	MORT	LC50		1	d	38.76		ae mg/L	48	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	MOR	MOR	MORT	LC50		2	d	38.76		ae mg/L	48	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	BCM	ENZ	ACHE	LOAEL		2	d	1.85		ae mg/L	48	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	BCM	ENZ	BCHE	LOAEL		2	d	1.85		ae mg/L	48	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	BCM	ENZ	ALIE	LOAEL		2	d	1.85		ae mg/L	48	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	BCM	ENZ	GSTR	LOAEL		2	d	1.85		ae mg/L	48	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	MOR	MOR	MORT	LC50		0.25	d	96.87		ae mg/L	48	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	MOR	MOR	MORT	LC50		0.5	d	77.52		ae mg/L	48	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	MOR	MOR	MORT	LC50		1	d	73.77		ae mg/L	48	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	MOR	MOR	MORT	LC50		2	d	73.77		ae mg/L	48	161996

Glyphosate ammonium salt	Rhinella	arenarum	Toad	BCM	ENZ	ACHE	LOAEL		2	d	1.85		ae mg/L	48	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	BCM	ENZ	BCHE	LOAEL		2	d	1.85		ae mg/L	48	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	BCM	ENZ	ALIE	LOAEL		2	d	1.85		ae mg/L	48	161996
Glyphosate ammonium salt	Rhinella	arenarum	Toad	BCM	ENZ	GSTR	LOAEL		2	d	1.85		ae mg/L	48	161996
Glyphosate	Glyptocidaris	crenularis	Sea Urchin	GRO	DVP	ABNM	EC50		0	d	13.2		uM	95	160866
Glyphosate	Glyptocidaris	crenularis	Sea Urchin	GRO	DVP	ABNM	EC50		0.0208	d	12.78		uM	95	160866
Glyphosate	Glyptocidaris	crenularis	Sea Urchin	GRO	DVP	ABNM	EC50		0.0417	d	10.78		uM	95	160866
Glyphosate	Glyptocidaris	crenularis	Sea Urchin	GRO	DVP	ABNM	EC50		0.4167	d	10.63		uM	95	160866
Glyphosate	Glyptocidaris	crenularis	Sea Urchin	GRO	DVP	ABNM	EC50		0.875	d	9.17		uM	95	160866
Glyphosate	Glyptocidaris	crenularis	Sea Urchin	GRO	DVP	ABNM	EC50		2.0833	d	6.35		uM	95	160866
Glyphosate	Glyptocidaris	crenularis	Sea Urchin	REP	REP	FERZ	EC50		0.0556	d	29.3		uM	95	160866
Glyphosate potassium salt	Lithobates	clamitans	Green Frog	MOR	MOR	SURV	NOAEL		14	d			ae kg/ha	100	161819
Glyphosate potassium salt	Lithobates	clamitans	Green Frog	GRO	MPH	SMIX	NOAEL		14	d			ae kg/ha	100	161819
Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	CEL	CEL	HCYT	LOAEL		3	d	0.02		mg/L	48	161812
Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	CEL	CEL	HCYT	LOAEL		7	d	0.02		mg/L	48	161812
Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	CEL	CEL	HCYT	NOAEL		0.25	d	0.02		mg/L	48	161812
Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	CEL	CEL	HCYT	NOAEL		1	d	0.02		mg/L	48	161812
Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	CEL	CEL	HCYT	NOAEL		7	d	0.02		mg/L	48	161812
Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	CEL	CEL	HCYT	LOAEL		0.25	d	0.02		mg/L	48	161812
Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	CEL	CEL	HCYT	LOAEL		1	d	0.02		mg/L	48	161812

Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	CEL	CEL	HCYT	LOAEL		3	d	0.02		mg/L	48	161812
Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	CEL	CEL	HCYT	NOAEL		7	d	0.02		mg/L	48	161812
Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	CEL	CEL	HCYT	LOAEL		0.25	d	0.02		mg/L	48	161812
Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	CEL	CEL	HCYT	LOAEL		1	d	0.02		mg/L	48	161812
Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	CEL	CEL	HCYT	LOAEL		3	d	0.02		mg/L	48	161812
Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	CEL	CEL	HCYT	NOAEL		7	d	0.02		mg/L	48	161812
Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	PHY	IMM	PHAG	LOAEL		0.25	d	0.02		mg/L	48	161812
Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	PHY	IMM	PHAG	NOAEL		1	d	0.02		mg/L	48	161812
Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	PHY	IMM	PHAG	LOAEL		7	d	0.02		mg/L	48	161812
Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	CEL	CEL	HCYT	NOAEL		0.25	d	0.02		mg/L	48	161812
Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	CEL	CEL	HCYT	LOAEL		1	d	0.02		mg/L	48	161812
Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	CEL	CEL	HCYT	NOAEL		3	d	0.02		mg/L	48	161812
Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	PHY	IMM	PHAG	LOAEL		3	d	0.02		mg/L	48	161812
Glyphosate isopropylamine salt	Parachlorella	kessleri	Green Algae	BCM	BCM	MLDH	NOAEL	LOAEL	4	d	40	50	mg/L	48	161954
Glyphosate isopropylamine salt	Parachlorella	kessleri	Green Algae	POP	POP	ABND	NOAEL	LOAEL	4	d	50	60	mg/L	48	161954

Glyphosate isopropylamine salt	Parachlo rella	kessleri	Green Algae	BCM	ENZ	CTLS	LOAEL		4	d	40		mg/L	48	161954
Glyphosate isopropylamine salt	Parachlo rella	kessleri	Green Algae	POP	POP	PGRT	EC50		4	d	55.62		mg/L	48	161954
Glyphosate isopropylamine salt	Caridina	nilotica	Shrimp	MOR	MOR	MORT	LOAEL		3	d	19.6		mg/L	98	156113
Glyphosate isopropylamine salt	Caridina	nilotica	Shrimp	MOR	MOR	MORT	LOAEL		4	d	19.6		mg/L	98	156113
Glyphosate isopropylamine salt	Caridina	nilotica	Shrimp	MOR	MOR	MORT	LC50		4	d	59.7408		mg/L	98	156113
Glyphosate isopropylamine salt	Caridina	nilotica	Shrimp	MOR	MOR	MORT	NOAEL		1	d	39.2		mg/L	98	156113
Glyphosate isopropylamine salt	Caridina	nilotica	Shrimp	MOR	MOR	MORT	LOAEL		1	d	78.4		mg/L	98	156113
Glyphosate isopropylamine salt	Caridina	nilotica	Shrimp	MOR	MOR	MORT	LOAEL		2	d	39.2		mg/L	98	156113
Glyphosate isopropylamine salt	Caridina	nilotica	Shrimp	MOR	MOR	MORT	NOAEL		2	d	19.6		mg/L	98	156113
Glyphosate isopropylamine salt	Caridina	nilotica	Shrimp	MOR	MOR	MORT	LC50		3	d	105.3794		mg/L	98	156113
Glyphosate isopropylamine salt	Phyllodia ptomus	annae	Copepod	MOR	MOR	MORT	LOAEL		2	d	0.098		mg/L	98	156113
Glyphosate isopropylamine salt	Phyllodia ptomus	annae	Copepod	MOR	MOR	MORT	LC50		2	d	1.03782		mg/L	98	156113
Glyphosate isopropylamine salt	Helix	aspersa	Brown Gardensnail	GRO	GRO	WGHT	LOAEL		12	d	856.9		g/ha	100	155488
Glyphosate isopropylamine salt	Helix	aspersa	Brown Gardensnail	MOR	MOR	MORT	NOAEL		12	d	856.9		g/ha	100	155488
Glyphosate isopropylamine salt	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	NOEC	LOEC	20	d	178	231	ppm	100	155483

Glyphosate isopropylamine salt	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	EC50		20	d	219		ppm	100	155483
Glyphosate isopropylamine salt	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	NOEC		20	d	300		ppm	100	155483
Glyphosate isopropylamine salt	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	NOEC	LOEC	20	d	20	40	ppm	100	155483
Glyphosate isopropylamine salt	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	EC10		20	d	31.2		ppm	100	155483
Glyphosate isopropylamine salt	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	EC50		20	d	43.1		ppm	100	155483
Glyphosate isopropylamine salt	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	NOEC	LOEC	20	d	44.4	66.7	ppm	100	155483
Glyphosate isopropylamine salt	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	EC10		20	d	47.3		ppm	100	155483
Glyphosate isopropylamine salt	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	EC50		20	d	55.3		ppm	100	155483
Glyphosate isopropylamine salt	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	NOEC	LOEC	20	d	45	90	ppm	100	155483
Glyphosate isopropylamine salt	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	EC10		20	d	50		ppm	100	155483
Glyphosate isopropylamine salt	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	EC50		20	d	90.3		ppm	100	155483
Glyphosate isopropylamine salt	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	NOEC	LOEC	20	d	90	130	ppm	100	155483
Glyphosate isopropylamine salt	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	EC10		20	d	64.7		ppm	100	155483
Glyphosate isopropylamine salt	Helix	aspersa	Brown Gardensnail	MOR	MOR	HTCH	EC50		20	d	130.5		ppm	100	155483
Glyphosate	Cynodon	sp.	Bermudagrass	PHY	INJ	DAMG	IC50		17	d	0.63		ae kg/ha	100	155802
Glyphosate	Cynodon	sp.	Bermudagrass	GRO	GRO	VGOR	IC50		31	d	0.71		ae kg/ha	100	155802

Glyphosate	Cynodon	sp.	Bermudagrass	PHY	INJ	DAMG	IC50		17	d	0.54		ae kg/ha	100	155802
Glyphosate	Cynodon	sp.	Bermudagrass	GRO	GRO	VGOR	IC50		31	d	0.52		ae kg/ha	100	155802
Glyphosate	Cynodon	sp.	Bermudagrass	PHY	INJ	DAMG	IC50		17	d	0.52		ae kg/ha	100	155802
Glyphosate	Cynodon	sp.	Bermudagrass	GRO	GRO	VGOR	IC50		31	d	0.56		ae kg/ha	100	155802
Glyphosate	Cynodon	sp.	Bermudagrass	PHY	INJ	DAMG	IC50		17	d	0.34		ae kg/ha	100	155802
Glyphosate	Cynodon	sp.	Bermudagrass	GRO	GRO	VGOR	IC50		31	d	0.39		ae kg/ha	100	155802
Glyphosate	Cynodon	sp.	Bermudagrass	PHY	INJ	DAMG	IC50		17	d	0.63		ae kg/ha	100	155802
Glyphosate	Cynodon	sp.	Bermudagrass	GRO	GRO	VGOR	IC50		31	d	0.57		ae kg/ha	100	155802
Glyphosate	Cynodon	sp.	Bermudagrass	PHY	INJ	DAMG	IC50		17	d	0.61		ae kg/ha	100	155802
Glyphosate	Cynodon	sp.	Bermudagrass	GRO	GRO	VGOR	IC50		31	d	0.66		ae kg/ha	100	155802
Glyphosate	Cynodon	sp.	Bermudagrass	PHY	INJ	DAMG	IC50		17	d	0.81		ae kg/ha	100	155802
Glyphosate	Cynodon	sp.	Bermudagrass	GRO	GRO	VGOR	IC50		31	d	0.92		ae kg/ha	100	155802
Glyphosate	Cynodon	sp.	Bermudagrass	PHY	INJ	DAMG	IC50		17	d	0.56		ae kg/ha	100	155802
Glyphosate	Cynodon	sp.	Bermudagrass	GRO	GRO	VGOR	IC50		31	d	0.83		ae kg/ha	100	155802
Glyphosate	Cynodon	sp.	Bermudagrass	PHY	INJ	DAMG	IC50		17	d	0.54		ae kg/ha	100	155802
Glyphosate	Cynodon	sp.	Bermudagrass	GRO	GRO	VGOR	IC50		31	d	0.8		ae kg/ha	100	155802
Glyphosate	Cynodon	sp.	Bermudagrass	PHY	INJ	DAMG	IC50		17	d	0.77		ae kg/ha	100	155802
Glyphosate	Cynodon	sp.	Bermudagrass	GRO	GRO	VGOR	IC50		31	d	1		ae kg/ha	100	155802
Glyphosate	Cynodon	dactylon	Bermudagrass	PHY	INJ	DAMG	IC50		17	d	1.14		ae kg/ha	100	155802
Glyphosate	Cynodon	dactylon	Bermudagrass	GRO	GRO	VGOR	IC50		31	d	0.99		ae kg/ha	100	155802
Glyphosate	Cynodon	sp.	Bermudagrass	PHY	INJ	DAMG	IC50		17	d	0.51		ae kg/ha	100	155802
Glyphosate	Cynodon	sp.	Bermudagrass	GRO	GRO	VGOR	IC50		31	d	0.76		ae kg/ha	100	155802
Glyphosate isopropylamine salt	Cyprinus	carpio	Common Carp	BCM	ENZ	ACHE	LOAEL		4	d	0.48		mg/L	100	161752

Glyphosate isopropylamine salt	Cyprinus	carpio	Common Carp	BCM	BCM	TBAR	LOAEL		4	d	0.48		mg/L	100	161752
Glyphosate isopropylamine salt	Cyprinus	carpio	Common Carp	BCM	ENZ	ACHE	LOAEL		4	d	0.48		mg/L	100	161752
Glyphosate isopropylamine salt	Astyanax	sp.	Astynaxes	BCM	ENZ	CTLS	NOAEL		4	d	0.006		ml/L	100	160633
Glyphosate isopropylamine salt	Astyanax	sp.	Astynaxes	PHY	PHY	LDPX	LOAEL		4	d	0.006		ml/L	100	160633
Glyphosate isopropylamine salt	Astyanax	sp.	Astynaxes	BCM	ENZ	GSTR	NOAEL		4	d	0.006		ml/L	100	160633
Glyphosate isopropylamine salt	Astyanax	sp.	Astynaxes	BCM	ENZ	ACHE	NOAEL		4	d	0.006		ml/L	100	160633
Glyphosate isopropylamine salt	Astyanax	sp.	Astynaxes	PHY	PHY	LDPX	NOAEL		4	d	0.003		ml/L	100	160633
Glyphosate isopropylamine salt	Astyanax	sp.	Astynaxes	CEL	GEN	DAMG	LOAEL		4	d	0.006		ml/L	100	160633
Glyphosate isopropylamine salt	Astyanax	sp.	Astynaxes	CEL	GEN	DAMG	NOAEL		4	d	0.003		ml/L	100	160633
Glyphosate isopropylamine salt	Ischaemum	magnum	Grass	POP	POP	BMAS	LOAEL		84	d	1.92672		lb/acre	100	155608
Glyphosate isopropylamine salt	NR	Plantae	Plant Kingdom	POP	POP	BMAS	LOAEL		45	d	0.8028		lb/acre	100	155644
Glyphosate isopropylamine salt	NR	Plantae	Plant Kingdom	POP	POP	BMAS	LOAEL		90	d	0.8028		lb/acre	100	155644
Glyphosate isopropylamine salt	NR	Plantae	Plant Kingdom	POP	POP	BMAS	LOAEL		165	d	0.8028		lb/acre	100	155644
Glyphosate isopropylamine salt	NR	Plantae	Plant Kingdom	POP	POP	BMAS	LOAEL		210	d	0.8028		lb/acre	100	155644
Glyphosate isopropylamine salt	NR	Plantae	Plant Kingdom	POP	POP	ABND	LOAEL		45	d	0.8028		lb/acre	100	155644

Glyphosate isopropylamine salt	NR	Plantae	Plant Kingdom	POP	POP	ABND	LOAEL		90	d	0.8028		lb/acre	100	155644
Glyphosate	Pardosa	milvina	Wolf Spider	BEH	AVO	CHEM	LOAEL		0.2917	d	4920		ppm	41	161972
Glyphosate	Pardosa	milvina	Wolf Spider	BEH	BEH	SMEL	NOAEL		0.0139	d	3148.8		ppm	41	161972
Glyphosate	Pardosa	milvina	Wolf Spider	BEH	BEH	SMEL	LOAEL		0.0139	d	3148.8		ppm	41	161972
Glyphosate	Pardosa	milvina	Wolf Spider	BEH	AVO	CHEM	LOAEL		0.2917	d	4920		ppm	41	161972
Glyphosate isopropylamine salt	Eisenia	andrei	Earthworm	POP	POP	ABND	NOAEL		28	d			ppm	100	160452
Glyphosate isopropylamine salt	Eisenia	andrei	Earthworm	GRO	GRO	WGHT	NOAEL		28	d			ppm	100	160452
Glyphosate isopropylamine salt	Eisenia	andrei	Earthworm	BEH	FDB	FCNS	NOAEL		7	d			ppm	100	160452
Glyphosate isopropylamine salt	Brassica	rapa	Bird Rape	REP	REP	GERM	NOAEL	LOAEL	28	d			ppm	100	160452
Glyphosate isopropylamine salt	Brassica	rapa	Bird Rape	GRO	GRO	LGTH	NOAEL		28	d			ppm	100	160452
Glyphosate isopropylamine salt	Porcellio nides	pruinosus	Tropical Isopod	MOR	MOR	SURV	NOAEL		28	d			ppm	100	160452
Glyphosate isopropylamine salt	Porcellio nides	pruinosus	Tropical Isopod	PHY	PHY	LDPX	NOAEL		28	d			ppm	100	160452
Glyphosate isopropylamine salt	Porcellio nides	pruinosus	Tropical Isopod	BCM	ENZ	ACHE	NOAEL		28	d			ppm	100	160452
Glyphosate isopropylamine salt	Cyprinus	carpio	Common Carp	MOR	MOR	SURV	NOAEL	LOAEL	2	d	0.001	0.01	mg/dm3	100	161361
Glyphosate isopropylamine salt	Cyprinus	carpio	Common Carp	MOR	MOR	SURV	LOAEL		3	d	0.001		mg/dm3	100	161361
Glyphosate isopropylamine salt	Cyprinus	carpio	Common Carp	MOR	MOR	MORT	NOAEL	LOAEL	1	d	0.08	0.8	mg/dm3	100	161361
Glyphosate isopropylamine salt	Cyprinus	carpio	Common Carp	MOR	MOR	MORT	NOAEL	LOAEL	1	d	0.04	0.08	mg/dm3	100	161361
Glyphosate isopropylamine salt	Cyprinus	carpio	Common Carp	MOR	MOR	SURV	NOAEL	LOAEL	4	d	0.001	0.01	mg/dm3	100	161361

Glyphosate	Coturnix	japonica	Japanese Quail	GRO	GRO	WGHT	NOAEL		8	d	3470		ppm	100	161959
Glyphosate	Coturnix	japonica	Japanese Quail	BEH	FDB	FCNS	NOAEL		8	d	3470		ppm	100	161959
Glyphosate	Coturnix	japonica	Japanese Quail	GRO	MPH	WGHT	NOAEL		8	d	3470		ppm	100	161959
Glyphosate	Coturnix	japonica	Japanese Quail	GRO	MPH	WGHT	NOAEL		8	d	3470		ppm	100	161959
Glyphosate	Coturnix	japonica	Japanese Quail	BCM	BCM	LIPD	NOAEL		8	d	3470		ppm	100	161959
Glyphosate	Coturnix	japonica	Japanese Quail	BCM	BCM	LIPD	NOAEL		8	d	3470		ppm	100	161959
Glyphosate	Daucus	carota	Wild Carrot	PHY	INJ	GINJ	LOAEL		21	d	0.06244		lb/acre	100	157165
Glyphosate	Daucus	carota	Wild Carrot	POP	POP	BMAS	NOAEL		85	d	0.06244		lb/acre	100	157165
Glyphosate	Cuscuta	gronovii	Swamp Dodder	POP	POP	CNTL	LOAEL		21	d	0.06244		lb/acre	100	157165
Glyphosate	Kochia	scoparia	Kochia	PHY	INJ	GINJ	LOAEL		17	d	1.7		ae kg/ha	100	157230
Glyphosate	Kochia	scoparia	Kochia	POP	POP	CNTL	LOAEL		32	d	1.7		ae kg/ha	100	157230
Glyphosate	Kochia	scoparia	Kochia	PHY	INJ	GINJ	LOAEL		14	d	1.7		ae kg/ha	100	157230
Glyphosate	Kochia	scoparia	Kochia	POP	POP	CNTL	LOAEL		30	d	1.7		ae kg/ha	100	157230
Glyphosate	Kochia	scoparia	Kochia	POP	POP	COVR	LOAEL		39	d	1.7		ae kg/ha	100	157230
Glyphosate	Kochia	scoparia	Kochia	POP	POP	COVR	LOAEL		41	d	1.7		ae kg/ha	100	157230
Glyphosate	Kochia	scoparia	Kochia	POP	POP	COVR	NOAEL		90	d	1.7		ae kg/ha	100	157230
Glyphosate	Cuscuta	campestris	Field Dodder	POP	POP	ABND	LOAEL		5	d	0.011125		lb/acre	100	157176
Glyphosate	Cuscuta	campestris	Field Dodder	POP	POP	ABND	LOAEL		5	d	0.011125		lb/acre	100	157176
Glyphosate	Guizotia	abyssinica	Ramtilla	POP	POP	BMAS	NOAEL			hv	0.0445		lb/acre	100	157176
Glyphosate	Guizotia	abyssinica	Ramtilla	POP	POP	BMAS	NOAEL			hv	0.0445		lb/acre	100	157176
Glyphosate isopropylamine salt	Euseius	victoriensis	Victorian Predator Mite	MOR	MOR	MORT	NOAEL		7	d	2187		ppm	100	156426
Glyphosate isopropylamine salt	Euseius	victoriensis	Victorian Predator Mite	REP	REP	FCND	NOAEL			d	2187		ppm	100	156426
Glyphosate isopropylamine salt	Goodea	atripinnis	Blackfin Goodea	MOR	MOR	MORT	LC50		4	d	38.95		mg/L	100	161311
Glyphosate isopropylamine salt	Goodea	atripinnis	Blackfin Goodea	BCM	BCM	MLDH	NOAEL	LOAEL	4	d	3.89	7.79	mg/L	100	161311
Glyphosate isopropylamine salt	Goodea	atripinnis	Blackfin Goodea	BCM	BCM	MLDH	LOAEL		4	d	3.89		mg/L	100	161311
Glyphosate isopropylamine salt	Goodea	atripinnis	Blackfin Goodea	BCM	ENZ	CTLS	NOAEL	LOAEL	4	d	3.89	7.79	mg/L	100	161311
Glyphosate isopropylamine salt	Goodea	atripinnis	Blackfin Goodea	BCM	ENZ	CTLS	LOAEL		4	d	3.89		mg/L	100	161311

Glyphosate isopropylamine salt	Goodea	atripinnis	Blackfin Goodea	BCM	BCM	GLYC	NOAEL	LOAEL		4	d	3.89	7.79	mg/L	100	161311
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	PRCO	LOAEL			4	d	3		mg/L	100	161768
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	PRCO	LOAEL			4	d	3		mg/L	100	161768
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	MLDH	LOAEL			4	d	3		mg/L	100	161768
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	MLDH	LOAEL			4	d	3		mg/L	100	161768
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	PCAR	LOAEL			4	d	3		mg/L	100	161768
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	ENZ	CTLS	NOAEL	LOAEL		4	d	3	6	mg/L	100	161768
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	GLUC	LOAEL			4	d	3		mg/L	100	161768
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	GLUC	LOAEL			4	d	3		mg/L	100	161768
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	LACT	LOAEL			4	d	3		mg/L	100	161768
Glyphosate isopropylamine salt	Leporinus	obtusidens	Characin	BCM	BCM	MLDH	NOAEL			4	d	20		mg/L	100	161768
Glyphosate	Cherax	quadricarinatus	Australian Redclaw Crayfish	MOR	MOR	MORT	NR-ZERO			50	d	22.5		mg/L	100	161792
Glyphosate	Cherax	quadricarinatus	Australian Redclaw Crayfish	GRO	GRO	GAIN	NOAEL			50	d	22.5		mg/L	100	161792
Glyphosate	Cherax	quadricarinatus	Australian Redclaw Crayfish	PHY	PHY	OXYG	LOAEL			50	d	22.5		mg/L	100	161792
Glyphosate	Cherax	quadricarinatus	Australian Redclaw Crayfish	BCM	BCM	GLYC	LOAEL			50	d	22.5		mg/L	100	161792

Glyphosate	Cherax	quadricarinatus	Australian Redclaw Crayfish	BCM	BCM	GLYC	LOAEL		50	d	22.5		mg/L	100	161792
Glyphosate	Cherax	quadricarinatus	Australian Redclaw Crayfish	BCM	BCM	PRTL	NOAEL		50	d	22.5		mg/L	100	161792
Glyphosate	Cherax	quadricarinatus	Australian Redclaw Crayfish	BCM	BCM	PRTL	NOAEL		50	d	22.5		mg/L	100	161792
Glyphosate	Cherax	quadricarinatus	Australian Redclaw Crayfish	BCM	BCM	LIPD	NOAEL		50	d	22.5		mg/L	100	161792
Glyphosate	Cherax	quadricarinatus	Australian Redclaw Crayfish	BCM	BCM	LIPD	NOAEL		50	d	22.5		mg/L	100	161792
Glyphosate	Cherax	quadricarinatus	Australian Redclaw Crayfish	BCM	BCM	GLUC	NOAEL		50	d	22.5		mg/L	100	161792
Glyphosate	Cherax	quadricarinatus	Australian Redclaw Crayfish	BCM	BCM	PRTL	NOAEL		50	d	22.5		mg/L	100	161792
Glyphosate	Cherax	quadricarinatus	Australian Redclaw Crayfish	BCM	BCM	LIPD	NOAEL		50	d	22.5		mg/L	100	161792
Glyphosate isopropylamine salt	Rattus	norvegicus	Norway Rat	REP	REP	COUR	LOAEL		63	d	50		mg/kg bdwt	100	161810
Glyphosate isopropylamine salt	Rattus	norvegicus	Norway Rat	BCM	HRM	TSTR	LOAEL		63	d	50		mg/kg bdwt	100	161810
Glyphosate isopropylamine salt	Rattus	norvegicus	Norway Rat	CEL	GEN	LHMR	LOAEL		63	d	50		mg/kg bdwt	100	161810
Glyphosate isopropylamine salt	Rattus	norvegicus	Norway Rat	BCM	BCM	PRCO	LOAEL		63	d	50		mg/kg bdwt	100	161810
Glyphosate isopropylamine salt	Rattus	norvegicus	Norway Rat	GRO	MPH	WGHT	LOAEL		63	d	50		mg/kg bdwt	100	161810
Glyphosate isopropylamine salt	Rattus	norvegicus	Norway Rat	GRO	DVP	SXDP	LOAEL		46	d	50		mg/kg bdwt	100	161810
Glyphosate isopropylamine salt	Rattus	norvegicus	Norway Rat	GRO	GRO	WGHT	LOAEL		46	d	50		mg/kg bdwt	100	161810
Glyphosate	NR	Ostreoida	Bivalve Order	CEL	GEN	DAMG	NOAEL		0.0417	d	0.005		mg/L	100	161689

Glyphosate isopropylamine salt	NR	Ostreoida	Bivalve Order	CEL	GEN	DAMG	NOAEL		0.0417	d	0.005		mg/L	100	161689
Glyphosate	NR	Ostreoida	Bivalve Order	GRO	DVP	ABNM	NOAEL			ma	5		AI ug/L	100	161689
Glyphosate isopropylamine salt	NR	Ostreoida	Bivalve Order	GRO	DVP	ABNM	NOAEL			ma	5		AI ug/L	100	161689
Glyphosate isopropylamine salt	NR	Ostreoida	Bivalve Order	GRO	DVP	ABNM	NOAEL			ma	5		AI ug/L	100	161689
Glyphosate	NR	Ostreoida	Bivalve Order	GRO	DVP	ABNM	NOAEL			ma	5		AI ug/L	100	161689
Glyphosate isopropylamine salt	NR	Ostreoida	Bivalve Order	GRO	DVP	ABNM	NOAEL			ma	5		AI ug/L	100	161689
Glyphosate	NR	Ostreoida	Bivalve Order	GRO	DVP	ABNM	NOAEL	LOAEL		ma	1.5	2.5	AI ug/L	100	161689
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	ATPH,NCRO	NOAEL	LOAEL	4	d	3.735	7.47	mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	ATPH,NCRO	LOAEL		4	d	3.735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	EDMA,IFLM	NOAEL		4	d	26.145		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	ATPH,CNGT,EDMA,HEMR,HYPL,HYPT,IFLM,NCRO	LOAEL		4	d	3.735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	ATPH,CNGT,EDMA,HEMR,HYPL,HYPT,IFLM,NCRO	LOAEL		4	d	3.735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	ATPH,CNGT,EDMA,HEMR,HYPL,HYPT,IFLM,NCRO	LOAEL		4	d	3.735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	LMLL	NOAEL	LOAEL	4	d	7.47	14.94	mg/L	74.7	161672

Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	GHIS	NOAEL	LOAEL		4	d	14.94	26.145	mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	CEL	LMFI	NOAEL	LOAEL		4	d	7.47	14.94	mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	MOR	MOR	MORT	LC50			4	d	14.20794		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	MOR	MOR	MORT	NR-ZERO			4	d	3.735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	MOR	MOR	MORT	NR-LETH			4	d	44.82		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	CNGT,HEMR	NOAEL			4	d	26.145		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	HYPL,HYPT	NOAEL	LOAEL		4	d	3.735	7.47	mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	EDMA,IFLM	NOAEL			4	d	26.145		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	CNGT,HEMR	LOAEL			4	d	3.735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	LMLL	LOAEL			4	d	3.735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	LMLL	LOAEL			4	d	3.735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	REP	REP	MONT	LOAEL			28	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	CNGT,HEMR	NOAEL			7	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	CNGT,HEMR	NOAEL			28	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	ATPH,NCRO	NOAEL			7	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	ATPH,NCRO	NOAEL			28	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	HYPL,HYPT	NOAEL			7	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	HYPL,HYPT	NOAEL			28	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	EDMA,IFLM	NOAEL			7	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	EDMA,IFLM	NOAEL			28	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	CNGT,HEMR	NOAEL			7	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	CNGT,HEMR	NOAEL			7	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	ATPH,NCRO	NOAEL			28	d	0.3735		mg/L	74.7	161672

Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	EDMA,IFLM	NOAEL		7	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	ATPH,CNGT,EDMA,HEMR,HYPL,HYPT,IFLM,NCRO	LOAEL		7	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	ATPH,CNGT,EDMA,HEMR,HYPL,HYPT,IFLM,NCRO	LOAEL		7	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	ATPH,CNGT,EDMA,HEMR,HYPL,HYPT,IFLM,NCRO	LOAEL		28	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	ATPH,CNGT,EDMA,HEMR,HYPL,HYPT,IFLM,NCRO	LOAEL		7	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	LMLL	NOAEL		7	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	LMLL	NOAEL		7	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	LMLL	NOAEL		28	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	LMLL	NOAEL		7	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	LMLL	NOAEL		28	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	LMLL	NOAEL		7	d	0.3735		mg/L	74.7	161672

Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	LMLL	NOAEL		28	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	CEL	LMFI	LOAEL		7	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	CEL	LMFI	LOAEL		28	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	REP	REP	MONT	NOAEL		7	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	REP	REP	MONT	NOAEL		28	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	REP	REP	MONT	NOAEL		7	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	REP	REP	MONT	NOAEL		28	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	REP	REP	MONT	LOAEL		7	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	REP	REP	MONT	LOAEL		28	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	REP	REP	MONT	LOAEL		7	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	MOR	MOR	MORT	NR-ZERO		28	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	ATPH,NCRO	NOAEL		7	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	ATPH,CNGT,EDMA,HEMR,HYPL,HYPT,IFLM,NCRO	LOAEL		28	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	LMLL	NOAEL		28	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	EDMA,IFLM	NOAEL		28	d	0.3735		mg/L	74.7	161672
Glyphosate	Jenynsia	multidentata	Onesided Livebearer	CEL	HIS	ATPH,CNGT,EDMA,HEMR,HYPL,HYPT,IFLM,NCRO	LOAEL		28	d	0.3735		mg/L	74.7	161672
Glyphosate	Cnesterodon	decemmaculatus	Ten-Spotted Livebearer	BCM	ENZ	ACHE	LOAEL		4	d	1		mg/L	95	161670

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Glyphosate	Cnesterodon	decemmaculatus	Ten-Spotted Livebearer	GRO	GRO	COND	NOAEL		4	d			mg/L	95	161670
Glyphosate	Cnesterodon	decemmaculatus	Ten-Spotted Livebearer	BCM	ENZ	ACHE	NOAEL		4	d			mg/L	95	161670
Glyphosate	Cnesterodon	decemmaculatus	Ten-Spotted Livebearer	MOR	MOR	MORT	NR-ZERO		4	d			mg/L	95	161670
Glyphosate	Cnesterodon	decemmaculatus	Ten-Spotted Livebearer	BCM	ENZ	ACHE	NOAEL		4	d			mg/L	95	161670
Glyphosate	Hydra	attenuata	Hydra	MOR	MOR	MORT	LC01		4	d	10.7		mg/L	100	159864
Glyphosate	Hydra	attenuata	Hydra	MOR	MOR	MORT	LC05		4	d	13.3		mg/L	100	159864
Glyphosate	Hydra	attenuata	Hydra	MOR	MOR	MORT	LC10		4	d	14.8		mg/L	100	159864
Glyphosate	Hydra	attenuata	Hydra	MOR	MOR	MORT	LC15		4	d	15.9		mg/L	100	159864
Glyphosate	Hydra	attenuata	Hydra	MOR	MOR	MORT	LC50		4	d	21.8		mg/L	100	159864
Glyphosate	Hydra	attenuata	Hydra	MOR	MOR	MORT	LC85		4	d	29.9		mg/L	100	159864
Glyphosate	Hydra	attenuata	Hydra	MOR	MOR	MORT	LC01		4	d	14.8		mg/L	100	159864
Glyphosate	Hydra	attenuata	Hydra	MOR	MOR	MORT	LC05		4	d	15.7		mg/L	100	159864
Glyphosate	Hydra	attenuata	Hydra	MOR	MOR	MORT	LC10		4	d	16.2		mg/L	100	159864
Glyphosate	Hydra	attenuata	Hydra	MOR	MOR	MORT	LC15		4	d	16.6		mg/L	100	159864
Glyphosate	Hydra	attenuata	Hydra	MOR	MOR	MORT	LC50		4	d	18.2		mg/L	100	159864
Glyphosate	Hydra	attenuata	Hydra	MOR	MOR	MORT	LC85		4	d	20		mg/L	100	159864
Glyphosate isopropylamine salt	Lithobates	pipiens	Leopard Frog	MOR	MOR	MORT	LOEC		4	d	1.32		ae mg/L	29.7	161774
Glyphosate isopropylamine salt	Lithobates	pipiens	Leopard Frog	MOR	MOR	MORT	NOEC		4	d	1.29		ae mg/L	29.7	161774
Glyphosate isopropylamine salt	Lithobates	pipiens	Leopard Frog	MOR	MOR	MORT	MATC		4	d	1.31		ae mg/L	29.7	161774
Glyphosate isopropylamine salt	Lithobates	pipiens	Leopard Frog	MOR	MOR	MORT	LC50		4	d	1.8		ae mg/L	29.7	161774
Glyphosate isopropylamine salt	Lithobates	sphenocephalus ssp. sphenocephalus	Florida Leopard Frog	MOR	MOR	MORT	MATC		4	d	1.67		ae mg/L	29.7	161774
Glyphosate isopropylamine salt	Lithobates	sphenocephalus ssp. sphenocephalus	Florida Leopard Frog	MOR	MOR	MORT	LC50		4	d	2.05		ae mg/L	29.7	161774
Glyphosate isopropylamine salt	Lithobates	sphenocephalus ssp. sphenocephalus	Florida Leopard Frog	MOR	MOR	MORT	NOEC		4	d	1.52		ae mg/L	29.7	161774

Glyphosate isopropylamine salt	Lithobates	sphenocephalus ssp. sphenocephalus	Florida Leopard Frog	MOR	MOR	MORT	LOEC		4	d	1.81		ae mg/L	29.7	161774
Glyphosate isopropylamine salt	Hyla	chrysoscelis	Southern Grey Tree Frog	MOR	MOR	MORT	LC50		4	d	2.5		ae mg/L	29.7	161774
Glyphosate isopropylamine salt	Hyla	chrysoscelis	Southern Grey Tree Frog	MOR	MOR	MORT	NOEC		4	d	1.74		ae mg/L	29.7	161774
Glyphosate isopropylamine salt	Hyla	chrysoscelis	Southern Grey Tree Frog	MOR	MOR	MORT	LOEC		4	d	2.1		ae mg/L	29.7	161774
Glyphosate isopropylamine salt	Hyla	chrysoscelis	Southern Grey Tree Frog	MOR	MOR	MORT	MATC		4	d	1.92		ae mg/L	29.7	161774
Glyphosate isopropylamine salt	Rana	catesbeiana	Bullfrog	MOR	MOR	MORT	MATC		4	d	2.27		ae mg/L	29.7	161774
Glyphosate isopropylamine salt	Rana	catesbeiana	Bullfrog	MOR	MOR	MORT	LC50		4	d	2.77		ae mg/L	29.7	161774
Glyphosate isopropylamine salt	Rana	catesbeiana	Bullfrog	MOR	MOR	MORT	NOEC		4	d	2.02		ae mg/L	29.7	161774
Glyphosate isopropylamine salt	Rana	catesbeiana	Bullfrog	MOR	MOR	MORT	LOEC		4	d	2.52		ae mg/L	29.7	161774
Glyphosate isopropylamine salt	Anaxyrus	fowleri	Fowler's Toad	MOR	MOR	MORT	MATC		4	d	3.68		ae mg/L	29.7	161774
Glyphosate isopropylamine salt	Anaxyrus	fowleri	Fowler's Toad	MOR	MOR	MORT	LC50		4	d	4.21		ae mg/L	29.7	161774
Glyphosate isopropylamine salt	Anaxyrus	fowleri	Fowler's Toad	MOR	MOR	MORT	NOEC		4	d	3.4		ae mg/L	29.7	161774
Glyphosate isopropylamine salt	Anaxyrus	fowleri	Fowler's Toad	MOR	MOR	MORT	LOEC		4	d	3.95		ae mg/L	29.7	161774
Glyphosate isopropylamine salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	MATC		4	d	3.48		ae mg/L	29.7	161774
Glyphosate isopropylamine salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	LC50		4	d	4.22		ae mg/L	29.7	161774

Glyphosate isopropylamine salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	NOEC		4	d	3.27		ae mg/L	29.7	161774
Glyphosate isopropylamine salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	LOEC		4	d	3.68		ae mg/L	29.7	161774
Glyphosate, Monopotassium salt	Lithobates	sphenocephalus ssp. sphenocephalus	Florida Leopard Frog	MOR	MOR	MORT	MATC		4	d	0.83		ae mg/L	39.9	161774
Glyphosate, Monopotassium salt	Lithobates	sphenocephalus ssp. sphenocephalus	Florida Leopard Frog	MOR	MOR	MORT	LC50		4	d	1.33		ae mg/L	39.9	161774
Glyphosate, Monopotassium salt	Lithobates	sphenocephalus ssp. sphenocephalus	Florida Leopard Frog	MOR	MOR	MORT	NOEC		4	d	0.68		ae mg/L	39.9	161774
Glyphosate, Monopotassium salt	Lithobates	sphenocephalus ssp. sphenocephalus	Florida Leopard Frog	MOR	MOR	MORT	LOEC		4	d	0.98		ae mg/L	39.9	161774
Glyphosate, Monopotassium salt	Anaxyrus	fowleri	Fowler's Toad	MOR	MOR	MORT	MATC		4	d	1.55		ae mg/L	39.9	161774
Glyphosate, Monopotassium salt	Anaxyrus	fowleri	Fowler's Toad	MOR	MOR	MORT	LC50		4	d	1.96		ae mg/L	39.9	161774
Glyphosate, Monopotassium salt	Anaxyrus	fowleri	Fowler's Toad	MOR	MOR	MORT	NOEC		4	d	1.54		ae mg/L	39.9	161774
Glyphosate, Monopotassium salt	Anaxyrus	fowleri	Fowler's Toad	MOR	MOR	MORT	LOEC		4	d	1.56		ae mg/L	39.9	161774
Glyphosate, Monopotassium salt	Rana	catesbeiana	Bullfrog	MOR	MOR	MORT	LC50		4	d	1.97		ae mg/L	39.9	161774
Glyphosate, Monopotassium salt	Rana	catesbeiana	Bullfrog	MOR	MOR	MORT	NOEC		4	d	1.33		ae mg/L	39.9	161774
Glyphosate, Monopotassium salt	Rana	catesbeiana	Bullfrog	MOR	MOR	MORT	LOEC		4	d	1.37		ae mg/L	39.9	161774
Glyphosate, Monopotassium salt	Rana	catesbeiana	Bullfrog	MOR	MOR	MORT	MATC		4	d	1.35		ae mg/L	39.9	161774

Glyphosate, Monopotassium salt	Lithobates	pipiens	Leopard Frog	MOR	MOR	MORT	LC50		4	d	2.27		ae mg/L	39.9	161774
Glyphosate, Monopotassium salt	Lithobates	pipiens	Leopard Frog	MOR	MOR	MORT	NOEC		4	d	1.65		ae mg/L	39.9	161774
Glyphosate, Monopotassium salt	Lithobates	pipiens	Leopard Frog	MOR	MOR	MORT	LOEC		4	d	1.68		ae mg/L	39.9	161774
Glyphosate, Monopotassium salt	Lithobates	pipiens	Leopard Frog	MOR	MOR	MORT	MATC		4	d	1.67		ae mg/L	39.9	161774
Glyphosate, Monopotassium salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	MATC		4	d	2.14		ae mg/L	39.9	161774
Glyphosate, Monopotassium salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	LC50		4	d	2.77		ae mg/L	39.9	161774
Glyphosate, Monopotassium salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	NOEC		4	d	1.91		ae mg/L	39.9	161774
Glyphosate, Monopotassium salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	LOEC		4	d	2.37		ae mg/L	39.9	161774
Glyphosate, Monopotassium salt	Hyla	chrysoscelis	Southern Grey Tree Frog	MOR	MOR	MORT	LC50		4	d	3.26		ae mg/L	39.9	161774
Glyphosate, Monopotassium salt	Hyla	chrysoscelis	Southern Grey Tree Frog	MOR	MOR	MORT	NOEC		4	d	2.48		ae mg/L	39.9	161774
Glyphosate, Monopotassium salt	Hyla	chrysoscelis	Southern Grey Tree Frog	MOR	MOR	MORT	LOEC		4	d	2.87		ae mg/L	39.9	161774
Glyphosate, Monopotassium salt	Hyla	chrysoscelis	Southern Grey Tree Frog	MOR	MOR	MORT	MATC		4	d	2.68		ae mg/L	39.9	161774
Glyphosate	Planktothrix	sp.	Blue-green Algae	POP	POP	ABND	NOAEL		2	d	1		uM	100	161943
Glyphosate	Aulacoseira	sp.	Diatom	POP	POP	ABND	NOAEL		2	d	1		uM	100	161943
Glyphosate	Microcystis	sp.	Blue-Green Algae	POP	POP	ABND	LOAEL		2	d	1		uM	100	161943
Glyphosate	Aquatic	community	Aquatic Community	POP	POP	CHLA	NOAEL		2	d	1		uM	100	161943
Glyphosate	Aquatic	community	Aquatic Community	POP	POP	CHLA	NOAEL		2	d	1		uM	100	161943

Glyphosate	Planktot hrix	sp.	Blue-green Algae	POP	POP	ABND	NOAEL		2	d	1		uM	100	161943
Glyphosate	Microcys tis	sp.	Blue-Green Algae	POP	POP	ABND	NOAEL		2	d	1		uM	100	161943
Glyphosate	Aulacose ira	sp.	Diatom	POP	POP	ABND	LOAEL		2	d	1		uM	100	161943
Glyphosate isopropylamine salt	Pardosa	agricola	Shore Wolf Spider	BEH	FDB	FCNS	NOAEL		0.25	d	0.0385		%	100	162000
Glyphosate isopropylamine salt	Pardosa	agricola	Shore Wolf Spider	BEH	BEH	LOCO	NOAEL		0.0833	d	0.0385		%	100	162000
Glyphosate isopropylamine salt	Pterostic hus	cupreus	Ground Beetle	BEH	FDB	FCNS	NOAEL		0.25	d	0.0385		%	100	162000
Glyphosate isopropylamine salt	Pterostic hus	cupreus	Ground Beetle	BEH	BEH	LOCO	LOAEL		0.0833	d	0.0385		%	100	162000
Glyphosate isopropylamine salt	Pardosa	agricola	Shore Wolf Spider	BEH	AVO	CHEM	NOAEL		0.0833	d	0.0385		%	100	162000
Glyphosate isopropylamine salt	Pterostic hus	cupreus	Ground Beetle	BEH	AVO	CHEM	LOAEL		0.0833	d	0.0385		%	100	162000
Glyphosate isopropylamine salt	Pardosa	agricola	Shore Wolf Spider	BEH	BEH	PRVU	NOAEL		0.0938	d	0.0385		%	100	162000
Glyphosate isopropylamine salt	Pardosa	agricola	Shore Wolf Spider	REP	REP	MIDX	NOAEL		0.1111	d	0.0385		%	100	162000
Glyphosate isopropylamine salt	Telenom us	remus	Parasitoid Wasp	POP	POP	ABND	LOAEL		2	d	1200		ae g/200 L	100	157409
Glyphosate isopropylamine salt	Telenom us	remus	Parasitoid Wasp	GRO	DVP	EMRG	NOAEL		2	d	1200		ae g/200 L	100	157409
Glyphosate	Telenom us	remus	Parasitoid Wasp	POP	POP	ABND	LOAEL		2	d	2880		ae g/200 L	100	157409
Glyphosate	Telenom us	remus	Parasitoid Wasp	GRO	DVP	EMRG	NOAEL		1	d	2880		ae g/200 L	100	157409
Glyphosate isopropylamine salt	Telenom us	remus	Parasitoid Wasp	GRO	DVP	EMRG	NOAEL		1	d	1920		ae g/200 L	100	157409
Glyphosate isopropylamine salt	Telenom us	remus	Parasitoid Wasp	POP	POP	ABND	LOAEL		2	d	1920		ae g/200 L	100	157409

Glyphosate isopropylamine salt	Lithobat es	pipiens	Leopard Frog	GRO	GRO	LGTH	LOAEL		21	d			mg/L	100	160519
Glyphosate isopropylamine salt	Lithobat es	pipiens	Leopard Frog	GRO	GRO	WGHT	NOAEL		21	d			mg/L	100	160519
Glyphosate isopropylamine salt	Lithobat es	pipiens	Leopard Frog	GRO	MPH	SMIX	NOAEL		21	d			mg/L	100	160519
Glyphosate isopropylamine salt	Lithobat es	pipiens	Leopard Frog	GRO	MPH	SMIX	NOAEL		21	d			mg/L	100	160519
Glyphosate isopropylamine salt	Lithobat es	pipiens	Leopard Frog	MOR	MOR	SURV	NOAEL		21	d			mg/L	100	160519
Glyphosate isopropylamine salt	Lithobat es	pipiens	Leopard Frog	CEL	~HIS	MELM	NOAEL		94	d			mg/L	100	160519
Glyphosate isopropylamine salt	Lithobat es	pipiens	Leopard Frog	CEL	~HIS	MELM	NOAEL		94	d			mg/L	100	160519
Glyphosate isopropylamine salt	Lithobat es	pipiens	Leopard Frog	CEL	~HIS	GRNM	NOAEL		94	d			mg/L	100	160519
Glyphosate isopropylamine salt	Lithobat es	pipiens	Leopard Frog	CEL	~HIS	GRNM	NOAEL		94	d			mg/L	100	160519
Glyphosate isopropylamine salt	Lithobat es	pipiens	Leopard Frog	CEL	~HIS	MELM	NOAEL		94	d			mg/L	100	160519
Glyphosate isopropylamine salt	Lithobat es	pipiens	Leopard Frog	CEL	~HIS	MELM	NOAEL		94	d			mg/L	100	160519
Glyphosate isopropylamine salt	Lithobat es	pipiens	Leopard Frog	CEL	~CEL	NLCR	NOAEL		94	d			mg/L	100	160519
Glyphosate isopropylamine salt	Enallagm a	cyathigerum	Damselfly	BEH	~BEH	LOCO	LOAEL		1.0118	d		1.5	mg/L	100	160532
Glyphosate isopropylamine salt	Enallagm a	cyathigerum	Damselfly	BEH	~BEH	LOCO	LOAEL		1.0236	d		1.5	mg/L	100	160532
Glyphosate isopropylamine salt	Enallagm a	cyathigerum	Damselfly	BEH	~BEH	ORNT	LOAEL		1.0236	d		1.5	mg/L	100	160532

Glyphosate isopropylamine salt	Enallagma	cyathigerum	Damselfly	BEH	~BEH	ORNT	LOAEL		1.0118	d	1.5		mg/L	100	160532
Glyphosate isopropylamine salt	Enallagma	cyathigerum	Damselfly	BEH	~FDB	STRK	LOAEL		1.0118	d	1.5		mg/L	100	160532
Glyphosate isopropylamine salt	Enallagma	cyathigerum	Damselfly	BEH	~FDB	STRK	LOAEL		1.0236	d	1.5		mg/L	100	160532
Glyphosate isopropylamine salt	Enallagma	cyathigerum	Damselfly	BEH	~BEH	SWIM	LOAEL		1.0069	d	1.5		mg/L	100	160532
Glyphosate isopropylamine salt	Enallagma	cyathigerum	Damselfly	BEH	~BEH	SWIM	LOAEL		1.0069	d	1.5		mg/L	100	160532
Glyphosate isopropylamine salt	Enallagma	cyathigerum	Damselfly	BEH	~BEH	PRVU	NOAEL			d	1.5		mg/L	100	160532
Glyphosate isopropylamine salt	Enallagma	cyathigerum	Damselfly	BEH	BEH	LOCO	NOAEL	LOAEL	1	d	1	2	mg/L	100	160532
Glyphosate isopropylamine salt	Enallagma	cyathigerum	Damselfly	BEH	FDB	STRK	LOEC		1	d	1		mg/L	100	160532
Glyphosate	Trigonella	foenum-graecum	Fenugreek	CEL	GEN	MITI	LOAEL		3.0833	d	0.1		%	100	161292
Glyphosate	Trigonella	foenum-graecum	Fenugreek	CEL	GEN	CABR	LOAEL		3.25	d	0.1		%	100	161292
Glyphosate	Trigonella	foenum-graecum	Fenugreek	CEL	GEN	CABR	NOAEL	LOAEL	3.0417	d	0.1	0.2	%	100	161292
Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	EC50		0.25	d	11.7		mg/L	100	159498
Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	NOAEL		0.25	d	1000		mg/L	100	159498
Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	BCM	ENZ	CTLS	NOAEL		0.25	d	1000		mg/L	100	159498
Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	BCM	ENZ	SODA	NOAEL		0.25	d	1000		mg/L	100	159498
Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	EC50		0.25	d	67.4		mg/L	100	159498

Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	NOAEL		0.25	d	1000		mg/L	100	159498
Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	NOAEL		0.25	d	1000		mg/L	100	159498
Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	EC50		0.25	d	6.1		mg/L	100	159498
Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	EC50		0.25	d	9.8		mg/L	100	159498
Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	NOAEL		0.25	d	1000		mg/L	100	159498
Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	NOAEL		0.25	d	1000		mg/L	100	159498
Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	NOAEL		0.25	d	1000		mg/L	100	159498
Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	NOAEL	LOAEL	0.25	d	1	10	mg/L	100	159498
Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	BCM	ENZ	CTLS	NOAEL		0.25	d	1000		mg/L	100	159498
Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	BCM	ENZ	SODA	NOAEL		0.25	d	1000		mg/L	100	159498
Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	EC50		0.25	d	35.6		mg/L	100	159498
Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	EC50		0.25	d	1066.9		mg/L	100	159498
Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	NOAEL		0.25	d	1000		mg/L	100	159498
Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	NOAEL		0.25	d	1000		mg/L	100	159498
Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	NOAEL		0.25	d	1000		mg/L	100	159498

Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	NOAEL		0.25	d	1000		mg/L	100	159498
Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	BCM	ENZ	CTLS	NOAEL		0.25	d	1000		mg/L	100	159498
Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	BCM	ENZ	SODA	NOAEL		0.25	d	1000		mg/L	100	159498
AMPA	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	NOAEL		0.25	d	500		mg/L	100	159498
AMPA	Aquatic	community	Aquatic Community	BCM	ENZ	CTLS	NOAEL		0.25	d	500		mg/L	100	159498
AMPA	Aquatic	community	Aquatic Community	BCM	ENZ	SODA	NOAEL		0.25	d	500		mg/L	100	159498
AMPA	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	NOAEL		0.25	d	500		mg/L	100	159498
AMPA	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	NOAEL		0.25	d	500		mg/L	100	159498
AMPA	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	NOAEL		0.25	d	500		mg/L	100	159498
AMPA	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	NOAEL		0.25	d	500		mg/L	100	159498
AMPA	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	NOAEL		0.25	d	500		mg/L	100	159498
AMPA	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	NOAEL		0.25	d	500		mg/L	100	159498
AMPA	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	NOAEL		0.25	d	500		mg/L	100	159498
AMPA	Aquatic	community	Aquatic Community	BCM	ENZ	CTLS	NOAEL		0.25	d	500		mg/L	100	159498
AMPA	Aquatic	community	Aquatic Community	BCM	ENZ	SODA	NOAEL		0.25	d	500		mg/L	100	159498
AMPA	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	NOAEL		0.25	d	500		mg/L	100	159498
AMPA	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	NOAEL		0.25	d	500		mg/L	100	159498
AMPA	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	NOAEL		0.25	d	500		mg/L	100	159498
AMPA	Aquatic	community	Aquatic Community	PHY	PHY	PSYN	NOAEL		0.25	d	500		mg/L	100	159498
AMPA	Aquatic	community	Aquatic Community	BCM	ENZ	CTLS	NOAEL		0.25	d	500		mg/L	100	159498
AMPA	Aquatic	community	Aquatic Community	BCM	ENZ	SODA	NOAEL		0.25	d	500		mg/L	100	159498

Glyphosate isopropylamine salt	Lithobates	pipiens	Leopard Frog	MOR	MOR	MORT	NOAEL		4	d	41.48		ae mg/L	100	161671
Glyphosate isopropylamine salt	Hyla	chrysoscelis	Southern Grey Tree Frog	MOR	MOR	MORT	NOAEL		4	d	41.48		ae mg/L	100	161671
Glyphosate isopropylamine salt	Rana	catesbeiana	Bullfrog	MOR	MOR	MORT	NOAEL		4	d	41.48		ae mg/L	100	161671
Glyphosate isopropylamine salt	Anaxyrus	fowleri	Fowler's Toad	MOR	MOR	MORT	NOAEL		4	d	41.48		ae mg/L	100	161671
Glyphosate isopropylamine salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	NOAEL		4	d	41.48		ae mg/L	100	161671
Glyphosate isopropylamine salt	Lithobates	pipiens	Leopard Frog	MOR	MOR	MORT	NOEC		4	d	1.29		ae mg/L	46	161671
Glyphosate isopropylamine salt	Lithobates	pipiens	Leopard Frog	MOR	MOR	MORT	LC50		4	d	1.8		ae mg/L	46	161671
Glyphosate isopropylamine salt	Hyla	chrysoscelis	Southern Grey Tree Frog	MOR	MOR	MORT	NOEC		4	d	1.74		ae mg/L	46	161671
Glyphosate isopropylamine salt	Hyla	chrysoscelis	Southern Grey Tree Frog	MOR	MOR	MORT	LC50		4	d	2.5		ae mg/L	46	161671
Glyphosate isopropylamine salt	Rana	catesbeiana	Bullfrog	MOR	MOR	MORT	NOEC		4	d	2.02		ae mg/L	46	161671
Glyphosate isopropylamine salt	Rana	catesbeiana	Bullfrog	MOR	MOR	MORT	LC50		4	d	2.77		ae mg/L	46	161671
Glyphosate isopropylamine salt	Anaxyrus	fowleri	Fowler's Toad	MOR	MOR	MORT	NOEC		4	d	3.4		ae mg/L	46	161671
Glyphosate isopropylamine salt	Anaxyrus	fowleri	Fowler's Toad	MOR	MOR	MORT	LC50		4	d	4.21		ae mg/L	46	161671
Glyphosate isopropylamine salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	NOEC		4	d	3.27		ae mg/L	46	161671
Glyphosate isopropylamine salt	Lithobates	clamitans ssp. clamitans	Bronze Frog	MOR	MOR	MORT	LC50		4	d	4.22		ae mg/L	46	161671
Glyphosate	Apis	mellifera	Honey Bee	CEL	GEN	PPOM	LOAEL		4	d	200		ppm	100	157769

Glyphosate isopropylamine salt	Poecilia	reticulata	Guppy	MOR	MOR	MORT	NR-ZERO		4	d	0.36		mg/L	100	161706
Glyphosate isopropylamine salt	Poecilia	reticulata	Guppy	MOR	MOR	MORT	NR-LETH		4	d	36		mg/L	100	161706
Glyphosate isopropylamine salt	Poecilia	reticulata	Guppy	MOR	MOR	MORT	LC50		1	d	15.81		mg/L	100	161706
Glyphosate isopropylamine salt	Poecilia	reticulata	Guppy	MOR	MOR	MORT	LC50		4	d	9		mg/L	100	161706
Glyphosate isopropylamine salt	Poecilia	reticulata	Guppy	MOR	MOR	MORT	LC50		4	d	10.08		mg/L	100	161706
Glyphosate isopropylamine salt	Poecilia	reticulata	Guppy	MOR	MOR	MORT	LC50		4	d	9.76		mg/L	100	161706
Glyphosate isopropylamine salt	Poecilia	reticulata	Guppy	BEH	BEH	SURF	LOAEL		1	d	3.6		mg/L	100	161706
Glyphosate isopropylamine salt	Poecilia	reticulata	Guppy	MOR	MOR	MORT	LC50		1	d	14.37		mg/L	100	161706
Glyphosate isopropylamine salt	Poecilia	reticulata	Guppy	MOR	MOR	MORT	LC50		1	d	15		mg/L	100	161706
Glyphosate isopropylamine salt	Poecilia	reticulata	Guppy	MOR	MOR	MORT	LC50		4	d	10.25		mg/L	100	161706
Glyphosate isopropylamine salt	Poecilia	reticulata	Guppy	MOR	MOR	MORT	LC50		1	d	15.14		mg/L	100	161706
Glyphosate	Lithobates	sylvaticus	Wood Frog	MOR	MOR	MORT	LC50		20	d	2.63		ae mg/L	100	159327
Glyphosate	Lithobates	sylvaticus	Wood Frog	MOR	MOR	MORT	NOAEL	LOAEL	20	d	1.8	3.4	ae mg/L	100	159327
Glyphosate	Lithobates	sylvaticus	Wood Frog	GRO	GRO	WGHT	NOAEL		20	d	3.4		ae mg/L	100	159327
Glyphosate	Lithobates	pipiens	Leopard Frog	MOR	MOR	MORT	LC50		20	d	2.91		ae mg/L	100	159327
Glyphosate	Lithobates	pipiens	Leopard Frog	MOR	MOR	MORT	NOAEL	LOAEL	20	d	1.8	3.4	ae mg/L	100	159327
Glyphosate	Lithobates	pipiens	Leopard Frog	GRO	GRO	WGHT	NOAEL		20	d	3.4		ae mg/L	100	159327
Glyphosate	Lithobates	pipiens	Leopard Frog	MOR	MOR	MORT	LC50		20	d	3.26		ae mg/L	100	159327

Glyphosate	Lithobates	pipiens	Leopard Frog	MOR	MOR	MORT	NOAEL	LOAEL	20	d	1.8	3.4	ae mg/L	100	159327
Glyphosate	Lithobates	pipiens	Leopard Frog	GRO	GRO	WGHT	NOAEL	LOAEL	20	d	1.8	3.4	ae mg/L	100	159327
Glyphosate	Bufo	americanus	American Toad	MOR	MOR	MORT	LC50		20	d	2.46		ae mg/L	100	159327
Glyphosate	Bufo	americanus	American Toad	GRO	GRO	WGHT	NOEC		20	d	3.4		ae mg/L	100	159327
Glyphosate	Bufo	americanus	American Toad	MOR	MOR	MORT	LC50		20	d	2.44		ae mg/L	100	159327
Glyphosate	Bufo	americanus	American Toad	GRO	GRO	WGHT	NOAEL		20	d	3.4		ae mg/L	100	159327
Glyphosate	Lithobates	sylvaticus	Wood Frog	MOR	MOR	MORT	LC50		20	d	2.95		ae mg/L	100	159327
Glyphosate	Lithobates	sylvaticus	Wood Frog	GRO	GRO	WGHT	NOAEL	LOAEL	20	d	1.8	3.4	ae mg/L	100	159327
Glyphosate	Lithobates	sylvaticus	Wood Frog	MOR	MOR	MORT	NOAEL	LOAEL	20	d	1.8	3.4	ae mg/L	100	159327
Glyphosate	Lithobates	sylvaticus	Wood Frog	GRO	GRO	THIK	NOAEL	LOAEL	20	d	0.9	1.8	ae mg/L	100	159327
Glyphosate	Lithobates	sylvaticus	Wood Frog	GRO	GRO	THIK	NOAEL	LOAEL	20	d	0.9	1.8	ae mg/L	100	159327
Glyphosate	Lithobates	sylvaticus	Wood Frog	GRO	GRO	THIK	NOAEL		20	d	1.8		ae mg/L	100	159327
Glyphosate	Lithobates	sylvaticus	Wood Frog	GRO	GRO	LGTH	NOAEL		20	d	1.8		ae mg/L	100	159327
Glyphosate	Lithobates	sylvaticus	Wood Frog	GRO	GRO	WGHT	NOAEL	LOAEL	20	d	1.8	3.4	ae mg/L	100	159327
Glyphosate	Lithobates	sylvaticus	Wood Frog	MOR	MOR	MORT	LC50		20	d	3.09		ae mg/L	100	159327
Glyphosate	Lithobates	sylvaticus	Wood Frog	MOR	MOR	MORT	NOAEL	LOAEL	20	d	1.8	3.4	ae mg/L	100	159327
Glyphosate	Lithobates	pipiens	Leopard Frog	GRO	GRO	WGHT	NOAEL		20	d	3.4		ae mg/L	100	159327
Glyphosate	Lithobates	pipiens	Leopard Frog	MOR	MOR	MORT	LC50		20	d	3.02		ae mg/L	100	159327
Glyphosate	Lithobates	pipiens	Leopard Frog	MOR	MOR	MORT	NOAEL	LOAEL	20	d	1.8	3.4	ae mg/L	100	159327
Glyphosate	Lithobates	pipiens	Leopard Frog	GRO	GRO	THIK	NOAEL	LOAEL	20	d	0.9	1.8	ae mg/L	100	159327
Glyphosate	Lithobates	pipiens	Leopard Frog	GRO	GRO	THIK	NOAEL	LOAEL	20	d	0.9	1.8	ae mg/L	100	159327
Glyphosate	Lithobates	pipiens	Leopard Frog	GRO	GRO	LGTH	NOAEL		20	d	1.8		ae mg/L	100	159327
Glyphosate	Bufo	americanus	American Toad	MOR	MOR	SURV	NOAEL	LOAEL	20	d	0.9	1.8	ae mg/L	100	159327

Chemical	Genus	Species	Common Name						Dur		Conc1	Conc2	Units	%	Ref
Glyphosate	Bufo	americanus	American Toad	GRO	GRO	WGHT	NOAEL		20	d	3.4		ae mg/L	100	159327
Glyphosate	Bufo	americanus	American Toad	MOR	MOR	MORT	LC50		20	d	2.82		ae mg/L	100	159327
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		1	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		1	d	0.058		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		1	d	0.058		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		3	d	0.058		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		3	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		1	d	0.058		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		1	d	0.058		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL	LOAEL	3	d	0.058	0.116	mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL	LOAEL	3	d	0.058	0.116	mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		1	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		1	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL	LOAEL	1	d	0.058	0.116	mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL	LOAEL	1	d	0.058	0.116	mg/L	100	159190

Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		3	d	0.058		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL	LOAEL	1	d	0.058	0.116	mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		1	d	0.058		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		3	d	0.058		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		3	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		1	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		1	d	0.058		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL	LOAEL	3	d	0.058	0.116	mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL	LOAEL	3	d	0.058	0.116	mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL	LOAEL	3	d	0.058	0.116	mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	SODA	NOAEL		1	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	GSTR	NOAEL		3	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	GLPX	NOAEL		1	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	BCM	GLTH	NOAEL		3	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	BCM	GLTH	NOAEL		1	d	0.116		mg/L	100	159190

Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	GLRE	NOAEL		1	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	CTLS	NOAEL	LOAEL	3	d	0.058	0.116	mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	CTLS	NOAEL		3	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	SODA	NOAEL		1	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	GSTR	NOAEL		3	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	GLPX	NOAEL		1	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	GLPX	NOAEL		3	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	BCM	GLTH	NOAEL		3	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	BCM	GLTH	NOAEL		1	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	GLRE	NOAEL		1	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	GLRE	NOAEL		3	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	CTLS	NOAEL		3	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	CTLS	NOAEL		1	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL	LOAEL	3	d	0.058	0.116	mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		3	d	0.058		mg/L	100	159190

	Genus	Species	Common												
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL	LOAEL	3	d	0.058	0.116	mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		1	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		1	d	0.058		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL	LOAEL	3	d	0.058	0.116	mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		3	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		3	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	SODA	NOAEL		3	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	GSTR	NOAEL		1	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	GLPX	NOAEL		3	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	GLRE	NOAEL		3	d	0.116		mg/L	100	159190
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	BCM	ENZ	GSTR	NOAEL		1	d	0.116		mg/L	100	159190
Sulfosate	Caenorhabditis	elegans	Nematode	CEL	HIS	DEGN	NOAEL	LOAEL	1	d	7	10	AI %	100	161953
Sulfosate	Caenorhabditis	elegans	Nematode	CEL	HIS	DEGN	NOAEL	LOAEL	1	d	5.5	9.8	AI %	100	161953
Sulfosate	Caenorhabditis	elegans	Nematode	CEL	HIS	DEGN	NOAEL	LOAEL	1	d	3	7	AI %	100	161953
Sulfosate	Caenorhabditis	elegans	Nematode	CEL	HIS	DEGN	LOAEL		1	d	2.7		AI %	100	161953
Glyphosate	Capoeta	capoeta	Barb	BCM	BCM	NOCO	NOAEL		10	d	0.02		mg/L	100	159407
Glyphosate	Capoeta	capoeta	Barb	BCM	BCM	MLDH	NOAEL	LOAEL	10	d	0.01	0.02	mg/L	100	159407
Glyphosate	Asterionella	formosa	Diatom	PHY	PHY	PSII	LOAEL		0.0556	d	89.1		uM	99	158970

Glyphosate	Chlamyd omonas	reinhardtii	Green Algae	PHY	PHY	PSII	LOAEL		0.0556	d	435.6		uM	99	158970
Glyphosate	Synura	petersenii	Algae	PHY	PHY	PSII	LOAEL		0.0556	d	435.6		uM	99	158970
Glyphosate	Pseudoki rchneriel la	subcapitata	Green Algae	PHY	PHY	PSII	LOAEL		0.0556	d	435.6		uM	99	158970
Glyphosate	Navicula	pelliculosa	Diatom	PHY	PHY	PSII	LOAEL		0.0556	d	217.8		uM	99	158970
Glyphosate	Cryptom onas	erosa	Cryptomonad	PHY	PHY	PSII	LOAEL		0.0556	d	217.8		uM	99	158970
Glyphosate isopropylamine salt	Caridina	nilotica	Shrimp	PHY	PHY	LDPX	NOAEL	LOAEL	4	d	25.6	40	mg/L	100	159402
Glyphosate isopropylamine salt	Caridina	nilotica	Shrimp	PHY	PHY	LDPX	NOAEL	LOAEL	21	d	2.8	3.4	mg/L	100	159402
Glyphosate isopropylamine salt	Algae	NR	Algae	POP	POP	CHLA	NOAEL		8	d	0.225		mg/L	100	161755
Glyphosate isopropylamine salt	Algae	NR	Algae	POP	POP	CHLA	LOAEL		21	d	0.225		mg/L	100	161755
Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	SYS	PRS	PPRO	LOAEL		22	d	0.225		mg/L	100	161755
Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	SYS	PRS	PPRO	LOAEL		1	d	0.225		mg/L	100	161755
Glyphosate isopropylamine salt	Algae	NR	Algae	POP	POP	CHLA	LOAEL		22	d	0.225		mg/L	100	161755
Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	SYS	PRS	PPRO	LOAEL		8	d	0.225		mg/L	100	161755
Glyphosate isopropylamine salt	Aquatic	community	Aquatic Community	SYS	PRS	PPRO	LOAEL		21	d	0.225		mg/L	100	161755
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		3	d	0.058		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		1	d	0.116		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		3	d	0.116		mg/L	100	160185

Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		3	d	0.058		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		1	d	0.058		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		1	d	0.116		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		3	d	0.116		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		3	d	0.116		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		1	d	0.116		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		1	d	0.116		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		1	d	0.116		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		1	d	0.116		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		1	d	0.058		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		1	d	0.058		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		3	d	0.116		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		3	d	0.058		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		3	d	0.116		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		1	d	0.058		mg/L	100	160185

Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		3	d	0.116		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		1	d	0.116		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		1	d	0.058		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		1	d	0.116		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		3	d	0.116		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		3	d	0.058		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		3	d	0.058		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		3	d	0.116		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		3	d	0.116		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		3	d	0.116		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		3	d	0.058		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		1	d	0.058		mg/L	100	160185
Glyphosate isopropylamine salt	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		1	d	0.058		mg/L	100	160185
Glyphosate	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		1	d	0.0179		mg/L	100	160185
Glyphosate	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		1	d	0.0179		mg/L	100	160185
Glyphosate	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		3	d	0.0179		mg/L	100	160185
Glyphosate	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		3	d	0.0179		mg/L	100	160185
Glyphosate	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		3	d	0.0179		mg/L	100	160185
Glyphosate	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		3	d	0.0357		mg/L	100	160185
Glyphosate	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		3	d	0.0357		mg/L	100	160185
Glyphosate	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		3	d	0.0357		mg/L	100	160185

Glyphosate	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		3	d	0.0179		mg/L	100	160185
Glyphosate	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		1	d	0.0179		mg/L	100	160185
Glyphosate	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		1	d	0.0357		mg/L	100	160185
Glyphosate	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		3	d	0.0357		mg/L	100	160185
Glyphosate	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		3	d	0.0179		mg/L	100	160185
Glyphosate	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		1	d	0.0179		mg/L	100	160185
Glyphosate	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		1	d	0.0357		mg/L	100	160185
Glyphosate	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		3	d	0.0179		mg/L	100	160185
Glyphosate	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		1	d	0.0179		mg/L	100	160185
Glyphosate	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		1	d	0.0357		mg/L	100	160185
Glyphosate	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		1	d	0.0357		mg/L	100	160185
Glyphosate	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	NOAEL		1	d	0.0357		mg/L	100	160185
Glyphosate	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		1	d	0.0179		mg/L	100	160185
Glyphosate	Anguilla	anguilla	Common Eel	CEL	GEN	DAMG	LOAEL		1	d	0.0179		mg/L	100	160185
Glyphosate	Panicum	coloratum	Kleingrass	POP	POP	BMAS	LOAEL		190	d	0.9812		lb/acre	100	159593
Glyphosate	NR	Plantae	Plant Kingdom	POP	POP	BMAS	NOAEL		190	d	0.9812		lb/acre	100	159593
Glyphosate	NR	Poaceae	Grass Family	POP	POP	BMAS	NOAEL		190	d	0.9812		lb/acre	100	159593
Glyphosate	Caladium	bicolor	Heart of Jesus	PHY	INJ	GINJ	LOAEL		20	d	0.74928		lb/acre	100	159712
Glyphosate	NR	Plantae	Plant Kingdom	POP	POP	COVR	LOAEL			d	0.99904		lb/acre	100	159615
Glyphosate	Rubus	sp.	Brambles	PHY	INJ	GINJ	LOAEL		1095	d	0.99904		lb/acre	100	159615
Glyphosate isopropylamine salt	Malva	sp.	Cheeseweed	POP	POP	ABND	NOAEL		27	d	2		AI lb/acre	100	159670
Glyphosate isopropylamine salt	Avena	sp.	Oat	POP	POP	ABND	LOAEL		27	d	2		AI lb/acre	100	159670
Glyphosate isopropylamine salt	Malva	sp.	Cheeseweed	POP	POP	ABND	NOAEL		8	d	2		AI lb/acre	100	159670
Glyphosate isopropylamine salt	Avena	sp.	Oat	POP	POP	ABND	NOAEL		8	d	2		AI lb/acre	100	159670
Glyphosate	Lantana	camara	Largeleaf Lantana	MOR	MOR	MORT	LOAEL		30	d	0.8		L/ha	100	159692
Glyphosate	Lantana	camara	Largeleaf Lantana	GRO	GRO	BMAS	LOAEL		2	gs	0.8		L/ha	100	159692
Glyphosate	Lantana	camara	Largeleaf Lantana	GRO	MPH	AREA	LOAEL		2	gs	0.8		L/ha	100	159692
Glyphosate	Lantana	camara	Largeleaf Lantana	MOR	MOR	MORT	LOAEL		30	d	0.8		L/ha	100	159692
Glyphosate	Lantana	camara	Largeleaf Lantana	GRO	GRO	BMAS	LOAEL		2	gs	0.8		L/ha	100	159692
Glyphosate	Lantana	camara	Largeleaf Lantana	GRO	MPH	AREA	LOAEL		2	gs	0.8		L/ha	100	159692

Glyphosate	Artemisia	roxburghiana	Artemisia	MOR	MOR	MORT	LOAEL		30	d	0.8		L/ha	100	159692
Glyphosate	Artemisia	roxburghiana	Artemisia	GRO	GRO	BMAS	LOAEL		2	gs	0.8		L/ha	100	159692
Glyphosate	Artemisia	roxburghiana	Artemisia	GRO	MPH	AREA	LOAEL		2	gs	0.8		L/ha	100	159692
Glyphosate	Lantana	camara	Largeleaf Lantana	MOR	MOR	MORT	LOAEL		30	d	0.8		L/ha	100	159692
Glyphosate	Lantana	camara	Largeleaf Lantana	GRO	GRO	BMAS	LOAEL		2	gs	0.8		L/ha	100	159692
Glyphosate	Lantana	camara	Largeleaf Lantana	GRO	MPH	AREA	LOAEL		2	gs	0.8		L/ha	100	159692
Glyphosate	Artemisia	roxburghiana	Artemisia	MOR	MOR	MORT	LOAEL		30	d	0.8		L/ha	100	159692
Glyphosate	Artemisia	roxburghiana	Artemisia	GRO	GRO	BMAS	LOAEL		2	gs	0.8		L/ha	100	159692
Glyphosate	Artemisia	roxburghiana	Artemisia	GRO	MPH	AREA	LOAEL		2	gs	0.8		L/ha	100	159692
Glyphosate	Artemisia	roxburghiana	Artemisia	MOR	MOR	MORT	LOAEL		30	d	0.8		L/ha	100	159692
Glyphosate	Artemisia	roxburghiana	Artemisia	GRO	GRO	BMAS	LOAEL		2	gs	0.8		L/ha	100	159692
Glyphosate	Artemisia	roxburghiana	Artemisia	GRO	MPH	AREA	LOAEL		2	gs	0.8		L/ha	100	159692
Glyphosate	Arachis	pintoi	Peanut	POP	POP	BMAS	LOAEL		28	d	0.5352		lb/acre	100	159743
Glyphosate	Arachis	pintoi	Peanut	GRO	GRO	WGHT	LOAEL		56	d	0.36		ae kg/ha	100	159729
Glyphosate potassium salt	Chlamydomonas	reinhardtii	Green Algae	POP	POP	ABND	NOAEL		3	d	14.5		uM	100	161957
Glyphosate potassium salt	Chlamydomonas	reinhardtii	Green Algae	POP	POP	PSII	NOAEL		3	d	14.5		uM	100	161957
Glyphosate isopropylamine salt	Eccritotarsus	catarinensis	Plant Bug	MOR	MOR	MORT	LC50		1	d	10.1		% v/v	100	161287
Glyphosate isopropylamine salt	Eccritotarsus	catarinensis	Plant Bug	MOR	MOR	MORT	LC50		5	d	7.8		% v/v	100	161287
Sulfosate	Eccritotarsus	catarinensis	Plant Bug	MOR	MOR	MORT	LC50		1	d	0.01		% v/v	100	161287
Sulfosate	Eccritotarsus	catarinensis	Plant Bug	MOR	MOR	MORT	LC50		5	d	1.46		% v/v	100	161287
Glyphosate isopropylamine salt	Eccritotarsus	catarinensis	Plant Bug	MOR	MOR	MORT	LC50		1	d	18		% v/v	100	161287

Glyphosate isopropylamine salt	Eccritota rsus	catarinensis	Plant Bug	MOR	MOR	MORT	LC50		5	d	18		% v/v	100	161287
Glyphosate isopropylamine salt	Eccritota rsus	catarinensis	Plant Bug	MOR	MOR	MORT	LC50		1	d	4.38		% v/v	100	161287
Glyphosate isopropylamine salt	Eccritota rsus	catarinensis	Plant Bug	MOR	MOR	MORT	LC50		5	d	2		% v/v	100	161287
Sulfosate	Neocheti na	eichhorniae	Weevil	MOR	MOR	MORT	LC50		1	d	10.73		% v/v	100	161287
Sulfosate	Neocheti na	eichhorniae	Weevil	MOR	MOR	MORT	LC50		5	d	8.54		% v/v	100	161287
Glyphosate isopropylamine salt	Eccritota rsus	catarinensis	Plant Bug	MOR	MOR	MORT	LC50		1	d	26		% v/v	100	161287
Glyphosate isopropylamine salt	Eccritota rsus	catarinensis	Plant Bug	MOR	MOR	MORT	LC50		5	d	26		% v/v	100	161287
Glyphosate isopropylamine salt	Eccritota rsus	catarinensis	Plant Bug	MOR	MOR	MORT	LC50		1	d	8.56		% v/v	100	161287
Glyphosate isopropylamine salt	Eccritota rsus	catarinensis	Plant Bug	MOR	MOR	MORT	LC50		5	d	4.2		% v/v	100	161287
Sulfosate	Eccritota rsus	catarinensis	Plant Bug	MOR	MOR	MORT	LC50		1	d	20		% v/v	100	161287
Sulfosate	Eccritota rsus	catarinensis	Plant Bug	MOR	MOR	MORT	LC50		5	d	0.01		% v/v	100	161287
Glyphosate isopropylamine salt	Eccritota rsus	catarinensis	Plant Bug	MOR	MOR	MORT	LC50		1	d	10.48		% v/v	100	161287
Glyphosate isopropylamine salt	Eccritota rsus	catarinensis	Plant Bug	MOR	MOR	MORT	LC50		5	d	3.61		% v/v	100	161287
Glyphosate isopropylamine salt	Neocheti na	eichhorniae	Weevil	MOR	MOR	MORT	LC50		1	d	26		% v/v	100	161287
Glyphosate isopropylamine salt	Neocheti na	eichhorniae	Weevil	MOR	MOR	MORT	LC50		5	d	18.89		% v/v	100	161287
Glyphosate isopropylamine salt	Pimepha les	promelas	Fathead Minnow	MOR	MOR	MORT	LC50		4	d	7.33		ae mg/L	100	160505
Glyphosate isopropylamine salt	Ceriodap hnia	dubia	Water Flea	MOR	MOR	MORT	LC50		2	d	7.33		ae mg/L	100	160505

Glyphosate isopropylamine salt	Ceriodaphnia	dubia	Water Flea	MOR	MOR	MORT	LC50		2	d	5.5		ae mg/L	100	160505
Glyphosate isopropylamine salt	Pimephales	promelas	Fathead Minnow	MOR	MOR	MORT	LC50		4	d	5.5		ae mg/L	100	160505
Glyphosate	Folsomia	candida	Springtail	REP	REP	RSUC	EC50		28	d	0.54		AI mg/kg d soil	30.8	160179
Glyphosate	Folsomia	candida	Springtail	MOR	MOR	MORT	LC50		28	d	1.13		AI mg/kg d soil	30.8	160179
Glyphosate isopropylamine salt	Eisenia	fetida ssp. andrei	Earthworm	BEH	FDB	FCNS	LOAEL		3	d	0.05		ppm	100	160273
Glyphosate isopropylamine salt	Eisenia	fetida ssp. andrei	Earthworm	MOR	MOR	MORT	NOAEL		28	d	0.05		ppm	100	160273
Glyphosate isopropylamine salt	Eisenia	fetida ssp. andrei	Earthworm	REP	REP	PROG	NOAEL		56	d	0.05		ppm	100	160273
Glyphosate isopropylamine salt	Eisenia	fetida ssp. andrei	Earthworm	MOR	MOR	HTCH	NOAEL		56	d	0.05		ppm	100	160273
Glyphosate isopropylamine salt	Eisenia	fetida ssp. andrei	Earthworm	MOR	MOR	HTCH	LOAEL		56	d	0.05		ppm	100	160273
Glyphosate isopropylamine salt	Eisenia	fetida ssp. andrei	Earthworm	REP	REP	PROG	LOAEL		56	d	0.05		ppm	100	160273
Glyphosate isopropylamine salt	Eisenia	fetida ssp. andrei	Earthworm	REP	REP	PROG	NOAEL		56	d	0.05		ppm	100	160273
Glyphosate isopropylamine salt	Eisenia	fetida ssp. andrei	Earthworm	MOR	MOR	MORT	NR-ZERO		28	d	0.05		ppm	100	160273
Glyphosate isopropylamine salt	Eisenia	fetida ssp. andrei	Earthworm	BEH	AVO	CHEM	LOAEL		3	d	0.05		ppm	100	160273
Glyphosate isopropylamine salt	Eisenia	fetida ssp. andrei	Earthworm	BEH	AVO	CHEM	LOAEL		3	d	0.05		ppm	100	160273
Glyphosate isopropylamine salt	Eisenia	fetida ssp. andrei	Earthworm	BEH	AVO	CHEM	LOAEL		3	d	0.05		ppm	100	160273
Glyphosate isopropylamine salt	Eisenia	fetida ssp. andrei	Earthworm	CEL	GEN	DAMG	NOAEL		7	d	0.05		ppm	100	160273

Chemical	Genus	Species	Common Name						Dur	Unit	Conc	Conc2	Units	%	Ref
Glyphosate isopropylamine salt	Eisenia	fetida ssp. andrei	Earthworm	CEL	GEN	DAMG	NOAEL		7	d	0.05		ppm	100	160273
Glyphosate isopropylamine salt	Eisenia	fetida ssp. andrei	Earthworm	PHY	PHY	NRUP	LOAEL		7	d	0.05		ppm	100	160273
Glyphosate isopropylamine salt	Eisenia	fetida ssp. andrei	Earthworm	PHY	PHY	NRUP	LOAEL		28	d	0.05		ppm	100	160273
Glyphosate isopropylamine salt	Eisenia	fetida ssp. andrei	Earthworm	PHY	PHY	NRUP	NOAEL		7	d	0.05		ppm	100	160273
Glyphosate isopropylamine salt	Eisenia	fetida ssp. andrei	Earthworm	PHY	PHY	NRUP	LOAEL		28	d	0.05		ppm	100	160273
Glyphosate	Eisenia	fetida	Earthworm	MOR	MOR	MORT	LC50		2	d	566.1		ug/cm2	95	159988
Glyphosate	Eisenia	fetida	Earthworm	MOR	MOR	MORT	LC50		14	d	327.8		mg/kg d soil	95	159988
Glyphosate	Eisenia	fetida	Earthworm	MOR	MOR	MORT	LC50		7	d	345.8		mg/kg d soil	95	159988
Glyphosate isopropylamine salt	Allium	cepa	Common Onion	CEL	GEN	MUTA	NOAEL	LOAEL	0.8333	d	0.073	0.146	%	100	160334
Glyphosate	Eisenia	fetida	Earthworm	MOR	MOR	MORT	NR-ZERO		2	d	2000		ppm	100	161836
Glyphosate	Eisenia	fetida	Earthworm	BCM	ENZ	SODA	NOAEL		2	d	2000		ppm	100	161836
Glyphosate	Eisenia	fetida	Earthworm	BCM	BCM	GLTH	NOAEL		2	d	2000		ppm	100	161836
Glyphosate	Eisenia	fetida	Earthworm	BCM	ENZ	ACHE	NOAEL		2	d	2000		ppm	100	161836
Glyphosate	Cyperus	entrerianus	Woodrush Flatsedge	POP	POP	BMAS	LOAEL		42	d	1.9624		lb/acre	100	160465
Glyphosate isopropylamine salt	Arundinaria	tecta	Cane	POP	POP	ABND	LOAEL		456.6	d	2		AI %	100	160468
Glyphosate isopropylamine salt	Kyllinga	polyphylla	Navua Sedge	POP	POP	ABND	LOAEL		112	d	2160		ae g/ha	100	160474
Glyphosate isopropylamine salt	Kyllinga	polyphylla	Navua Sedge	POP	POP	ABND	LOAEL		135	d	2160		ae g/ha	100	160474
Glyphosate isopropylamine salt	Kyllinga	polyphylla	Navua Sedge	POP	POP	ABND	LOAEL		114	d	1080		ae g/ha	100	160474
Glyphosate isopropylamine salt	Kyllinga	polyphylla	Navua Sedge	MOR	MOR	MORT	LC50			d	113		ae g/ha	100	160474

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Glyphosate isopropylamine salt	Kyllinga	polyphylla	Navua Sedge	MOR	MOR	MORT	LC90			d	2132		ae g/ha	100	160474
Glyphosate isopropylamine salt	Kyllinga	polyphylla	Navua Sedge	MOR	MOR	MORT	LC99			d	23386		ae g/ha	100	160474
Glyphosate isopropylamine salt	NR	Chlorophyta	Green Algae Division	POP	POP	ABND	LOAEL		1	d	3.45		mg/L	48	162056
Glyphosate isopropylamine salt	Hexarthra	sp.	Rotifer	POP	POP	ABND	NOAEL		21	d	3.45		mg/L	48	162056
Glyphosate isopropylamine salt	Asplanchna	sp.	Rotifer	POP	POP	ABND	NOAEL		21	d	3.45		mg/L	48	162056
Glyphosate isopropylamine salt	Moina	sp.	Water Flea	POP	POP	ABND	NOAEL		21	d	3.45		mg/L	48	162056
Glyphosate isopropylamine salt	Algae	NR	Algae	BCM	BCM	MLDH	LOAEL		21	d	3.45		mg/L	48	162056
Glyphosate isopropylamine salt	Algae	NR	Algae	BCM	ENZ	SODA	LOAEL		1	d	3.45		mg/L	48	162056
Glyphosate isopropylamine salt	Algae	NR	Algae	POP	POP	BMAS	NOAEL		21	d	3.45		mg/L	48	162056
Glyphosate isopropylamine salt	NR	Cyanophycota	Blue-Green Algae Phylum	POP	POP	ABND	NOAEL		21	d	3.45		mg/L	48	162056
Glyphosate isopropylamine salt	NR	Animalia	Animal Kingdom	POP	POP	ABND	NOAEL		21	d	3.45		mg/L	48	162056
Glyphosate isopropylamine salt	NR	Cyclopoida	Copepod Order	POP	POP	ABND	NOAEL		21	d	3.45		mg/L	48	162056
Glyphosate isopropylamine salt	NR	Cyclopoida	Copepod Order	POP	POP	ABND	NOAEL		21	d	3.45		mg/L	48	162056
Glyphosate isopropylamine salt	NR	Calanoida	Copepod Order	POP	POP	ABND	NOAEL		21	d	3.45		mg/L	48	162056
Glyphosate isopropylamine salt	NR	Calanoida	Copepod Order	POP	POP	ABND	LOAEL		21	d	3.45		mg/L	48	162056

Glyphosate isopropylamine salt	Euchlanis	sp.	Rotifer	POP	POP	ABND	NOAEL		21	d	3.45		mg/L	48	162056
Glyphosate isopropylamine salt	Mytilina	sp.	Rotifer	POP	POP	ABND	NOAEL		21	d	3.45		mg/L	48	162056
Glyphosate isopropylamine salt	Platyias	sp.	Rotifer	POP	POP	ABND	NOAEL		21	d	3.45		mg/L	48	162056
Glyphosate isopropylamine salt	Brachionus	sp.	Rotifer	POP	POP	ABND	NOAEL		21	d	3.45		mg/L	48	162056
Glyphosate isopropylamine salt	Keratella	sp.	Rotifer	POP	POP	ABND	NOAEL		21	d	3.45		mg/L	48	162056
Glyphosate isopropylamine salt	Lecane	sp.	Rotifer	POP	POP	ABND	NOAEL		21	d	3.45		mg/L	48	162056
Glyphosate isopropylamine salt	Alona	sp.	Water Flea	POP	POP	ABND	NOAEL		21	d	3.45		mg/L	48	162056
Glyphosate potassium salt	Lithobates	clamitans	Green Frog	GRO	GRO	SIZE	NOAEL		365	d			ae ug/L	100	161200
Glyphosate potassium salt	Lithobates	clamitans	Green Frog	GRO	GRO	SIZE	NOAEL			d			ae ug/L	100	161200
Glyphosate potassium salt	Lithobates	clamitans	Green Frog	GRO	GRO	LGTH	NOAEL		365	d			ae ug/L	100	161200
Glyphosate potassium salt	Lithobates	clamitans	Green Frog	POP	POP	ABND	NOAEL		365	d			ae ug/L	100	161200
Glyphosate potassium salt	Lithobates	clamitans	Green Frog	POP	POP	ABND	NOAEL		365	d			ae ug/L	100	161200
Glyphosate potassium salt	Lithobates	clamitans	Green Frog	POP	POP	ABND	NOAEL			d			ae ug/L	100	161200
Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	BCM	BCM	GLUC	LOAEL		28	d	0.84		ppm	100	161199
Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	BCM	BCM	LACT	LOAEL		28	d	0.84		ppm	100	161199
Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	BCM	BCM	PRTL	LOAEL		28	d	0.84		ppm	100	161199
Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	BCM	BCM	GLYC	LOAEL		28	d	0.84		ppm	100	161199

Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	BCM	BCM	PYRV	LOAEL		28	d	0.84		ppm	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	BCM	BCM	TTAA	LOAEL		28	d	0.84		ppm	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	CEL	GEN	DNAC	LOAEL		28	d	0.84		ppm	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	CEL	GEN	RNAC	LOAEL		28	d	0.84		ppm	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	BCM	ENZ	GLPP	LOAEL		28	d	0.84		ppm	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	BCM	ENZ	G6PT	LOAEL		28	d	0.84		ppm	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	BCM	ENZ	LADH	LOAEL		28	d	0.84		ppm	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	BCM	ENZ	SCDH	LOAEL		28	d	0.84		ppm	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	BCM	ENZ	ACHE	LOAEL		28	d	0.84		ppm	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	BCM	ENZ	ACPH	LOAEL		28	d	0.84		ppm	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	BCM	ENZ	ALPH	LOAEL		28	d	0.84		ppm	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	BCM	ENZ	GOTR	LOAEL		28	d	0.84		ppm	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	BCM	ENZ	GPTR	LOAEL		28	d	0.84		ppm	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	BCM	ENZ	GLRE	LOAEL		28	d	0.84		ppm	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	BCM	BCM	LDPO	LOAEL		28	d	0.84		ppm	100	161199

Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	BCM	ENZ	SODA	LOAEL		28	d	0.84		ppm	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	BCM	ENZ	CTLS	LOAEL		28	d	0.84		ppm	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	REP	REP	ABNM	LOAEL		21	d	0.84		mg/L	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	MOR	MOR	MORT	LOAEL		7	d	0.84		mg/L	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	MOR	MOR	MORT	LOAEL		14	d	0.84		mg/L	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	MOR	MOR	MORT	LOAEL		21	d	0.84		mg/L	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	MOR	MOR	MORT	LOAEL		28	d	0.84		mg/L	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	MOR	MOR	MORT	LOAEL		35	d	0.84		mg/L	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	REP	REP	PROG	LOAEL		7	d	0.84		mg/L	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	REP	REP	PROG	LOAEL		14	d	0.84		mg/L	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	REP	REP	PROG	LOAEL		21	d	0.84		mg/L	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	REP	REP	ABNM	LOAEL		7	d	0.84		mg/L	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	REP	REP	ABNM	LOAEL		14	d	0.84		mg/L	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	MOR	MOR	HTCH	NOAEL		7	d	0.84		mg/L	100	161199
Glyphosate isopropylamine salt	Biompha laria	alexandrina	Snail	MOR	MOR	HTCH	LOAEL		14	d	0.84		mg/L	100	161199

Chemical	Genus	Species	Common	Code1	Code2	Code3	Effect	Effect2	Dur	Unit	Value	Value2	Conc Unit	%	ID
Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	MOR	MOR	MORT	NR-LETH		35	d	0.84		mg/L	100	161199
Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	REP	REP	PROG	LOAEL		28	d	0.84		mg/L	100	161199
Glyphosate isopropylamine salt	Biomphalaria	alexandrina	Snail	MOR	MOR	HTCH	LOAEL		21	d	0.84		mg/L	100	161199
Glyphosate monoammonium salt	Piaractus	mesopotamicus	Pacu	MOR	MOR	MORT	NR-LETH		1	d			mg/L	48	161196
Glyphosate monoammonium salt	Piaractus	mesopotamicus	Pacu	CEL	CEL	NCEL	LOAEL		2	d			mg/L	48	161196
Glyphosate monoammonium salt	Piaractus	mesopotamicus	Pacu	MOR	MOR	MORT	LC50		2	d	3.74		mg/L	48	161196
Glyphosate	Paspalum	notatum	Bahiagrass	PHY	INJ	GINJ	LOAEL		14	d	0.24976		lb/acre	100	161278
Glyphosate	Paspalum	notatum	Bahiagrass	PHY	INJ	GINJ	LOAEL		28	d	0.24976		lb/acre	100	161278
Glyphosate	Paspalum	notatum	Bahiagrass	PHY	INJ	GINJ	LOAEL		84	d	0.24976		lb/acre	100	161278
Glyphosate	Tetrao	urogallus	Western Capercaillie	GRO	GRO	GRRT	NOAEL		35	d	3000		ppm	100	161502
Glyphosate	Tetrao	urogallus	Western Capercaillie	GRO	GRO	GRRT	NOAEL		28	d	3000		ppm	100	161502
Glyphosate	Tetrao	urogallus	Western Capercaillie	GRO	GRO	GRRT	NOAEL		28	d	3000		ppm	100	161502
Glyphosate	Tetrao	urogallus	Western Capercaillie	GRO	GRO	GRRT	NOAEL	LOAEL	35	d	1000	3000	ppm	100	161502
Glyphosate	Lithobates	catesbeiana	Bullfrog	GRO	GRO	LGTH	NOAEL		45	d	2.1		ae mg/L	100	161314
Glyphosate	Lithobates	catesbeiana	Bullfrog	MOR	MOR	MORT	NR-ZERO		16	d	2.1		ae mg/L	100	161314
Glyphosate	Lithobates	catesbeiana	Bullfrog	GRO	GRO	WGHT	NOAEL		45	d	2.1		ae mg/L	100	161314
Glyphosate	Lithobates	catesbeiana	Bullfrog	MOR	MOR	MORT	LOAEL		45	d	2.1		ae mg/L	100	161314
Glyphosate	Lithobates	catesbeiana	Bullfrog	GRO	DVP	STGE	NOAEL		45	d	2.1		ae mg/L	100	161314
Glyphosate isopropylamine salt	Rhinella	arenarum	Toad	MOR	MOR	MORT	NR-LETH		2	d	50		ae mg/L	100	161313

Glyphosate isopropylamine salt	Daphnia	magna	Water Flea	PHY	ITX	IMBL	EC50		2	d			mg/L	40	161204
Glyphosate isopropylamine salt	Daphnia	magna	Water Flea	PHY	ITX	IMBL	EC50		2	d			mg/L	40	161204
Glyphosate isopropylamine salt	Daphnia	magna	Water Flea	PHY	ITX	IMBL	EC50		2	d			mg/L	40	161204
Glyphosate isopropylamine salt	Daphnia	magna	Water Flea	PHY	ITX	IMBL	EC50		2	d			mg/L	40	161204
Glyphosate isopropylamine salt	Daphnia	magna	Water Flea	PHY	ITX	IMBL	EC50		2	d			mg/L	40	161204
Glyphosate isopropylamine salt	Daphnia	magna	Water Flea	PHY	ITX	IMBL	EC50		2	d			mg/L	40	161204
Glyphosate isopropylamine salt	Daphnia	magna	Water Flea	PHY	ITX	IMBL	EC50		2	d	10		mg/L	40	161204
Glyphosate isopropylamine salt	Daphnia	magna	Water Flea	PHY	ITX	IMBL	EC50		2	d	22		mg/L	40	161204
Glyphosate isopropylamine salt	Daphnia	magna	Water Flea	GRO	GRO	LGTH	NOEC	LOEC	36	d	0.45	1.35	mg/L	40	161204
Glyphosate isopropylamine salt	Daphnia	magna	Water Flea	MOR	MOR	SURV	NOEC	LOEC	55	d	1.35	4.05	mg/L	40	161204
Glyphosate isopropylamine salt	Daphnia	magna	Water Flea	GRO	GRO	LGTH	NOAEL		6	d	4.05		mg/L	40	161204
Glyphosate isopropylamine salt	Daphnia	magna	Water Flea	GRO	GRO	LGTH	NOAEL		12	d	4.05		mg/L	40	161204
Glyphosate isopropylamine salt	Daphnia	magna	Water Flea	GRO	GRO	LGTH	NOAEL	LOAEL	24	d	1.35	4.05	mg/L	40	161204
Glyphosate isopropylamine salt	Daphnia	magna	Water Flea	REP	REP	FCND	NOEC	LOEC	55	d	0.45	1.35	mg/L	40	161204
Glyphosate isopropylamine salt	Daphnia	magna	Water Flea	REP	REP	ABRT	NOEC		55	d	0.45		mg/L	40	161204

Glyphosate isopropylamine salt	Daphnia	magna	Water Flea	GRO	GRO	SIZE	NOAEL	LOAEL	55	d	1.35	4.05	mg/L	40	161204
Glyphosate isopropylamine salt	Cnesterodon	decemmaculatus	Ten-Spotted Livebearer	MOR	MOR	MORT	LC50		1	d	8.016		mg/L	48	161770
Glyphosate isopropylamine salt	Cnesterodon	decemmaculatus	Ten-Spotted Livebearer	MOR	MOR	MORT	LC50		2	d	7.752		mg/L	48	161770
Glyphosate isopropylamine salt	Cnesterodon	decemmaculatus	Ten-Spotted Livebearer	MOR	MOR	MORT	LC50		3	d	7.7136		mg/L	48	161770
Glyphosate isopropylamine salt	Cnesterodon	decemmaculatus	Ten-Spotted Livebearer	MOR	MOR	MORT	LC50		4	d	7.5264		mg/L	48	161770
Glyphosate isopropylamine salt	Cnesterodon	decemmaculatus	Ten-Spotted Livebearer	MOR	MOR	MORT	LOAEL		1	d	0.048		mg/L	48	161770
Glyphosate isopropylamine salt	Cnesterodon	decemmaculatus	Ten-Spotted Livebearer	MOR	MOR	MORT	LOAEL		2	d	0.048		mg/L	48	161770
Glyphosate isopropylamine salt	Cnesterodon	decemmaculatus	Ten-Spotted Livebearer	MOR	MOR	MORT	LOAEL		3	d	0.048		mg/L	48	161770
Glyphosate isopropylamine salt	Cnesterodon	decemmaculatus	Ten-Spotted Livebearer	MOR	MOR	MORT	LOAEL		4	d	0.048		mg/L	48	161770
Glyphosate isopropylamine salt	Cnesterodon	decemmaculatus	Ten-Spotted Livebearer	MOR	MOR	MORT	LC50		1	d	47.28		mg/L	48	161770
Glyphosate isopropylamine salt	Cnesterodon	decemmaculatus	Ten-Spotted Livebearer	MOR	MOR	MORT	LC50		2	d	44.9904		mg/L	48	161770
Glyphosate isopropylamine salt	Cnesterodon	decemmaculatus	Ten-Spotted Livebearer	MOR	MOR	MORT	LC50		3	d	44.0304		mg/L	48	161770
Glyphosate isopropylamine salt	Cnesterodon	decemmaculatus	Ten-Spotted Livebearer	MOR	MOR	MORT	LC50		4	d	44.0304		mg/L	48	161770
Glyphosate isopropylamine salt	Cnesterodon	decemmaculatus	Ten-Spotted Livebearer	MOR	MOR	MORT	NR-ZERO		4	d	5.664		mg/L	48	161770
Glyphosate isopropylamine salt	Cnesterodon	decemmaculatus	Ten-Spotted Livebearer	CEL	CEL	NCEL	NOAEL		2	d	5.664		mg/L	48	161770

Glyphosate isopropylamine salt	Cnestero don	decemmacu latus	Ten-Spotted Livebearer	CEL	CEL	NCEL	NOAEL		4	d	5.664		mg/L	48	161770
Glyphosate isopropylamine salt	Cnestero don	decemmacu latus	Ten-Spotted Livebearer	MOR	MOR	MORT	NR-ZERO		4	d	33.024		mg/L	48	161770
Glyphosate isopropylamine salt	Cnestero don	decemmacu latus	Ten-Spotted Livebearer	CEL	GEN	MNUC	NOAEL		2	d	33.024		mg/L	48	161770
Glyphosate isopropylamine salt	Cnestero don	decemmacu latus	Ten-Spotted Livebearer	CEL	GEN	MNUC	LOAEL		4	d	10.992		mg/L	48	161770
Glyphosate isopropylamine salt	Cnestero don	decemmacu latus	Ten-Spotted Livebearer	CEL	CEL	NCEL	NOAEL		2	d	33.024		mg/L	48	161770
Glyphosate isopropylamine salt	Cnestero don	decemmacu latus	Ten-Spotted Livebearer	CEL	CEL	NCEL	NOAEL		4	d	33.024		mg/L	48	161770
Glyphosate	Gasteros teus	aculeatus	Threespine Stickleback	GRO	GRO	COND	NOAEL		42	d	0.096		mg/L	>=96	161769
Glyphosate	Gasteros teus	aculeatus	Threespine Stickleback	GRO	GRO	COND	NOAEL		42	d	0.078		mg/L	>=96	161769
Glyphosate	Gasteros teus	aculeatus	Threespine Stickleback	GRO	MPH	IMPS	NOAEL		42	d			mg/L	>=96	161769
Glyphosate isopropylamine salt	Corydora s	paleatus	Peppered Corydoras	CEL	GEN	DAMG	NOAEL		3	d	0.0032		mg/L	48	161192
Glyphosate isopropylamine salt	Corydora s	paleatus	Peppered Corydoras	CEL	GEN	DAMG	NOAEL		6	d	0.0032		mg/L	48	161192
Glyphosate isopropylamine salt	Corydora s	paleatus	Peppered Corydoras	CEL	GEN	DAMG	NOAEL		9	d	0.0032		mg/L	48	161192
Glyphosate isopropylamine salt	Corydora s	paleatus	Peppered Corydoras	CEL	GEN	DAMG	LOAEL		3	d	0.0032		mg/L	48	161192
Glyphosate isopropylamine salt	Corydora s	paleatus	Peppered Corydoras	CEL	GEN	DAMG	LOAEL		6	d	0.0032		mg/L	48	161192
Glyphosate isopropylamine salt	Corydora s	paleatus	Peppered Corydoras	CEL	GEN	DAMG	LOAEL		9	d	0.0032		mg/L	48	161192
Glyphosate isopropylamine salt	Corydora s	paleatus	Peppered Corydoras	CEL	GEN	DAMG	LOAEL		3	d	0.0032		mg/L	48	161192

Chemical	Genus	Species	Common name						Duration	Unit	Conc	Conc2	Units		ID
Glyphosate isopropylamine salt	Corydoras	paleatus	Peppered Corydoras	CEL	GEN	DAMG	LOAEL		6	d	0.0032		mg/L	48	161192
Glyphosate isopropylamine salt	Corydoras	paleatus	Peppered Corydoras	CEL	GEN	DAMG	LOAEL		9	d	0.0032		mg/L	48	161192
Glyphosate isopropylamine salt	Corydoras	paleatus	Peppered Corydoras	MOR	MOR	MORT	NR-ZERO		9	d	0.0032		mg/L	48	161192
Glyphosate isopropylamine salt	Rhinella	arenarum	Toad	MOR	MOR	MORT	NOEC	LOEC	2	d	10	20	mg/L	74.7	161310
Glyphosate isopropylamine salt	Rhinella	arenarum	Toad	BCM	ENZ	ACHE	LOAEL		2	d	10		mg/L	74.7	161310
Glyphosate isopropylamine salt	Rhinella	arenarum	Toad	BCM	ENZ	BCHE	LOAEL		2	d	10		mg/L	74.7	161310
Glyphosate isopropylamine salt	Rhinella	arenarum	Toad	BCM	ENZ	GSTR	LOAEL		2	d	10		mg/L	74.7	161310
Glyphosate isopropylamine salt	Rhinella	arenarum	Toad	MOR	MOR	MORT	LC50		2	d	13.2		mg/L	74.7	161310
Glyphosate isopropylamine salt	Rhinella	arenarum	Toad	CEL	GEN	NABN	NOAEL		2	d	10		mg/L	74.7	161310
Glyphosate isopropylamine salt	Callinectes	sapidus	Blue Crab	MOR	MOR	MORT	LC50		1	d	6.279		mg/L	50.2	161498
Glyphosate isopropylamine salt	Callinectes	sapidus	Blue Crab	MOR	MOR	MORT	LC50		1	d	316		mg/L	50.2	161498
Glyphosate isopropylamine salt	Callinectes	sapidus	Blue Crab	GRO	DVP	MMPH	LOAEL		2.6408	d	5.5		mg/L	50.2	161498
Glyphosate isopropylamine salt	Callinectes	sapidus	Blue Crab	GRO	DVP	MMPH	ET50		2.1692	d	5.5		mg/L	50.2	161498
Glyphosate isopropylamine salt	Callinectes	sapidus	Blue Crab	GRO	DVP	MOLT	NOAEL		2.6408	d	5.5		mg/L	50.2	161498
Glyphosate isopropylamine salt	Callinectes	sapidus	Blue Crab	MOR	MOR	MORT	LOAEL		2.6408	d	5.5		mg/L	50.2	161498

Glyphosate	Genus	Species	Common Name						Dur		Value		Unit	%	ID
Glyphosate isopropylamine salt	Franklini ella	fusca	Tobacco Thrip	POP	POP	ABND	LOAEL		21	d	9.4		AI kg/ha	100	161500
Glyphosate isopropylamine salt	Franklini ella	fusca	Tobacco Thrip	POP	POP	ABND	LOAEL		21	d	9.4		AI kg/ha	100	161500
Glyphosate isopropylamine salt	Franklini ella	fusca	Tobacco Thrip	POP	POP	ABND	LOAEL		42	d	9.4		AI kg/ha	100	161500
Glyphosate isopropylamine salt	Franklini ella	fusca	Tobacco Thrip	POP	POP	ABND	LOAEL		28	d	9.4		AI kg/ha	100	161500
Glyphosate isopropylamine salt	Franklini ella	fusca	Tobacco Thrip	POP	POP	ABND	NOAEL		28	d	9.4		AI kg/ha	100	161500
Glyphosate isopropylamine salt	Franklini ella	fusca	Tobacco Thrip	POP	POP	ABND	LOAEL		21	d	9.4		AI kg/ha	100	161500
Glyphosate isopropylamine salt	Franklini ella	fusca	Tobacco Thrip	POP	POP	ABND	LOAEL		29	d	9.4		AI kg/ha	100	161500
Glyphosate isopropylamine salt	Oryzias	latipes	Japanese Medaka	MOR	MOR	MORT	LC50		4	d	76.8		mg/L	100	161318
Glyphosate	Oryzias	latipes	Japanese Medaka	MOR	MOR	MORT	LC50		4	d	158.88		mg/L	>99.3	161318
Glyphosate	Oryzias	latipes	Japanese Medaka	CEL	GEN	GEXP	NOAEL		2	d	15.888		mg/L	>99.3	161318
Glyphosate isopropylamine salt	Pseudacr is	regilla	Pacific Chorus Frog	MOR	MOR	MORT	LC50		1	d	0.43		mg/L	50.2	161728
Glyphosate isopropylamine salt	Pseudacr is	regilla	Pacific Chorus Frog	MOR	MOR	MORT	LC50		7	d	0.32		mg/L	50.2	161728
Glyphosate isopropylamine salt	Pseudacr is	regilla	Pacific Chorus Frog	MOR	MOR	MORT	LC50		15	d	0.3		mg/L	50.2	161728
Glyphosate isopropylamine salt	Rana	luteiventris	Spotted Frog	MOR	MOR	MORT	LC50		1	d	1.65		mg/L	50.2	161728
Glyphosate isopropylamine salt	Rana	luteiventris	Spotted Frog	MOR	MOR	MORT	LC50		7	d	1.08		mg/L	50.2	161728
Glyphosate isopropylamine salt	Rana	luteiventris	Spotted Frog	MOR	MOR	MORT	LC50		15	d	0.98		mg/L	50.2	161728

Glyphosate isopropylamine salt	Rana	cascadae	Cascades Frog	MOR	MOR	MORT	LC50		1	d	2.11		mg/L	50.2	161728
Glyphosate isopropylamine salt	Rana	cascadae	Cascades Frog	MOR	MOR	MORT	LC50		7	d	1.4		mg/L	50.2	161728
Glyphosate isopropylamine salt	Rana	cascadae	Cascades Frog	MOR	MOR	MORT	LC50		15	d	1.33		mg/L	50.2	161728
Glyphosate isopropylamine salt	Anaxyrus	boreas	Western Toad	MOR	MOR	MORT	LC50		1	d	2.66		mg/L	50.2	161728
Glyphosate isopropylamine salt	Anaxyrus	boreas	Western Toad	MOR	MOR	MORT	LC50		7	d	2.08		mg/L	50.2	161728
Glyphosate isopropylamine salt	Anaxyrus	boreas	Western Toad	MOR	MOR	MORT	LC50		15	d	1.95		mg/L	50.2	161728
Glyphosate isopropylamine salt	Ambystoma	macrodactylum	Long-Toed Salamander	MOR	MOR	MORT	LC50		7	d	1.85		mg/L	50.2	161728
Glyphosate isopropylamine salt	Ambystoma	macrodactylum	Long-Toed Salamander	MOR	MOR	MORT	LC50		15	d	1.55		mg/L	50.2	161728
Glyphosate isopropylamine salt	Ambystoma	gracile	Northwestern Salamander	MOR	MOR	MORT	LC50		7	d	1.73		mg/L	50.2	161728
Glyphosate isopropylamine salt	Ambystoma	gracile	Northwestern Salamander	MOR	MOR	MORT	LC50		15	d	1.83		mg/L	50.2	161728
Glyphosate isopropylamine salt	Huso	huso	Beluga	MOR	MOR	MORT	LC50		0.5	d	27.5479		mg/L	41	161205
Glyphosate isopropylamine salt	Huso	huso	Beluga	MOR	MOR	MORT	LC50		7	d	3.4071		mg/L	41	161205
Glyphosate isopropylamine salt	Huso	huso	Beluga	MOR	MOR	MORT	LC50		0.25	d	30.5122		mg/L	41	161205
Glyphosate isopropylamine salt	Huso	huso	Beluga	MOR	MOR	MORT	LC50		4	d	8.1303		mg/L	41	161205
Glyphosate isopropylamine salt	Huso	huso	Beluga	MOR	MOR	MORT	LC50		1	d	16.933		mg/L	41	161205

Glyphosate isopropylamine salt	Huso	huso	Beluga	MOR	MOR	MORT	LC50		2	d	11.0372		mg/L	41	161205
Glyphosate isopropylamine salt	Acipenser	stellatus	Sevruga, Stellate Sturgeon	MOR	MOR	MORT	LC50		7	d	5.3218		mg/L	41	161205
Glyphosate isopropylamine salt	Acipenser	stellatus	Sevruga, Stellate Sturgeon	MOR	MOR	MORT	LC50		0.25	d	28.5852		mg/L	41	161205
Glyphosate isopropylamine salt	Acipenser	stellatus	Sevruga, Stellate Sturgeon	MOR	MOR	MORT	LC50		0.5	d	25.0715		mg/L	41	161205
Glyphosate isopropylamine salt	Acipenser	stellatus	Sevruga, Stellate Sturgeon	MOR	MOR	MORT	LC50		1	d	18.9297		mg/L	41	161205
Glyphosate isopropylamine salt	Acipenser	stellatus	Sevruga, Stellate Sturgeon	MOR	MOR	MORT	LC50		2	d	16.277		mg/L	41	161205
Glyphosate isopropylamine salt	Acipenser	stellatus	Sevruga, Stellate Sturgeon	MOR	MOR	MORT	LC50		4	d	10.1352		mg/L	41	161205
Glyphosate isopropylamine salt	Acipenser	persicus	Persian Sturgeon	MOR	MOR	MORT	LC50		0.25	d	31.6561		mg/L	41	161205
Glyphosate isopropylamine salt	Acipenser	persicus	Persian Sturgeon	MOR	MOR	MORT	LC50		0.5	d	25.1494		mg/L	41	161205
Glyphosate isopropylamine salt	Acipenser	persicus	Persian Sturgeon	MOR	MOR	MORT	LC50		1	d	18.3762		mg/L	41	161205
Glyphosate isopropylamine salt	Acipenser	persicus	Persian Sturgeon	MOR	MOR	MORT	LC50		2	d	14.0138		mg/L	41	161205
Glyphosate isopropylamine salt	Acipenser	persicus	Persian Sturgeon	MOR	MOR	MORT	LC50		4	d	10.6805		mg/L	41	161205
Glyphosate isopropylamine salt	Acipenser	persicus	Persian Sturgeon	MOR	MOR	MORT	LC50		7	d	4.3419		mg/L	41	161205
Glyphosate isopropylamine salt	Euphlyctis	cyanophlyctis	Indian Skittering Frog	MOR	MOR	MORT	LC50		10	d	2.12		ae mg/L	41	161702
Glyphosate isopropylamine salt	Euphlyctis	cyanophlyctis	Indian Skittering Frog	MOR	MOR	MORT	LC50		4	d	3.76		ae mg/L	41	161702

Chemical	Genus	Species	Common Name				Endpoint	Endpoint2	Dur	Unit	Value	Value2	Units	%	ID
Glyphosate isopropylamine salt	Euphlyctis	cyanophlyctis	Indian Skittering Frog	MOR	MOR	MORT	LC50		4	d	3.39		ae mg/L	41	161702
Glyphosate isopropylamine salt	Euphlyctis	cyanophlyctis	Indian Skittering Frog	MOR	MOR	MORT	LC50		10	d	1.91		ae mg/L	41	161702
Glyphosate isopropylamine salt	Euphlyctis	cyanophlyctis	Indian Skittering Frog	CEL	GEN	MNUC	NOAEL	LOAEL	2	d	1	2	ae mg/L	41	161702
Glyphosate isopropylamine salt	Euphlyctis	cyanophlyctis	Indian Skittering Frog	CEL	GEN	MNUC	NOAEL	LOAEL	3	d	1	2	ae mg/L	41	161702
Glyphosate isopropylamine salt	Euphlyctis	cyanophlyctis	Indian Skittering Frog	CEL	GEN	MNUC	NOAEL	LOAEL	4	d	1	2	ae mg/L	41	161702
Glyphosate isopropylamine salt	Euphlyctis	cyanophlyctis	Indian Skittering Frog	CEL	GEN	MNUC	NOAEL	LOAEL	1	d	1	2	ae mg/L	41	161702
Glyphosate isopropylamine salt	Euphlyctis	cyanophlyctis	Indian Skittering Frog	CEL	GEN	MNUC	NOAEL	LOAEL	1	d	1	2	ae mg/L	41	161702
Glyphosate isopropylamine salt	Euphlyctis	cyanophlyctis	Indian Skittering Frog	CEL	GEN	MNUC	NOAEL	LOAEL	2	d	1	2	ae mg/L	41	161702
Glyphosate isopropylamine salt	Euphlyctis	cyanophlyctis	Indian Skittering Frog	CEL	GEN	MNUC	NOAEL	LOAEL	3	d	1	2	ae mg/L	41	161702
Glyphosate isopropylamine salt	Euphlyctis	cyanophlyctis	Indian Skittering Frog	CEL	GEN	MNUC	NOAEL	LOAEL	4	d	1	2	ae mg/L	41	161702
Glyphosate isopropylamine salt	Caiman	latirostris	Broad-Snouted Caiman	CEL	GEN	MNUC	LOAEL		60	d			ppm	100	161703
Glyphosate isopropylamine salt	Caiman	latirostris	Broad-Snouted Caiman	GRO	GRO	LGTH	NOAEL		60	d			ppm	100	161703
Glyphosate isopropylamine salt	Caiman	latirostris	Broad-Snouted Caiman	GRO	GRO	WGHT	NOAEL		60	d			ppm	100	161703
Glyphosate	Orius	sp.	Minute Pirate Bug	POP	POP	ABND	NOAEL		1	gs	1.08		AI kg/ha	100	161690
Glyphosate	Orius	sp.	Minute Pirate Bug	POP	POP	ABND	NOAEL		1	gs	1.08		AI kg/ha	100	161690
Glyphosate	Nabis	sp.	Damsel Bug	POP	POP	ABND	NOAEL		1	gs	1.08		AI kg/ha	100	161690
Glyphosate	NR	Insecta	Insect Class	POP	POP	ABND	NOAEL		1	gs	1.08		AI kg/ha	100	161690
Glyphosate	NR	Aphididae	Aphid Family	POP	POP	ABND	NOAEL		1	gs	1.08		AI kg/ha	100	161690
Glyphosate	NR	Aphididae	Aphid Family	POP	POP	ABND	NOAEL		1	gs	1.08		AI kg/ha	100	161690

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Chemical	Genus	Species	Common Name			Effect	Endpoint	Endpoint2	Dur	Unit	Conc1	Conc2	Units	Pct	Ref
Glyphosate	NR	Thysanoptera	Thrip Order	POP	POP	ABND	NOAEL		1	gs	1.08		AI kg/ha	100	161690
Glyphosate	NR	Plantae	Plant Kingdom	POP	POP	ABND	LOAEL		1	gs	0.96336		lb/acre	100	161690
Glyphosate	NR	Plantae	Plant Kingdom	POP	POP	ABND	LOAEL		1	gs	0.96336		lb/acre	100	161690
Glyphosate	Nabis	sp.	Damsel Bug	POP	POP	ABND	LOAEL		1	gs	1.08		AI kg/ha	100	161690
Glyphosate	NR	Insecta	Insect Class	POP	POP	ABND	NOAEL		1	gs	1.08		AI kg/ha	100	161690
Glyphosate	NR	Thysanoptera	Thrip Order	POP	POP	ABND	NOAEL		1	gs	1.08		AI kg/ha	100	161690
Glyphosate	Lolium	multiflorum	Annual Ryegrass	MOR	MOR	SURV	LOAEL		7	d	0.8		L/ha	100	161696
Glyphosate	Lolium	multiflorum	Annual Ryegrass	BCM	BCM	CHLO	LOAEL		7	d	0.8		L/ha	100	161696
Glyphosate	NR	Fungi	Fungi Kingdom	MOR	MOR	SURV	LOAEL		10	d	0.8		L/ha	100	161696
Glyphosate	NR	Fungi	Fungi Kingdom	POP	POP	RCLN	LOAEL		10	d	0.8		L/ha	100	161696
AMPA	Crassostrea	gigas	Pacific Oyster	MOR	MOR	MORT	NR-ZERO		2	d	100000		ae ug/L	100	161544
AMPA	Crassostrea	gigas	Pacific Oyster	GRO	DVP	NORM	NOAEL	LOAEL	2	d	10000	20000	ae ug/L	100	161544
AMPA	Crassostrea	gigas	Pacific Oyster	GRO	DVP	ABNM	EC10		2	d	10299		ae ug/L	100	161544
AMPA	Crassostrea	gigas	Pacific Oyster	GRO	DVP	ABNM	EC50		2	d	40617		ae ug/L	100	161544
AMPA	Crassostrea	gigas	Pacific Oyster	GRO	DVP	ABNM	EC50		2	d	46105		ae ug/L	100	161544
AMPA	Crassostrea	gigas	Pacific Oyster	GRO	DVP	ABNM	EC10		2	d	11032		ae ug/L	100	161544
Glyphosate	Crassostrea	gigas	Pacific Oyster	GRO	DVP	NORM	NOAEL	LOAEL	2	d	20000	40000	ae ug/L	100	161544
Glyphosate	Crassostrea	gigas	Pacific Oyster	GRO	DVP	ABNM	EC10		2	d	13347		ae ug/L	100	161544
Glyphosate	Crassostrea	gigas	Pacific Oyster	MOR	MOR	MORT	NR-ZERO		2	d	100000		ae ug/L	100	161544
Glyphosate	Crassostrea	gigas	Pacific Oyster	GRO	DVP	ABNM	EC50		2	d	27175		ae ug/L	100	161544
Glyphosate	Crassostrea	gigas	Pacific Oyster	GRO	DVP	ABNM	EC10		2	d	13457		ae ug/L	100	161544
Glyphosate	Crassostrea	gigas	Pacific Oyster	GRO	DVP	ABNM	EC50		2	d	28315		ae ug/L	100	161544
Glyphosate isopropylamine salt	Crassostrea	gigas	Pacific Oyster	GRO	DVP	ABNM	EC50		2	d	1168		ae ug/L	100	161544
Glyphosate isopropylamine salt	Crassostrea	gigas	Pacific Oyster	MOR	MOR	MORT	NR-LETH		2	d	10000		ae ug/L	100	161544
Glyphosate isopropylamine salt	Crassostrea	gigas	Pacific Oyster	GRO	DVP	NORM	NOAEL	LOAEL	2	d	1100	1200	ae ug/L	100	161544

Chemical	Genus	Species	Common Name								Value		Units		Ref
Glyphosate isopropylamine salt	Crassostrea	gigas	Pacific Oyster	GRO	DVP	ABNM	EC10		2	d	1006		ae ug/L	100	161544
Glyphosate isopropylamine salt	Crassostrea	gigas	Pacific Oyster	GRO	DVP	ABNM	EC50		2	d	1133		ae ug/L	100	161544
Glyphosate isopropylamine salt	Crassostrea	gigas	Pacific Oyster	GRO	DVP	ABNM	EC10		2	d	1037		ae ug/L	100	161544
Glyphosate	Crassostrea	gigas	Pacific Oyster	GRO	DVP	ABNM	EC10		2	d	1628		ae ug/L	100	161544
Glyphosate	Crassostrea	gigas	Pacific Oyster	GRO	DVP	ABNM	EC50		2	d	1672		ae ug/L	100	161544
Glyphosate	Crassostrea	gigas	Pacific Oyster	GRO	DVP	NORM	NOAEL	LOAEL	2	d	1600	1700	ae ug/L	100	161544
Glyphosate	Crassostrea	gigas	Pacific Oyster	GRO	DVP	ABNM	EC50		2	d	2001		ae ug/L	100	161544
Glyphosate	Crassostrea	gigas	Pacific Oyster	MOR	MOR	MORT	NR-LETH		2	d	10000		ae ug/L	100	161544
Glyphosate	Crassostrea	gigas	Pacific Oyster	GRO	DVP	ABNM	EC10		2	d	1951		ae ug/L	100	161544
Glyphosate	Crassostrea	gigas	Pacific Oyster	MOR	MOR	MORT	EC10		1	d	100000		ae ug/L	100	161544
Glyphosate	Crassostrea	gigas	Pacific Oyster	MOR	MOR	MORT	EC50		1	d	100000		ae ug/L	100	161544
Glyphosate	Crassostrea	gigas	Pacific Oyster	GRO	DVP	MMPH	EC10		1	d	100000		ae ug/L	100	161544
Glyphosate	Crassostrea	gigas	Pacific Oyster	GRO	DVP	MMPH	EC50		1	d	100000		ae ug/L	100	161544
Glyphosate	Crassostrea	gigas	Pacific Oyster	GRO	DVP	MMPH	EC10		1	d	100000		ae ug/L	100	161544
Glyphosate	Crassostrea	gigas	Pacific Oyster	GRO	DVP	MMPH	EC50		1	d	100000		ae ug/L	100	161544
Glyphosate	Crassostrea	gigas	Pacific Oyster	GRO	DVP	MMPH	NOAEL	LOAEL	1	d	10000	100000	ae ug/L	100	161544
Glyphosate isopropylamine salt	Crassostrea	gigas	Pacific Oyster	GRO	DVP	MMPH	NOAEL	LOAEL	1	d	6400	6600	ae ug/L	100	161544
Glyphosate isopropylamine salt	Crassostrea	gigas	Pacific Oyster	GRO	DVP	MMPH	EC10		1	d	5215		ae ug/L	100	161544
Glyphosate isopropylamine salt	Crassostrea	gigas	Pacific Oyster	GRO	DVP	MMPH	EC50		1	d	6366		ae ug/L	100	161544
Glyphosate isopropylamine salt	Crassostrea	gigas	Pacific Oyster	MOR	MOR	MORT	EC10		1	d	6601		ae ug/L	100	161544

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Chemical	Genus	Species	Common Name												
Glyphosate isopropylamine salt	Crassostrea	gigas	Pacific Oyster	MOR	MOR	MORT	EC50		1	d	8502		ae ug/L	100	161544
Glyphosate isopropylamine salt	Crassostrea	gigas	Pacific Oyster	GRO	DVP	MMPH	EC50		1	d	6940		ae ug/L	100	161544
Glyphosate isopropylamine salt	Crassostrea	gigas	Pacific Oyster	GRO	DVP	MMPH	EC10		1	d	5778		ae ug/L	100	161544
AMPA	Crassostrea	gigas	Pacific Oyster	GRO	DVP	MMPH	EC10		1	d	100000		ae ug/L	100	161544
AMPA	Crassostrea	gigas	Pacific Oyster	GRO	DVP	MMPH	EC50		1	d	100000		ae ug/L	100	161544
AMPA	Crassostrea	gigas	Pacific Oyster	GRO	DVP	MMPH	NOAEL		1	d	100000		ae ug/L	100	161544
AMPA	Crassostrea	gigas	Pacific Oyster	MOR	MOR	MORT	EC10		1	d	100000		ae ug/L	100	161544
AMPA	Crassostrea	gigas	Pacific Oyster	MOR	MOR	MORT	EC50		1	d	100000		ae ug/L	100	161544
AMPA	Crassostrea	gigas	Pacific Oyster	GRO	DVP	MMPH	EC10		1	d	100000		ae ug/L	100	161544
AMPA	Crassostrea	gigas	Pacific Oyster	GRO	DVP	MMPH	EC50		1	d	100000		ae ug/L	100	161544
Glyphosate	Crassostrea	gigas	Pacific Oyster	GRO	DVP	MMPH	NOAEL	LOAEL	1	d	6000	6200	ae ug/L	100	161544
Glyphosate	Crassostrea	gigas	Pacific Oyster	GRO	DVP	MMPH	EC50		1	d	7550		ae ug/L	100	161544
Glyphosate	Crassostrea	gigas	Pacific Oyster	GRO	DVP	MMPH	EC10		1	d	5244		ae ug/L	100	161544
Glyphosate	Crassostrea	gigas	Pacific Oyster	GRO	DVP	MMPH	EC10		1	d	4150		ae ug/L	100	161544
Glyphosate	Crassostrea	gigas	Pacific Oyster	GRO	DVP	MMPH	EC50		1	d	6060		ae ug/L	100	161544
Glyphosate	Crassostrea	gigas	Pacific Oyster	MOR	MOR	MORT	EC10		1	d	4991		ae ug/L	100	161544
Glyphosate	Crassostrea	gigas	Pacific Oyster	MOR	MOR	MORT	EC50		1	d	7934		ae ug/L	100	161544
Glyphosate isopropylamine salt	Microcystis	wesenbergii	Blue-green Algae	POP	POP	CHLA	EC50		4	d	6.84		umol/L	41	161739
Glyphosate isopropylamine salt	Microcystis	wesenbergii	Blue-green Algae	POP	POP	PSII	NOAEL	LOAEL	0.25	d	132.17	329.53	nmol/L	41	161739
Glyphosate, Monopotassium salt	Lithobates	sylvaticus	Wood Frog	GRO	DVP	MMPH	NOAEL		63	d	0.21		ae mg/L	100	161997

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Chemical	Genus	Species	Common Name										Units		ID
Glyphosate potassium salt	Caiman	latirostris	Broad-Snouted Caiman	CEL	GEN	MNUC	NOAEL	LOAEL		d	264.8	331	ug/egg	66.2	161735
Glyphosate potassium salt	Caiman	latirostris	Broad-Snouted Caiman	CEL	GEN	DAMG	NOAEL	LOAEL		d	264.8	331	ug/egg	66.2	161735
Glyphosate potassium salt	Caiman	latirostris	Broad-Snouted Caiman	CEL	GEN	MNUC	LOAEL			d	331		ug/egg	66.2	161735
Glyphosate potassium salt	Caiman	latirostris	Broad-Snouted Caiman	CEL	GEN	DAMG	LOAEL			d	331		ug/egg	66.2	161735
Glyphosate isopropylamine salt	NR	Arthropoda	Arthropod Phylum	POP	POP	ABND	NOAEL		30	d	7200		ppm	100	161775
Glyphosate isopropylamine salt	NR	Diptera	Fly/Mosquito/Midge Order	POP	POP	ABND	NOAEL		3	d	7200		ppm	100	161775
Glyphosate isopropylamine salt	NR	Formicidae	Ant Family	POP	POP	ABND	NOAEL		30	d	7200		ppm	100	161775
Glyphosate	Amaranthus	sp.	Amaranth	POP	POP	ABND	LOAEL		1	gs	0.96336		lb/acre	100	162049
Glyphosate	Capsella	bursa-pastoris	Shepherd's Purse	POP	POP	ABND	NOAEL		1	gs	0.96336		lb/acre	100	162049
Glyphosate	Chenopodium	album	Lamb's-Quarters	POP	POP	ABND	LOAEL		1	gs	0.96336		lb/acre	100	162049
Glyphosate	Rumex	sp.	Dock Species	POP	POP	ABND	NOAEL		1	gs	0.96336		lb/acre	100	162049
Glyphosate	Veronica	sp.	Speedwell	POP	POP	ABND	NOAEL		1	gs	0.96336		lb/acre	100	162049
Glyphosate	NR	Plantae	Plant Kingdom	POP	POP	ABND	LOAEL		1	gs	0.96336		lb/acre	100	162049
Glyphosate	NR	Cicadellidae	Leafhopper Family	POP	POP	ABND	NOAEL		1	gs	1.08		AI kg/ha	100	162049
Glyphosate	NR	Thysanoptera	Thrip Order	POP	POP	ABND	NOAEL		1	gs	1.08		AI kg/ha	100	162049
Glyphosate	Nabis	sp.	Damsel Bug	POP	POP	ABND	LOAEL		1	gs	1.08		AI kg/ha	100	162049
Glyphosate	NR	Miridae	Leaf Bug Family	POP	POP	ABND	NOAEL		1	gs	1.08		AI kg/ha	100	162049
Glyphosate	NR	Collembola	Springtail Order	POP	POP	ABND	NOAEL		1	gs	1.08		AI kg/ha	100	162049
Glyphosate	NR	Insecta	Insect Class	POP	POP	ABND	NOAEL		1	gs	1.08		AI kg/ha	100	162049
Glyphosate	NR	Braconidae	Braconid Wasp Family	POP	POP	ABND	NOAEL		1	gs	1.08		AI kg/ha	100	162049
Glyphosate	NR	Ichneumonidae	Wasp Family	POP	POP	ABND	NOAEL		1	gs	1.08		AI kg/ha	100	162049
Glyphosate	NR	Chloropidae	Chloropid Fly Family	POP	POP	ABND	NOAEL		1	gs	1.08		AI kg/ha	100	162049
Glyphosate	NR	Insecta	Insect Class	POP	POP	ABND	NOAEL		1	gs	1.08		AI kg/ha	100	162049
Glyphosate	NR	Myriapoda	Arthropod Subphylum	POP	POP	ABND	NOAEL		1	gs	1.08		AI kg/ha	100	162049

Glyphosate	Abutilon	theophrasti	Butter Print	POP	POP	ABND	NOAEL			1	gs	0.96336		lb/acre	100	162049
Glyphosate	Datura	stramonium	Jimsonweed	POP	POP	ABND	NOAEL			1	gs	0.96336		lb/acre	100	162049
Glyphosate	Cyperus	rotundus	Purple Nutsedge	POP	POP	ABND	NOAEL			1	gs	0.96336		lb/acre	100	162049
Glyphosate	NR	Poaceae	Grass Family	POP	POP	ABND	LOAEL			1	gs	0.96336		lb/acre	100	162049
Glyphosate	Lolium	sp.	Ryegrass	POP	POP	ABND	LOAEL			1	gs	0.96336		lb/acre	100	162049
Glyphosate	Medicago	sativa	Alfalfa	POP	POP	ABND	NOAEL			1	gs	0.96336		lb/acre	100	162049
Glyphosate	Portulaca	oleracea	Wild Portulaca	POP	POP	ABND	NOAEL			1	gs	0.96336		lb/acre	100	162049
Glyphosate	NR	Aphididae	Aphid Family	POP	POP	ABND	NOAEL			1	gs	1.08		AI kg/ha	100	162049
Glyphosate	Orius	sp.	Minute Pirate Bug	POP	POP	ABND	LOAEL			1	gs	1.08		AI kg/ha	100	162049
Glyphosate	NR	Coccinellidae	Ladybird Beetle Family	POP	POP	ABND	NOAEL			1	gs	1.08		AI kg/ha	100	162049
Glyphosate	NR	Carabidae	Ground Beetle Family	POP	POP	ABND	LOAEL			1	gs	1.08		AI kg/ha	100	162049
Glyphosate	NR	Staphylinidae	Rove Beetle Family	POP	POP	ABND	NOAEL			1	gs	1.08		AI kg/ha	100	162049
Glyphosate	NR	Chrysopidae	Lacewing Family	POP	POP	ABND	NOAEL			1	gs	1.08		AI kg/ha	100	162049
Glyphosate	NR	Syrphidae	Syrphid Fly Family	POP	POP	ABND	NOAEL			1	gs	1.08		AI kg/ha	100	162049
Glyphosate	NR	Thysanoptera	Thrip Order	POP	POP	ABND	NOAEL			1	gs	1.08		AI kg/ha	100	162049
Glyphosate	NR	Trombiididae	Mite Tick Family	POP	POP	ABND	NOAEL			1	gs	1.08		AI kg/ha	100	162049
Glyphosate	NR	Insecta	Insect Class	POP	POP	ABND	NOAEL			1	gs	1.08		AI kg/ha	100	162049
Glyphosate	NR	Araneae	Araneoid Spider Order	POP	POP	ABND	LOAEL			1	gs	1.08		AI kg/ha	100	162049
Glyphosate	NR	Collembola	Springtail Order	POP	POP	ABND	NOAEL			1	gs	1.08		AI kg/ha	100	162049
Glyphosate	NR	Dermaptera	Earwig Order	POP	POP	ABND	NOAEL			1	gs	1.08		AI kg/ha	100	162049
Glyphosate	NR	Thysanoptera	Thrip Order	POP	POP	ABND	LOAEL			1	gs	1.08		AI kg/ha	100	162049
Glyphosate	NR	Chalcididae	Chalcidid Wasp Family	POP	POP	ABND	NOAEL			1	gs	1.08		AI kg/ha	100	162049
Glyphosate	NR	Mymaridae	Fairyfly Family	POP	POP	ABND	NOAEL			1	gs	1.08		AI kg/ha	100	162049
Glyphosate isopropylamine salt	Mus	musculus	House Mouse	GRO	GRO	WGHT	NOAEL			1	d	600		mg/kg bdwt	100	161750
Glyphosate isopropylamine salt	Mus	musculus	House Mouse	GRO	MPH	WGHT	LOAEL			1	d	600		mg/kg bdwt	100	161750

Glyphosate	NR	Plantae	Plant Kingdom	POP	POP	COVR	NOAEL		974.08	d		1.9624		lb/acre	100	162026
Glyphosate	NR	Plantae	Plant Kingdom	POP	POP	BMAS	LOAEL		397	d		1.9624		lb/acre	100	162026
Glyphosate	Anthonomus	grandis ssp. grandis	Boll Weevil	MOR	MOR	SURV	LOAEL		273.96	d		2.2		AI kg/ha	100	162026
Glyphosate	Quercus	harvardii	Oak, Sand Shinn	POP	POP	COVR	LOAEL		608.8	d		1.9624		lb/acre	100	162026
Glyphosate	NR	Plantae	Plant Kingdom	POP	POP	COVR	NOAEL		974.08	d		1.9624		lb/acre	100	162026

National Management Measures to Control Nonpoint Source Pollution from Forestry
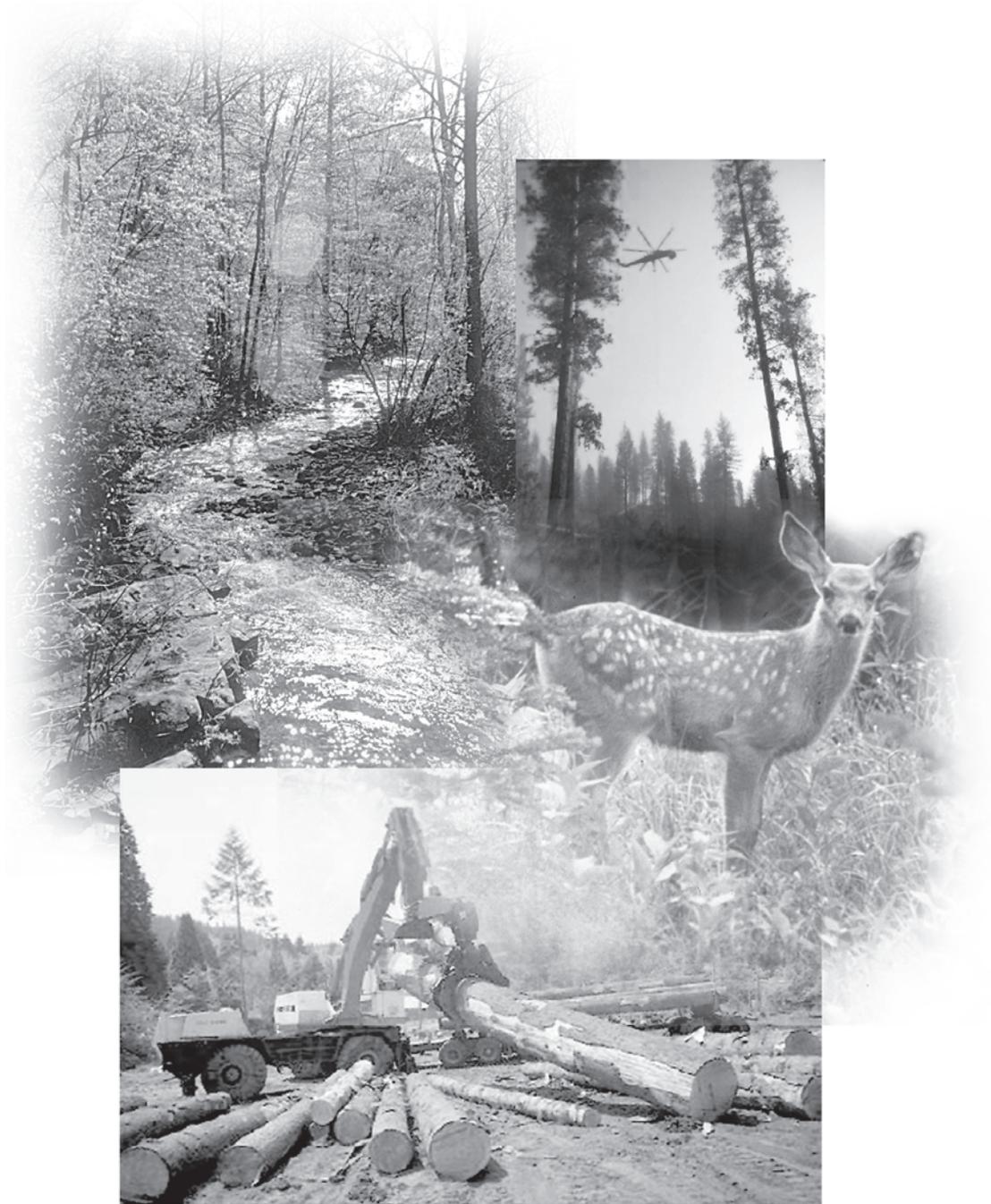
United States Environmental Protection Agency
Office of Water
Washington, DC 20460
(4503F)

EPA-841-B-05-001

April 2005

National Management Measures to Control Nonpoint Source Pollution from Forestry

Nonpoint Source Control Branch
Office of Wetlands, Oceans and Watersheds
Office of Water
U.S. Environmental Protection Agency

April 2005

DISCLAIMER

This document provides guidance to States, Territories, authorized
Tribes, commercial and non-industrial private forest owners and
managers, and the public regarding management measures that may be used
to reduce nonpoint source pollution from forestry activities. At times
this document refers to statutory and regulatory provisions which
contain legally binding requirements. This document does not substitute
for those provisions or regulations, nor is it a regulation itself.
Thus, it does not impose legally-binding requirements on EPA, States,
Territories, authorized Tribes, or the public and may not apply to a
particular situation based upon the circumstances. EPA, State,
Territory, and authorized Tribe decision makers retain the discretion to
adopt approaches to control nonpoint source pollution from forestry
activities on a case-by-case basis that differ from this guidance where
appropriate. EPA may change this guidance in the future.

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CHAPTER 1: INTRODUCTION

The Nation's aquatic resources are among its most valuable assets. Although environmental protection programs in the United States have successfully improved water quality during the past 25 years, many challenges remain. Significant strides have been made in reducing the effects of discrete pollutant sources, such as factories and sewage treatment plants (called point sources). But aquatic ecosystems remain impaired, mostly because of complex problems caused by polluted runoff, known as nonpoint source pollution.

Every 2 years the U.S. Environmental Protection Agency (EPA) reports to Congress on the status of the Nation's waters. The *1998 National Water Quality Inventory* (USEPA, 2000) reports that the most significant source of water quality impairment to rivers and streams and lakes, ponds, and reservoirs is agriculture, and the most significant source of impairment to estuaries is municipal point sources of pollution (Table 1-1). Other important sources of impairment or alterations that can impair water quality include hydrologic modifications like dams and channelization (a leading cause of impairment to rivers and streams and lakes, ponds, and reservoirs), urban runoff and storm sewer discharges (leading sources of impairment to all surface waters), and pollutants deposited from the atmosphere (a leading source of impairment to estuaries). The five leading pollutants impairing the Nation's waters are siltation, nutrients (from fertilizers and animal waste), bacteria, toxic metals, and organic enrichment that lowers dissolved oxygen (USEPA, 2000).[1] Siltation is the leading cause of water quality impairment to rivers and streams and the third leading cause of impairment to lakes, ponds, and reservoirs. Nine states list silviculture as a leading source of impairment to rivers and streams.[2]

> This guidance is designed to provide current information to state forestry program managers and foresters, commercial forest managers, private foresters and loggers, and nonindustrial private forest owners on nonpoint source pollution from forestry activities.

The Purpose and Scope of This Guidance

This guidance document is intended to provide technical assistance to state water quality and forestry program managers, nonindustrial private forest owners, industrial forest owners, and others involved with forest management on the best available, most economically achievable means of reducing the nonpoint source pollution of surface and groundwaters that can result from forestry activities. The guidance provides background information about nonpoint source pollution from forestry activities, including where it

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[1] The term *pollutant* means dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt and industrial, municipal, and agricultural waste discharged into water (Clean Water Act [Title 33, Chapter 26, Subchapter III, Section 1329]). The term *pollution* means the man-made or man-induced alteration of the chemical, physical, biological, and radiological integrity of water (Clean Water Act [Title 33, Chapter 26, Subchapter V, Sec. 1362(19)]).

[2] Nine states list silviculture as a major source of impairment to assessed rivers and streams: Arizona, California, Kentucky, Louisiana, Maine, New Mexico, Tennessee, Vermont, and West Virginia; 11 states/tribes list silviculture as a minor/moderate source of impairment to assessed rivers and streams: Coyote Valley Reservation, Florida, Hawaii, Minnesota, Mississippi, Ohio, Oklahoma, Oregon, South Carolina, Virginia, and Wisconsin; 6 states list silviculture as a source of impairment to assessed rivers and streams without specifying whether it is a major or minor/moderate source: Alaska, Colorado, Montana, North Carolina, Pennsylvania, and Washington. (Source: USEPA, 2000; National Water Quality Inventory, Appendix A-5.)

Table 1-1.   Leading Pollutants and Sources Causing Impairment in Assessed Rivers, Lakes, and Estuaries (USEPA, 2000)

	Rivers and Streams[a]	Lakes, Ponds, and Reservoirs[b]	Estuaries[c]
Pollutants	Siltation	Nutrients	Pathogens (bacteria)
	Pathogens (bacteria)	Metals	Organic enrichment/ Low dissolved oxygen
	Nutrients	Siltation	Metals
Sources	Agriculture	Agriculture	Municipal Point Sources
	Hydromodification	Hydromodification	Urban runoff/ Storm sewers
	Urban runoff/ Storm sewers	Urban runoff/ Storm sewers	Atmospheric deposition

[a] Based on states' surveys of 23% of total river and stream miles.
[b] Based on states' surveys of 42% of total lake, reservoir, and pond acres.
[c] Based on states' surveys of 32% of total estuary square miles.

comes from and how it enters our waters. It presents the most current technical information about how to minimize and reduce nonpoint source pollution to forest waters, and it discusses the broad concept of assessing and addressing water quality problems on a watershed level. By assessing and addressing water quality problems at the watershed level, state program managers and others involved with forest management can integrate concerns about forestry activities with those of other resource management activities to identify conflicting requirements and provide balance between short-term impacts and long-term benefits (Table 1-2). This approach can maximize the potential for overall improvement and protection of watershed conditions and provide multiple environmental benefits.

The causes of nonpoint source pollution from forestry activities, the specific pollutants of concern, and general approaches to reducing the effect of such pollutants on aquatic resources are discussed in the Overview (Chapter 2). Also included in Chapter 2 is a general discussion of best management practices (BMPs) and the use of combinations of individual practices (BMP systems) to protect surface and groundwaters. Management measures for forest management and management practices that can be used to achieve the management measures are described in Chapter 3. Chapter 4 summarizes watershed planning principles and the application of management measures in a watershed context. Chapter 5 provides an overview of nonpoint source monitoring and tracking techniques.

This guidance does **not** replace the 1993 *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters.* The 1993 guidance still applies to coastal states.

Because this document is national in scope, it cannot address all practices or techniques specific to local or regional soils, climate, or forest types. Field research on management practices is ongoing in different parts of the country and under different harvesting circumstances to provide more guidance on how the practices mentioned in this guide and other management practices should be applied under specific circumstances. State laws and programs, or regional guidances published by the U.S. Forest Service, for instance, will have the criteria for site-specific management practice implementation. EPA encourages states to review their existing laws and programs for their relevance to forestry activities and to implement the management measures in this guidance within the context of state laws and programs wherever possible. In some cases very few adjustments to state laws and programs will be necessary to fully meet EPA's management measures. In other cases, major revisions or an entirely new program focus may be necessary. This guidance should prove useful in directing states toward those improvements that are necessary to protect water quality from forestry activities. Consult with

Table 1-2.   Miles of Rivers and Streams Affected By Sources (USEPA, 2000).

SOURCE	MAJOR	MINOR	NOT SPECIFIED	TOTAL	TOTAL as Percent of Assessed Miles
Agriculture	21,856	102,264	46,630	170,750	20.3
Hydromodification	7,930	30,266	19,567	57,763	6.9
Nonirrigated Crop Production	2,551	34,747	9,186	46,484	5.5
Natural Sources	7,437	11,980	13,587	33,004	3.9
Urban Runoff/ Storm Sewers	5,747	20,060	6,504	32,310	3.8
Irrigated Crop Production	3,123	20,784	7,250	31,156	3.7
Municipal Point Sources	6,667	15,293	7,127	29,087	3.5
Animal Feeding Operations	2,736	24,908	108	27,751	3.3
Resource Extraction	5,948	9,771	9,612	25,231	3.0
Silviculture	717	14,884	4,420	20,020	2.4
Land Disposal	2,030	9,565	8,333	19,928	2.4
Range Grazing - Riparian and/or Upland	2,434	10,382	6,653	19,469	2.3
Habitat Modification (other than Hydro)	2,169	11,713	4,569	18,451	2.2
Channelization	3,024	9,677	4,802	17,503	2.1
Industrial Point Sources	3,409	7,335	3,051	13,795	1.6
Construction	1,653	6,331	4,452	12,436	1.5
Onsite Wastewater Systems (Septic Tanks)	874	3,123	7,834	11,831	1.4
Pasture Grazing - Riparian and/or Upland	1,262	9,335	0	10,597	1.3
Bank or Shoreline Modification	1,308	4,472	4,114	9,894	1.2
Other	768	4,375	2,495	7,638	0.9

state or local agencies, including the U.S. Department of Agriculture's Forest Service (USDA-FS), Natural Resources Conservation Service (NRCS), and Cooperative State, Research, Education, and Extension Service (CSREES); soil and water conservation districts; state forestry agencies; local cooperative extension services; and professional forestry organizations for additional information on nonpoint source pollution controls for forestry activities applicable to your local area. Resources and Internet sites related to forestry are listed in Appendices A and B.

This document provides guidance to states, territories, authorized tribes; commercial and nonindustrial private forest owners and managers; and the public regarding management measures that may be used to reduce nonpoint source pollution from forestry activities. At times this document refers to statutory and regulatory provisions that contain legally binding requirements. This document does not substitute for those provisions or regulations, nor is it a regulation itself. Thus, it does not impose legally binding requirements on EPA, states, territories, authorized tribes, or the public and may not apply to a particular situation based upon the circumstances. EPA, state, territory, and authorized tribe decision makers retain the discretion to adopt on a case-by-case basis approaches to control nonpoint source pollution from forestry activities that differ from this guidance where appropriate. EPA may change this guidance in the future.

Readers should note that this guidance is entirely consistent with the *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters* (USEPA, 1993), published under section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA). This guidance, however, does not supplant or replace the 1993 coastal management measures guidance for the purpose of implementing programs under section 6217.

Under CZARA, states that participate in the Coastal Zone Management Program under the Coastal Zone Management Act are required to develop coastal nonpoint pollution control programs that ensure the implementation of EPA's management measures in their coastal management area. The 1993 guidance continues to apply to that program.

This document modifies and expands upon supplementary technical information contained in the 1993 coastal management measures guidance both to reflect circumstances relevant to differing inland conditions and to provide current technical information. It does not set new or additional standards for section 6217 or Clean Water Act section 319 programs. It does, however, provide information that government agencies, private sector groups, and individuals can use to understand and apply measures and practices to address sources of nonpoint source pollution from forestry.

What Is Nonpoint Source Pollution?

Nonpoint source pollution usually results from precipitation, atmospheric deposition, land runoff, infiltration, drainage, seepage, or hydrologic modification. As runoff from rainfall or snowmelt moves, it picks up and carries natural pollutants and pollutants resulting from human activity, ultimately dumping them into rivers, lakes, wetlands, coastal waters, and groundwater. Technically, the term *nonpoint source* is defined to mean any source of water pollution that does not meet the legal definition of *point source* in section 502(14) of the Clean Water Act of 1987:

> The term *point source* means any discernible, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft from which pollutants are or may be discharged. This term does not include agricultural storm water and return flows from irrigated agriculture.

Nonpoint sources, i.e., sources not defined by statute as point sources as described above, include return flow from irrigated agriculture, other agricultural runoff and infiltration, urban runoff from small or non-sewered urban areas, flow from abandoned mines, hydrologic modification, and runoff from forestry activities.

Although diffuse runoff is typically treated as nonpoint source pollution, runoff that enters and is discharged from conveyances such as those described above is treated as a point source discharge and therefore is subject to the permit requirements of the Clean Water Act. In contrast, nonpoint sources, including runoff from forestry activities, are not subject to federal permit requirements. Point source discharges usually enter receiving water bodies at some identifiable site and carry pollutants whose generation is controlled by some internal (e.g., industrial) process or activity, not by the weather. Point source discharges like municipal and industrial wastewaters, runoff or leachate from solid waste disposal sites, and storm sewer outfalls from large urban centers are regulated and permitted under the Clean Water Act.

Although water program managers understand and manage nonpoint sources in accordance with legal definitions and requirements, the nonlegal community often characterizes nonpoint sources in the following ways:

- Nonpoint source discharges enter surface and/or groundwaters in a diffuse manner at irregular intervals related mostly to weather.

- The pollutants arise over an extensive land area and move overland before they reach surface waters or infiltrate into groundwaters.

- The extent of nonpoint source pollution is related to uncontrollable climatic events and to geographic and geologic conditions and varies greatly from place to place and from year to year.

- Nonpoint sources are often more difficult or expensive to monitor at their point(s) of origin than point sources.

- Abatement of nonpoint sources is focused on land and runoff management practices, rather than on effluent treatment.

- Nonpoint source pollutants can be transported and deposited as airborne contaminants.

The nonpoint source pollutant of greatest concern with respect to forestry activities is sediment. The potential for sediment delivery to streams is a long-term (beyond 2 years) concern from almost all forestry harvesting activities and from forest roads regardless of their level of use or age (i.e., for the life of the road). Other pollutants of significance, including nutrients, temperature, toxic chemicals and metals, organic matter, pathogens, herbicides, and pesticides, are also of concern, and problems associated with these other pollutants (in the context of forestry activities) generally do not extend beyond 2 years from the time of harvest or are associated with a specific activity, such as an herbicide application. Nevertheless, all of these pollutants have the potential to affect water quality and aquatic habitat, and minimizing their delivery to surface waters and groundwater deserves serious consideration before and during forestry activities. Forest harvesting can also affect the hydrology of a watershed, and hydrologic alterations within a watershed have the potential to degrade water quality.

Programs to Control Nonpoint Source Pollution

During the first 15 years of the national program to abate and control water pollution (1972–1987), EPA and the states focused most of their water pollution control activities on traditional point sources. They regulated these point sources (and continue to regulate them) through the National Pollutant Discharge Elimination System (NPDES) permit program established by section 402 of the 1972 Federal Water Pollution Control Act (Clean Water Act). Under section 404 of the Clean Water Act, the U.S. Army Corps of Engineers and EPA also have regulated discharges of dredged and fill materials into wetlands.

As a result of the above activities, the United States has greatly reduced pollutant loads from point source discharges and has made considerable progress in restoring and maintaining water quality. However, the gains in controlling point sources have not solved all of our water quality problems. Studies and surveys conducted by EPA, other federal agencies, and state water quality agencies indicate that most of the remaining water quality impairments in our rivers, streams, lakes, estuaries, coastal waters, and wetlands result from nonpoint source pollution and other nontraditional sources, such as urban storm water discharges and overflows from combined sewers (sewers that carry both wastewater and storm water runoff). Summarized below are some legislative and programmatic efforts to control nonpoint source pollution from forestry activities.

Coastal Nonpoint Pollution Control Program

The Federal Coastal Nonpoint Pollution Control Program (6217) is designed to enhance state and local efforts to manage land use activities that degrade coastal habitats and waters.

In November 1990, Congress enacted the Coastal Zone Act Reauthorization Amendments (CZARA). These amendments were intended to address several concerns, including the effect of nonpoint source pollution on coastal waters.

To more specifically address the effects of nonpoint source pollution on coastal water quality, Congress enacted section 6217, *Protecting Coastal Waters* (codified as 16 U.S.C. section 1455b). Section 6217 requires that each state with an approved Coastal Zone Management Program develop a Coastal Nonpoint Pollution Control Program and submit it to EPA and the National Oceanic and Atmospheric Administration (NOAA) for approval. The purpose of the program is "to develop and implement management measures for nonpoint source pollution to restore and protect coastal waters, working in close conjunction with other state and local authorities."

Coastal Nonpoint Pollution Control Programs are not intended to replace existing coastal zone management programs and nonpoint source management programs. Rather, they are intended to serve as an update and expansion of existing programs and are to be coordinated closely with the coastal zone management programs that states and territories are already implementing in keeping with the Coastal Zone Management Act of 1972. The legislative history indicates that the central purpose of section 6217 is to strengthen the links between federal and state coastal zone management and water quality programs and to enhance state and local efforts to manage land use activities that degrade coastal waters and habitats.

Section 6217(g) of CZARA requires EPA to publish, in consultation with NOAA, the U.S. Fish and Wildlife Service, and other federal agencies, "guidance for specifying management measures for sources of nonpoint pollution in coastal waters." Section 6217(g)(5) defines management measures as

> economically achievable measures for the control of the addition of pollutants from existing and new categories and classes of nonpoint sources of pollution, which reflect the greatest degree of pollutant reduction achievable through the application of the best available nonpoint source control practices, technologies, processes, siting criteria, operating methods, and other alternatives.

EPA published *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters* (USEPA, 1993). In that document, management measures for urban areas; agricultural sources; forestry; marinas and recreational boating; hydromodification (channelization and channel modification, dams, and streambank and shoreline erosion); and wetlands, riparian areas, and vegetated treatment systems were defined and described. The management measures for controlling forestry nonpoint source pollution discussed in Chapter 3 of this document are based on those outlined by EPA in the coastal management measures guidance.

Nonpoint Source Program—Section 319 of the Clean Water Act

In 1987, in view of the progress achieved in controlling point sources and the growing national awareness of the increasingly dominant influence of nonpoint source pollution on water quality, Congress amended the Clean Water Act to focus greater national effort on nonpoint sources. Under this amended version, called the 1987 Water Quality Act,

Congress revised section 101, "Declaration of Goals and Policy," to add the following fundamental principle:

> It is the national policy that programs for the control of nonpoint sources of pollution be developed and implemented in an expeditious manner so as to enable the goals of this Act to be met through the control of both point and nonpoint sources of pollution.

More important, Congress enacted section 319 of the 1987 Water Quality Act, which established a national program to control nonpoint sources of water pollution. Under section 319, states, tribes, and territories address nonpoint source pollution by assessing the causes and sources of nonpoint source pollution and implementing management programs to control them. Section 319 authorizes EPA to issue grants to states, tribes, and territories to assist them in implementing management programs or portions of management programs that have been approved by EPA. In fiscal year 2001, Congress appropriated $237,476,800 for this purpose.

Section 319 nonpoint source pollution control programs are an important element of coastal states' efforts to comply with section 6217 Coastal Nonpoint Pollution Control Programs. Under section 6217, coastal states are directed to coordinate development of their coastal waters protection programs with their section 319 programs and related programs developed under other sections of the Clean Water Act, and two primary means of complying with section 6217 are through changes made to section 319 and Coastal Zone Management Programs.

> Section 319 requires states to assess nonpoint source pollution and implement management programs, and authorizes EPA to provide grants to assist state nonpoint source pollution control programs.

National Estuary Program—Section 320 of the Clean Water Act

EPA also administers the National Estuary Program under section 320 of the Clean Water Act. This program focuses on point source and nonpoint source pollution in geographically targeted, high-priority estuarine waters. In this program, EPA assists state, regional, and local governments in developing comprehensive conservation and management plans that recommend priority corrective actions to restore estuarine water quality, fish populations, and other designated uses of the waters.

Section 404 of the Clean Water Act

Section 404 of the Clean Water Act establishes a program to regulate the discharge of dredged and fill materials into waters of the United States, including wetlands. Activities regulated under this program include fills for development, water resource projects (such as dams and levees), infrastructure development (such as highways and airports), and conversion of wetlands to uplands for farming and forestry. The U.S. Army Corps of Engineers and EPA jointly administer the section 404 program. The Corps administers the day-to-day program, including permit decisions and jurisdictional determinations; develops policy and guidance; and enforces section 404 provisions. EPA develops and interprets environmental criteria used in evaluating permit applications; determines the scope of geographic jurisdiction; and approves and oversees state assumption. EPA also identifies activities that are exempt, enforces section 404 provisions, and has the authority to elevate or veto Corps permit decisions. In addition, the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, and state resource agencies have important advisory roles.

Clean Water State Revolving Fund

The Water Quality Act of 1987, the last full reauthorization of the Clean Water Act, replaced the act's Clean Water Construction Grants Program with the Clean Water State Revolving Fund (CWSRF). The CWSRF is a state-based program to provide assistance to municipalities to construct wastewater treatment works, nonpoint source pollution control projects, and estuary protection. Congress insured that CWSRF could address all state water quality program priorities. CWSRF programs provided an average of $3.4 billion per year over the past 5 years, primarily in low-interest loans, to fund such water quality protection projects as well as watershed management projects. The CWSRF have provided more than $38.7 billion in funding over the life of the program.

Nationally, interest rates for CWSRF loans in 2002 averaged 2.5 percent, compared to market rates that averaged 5.1 percent. A CWSRF-funded project would therefore cost about 21 percent less than a project funded at the market rate. CWSRF loans can fund 100 percent of the project cost and provide flexible repayment terms up to 20 years.

States are required to match the federal funds received from CWSRF, but this match requirement is not passed on to loan recipients. Furthermore, the money received as a CWSRF loan can be leveraged as matching funds to obtain funding under other federal programs, such as 319 grants and USDA cost-share programs. This is because much of the CWSRF funds are recycled through loans, so fewer federal requirements apply to them compared to other federal funding sources.

CWSRF loans provide more than $200 million annually to control pollution from nonpoint sources and to protect estuaries, and total funding for these purposes has exceeded $1.6 billion. Some innovative funding examples follow.

❑ The Ohio EPA and Ohio Department of Natural Resources, Division of Forestry, are using Ohio's CWSRF to help Master Loggers and Certified Foresters purchase logging and tree planting equipment. Financed equipment includes bulldozers, tracked forwarders and hydro-bunchers, bridges, and mulching machines. Ohio hopes that this type of funding will support the successful use of BMPs on logging operations.

❑ The California CWSRF provided funds to landowners in the Tahoe Basin to assist them with the removal of dead and dying trees in a manner that minimized erosion and fully protected water quality. The area had a high risk of fire due to the large quantities of natural fuel for fires located on public and private lands throughout the basin.

❑ The Nature Conservancy of Ohio received three CWSRF loans totaling $264,000 for riparian zone conservation. The funds are used to protect 383 acres along Ohio's Brush Creek. The Nature Conservancy purchased 62 acres and obtained conservation easements on 321 acres. Protection measures include planting the riparian corridor with hardwood trees for streambank stabilization. "Restoring and preserving these riparian areas is an important part of controlling contaminated runoff that threatens water quality and stream habitat," said the director of Ohio EPA.

❑ Ohio EPA has worked to fund both point and nonpoint source projects through the newly developed Water Resource Restoration Sponsor Program (WRRSP). The WRRSP provides low-interest loans to communities for wastewater treatment plant improvements if the communities also sponsor water resource restoration projects. Provided that both projects qualify, CWSRF provides the financial support for both projects and reduces a community's interest rate on the total amount borrowed. As a result, the total amount repaid on the CWSRF loan for both projects is less than what would have been repaid on the wastewater treatment plant project alone. Ohio communities used $24 million of CWSRF loan funds to protect and restore 1,850 acres of riparian lands and wetlands and 38 miles of Ohio's stream corridors in 2000 and 2001. The WRRSP was designed to help prevent the loss of biodiversity and to maintain ecological health, and it has supported the acquisition of conservation easements, restoration of habitats, and modification of dams. The CWSRF program has assisted a variety of borrowers such as municipalities, communities of all sizes, farmers, homeowners, businesses, and nonprofit organizations. CWSRF recipients often partner with banks, nonprofits, local governments, and other federal and state agencies to leverage the maximum financing for their communities.

Sources: USEPA, undated a, undated b, 2002a, 2002b.

The basic premise of the program is that no discharge of dredged or fill material can be permitted if a practicable alternative exists that is less damaging to the aquatic environment or if the Nation's waters would be significantly degraded. In other words, an applicant for a permit is asked to show that

- Wetland effects have been avoided to the maximum extent practicable.
- Potential effects on wetlands have been minimized.
- Compensation has been provided for any remaining unavoidable effects through activities such as wetlands restoration and creation.

Regulated activities are controlled by a permit review process. An individual permit is required for potentially significant effects. However, for most discharges that will have only minimal adverse effects, the Army Corps of Engineers often grants general permits. These may be issued on a nationwide, regional, or state basis for particular categories of activities (for example, minor road crossings, utility line backfill and bedding) as a means to expedite the permitting process.

Section 404(f) exempts normal forestry activities that are part of an established, ongoing forestry operation. This exemption does not apply to activities that represent a new use of the wetland and that would result in a reduction in reach or impairment of flow or circulation of waters of the United States, including wetlands. In addition, section 404(f) provides an exemption of discharges of dredged or fill material for the purpose of constructing or maintaining forest roads, where such roads are constructed or maintained in accordance with BMPs to ensure that the flow and circulation patterns and chemical and biological characteristics of the navigable waters are not impaired, that the reach of the navigable waters is not reduced, and that any adverse effect on the aquatic environment will be otherwise minimized. (More information on wetlands and forestry, including a list of the aforementioned BMPs, is provided in Chapter 3, section J.)

Total Maximum Daily Loads—Section 303 of the Clean Water Act

A Total Maximum Daily Load (TMDL) is a statement of the total quantity of a pollutant that can be released to a water body or stretch of stream or river on a daily basis to maintain the water quality standard for the pollutant. A single water body might have many TMDLs, one for each pollutant of concern. A TMDL is the sum of the individual wasteload allocations for point sources, load allocations for nonpoint sources and natural background sources, plus a margin of safety for an individual body of water. TMDLs can be expressed in terms of mass of pollutant per unit time, to aquatic organisms toxicity, or other appropriate measures that relate to state water quality standards.

The process of creating TMDLs was established by Clean Water Act section 303(d) to guide the application of state standards to protect the designated "beneficial uses" (e.g. fishing, swimming, drinking water, fish habitat, aesthetics) of individual water bodies. Beginning in 1992, states, territories and authorized tribes were to submit lists of impaired waters (i.e., waters that do not meet water quality standards) to EPA every two years. Beginning in 1994, lists were due to EPA on April 1 of even-numbered years. States, territories, and authorized tribes rank the listed waters by priority, taking into account the severity of the pollution and the water body's designated uses.

A TMDL is established to identify reduction targets for two types of water pollution sources in rivers and streams:

- Point source pollution
- Nonpoint source pollution

While point sources of water pollution are regulated by discharge permits, nonpoint sources are controlled by the installation of BMPs, either voluntarily or by regulatory requirement, depending on the state.

A TMDL is a process as well as an outcome. The following are components of TMDL development:

- Problem identification
- Identification of water quality indicators and target values
- Source assessment
- Linkage between water quality targets and sources
- Allocations
- Follow-up monitoring and evaluation plan
- Assembling the TMDL

Forest harvesting; road construction, maintenance, and use; and abandoned roads in forests are the primary sources of sediment and other pollutants to water bodies from forestry activities. If a state determines that a priority water body is impaired by a pollutant that partially or wholly arises from forestry activities, the state develops a TMDL for the water body and in it determines the maximum allowable quantity of the pollutant that may be released from forestry activities. Some means of ensuring that no more than this quantity is released must then be implemented. BMPs are one method that could be used in conjunction with other methods chosen.
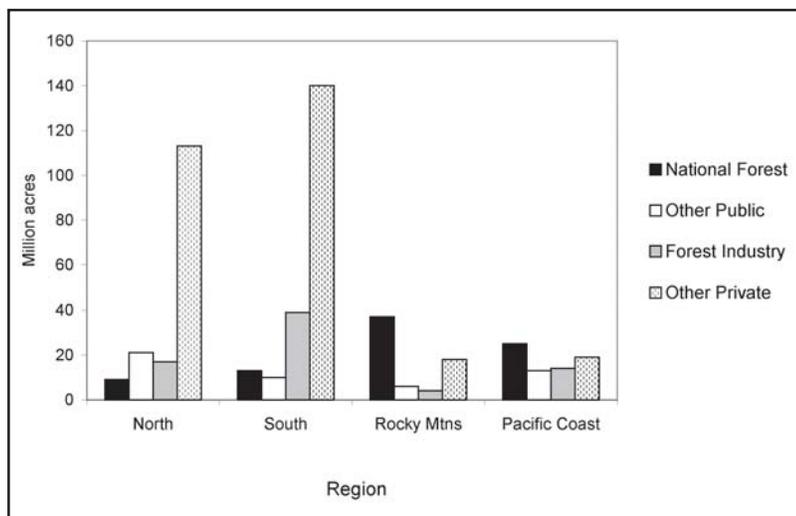
Figure 1-1. Timberland ownership by region (Smith et al., 2001).

Forest Stewardship

Forest stewardship, including implementation of the management measures and BMPs in this guidance or similar ones (for instance, state-recommended BMPs) to minimize water quality impairment due to forest harvesting and associated activities, is the responsibility of those who own and harvest the land. In the United States, timberland ownership is divided among public agencies, the commercial forest industry, and other private timberland owners. On a national scale, 71 percent of timberland is owned privately and 29 percent publicly (Smith et al., 2001). The distribution of ownership among different public and private entities differs widely by region, as summarized in Figure 1-1. Figure 1-2 shows the distribution of forested land throughout the country.

This guidance is oriented toward the implementation of management measures and BMPs that will promote the protection of water quality, but it does not focus on assessing the quality of water that results from forestry activities. Other requirements, notably state water quality standards and designated uses, apply to all ownership categories and types of land-based activities. Thus, while different management measures and BMPs are recommended for forestry activities and agriculture, for instance, maintaining state water quality standards is the responsibility of those who undertake both activities.

Finally, it is important to mention that forests, especially well-managed forests, are a key element in any state, local, or federal water quality protection program. Forests and forested land, whether in a rural setting, along streams on agricultural land, intermixed with other land uses in suburban settings, or in urban locations, are natural filters for storm water runoff and one of the least expensive and most effective means of protecting water quality. It is the hope of EPA that the management measures and BMPs contained in this guidance, and the suggestions for their implementation, will help all persons involved with forestry activities and forest management to maintain the quality of the Nation's surface and groundwaters.
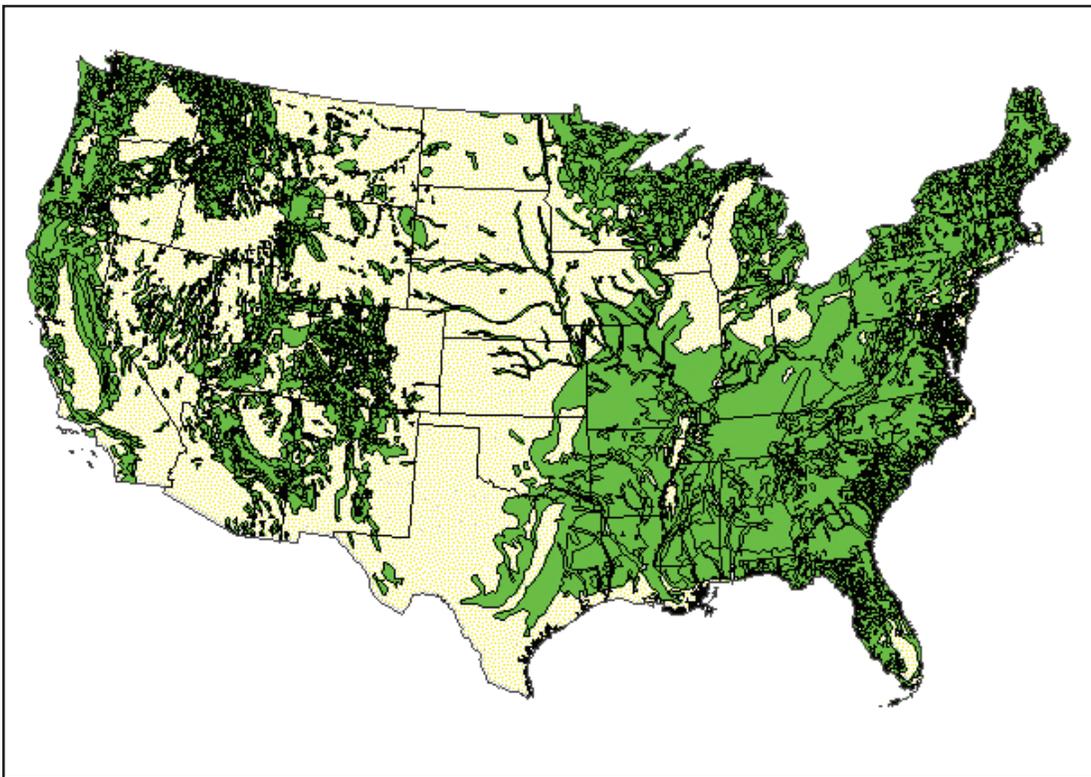
Figure 1-2.   Forested lands of the United States.

CHAPTER 2: WATER QUALITY AND FORESTRY ACTIVITIES

Nonpoint source pollution remains a major challenge to meeting water quality standards and designated uses in much of the Nation. Chapter 1 defines and describes nonpoint source pollution. The potential for sediment delivery to streams is a long-term (beyond 2 years) concern from almost all forestry harvesting activities and from forest roads regardless of their level of use or age (i.e., for the life of the road). Other pollutants of significance, including nutrients, increased temperature, toxic chemicals and metals, organic matter, pathogens, herbicides, and pesticides, are also of concern, and problems associated with these other pollutants (in the context of forestry activities) generally do not extend beyond 2 years from the time of harvest or are associated with a specific activity, such as an herbicide application. Temperature effects might generally extend beyond 2 years because of the time necessary for regrowth to occur in harvested streamside management areas (SMAs). Nevertheless, all of these pollutants have the potential to affect water quality and aquatic habitat and minimizing their delivery to surface waters and groundwater deserves serious consideration before and during forestry activities. Forest harvesting can also affect the hydrology of a watershed, and hydrologic alterations within a watershed also have the potential to degrade water quality. Forestry activities can also affect the habitats of aquatic species through physical disturbances caused by construction of stream crossings, equipment use within stream corridors, and placement of slash or other debris generated by forestry activities within streams. The effects of sediment and other pollutants on water quality in forested areas are discussed below.

The effects of forestry activities on surface waters are of concern to EPA and state and local authorities because healthy, clean waters are important for aquatic life, drinking water, and recreational use. Surface waters and their ecology can be affected by inputs of sediment, nutrients, and chemicals, and by alterations to stream flow that can result from forestry activities. The purpose of implementing management measures and best management practices (BMPs) to protect surface waters during and after forestry activities is to protect important ecological conditions and characteristics of the surface waters in roaded and logged forested areas. These conditions vary with water body type, but in general the ecological conditions that management measures and BMPs are intended to protect include the following:

- General water quality, by minimizing inputs of polluted runoff.
- Water temperature, by ensuring an adequate (but not excessive) and appropriate amount of shade along shorelines and streambanks.
- Nutrient balance, by providing for an adequate influx of carbon and nutrients that serve as the basis of aquatic food chains.
- Habitat diversity, by ensuring that inputs of large organic debris to the aquatic system are appropriate for the system.

- Hydrologic processes, by limiting disturbances to stream flow patterns, both seasonal and annual.

A great deal has been learned over the past 20 to 30 years about effective ways to reduce nonpoint source pollution from forestry activities. Developing more effective ways to control nonpoint source pollution in forested settings requires a basic understanding of forest hydrology and how forestry activities affect it. This chapter discusses the hydrologic processes of forested watersheds, the interaction of forestry activities with those processes, the general causes of nonpoint source pollution due to forestry activities, the specific pollutants and water quality concerns related to forestry activities, and general approaches to reducing the generation of pollutants. The information helps the reader understand how the management measures and BMPs discussed in Chapter 3 can minimize nonpoint source pollution and why proper implementation of BMPs is so critical to maintaining water quality in our forests.

Forested Watershed Hydrology

A watershed is an area that, due to its natural drainage pattern, collects precipitation and deposits it into a particular body of water. In western regions of the country these land areas are often called "drainages," and throughout the Nation they're sometimes referred to as river or stream "basins" (CWP, 2000). Streamflow is a critical element in understanding watershed processes and the effects of land use on those processes because it is the primary medium through which water, sediment, nutrients, organic material, thermal energy, and aquatic species move.

Streamflow is produced by vadose zone flow and groundwater seepage. Vadose zone flow is the flow that occurs between the ground surface and saturated soil, or the water table where groundwater lies. Rainfall and snowmelt supply and replenish both, but in a forested area only a portion of rainfall and snowmelt reaches surface waters. A portion is evaporated back to the atmosphere from the surface of leaves, other vegetative surfaces, and the ground. Some is absorbed by vegetation and either metabolized or transpired back to the atmosphere; and another portion is retained by the soil. Factors such as climate, soil type, topography, elapsed time since the last precipitation event, and amount of vegetation determine the portion of rainfall or snowmelt that actually reaches surface waters. The same factors, as well as soil structure (for instance, the presence of macropores created by animals or decayed roots, etc.) and geomorphology (e.g., depth to bedrock and type of underlying rock), determine how quickly moisture that infiltrates the soil reaches surface waters. If soil is already saturated or the quantity of rainfall or snowmelt is sufficient to exceed the soil's capacity to absorb moisture, surface runoff will occur, though it is not common in forested areas.

Surface runoff in a forested area is more likely to be caused by changes within a watershed than by excessive precipitation, and it is of concern because it has far more erosive power than subsurface flow. There is little storage of water that flows over a forest floor, whereas subsurface storage in soil can be substantial. For this reason, surface water flows down hillslopes more than 10 times faster than it flows through soil. Obstacles on the ground, such as leaf litter and woody debris, help slow surface runoff, but other factors can increase its velocity or volume. Such factors include a loss of vegetative cover that would contribute to evaporation and evapotranspiration, soil compaction, impervious surfaces, and cutslopes of roads or other soil disturbances where subsurface flow can be

transformed into surface flow. Both the extent to which precipitation is delivered directly to the ground and prevented from infiltrating the soil and the amount of subsurface flow that is converted to overland flow are important factors that can affect the timing and volume of streamflow. When more water is delivered to streams faster than usual, stream flow peaks sooner and higher than normal, and instream erosion can occur.

Stormflow response in small basins depends primarily on hillslope processes, whereas that in large basins depends primarily on the geomorphology of the stream channel network. Consequently, land use changes and other site factors as mentioned above (e.g., soil compaction) affect streamflow in small basins more than in large basins. In any watershed, however, streamflow response to a given rain event largely depends on the capacity of the vegetation and soil to intercept rainfall or snowmelt. Saturated soil and little vegetative cover would tend to lead to a much faster streamflow response than dry soil and complete vegetative cover.

Streamflow during a season, the variability of streamflow within a season, and the variability of streamflow between seasons strongly influence channel form and processes. These factors also strongly affect aquatic and riparian species. In a stable stream—that is, one in equilibrium—each channel segment carries off sediment contributed from up-stream locations and from tributaries. When the sediment input rate is greater than the energy in the stream to carry off sediment, sediment accumulates and a channel aggrades. When a stream has more energy than what is necessary to carry the sediment the water is carrying, it can pick up extra sediment and incise the stream.

Forested riparian buffers can provide some measure of flow regulation under certain watershed conditions (Desbonnet et al., 1994). A primary way in which buffers reduce flow velocity is by slowing flow velocity and allowing absorption of water into soil. They also maintain streamside soils in a condition to absorb water by virtue of their extensive root systems that provide the soil structure necessary for a large quantity of absorption. Rainfall and runoff intensity, soil characteristics, hydrologic regime, and slope of the buffer and runoff source area are once again some of the factors that determine a forested riparian buffer's ability to regulate stream flow. A narrow forested buffer on a steep, nonvegetated slope has little ability to regulate flow, whereas a wide forested buffer on a gentle, vegetated slope could help reduce peak flow levels and provide for dry season flow.

Forestry Activities and Forest Hydrology

When one factor in a system changes, other factors may be affected as well. In a forested watershed, logging has the effect of both compacting and loosening soils due to the construction and use of roads, use of heavy machinery, logs being dragged over the ground or otherwise transported to yarding areas, and vegetation being removed. Roads and road ditches, ruts on the ground, and areas cleared of leaf litter or other soil coverings create opportunities for water channelling and flow diversion, which, if not properly controlled and directed, can generate erosive flows. Thus, the disturbances caused by logging in a forested watershed can lead to hydrologic changes within the same water-shed, which can in turn lead to nonpoint source pollution. Forestry activities and their potential effects on forest hydrology and water quality (through nonpoint source pollution) are discussed below.

A note on the concept of disturbance ecology is in order here. A forest is not an ecosystem that has been in perfect equilibrium from its beginning as a grassland to its mature state, modified only by the slow successional changes that occur naturally. Numerous disturbances occur along the way, ranging from those on a small scale (such as a treefall) to those on a large scale (such as a wildfire). Forests react to these disturbances in ways that can increase biodiversity and promote overall forest health. For many years people have managed forests—including protection from disturbance and unnatural disturbance (such as harvesting and altering land use)—without paying attention to the natural disturbance regime of the particular forest. An ecosystem approach to forest management is evolving as more is learned about natural disturbance, and forest management approaches are being developed that benefit both forests and people by creating disturbance in spatial and temporal patterns that closely resemble those of natural disturbances. Thus, forest management activities can be done such that the disturbances they cause benefit the forest ecosystem. Managing a forest this way, however, requires good knowledge of the forest ecosystem dynamics and consideration of all past, present, and future disturbance-creating activities within the forest ecosystem that could cumulatively create more disturbance—and thus unintended damage—than the project being considered, for instance road construction or a harvest.

Road Construction and Road Use

Roads are generally considered to be the major source of sediment to water bodies from harvested forest lands. They have been found to contribute up to 90 percent of the total sediment production from forestry activities (Megahan, 1980; Patric, 1976; Rothwell, 1983). There is some evidence that modern road building practices, such as locating roads on ridgetops instead of middle slopes, removing excavated material to an offsite location, and using full bench construction is reducing the amount of sediment delivered to streams from forest roads (Copstead, 1997). Erosion from roads can be disproportionately high because roads lack vegetative cover, are exposed to direct rainfall, have a tendency to channel water on their surfaces, and are disturbed repeatedly when used. Erosion from roads can be exacerbated by instability on cut-and-fill slopes, water flow over the road surface or through a roadside ditch, flow from surrounding areas becoming concentrated and channelled by a road surface, and lack of a protective surfacing. Much of the sediment load to streams that is associated with roads can be attributed to older roads, which may have been constructed with steep gradients and deep cut-and-fill sections and which may have poorly maintained drainage structures.

Numerous factors need to be considered to protect water quality from the potential effects of forest roads. Stream crossings of both older and modern forest roads and old forest roads that were placed near streams are the most troublesome source of sediment to streams. While roads contribute more to erosion on forested land on a per-area basis (e.g., quantity of eroded soil per acre of road versus per acre of undisturbed forest), they also occupy a disproportionately small amount of a forested area. Evidence indicates that the total amount of eroded soil from roads is not much if any greater than the total amount of soil eroded from the non-roaded surface of a forested area (Gucinski et al., 2001). A related factor is that a small percentage of road area may be responsible for most of the erosion from roads. Rice and Lewis (1986, cited in Gucinski et al., 2001) found that major erosional features of roads occupied only 0.6 percent of the length of roads. A final factor to consider is that soil loss from roads tends to be greatest during and immediately after road construction because of the unstabilized road prism and

disturbance by passage of heavy trucks and equipment (Swift, 1984). Consideration of these factors to reduce water pollution from roads is provided in Chapter 3, section C, *Road Construction/Reconstruction*, and section D, *Road Management*.

Careful planning and proper road layout and design, however, can minimize erosion and substantially reduce the effects of roads on streams. The effect that a forest road network has on sediment input and flow changes in stream networks depends in part on how inter-connected the road and stream networks are. Roads generally are hydrologically connected to stream networks where subsurface groundwater flow is converted to channelled overland flow at road cuts, and road surface runoff drains directly to stream channels. Overland flow is delivered to streams much more quickly than subsurface flow, so the conversion of subsurface flow to overland flow and the connectivity of road networks to stream networks can have an effect on stormflow patterns in streams (Jones and Grant, 1996; Montgomery, 1994; Wemple et al., 1996). Careful road system planning, taking watershed processes, soil type, topography, and vegetative characteristics into account, and designing with natural drainage patterns to minimize hydrologic connections of the road network to streams and maximize opportunities for filtering surface drainage, can reduce these effects. Chapter 3, section A, *Preharvest Planning*, discusses these factors.

Timber Harvesting

Timber harvesting generally involves the use of forest roads (the effects of which are discussed separately above and in Chapter 3), skid trails (along which felled trees are dragged), yarding areas (where cut timber is collected for transport away from the harvest site), and machinery associated with harvesting, skidding, and yarding. Soil disturbance, soil compaction, and vegetation removal on the harvest site, skid trails, and yarding areas can contribute to water quality problems. Methods for minimizing the water quality effects of timber harvesting are discussed in Chapter 3, section E, *Timber Harvesting*.

The association between timber harvesting—especially clear-cut harvesting—and mass erosion events has been and continues to be controversial. Studies of landslides done up to the 1980s, primarily in the Pacific Northwest, found an association between clear-cutting and landslides, but the findings of the studies were inconclusive due to the way data were collected (Hockman-Wert, undated). Studies were often conducted using aerial photographs and concentrated on the steepest slopes. Aerial images cannot account for mass erosion that occurs under forest cover, and later research indicated that as much as 50 percent of mass erosion movements are unaccounted for on aerial photographs. While some studies found clear-cuts to lead to more landslides on steep slopes, when more gentle slopes were investigated the occurrence of landslides was found to be as common on forested sites as on clear-cut sites.

There is a general consensus that harvesting on steep slopes increases the landslide hazard for a period of time after the harvest. It is not clear, however, whether *more* or *larger* landslides occur due to harvesting. In an issue paper written for the Oregon Board of Forestry and to provide background information for policy decisions related to harvesting and public safety, Mills and Hinkle (2001) discuss the latest scientific evidence related to landslides and timber harvesting. They report that in three of four study areas higher landslide densities were found in stands that had been harvested within the previous nine years than in mature (i.e., more than 100 years old) forest stands, and that stands 30 to 100 years old had lower landslide densities than mature stands. They also report that the studies showed that average landslide volume was similar regardless of stand age.

Furthermore, landslides are known to be natural occurrences and important elements in stream ecology in that they are a primary means by which wood and gravel are delivered to streams to create fish habitat (Shaffer, undated). It may be, then, that landslides occur in steep areas regardless of land use history, but that harvesting may concentrate the occurrence of landslides into the 10 years after harvesting.

Geology, soil type, soil depth, and topography might have much more to do with determining whether a site is susceptible to landslides than land use history (Shaffer, nd). Underlying geology plays a role because porous bedrock drains water from soils quickly, while impermeable bedrock keeps water in the soil. Different types of bedrock, such as shales or granite, weather into different types of soils that will either promote or resist sliding. Soil type determines whether a soil binds well to itself and to bedrock to resist sliding or is easily dislodged to promote sliding. Soil depth determines how much soil volume there is above bedrock to absorb water before the soil becomes saturated and what the weight of soil available for sliding is. Water contributes to sliding not only by acting as a lubricant between soil and bedrock, but also by adding considerable weight to the soil. Two inches of rain in 24 hours adds 10 pounds of water in every square foot of soil. On flat topography, saturated soil will result in puddling or overland flow. On gently sloping topography, soil might "creep" downhill at the rate of a few inches a year. On steep topography, the combined weight of water and soil under saturated conditions can trigger a slide. Finally, vegetation provides soil binding to resist sliding, and root decay can make soils less cohesive. Root cohesion—the ability of roots to hold soil to a slope—is at its lowest about 10 years after a harvest (or some other event that kills trees, such as a wind storm after an ice storm). Depending on all of these factors—geology, soil type, soil depth, and topography, combined with the elements of precipitation and land use history—a landslide could occur before or after soil becomes saturated, before or after a harvest, and either slowly and progressively or suddenly and massively.

Finally, research on the effectiveness of different harvesting methods (e.g., clear-cutting or selective cutting) or logging practices to reduce landslide occurrence does not exist (Mills and Hinkle, 2001). The effectiveness of BMPs for minimizing the hazard of landslides from timber harvest sites is also not known.

Recent research in Canada has demonstrated that clear-cut harvesting can lead to increased mercury concentrations in runoff (McIlroy, 2001). Mercury is carried through the atmosphere from areas with sources such as coal combustion and incinerators, and can be deposited in forested areas. When those forested areas are clear-cut harvested, the additional runoff generated after the trees are removed might lead to increased mercury concentrations in the runoff. The Canadian study indicated that the effect is accentuated by heavy, clear-cut harvesting in large watersheds, and that the problem might be avoided by selective harvesting. Further study of the potential problem is needed to clearly portray the association, if any, between forest harvesting and mercury.

Another potential adverse effect of timber harvesting is an increase in stream water temperature—a water quality criterion for physical water quality—that can result if too much streamside vegetation is removed. Small streams are affected more by a loss of shade than are large streams. One reason that streamside buffer strips, or SMAs, are maintained is to minimize or prevent water temperature increases. Stream temperature maintenance is important for aquatic biota. For instance, stream temperature has been found to affect the time required for salmonid eggs to develop and hatch (Chamberlin et al., 1991). Fish and

aquatic invertebrates are cold-blooded adapted to ranges of water temperature, and can be adversely affected by the water temperature exceeding the high temperature of the range for which they are adapted. Maintaining streamside vegetation in an amount sufficient to provide shade that maintains the stream temperature within the proper range is a key goal of the Streamside Management Area Management Measure (see Chapter 3, section B, *Streamside Management Areas*).

Timber harvesting along a stream can also affect stream ecology by removing overhanging trees and branches from which twigs, leaves, branches, and sometimes entire trees fall into the stream channel. Overhanging vegetation contributes organic material in the form of leaves and needles, and large woody debris, or LWD, to surface waters. These materials serve as a source of energy and provide nutrients for aquatic life and provide habitat diversity. They are a primary source of nutrients in small, low-order streams high in watersheds where aquatic vegetation might not be abundant and upstream sources of nutrients are limited. Farther downstream, instream sources of nutrients, such as aquatic plants and organic matter transported from upstream sources, are more abundant and organic debris from overhanging trees is a less important source of energy and nutrients. LWD is still important in these streams, however, for the habitat diversity it creates. LWD creates eddies, provides shelter and anchoring points for small aquatic animals, and forms areas of relatively calm water in flowing streams and rivers. SMAs protect these important ecological processes and benefits, without which stream waters might be prevented from attaining the water quality criterion of supporting aquatic life.

Site Preparation and Forest Regeneration

Site preparation is done to prepare a harvested site for regeneration. It can be accomplished mechanically using wheeled or tracked machinery, by the use of prescribed burning, or with applications of chemicals (herbicides, fertilizers, and pesticides). These techniques may be used alone or in combination. These operations can affect water quality if chemicals used and/or spilled during site preparation operations or soils disturbed during site preparation are transported to surface waters.

The chemicals associated with forestry operations that are of most concern from a water quality perspective are petroleum compounds, lubricants, and other machinery-related chemicals. Herbicides, pesticides, and fertilizers pose little threat to water quality if used and applied according to the specific directions for the chemical being applied and state and EPA guidelines. The herbicides and pesticides used in forestry operations are generally specific to the target vegetation and pose little threat to aquatic organisms, and they generally are short-lived in the environment. Fertilizers pose little threat to aquatic environments because they are used very infrequently for forestry operations, perhaps as little as two applications on a harvest site in 50 years.

Mechanical site preparation by large tractors that shear, disk, drum-chop, or root-rake a site can result in considerable soil disturbance over large areas (Beasley, 1979). Site preparation techniques can result in the removal of vegetation left after a harvest and forest litter, soil compaction and a loss of infiltration capacity, and soil exposure and disturbance. All of these effects can lead to increased erosion and sedimentation. They are most pronounced soon after a harvest and decrease over time, usually within 2 years, as vegetative cover returns to the harvested site.

Forest regeneration methods can be divided into two general types: (1) regeneration from sprouts and seedlings, either planted seedlings or those present naturally on a harvest site, and (2) regeneration from seed, which can be natural seed in the soil or seed from a broadcast application after a harvest. Loss of soil from a harvest site is obviously undesirable from a water quality perspective, and also because of the lowered soil productivity and tree regeneration that can result. Protecting a harvest site from undue disturbance during site preparation, therefore, is desirable both from water quality (reduced erosion) and site productivity perspectives. Means to protect soils from erosion and undue disturbance during site preparation and forest regeneration are discussed in Chapter 3, section F, *Site Preparation and Forest Regeneration*, and section H, *Revegetation of Disturbed Areas*.

Prescribed Burning

Prescribed burning is a method used to prepare a site for regeneration after a harvest, however because the methods for minimizing water quality effects due to fire are some-what specialized, it is treated separately in this document (see Chapter 3, section G, *Fire Management*). Prescribed burning of slash can increase erosion on some soils by eliminating protective cover and altering soil properties (Megahan, 1980). Burning can have the effect of making some soils water repellent, which will tend to increase runoff (Reid, 1993; Ziemer and Lisle, 1998). This effect can penetrate to a depth of 6 inches and persist for 6 or more years after a fire. Burning enhances infiltration in other soils. Which soils will be affected in what way cannot be consistently predicted, and the effect is evidently dependent on the type of vegetation in the area burned. Burning also releases nutrients, immediately increasing nitrogen available to plants, but produces an overall effect of decreasing nitrogen in the forest floor (Reid, 1993). Little effect occurs on soils not affected by fire.

The degree of erosion following a prescribed burn depends on soil erodibility; slope; timing, volume, and intensity of precipitation after a burn; fire severity; cover remaining on the soil; and speed of revegetation. Erosion resulting from prescribed burning is generally less than that resulting from roads and skid trails and from site preparation techniques that cause severe soil disturbance (Golden et al., 1984). However, serious erosion can occur following a prescribed burn if the slash being burned is collected or piled and soil on the harvest site is disturbed in the process of preparing for the burn.

The effects of fire on a watershed depend on burn severity and hydrologic events that follow a fire (Robichaud et al., 2000). Burn severity is related to the amount of vegetation loss and heat-related changes in soil chemistry due to a fire. In general, wildfire has a more severe effect on watershed processes than prescribed burning because it is more intense than a prescribed burn. Prescribed burns are generally set under conditions such that they can be controlled and the fire will burn lower and less intensely than would a wildfire. Given the potential effects that a severe burn can have on watershed processes, prescribed burning can be used effectively both for site preparation and to reduce the chances of wildfire—and the often more severe effects that the latter can have on water-shed processes.

Forestry Pollutants and Water Quality Effects

The discussion above focused on forestry activities, the potential they have for generating nonpoint source pollution and pollutants, and the watershed processes that can be affected

by forestry activities. Below is a discussion of the pollutants that can be generated from forestry activities and the potential effects that these pollutants can have on water quality.

The nonpoint source pollution problem of greatest concern with respect to forestry activities is the addition of sediment to surface waters. Without adequate precautions, however, many water quality issues can arise from forestry operations:

- Sediment concentrations can increase because of accelerated erosion.
- Nutrients in water can increase after their release from decaying organic matter on the ground or in the water, or after a prescribed burn.
- Organic and inorganic chemical concentrations can increase because of harvesting and fertilizer and pesticide applications.
- Slash and other organic debris can accumulate in waterbodies, which can lead to dissolved oxygen depletion.
- Water temperatures can increase because of removal of riparian vegetation.
- Streamflow can increase because of reduced evapotranspiration and runoff channeling.

The discussions below of the individual pollutants that can be generated by forestry activities present the range of effects that might occur during and after road construction or use or a harvest. The particular effects of a forestry activities in a specific watershed will depend on the unique interaction of the characteristics of the area where the activities occur, time of year, harvesting method, and the BMPs used.

Sediment

Sediment deposited in surface waters is of concern in this guidance because of its potential to affect instream conditions and aquatic communities. Sediment is the pollutant most associated with forestry activities. Sediment is the solid material that is eroded from the land surface by water, ice, wind, or other processes and then transported or deposited away from its original location. Soil is lost from the forest floor by surface erosion or mass wasting (for example, landslides).

Surface erosion generally contributes minor quantities of sediment to streams in undisturbed forests, and the quantity of surface erosion depends on factors mentioned previously, such as soil type, topography, and amount of vegetative cover (Spence et al., 1996).

Rill erosion and channelized flow occur where rainwater and snowmelt are concentrated by landforms, including berms on roads and roadside ditches. They cause erosion most severely where water is permitted to travel for a long distance without interruption over steep slopes, because the combination of distance and slope tends to increase the volume and velocity of runoff. Sheet erosion, or overland flow, occurs occasionally on exposed soils where the conditions necessary for it, including saturated soil or a rainfall intensity that is greater than the ability of soil to absorb the water, but it is not common on forest soils.

Mass wasting—including slumps, earthflows, and landslides—occurs most often in mountainous regions where surface erosion is minor (Spence et al., 1996). It can contribute large quantities of sediment to streams—and stream ecology and fish populations may depend on this sediment; but it occurs episodically, usually following heavy rains. Clear-cutting can promote landslides on steep slopes where other factors, such as type and

depth of soil and type of bedrock, are favorable for landsliding. These other factors have a lot to do with whether a landslide will occur at a site, and tree removal increases the chance that a landslide will occur on a site that is prone to landsliding within a 10-year timeframe after a harvest (Mills and Hinkle, 2001). If topographic and geologic conditions at a site are favorable for landslides, then landslides are likely to occur at the site whether it is harvested or not, though harvesting may certainly affect the timing, volume, and composition of a slide. Many landslides occur on completely forested areas (Hockman-Wert, undated) and landslides are important to stream ecology in that they provide wood and gravel important to the creation of fish habitat (Shaffer, undated).

Gucinski and others (2000) reviewed the scientific information available on forest roads and forest road-related issues in a paper, *Forest Roads: A Synthesis of the Scientific Information*, for the U.S. Forest Service. The authors review information related to the direct physical and ecological effects, the indirect landscape effects, and the direct and indirect socioeconomic effects of forest roads. The reviewers conclude that forest roads can lead to mass failures if road fills and stream crossings are improperly located, culverts are too small to pass flood waters and debris, roads are sited poorly, surface and subsurface drainage is modified by a road, or water is diverted from a road to unstable soil areas. Furthermore, the reviewers emphasize that on most roads only a small percentage of a road's surface, as little as 1 percent or less, contributes to mass wasting. Many of the studies reviewed were conducted on roads that were constructed in the 1970s and 1980s. While studies of roads constructed with more modern road-building technologies, including technologies that incorporate the BMPs discussed in Chapter 3, *Road Construction/Reconstruction* (section C) and *Road Management* (section D), are not widely available yet, use of the modern technologies may lead to reduced mass wasting and water quality impacts from roads in general in the future.

Forest road stream crossings can be sites of sedimentation and hydrologic change if an inappropriate type and size of crossing is installed. A culvert that is too small will not permit the passage of debris and water during flood events, and can lead to instream erosion and culvert blowout. A culvert, ford, or bridge that is improperly installed can cause erosion at the site of the crossing. Problems associated with stream crossings can be avoided by proper planning (Wiest, 1998). Crossings can be located where gradient or channel alignment are relatively uniform and selected to be large enough for floodwaters and instream debris to pass through. The advantages and disadvantages of various stream crossing structures are summarized in Table 2-1. Management measures and BMPs for preventing problems at stream crossings associated with forestry activities are discussed in Chapter 3, sections C, *Road Construction/Reconstruction*, and D, *Road Management*.

An excessive quantity of sediment in a water body can cause or lead to a variety of problems. Sediment can reduce a water body's ability to support aquatic life when it fills the spaces between rocks and grains of sand where many organisms live, forage, and spawn, hindering these activities. Fine sediments, of the size that can be deposited between grains of sand, are most threatening to fish. If deposited on fish eggs, fine sediments can reduce egg-to-fry survival and fry quality by suffocating eggs and forming a physical barrier to emerging larvae. Different species have different tolerances to fine sediment due to the fry having different head diameters. Coarse sediment can cap a

Table 2-1.   Advantages and Disadvantages of Stream Crossing Structures

Stream Crossing Structure	Advantages	Disadvantages	Notes
Circular Pipe Ditch Relief Culvert	Stable and reliable for steep grades; less erosion and more economical than surface cross drains for high-traffic roads	Needs periodic maintenance and inspection to avoid plugging; if too small can plug and lead to erosion	Should be located far enough above stream crossings to avoid releasing ditch drainage water directly into streams
Bottomless or Log Culvert	Preserves natural streambed and gradient; no significant change in water velocity; maintains normal stream width	Vulnerable to erosion and downcutting; large logs might be required to achieve adequate flow with log culverts; expensive and can be difficult to install; not practical where footings cannot be placed in stable, nonerodible material	Generally spans the entire streambed and minimizes effects on the natural stream channel
Embedded Pipe Arch Culvert	When properly installed, maintains natural stream channel width, grade, and sediment transport characteristics	Complex and time-consuming installation; sizing must account for area lost to embedding; fitting with machinery possible only if the diameter is large enough to permit machine entry	Must be constructed on suitable bedding material; suitable on bedrock when concrete footings can be used
Ford	Useful for low-water crossings	Can be barriers to fish passage during low-flow conditions	Stream channel and slope must be suitable; useful where transportation requirements are seasonal
Bridge	Best option for maintaining natural stream channel	Expensive; requires special installation techniques; difficult to fit to tight road curves	Requires determination of 50- or 100-year flow

gravel streambed and restrict the emergence of alevins (Murphy and Miller, 1997). Murphy and Miller (1997) found that fine sediment deposited in spawning gravels after timber harvest contributed to a 25 percent reduction in chum salmon escapement.

High sediment concentrations in the water can cause pools—preferred by some salmon species such as coho—to fill with sediment and reduce or destroy essential rearing habitat. When streams are affected by high sediment deposition, these formerly productive low-gradient reaches become wide and shallow and recovery of fish habitat can take decades (Frissell, 1992).

Sediment suspended in water increases turbidity, limiting the depth to which light can penetrate if turbidity is increased to a sufficient degree and, thus, potentially reducing photosynthesis and oxygen replenishment. A quantity of suspended sediment far in excess of that normally present in a water body can suffocate aquatic animals and severely limit the ability of sight-feeding fish to find and obtain food.

Increased Temperature

Temperature increases in streams are of concern because of the potential effects on aquatic species. The water quality criterion for temperature is set for waters to protect aquatic biota, and the temperature tolerance limits of fish are used to indicate whether a water body's temperature has been adversely affected. When streamside vegetation is removed, any increase in solar radiation reaching the stream can increase the water temperature. The temperature increase can be dramatic in smaller (lower order)

streams and can heat the water to beyond the tolerance limits of some aquatic species. Increased water temperatures can also accelerate the chemical processes that occur in the water, decrease the ability of a water body to hold oxygen, and lower the concentration of dissolved oxygen.

Because streams in forests are shaded, fish species in forested streams tend to be cooler-water species, such as salmon and trout, than fish species in non-forested streams. The duration of an elevated temperature and the availability of cool pools of water are among the factors that determine how severe an effect a temperature increase has on fish and other biota. An elevated water temperature can retard growth, reduce reproductive success, increase susceptibility to disease, decrease the ability to avoid predators, and decrease the ability to compete for food (Spence et al., 1996).

Riparian forested buffers, as discussed above and in Chapter 3, section B (*Streamside Management Areas*) are a primary means of minimizing temperature increases due to timber harvesting. The role of riparian forested buffers in regulating ambient stream temperature, however, varies with stream width and vegetation type, as well as other factors such as stream depth, orientation to the sun, and surrounding topography. A narrow stream with a complete riparian forested buffer might receive as little as 1 to 3 percent of the total incoming solar radiation, whereas a wide midorder stream might receive as much as 10 to 25 percent. Riparian vegetation, therefore, has less ability to regulate water temperature as stream width increases (Spence et al., 1996).

Nutrients

Nutrients, such as nitrogen and phosphorus from fertilizers, soil, and plant material, are primary chemical water quality constituents. They can enter water bodies attached to sediments, dissolved in the water, or transported by air. Forest harvesting can increase nutrient leaching from the soil, though the effect generally subsides to near precutting levels within two years of a harvest. Low to moderate increases in nutrient levels may have no or a beneficial effect on an aquatic environment, but excessive amounts of nutrients can stimulate algal blooms or an overgrowth of other types of aquatic vegetation. This can in turn lead to an increase in the amount of decomposing plant material in an aquatic system and, in turn, increased turbidity and biological oxygen demand. The latter effect can decrease dissolved oxygen concentrations, with potentially detrimental effects to aquatic biota. Chapter 3, section I, *Forest Chemical Management*, discusses methods for minimizing the adverse effects of forestry activities on nutrient balances.

Organic debris, discussed below, can be an important source of nutrients in an aquatic environment, and SMAs play an important role in organic debris inputs and maintaining nutrient balances in aquatic forest ecosystems.

Organic Debris

Organic debris—primarily composed of leaves, twigs, branches, and fallen trees—is an important element of water quality in that it provides nutrients and stream structure that are important to supporting aquatic life. It ranges in size from suspended organic matter in water to fallen trees. Large woody debris, or LWD, can be whole trees or tree limbs that have fallen into streams. It creates the physical habitat diversity essential to support-

ing aquatic life. As a structural element, it influences the movement and storage of sediment and gravel in streams and stabilizes streambeds and banks (Spence et al., 1996). Small organic litter—primarily leaves in deciduous forests and cones and needles in coniferous forests—is an important source of nutrients for aquatic communities. It usually decomposes over a year or more, depending on forest type.

When streamside vegetation is removed, inputs of organic debris decrease and the amount of sunlight reaching the water increases. A stream that might previously have relied primarily on sources of nutrients external to the stream (fallen debris) can be forced to rely primarily on instream sources (such as algal growth and instream vegetation). The latter may not be present in high-order streams.

Organic debris generated during forestry activities includes residual logs, slash, litter, and soil organic matter. These materials can perform some of the same positive functions as naturally occurring LWD and organic litter. If their abundance in a stream is substantially greater than normal, however, they can also block or redirect streamflow, alter nutrient balances, and decrease the concentration of dissolved oxygen as they decompose and consume oxygen. Observing management guidelines for streamside management areas, discussed in Chapter 3, section B, *Streamside Management Areas*, is a key means to minimize ecological and water quality effects due to organic debris.

Forest Chemicals

Chemicals that enter surface waters can be toxic to aquatic biota, make it difficult to attain drinking water quality criteria, and degrade the aesthetics of streams. The most harmful substances considered under the general category of "forest chemicals" and used during forestry operations are fuel, oil, and lubricants; coolants; and others used for harvesting and road-building equipment. Simple precautions can prevent water quality deterioration, whereas improper use and management of chemicals used during forestry operations can result in degraded water quality.

Fertilizers, herbicides, and pesticides are used to prepare a site for regeneration and to protect forests from disease and pests. Adverse effects on water quality due to forest chemical applications typically result from not following the specific application instructions for the chemical being used, such as specifications for the quantity to apply and the distance to maintain around watercourses (Norris and Moore, 1971). Generally, the water quality and aquatic biota threats due to fertilizers, herbicides, and pesticides are small because the chemicals are applied at most only one to three times at a harvest site and they specifically target biochemical pathways present only in plants, rendering them of little danger to aquatic animals. Furthermore, the half-lives of forestry herbicides are on the order of less than 100 days, so bioaccumulation in aquatic species is rarely of concern. Precautions for minimizing water quality effects due to forest chemical use are discussed in Chapter 3, section I, *Forest Chemical Management*.

Hydrologic Modifications

Streamflow is a concern because of the instream changes that can occur if the quantity of streamflow or the timing of streamflow is changed substantially as a result of a forest harvest or repeated forest harvesting. The dynamics of forest harvesting and streamflow response are discussed above under *Forested Watershed Hydrology*. Methods of minimizing the streamflow effects of forest roads and timber

harvesting are discussed in Chapter 3, and particularly in sections C, *Road Construction/Reconstruction*, D, *Road Management*, and E, *Timber Harvesting*.

If forest roads or timber harvesting result in a more rapid delivery of runoff to streams than before roads were present or timber was harvested, peak flows can be increased. This can lead to increases in channel scouring, streambank erosion, downstream sedimentation, and flooding. The magnitude of changes in peak flows after logging depends on the size of the watershed and the amount of land harvested, and to a lesser extent on road building. Changes are usually greatest in small watersheds and where a large percentage of the surrounding watershed is logged at one time. Streamflow can be increased as a result of forest road building alone, but this usually occurs only in small, upland watersheds where streams and streamflow are small and the amount of impervious or heavily compacted surface from the harvest and associated activities is large in proportion to the areal extent of the watershed. Downstream flooding is rarely a consequence of logging in small, upstream watersheds (Adams and Ringer, 1994).

Normally, when only a small portion (e.g., less than 15 percent) of a watershed is harvested, flow is not altered in associated streams. Where more than 15 to 20 percent of the forest canopy is removed, streamflow typically increases. Any increase is greatest in the first years after harvest and typically becomes smaller with time as vegetation grows on harvested sites. Streamflow generally returns to the original level within 20 to 60 years, depending on forest and land type (Adams and Ringer, 1994).

Physical Barriers

Forest road stream crossings can be sites of hydrologic change, sedimentation, and debris buildup if the appropriate type and size of crossing are not selected. Improperly installed culverts at stream crossings can lead to erosion around the culvert and of the road surface when the design storm is exceeded or if debris inhibits or redirects flow. This can result in excessive sedimentation and channel alterations downstream. Culverts installed above the grade of a stream can create a barrier to upstream fish migration. Any of the following conditions associated with culverts can block fish passage: water velocity at the culvert is too fast, water depth at the culvert is too shallow, there is no resting pool below the culvert, the culvert is too high for a fish to jump, or the culvert is clogged because of lack of maintenance.

Problems associated with stream crossings can be avoided by proper planning (Wiest, 1998). Crossings can be located where they do not cause large increases in water velocity and there are not large changes in gradient or channel alignment. Doing so can minimize effects on sedimentation and fish passage. Planning for safe fish passage involves determining the type and extent of fish habitat, the species of fish present in the stream, and the window during which instream work can occur without harming fish habitat or interfering with fish migration. Adequate fish passage is that which conserves the free movement of fish in and about streams, lakes, and rivers in order that they can complete critical phases of their life cycles. It permits adult fish to migrate to spawning areas and juvenile fish to accompany adult fish or make local moves to rearing or overwintering areas. The advantages and disadvantages of various stream crossing structures are summarized in Table 2-1.

Fords, bridges, and culverts of various sizes, shapes, and materials can be installed to avoid hydrologic and habitat changes and to provide adequate fish passage. Road crossings and culverts also need to be installed to fail when the design storm is exceeded to prevent substantial sedimentation. Management measures and BMPs for preventing physical barriers in streams associated with forestry activities are discussed in Chapter 3, sections C, *Road Construction/Reconstruction*, and D, *Road Management*.

Cumulative Effects

Cumulative effects occur when two or more activities cause the same response within a watershed (e.g., lead to increased stream flow at a given time of year), when multiple responses disturb the same resource (e.g., increased stream flow and sediment yield both affect the same stream reach), when one response provokes another (e.g., increased stream flow induces scouring around culverts), or when responses interact to produce another (e.g., road construction on a steep slope and unusually heavy rains produce a mass soil movement) (Reid, 1993). Cumulative effects can occur spatially, when numerous activities conducted at different locations within a watershed contribute to instream responses, or temporally, when a single activity repeated in the same place or different activities conducted in different places at different times have an additive effect. Most land use activities affect only one of four environmental parameters—vegetation, soils, topography, or chemicals—and other watershed changes result from initial effects on these factors. If a change in vegetation or another one of these four factors is persistent or affects watershed transport processes or rates, cumulative effects can result.

Cumulative effects are of concern with respect to forest roads; forest road construction, use, and maintenance; and forest harvesting because the changes that can occur in watershed processes following these activities can persist for many years. This persistence increases the potential for cumulative effects to occur. Examples of potential persistent effects due to forestry activities include the delivery of sediment to streams from a forest road used repeatedly over a period of years and increased subsurface flow and decreased evapotranspiration due to a reduced amount of vegetation at a harvest site.

Forest roads and timber harvesting can cause changes to a landscape or stream on a temporal scale far different from that associated with the life of the road or duration of the harvest. A road may be constructed and used for many years, and its effect on a landscape can continue for years after it is no longer needed. Cafferata and Spittler (1998) found that "legacy" roads can be significant sources of sediment for decades after their construction. Reid (1998) also found that sedimentation rates may increase 25 years or more after logging roads are abandoned as they begin to fail and erode. A harvest might occur in one season, or numerous harvests in a watershed might occur over a number of years, and during the months or years afterward temporary roads and stream crossings might be removed and the ground or streambeds rehabilitated. In contrast, recovery of a forest, instream recovery from channel erosion, habitat recovery, and aquatic community recovery occur on time scales much longer than the harvest. The long-term recovery times provide ample opportunity for other disturbances to contribute to cumulative effects.

Consider the following study of cumulative effects, modeled using Monte Carlo simulations of four hypothetical watersheds (Ziemer et al., 1991). Each watershed was a 10,000-ha, fifth-order watershed typical of one that might be located in coastal Oregon or California at 300 to 500 meters of elevation and 30 kilometers inland from the coast. Annual rainfall was simulated at 1500 millimeters. The four watersheds were simulated to have the following treatments:

- One watershed was simulated as undisturbed.

- One watershed was simulated as clear-cut and roaded within 10 years of the commencement of harvesting, with harvesting beginning at the upper reaches of the watershed and progressing toward the mouth.

- One watershed was simulated as harvested at the rate of 1 percent per year, beginning at the mouth and progressing upstream.

- The fourth watershed was again simulated as harvested at a rate of 1 percent per year, but with the harvests widely dispersed throughout the watershed.

These harvesting patterns were simulated as being repeated each 100 years, and in each watershed (except the unharvested one) one-third of the road network was simulated to be rebuilt each 100 years. The greatest differences between the treatments were noticed in the first 100 years, and they related most to the rate of treatment. That is, to whether the harvests were concentrated or dispersed temporally. By the second 100 years, the primary difference between the treatments was in the timing of the impacts. Interestingly, the simulation indicated that temporally dispersing the harvest units did not reduce cumulative effects.

The conclusion reached by the authors was that current estimates of cumulative effects due to logging *underestimate* the effects because they accumulate over much longer periods than previously thought, but they *overestimate* the benefits of temporally dispersing harvests in a watershed. Concentrating the treatments (over 10 years instead of 100 years) increased the chances of cumulative effects on the affected resources.

A more detailed discussion of issues related to cumulative effect assessment is provided in Chapter 4, *Using Management Measures to Prevent and Solve Nonpoint Source Pollution Problems in Watersheds*.

Mechanisms to Control Forestry Nonpoint Source Pollution

Nonpoint source pollution control practices for forestry activities are referred to as *best management practices* (BMPs), *management practices*, *accepted forestry practices*, *management measures*, *BMP systems*, *management practice systems*, and the like. Some of these terms have specific uses in legislation and regulations, whereas other terms are found in technical manuals, journal articles, and informational materials. Forestry management practices have been developed by all states, though they may not exist as a separate program or set of rules or guidelines. In some states, forest protection guidelines are contained within watershed protection or water quality protection programs, in some they are incorporated into erosion and sedimentation control programs, while in others a separate program of forestry rules or guidelines governs harvesting activities. Links to all

state forestry programs, with information on the agencies that are involved in protecting forests in the states, can be found at the Web site www.usabmp.net.

BMPs are individual practices (such as leaving a streamside management area) that serve specific functions (such as protecting streams from temperature increases and filtering sediment and nutrients from runoff). *Management measures*, as the term is used in this guidance, are environmental goals to be attained by using one or more BMPs. For instance, minimizing sediment delivery to streams (part of the overall goal of the Management Measure for Streamside Management Areas [see Chapter 3, section B]) from harvest sites might be accomplished with the following BMPs: maintaining a riparian buffer; locating roads, yarding areas, and skid trails away from streams; and not using machinery in streams.

BMPs are the building blocks for BMP systems and management measures, and the implementation of the forestry management measures in this guidance, as appropriate to the situation, can result in comprehensive water quality protection for most harvesting operations.

Management Measures

The management measures in this guidance contain technology-based performance expectations and, in many cases, specific actions to be taken to prevent or minimize nonpoint source pollution. Management measures are means to control the entry of pollutants into surface waters. Management measures achieve nonpoint source pollutant control goals through the application of nonpoint pollution control BMPs, which may be technologies, processes, siting criteria, operating methods, or other alternatives. Chapter 3 contains the management measures and recommended BMPs controlling nonpoint source pollution from forestry activities.

For example, the Management Measure for Site Preparation and Forest Regeneration (see section F) contains the performance expectation *Confine on-site potential nonpoint source pollution and erosion resulting from site preparation and the regeneration of forest stands*. Statements of BMPs or actions that can be taken to achieve this performance expectation (e.g., *Conduct mechanical tree planting and ground-disturbing site preparation activities on the contour of sloping terrain*) are generally included in the management measure statement. Even so, in most cases there is considerable flexibility to determine how to best achieve the performance expectations for the management measures. EPA's management measures for forestry and BMPs recommended to be used to achieve them are described in Chapter 3.

Best Management Practices

BMPs can be structural (e.g., culverts, broad-based dips, windrows) or managerial (e.g., preharvest planning, forest chemical management, fire management). Both types are used to control the delivery of nonpoint source pollutants to receiving waters in one of three ways:

- They minimize the quantity of pollutants released (pollution prevention).
- They retard the transport or delivery of pollutants, either by reducing the amount of water (and thus the amount of the pollutant) transported or by improving deposition of the pollutant (delivery reduction).

- They render the pollutant harmless or less harmful before or after it is delivered to a water body through chemical or biological transformation.

BMPs are usually designed to control a particular type of pollutant from a specific land use or activity. For example, stream crossings are specified and designed to control erosion from stream banks where roads cross them and sediment delivery from roads to streams. BMPs might also provide secondary benefits. Streamside management areas, for instance, reduce sediment delivery to streams and protect streams from temperature increases, and they also provide a source of large organic debris to streams and habitat for wildlife.

Sometimes, however, a BMP might increase the generation, transport, or delivery of a pollutant and is best used in combination with other BMPs. Site preparation, for example, is generally performed for commercial timber regeneration, but can temporarily expose soil to erosive forces. Therefore, sedimentation control BMPs, such as establishing SMAs of widths suitable to retain the anticipated quantity of eroded soil and not conducting mechanical site preparation on steep slopes, are recommended to be combined with site preparation techniques.

Which BMP is *best* for in a given situation depends on many factors. Criteria for determining which BMP is best for a particular forestry activity might include the harvesting technique, frequency of road use, topography, soil type, climate, amount of maintenance feasible BMPs will require, the willingness of landowners to implement BMPs (in a program of voluntary implementation, for instance), and BMP cost and cost-effectiveness. The relative importance assigned to these and other criteria in judging what is best varies among states, within states, and among landowners, often for very good reasons. For example, erosion control considerations are very different in mountainous western regions versus relatively flat southeastern coastal plain regions. Some BMPs that can be used to achieve the forestry management measures are described in Chapter 3.

Best Management Practice Systems

The distinction between BMPs selected for particular areas or aspects (e.g., roads, yarding areas, skid trails, stream crossings) of a harvest activity and a *BMP system* is similar to the difference between controlling pollutant sources individually and controlling them based on a TMDL. Pollutant sources, especially point sources, controlled on an individual basis are analyzed independently relative to a standard for a type of industry and water quality criteria for the receiving water body. A TMDL incorporates all pollutant sources affecting a water body and limits loads for individual sources relative to the assimilative capacity of the water body. Similarly, BMPs selected for individual aspects of a harvest activity views those activities or areas independently of other activities and areas to control water pollution, while approaching water quality considerations from the point of view of a BMP system would involve considering the harvest and all of its activities and affected areas from a hydrologic perspective, examining the flow of surface water and groundwater over the entire site, and determining the best locations for sediment, nutrient, and other pollutant interception. As an example, consider a harvest operation that involves road repairs, a stream crossing, creation of a yarding area, and site preparation. Individual BMPs can be selected for each aspect of the harvest operation. That is, BMPs for sediment retention (for example) could be chosen for the road segment, others selected for the stream crossing, and still others placed on the yarding area.

Each set of BMPs for these separate areas would be selected to control sediment runoff from that area alone. Alternatively, the spatial relationship of the three areas from a water flow or hydrologic perspective could be considered to understand how BMPs selected for the site preparation work might be altered somewhat to capture sediment from the yarding area, thus eliminating the need for separate BMPs for the yarding area. Also, it might be noticed that a different type or orientation of BMPs along the road segment could significantly reduce the potential for sediment delivery along the road to the stream crossing, thus permitting a change in the stream crossing to better ensure retaining the natural stream shape. The BMP system approach might reduce the total number of BMPs required and increase the efficiency of the BMPs for protecting water quality, and thus reduce the cost of the operation.

Structural and managerial BMPs used as part of a BMP system can be selected, designed, implemented, and maintained in accordance with site-specific considerations (e.g., slope, soil type, proximity to streams, and layout of the harvest) so they work effectively together. Planning BMP use as part of a system also helps to ensure that design standards and specifications for the individual BMPs are compatible so they will achieve the greatest amount nonpoint source pollution control possible with the least cost.

Cost Estimates for Forest Practice Implementation

Estimates of the per acre cost of implementing BMPs for timber harvests were arrived at based on information obtained from published reports on regional studies of the cost of BMP implementation and cost estimates based on the regulatory structure of forestry practice programs. Studies have been conducted on the cost of implementing forestry practices for water quality and soil protection in the Southeast and some western states (Aust et al., 1996; Dissmeyer and Foster, 1987; Dubois et al., 1991; Henly, 1992; Lickwar, 1989; Olsen et al., 1987). Costs associated with complying with forest practices in states where their implementation is either voluntary or regulated, with differing numbers and types of requirements depending on the state, have also been estimated (Table 2-2) (Ellefson et al., 1995).

Some cost information for forest practice implementation is based on the average increased cost of conducting a harvest when management measures, i.e., a suite of practices, are used versus when they are not used (Table 2-3). Costs provided in this way emphasize the difficulty in separating the costs of implementing individual forest practices. This difficulty is due to incorporating the cost of using numerous BMPs into the accomplishment of a single harvesting or road construction activity, and spreading the cost for individual practices across the accomplishment of multiple activities. For example, the cost of adhering to a state regulation for stream crossings might be spread among the costs of planning a harvest to minimize the number of stream crossings, designing and constructing forest roads to accommodate the plan and minimize instream effect to water quality and fish, and the actual construction of the stream crossings. Furthermore, these costs differ with each harvest because the terrain, soils, location of harvest site relative to streams, and hydrology are different at each harvest site. Therefore, all costs presented here are best regarded as rough estimates.

Table 2-2.   Estimations of Overall Cost of Compliance with State Forestry BMP Programs by Program Type

Applicability	Cost Estimation	Reference

Virginia and southeastern states (applicable to central and northern states)	Voluntary-to-mandatory implementation ($)
	  Coastal plain region: = $11.70 per acre
	  Piedmont region: = $30.40 per acre
	  Mountain region: = $44.50 per acre
	
	Stringent/Enforceable implementation ($)
	  Coastal plain region: = $21.40 per acre
	  Piedmont region: = $38.00 per acre
	  Mountain region: = $49.10 per acre
		Aust et al., 1996

California	Average cost = $250 per acre Inland areas = $81 - $414 per acre[a] Coastal areas = $460 per acre[a]	Henly, 1992
Oregon, Washington, Alaska	Average cost = $175 - $373 per acre Noncoastal areas = $175 per acre Coastal areas = $373 per acre	Ellefson et al., 1995 (Division between coastal and noncoastal based on California model)
Nevada, New Mexico, Idaho	Other western states with forest practice regulation. Cost per acre is estimated as the average of costs in western states without forest practice regulation and the low-end cost given for Oregon noncoastal forests: ($125 + $175)/2 = $150 per acre	
Arizona, Colorado, Montana, Utah, Wyoming, Hawaii	Western states without forest practice regulation. Cost per acre is estimated as one-half of California's noncoastal cost: $250/2 = $125 per acre	

Note: All costs in 1998 dollars.
[a] Excluding most costly scenario.

The costs of implementing state forest practices arise from conducting timber surveys, preparing management plans, constructing roads, and implementing practices specifically designed to protect water quality. Many of these costs are borne whether or not a stream or other surface water is located on or near a harvest site, though additional costs (e.g., designing and flagging an SMA, constructing stream crossings) are incurred where streams are present. Costs also take the form of lost revenue from trees that are not harvested to ensure compliance with forest practices. Revenue might be reduced if merchantable trees are left standing in SMAs or when selective cutting is called for rather than clear-cutting. Although the loss of revenue is a real "cost" to landowners, it is very market- and species-dependent and is generally not included in the cost estimates provided here. The overall costs of complying with regulatory forestry BMP programs might be borne by forest landowners alone or shared among landowners, timber operators, and others (Figure 2-1).

Factors that typically affect the cost of implementing forest practices include the type of terrain on which a harvest occurs (with costs for harvesting on steeper

Table 2-3.   Estimations of Implementation Costs by Management Measure in the Southeast and Midwest

Practice	Average Cost	Cost Range	Comments	Reference
Planning			Savings were associated with avoiding problem soils, wet areas, and unstable slopes. Maintenance savings resulted from revegetating cut and fill slopes, which reduced erosion. Southern states.	Dissmeyer and Foster, 1987
Savings from road design/ location	($385/mi)			
Savings in maintenance	($231/mi)			
SMA	$3,996		Costs for average tract size of 1,361 ac; include marking and foregone timber value. Southern states.	Lickwar, 1989
Road Construction		$5,301/mi - $42,393	Lower end for no gravel and few culverts; upper end for complete graveling and more culverts. West Virginia.	Kockenderfer and Wendel, 1980
		$14,801 -$42,393	Lower end for 1,832-ac forest with slopes <3%; upper end for 1,148-ac forest with slopes >9%. Southern states.	Lickwar, 1989
		$229/mi - $11,604/mi	Lower end for grass surfacing; upper end for large stone surfacing. Appalachia.	Swift, 1984
Construction Phase (as percent of total cost)		10% 20 - 25% 20 - 25% 10% 30 - 40%	Equipment and Material Clearing, grubbing, and slash disposal Excavation Culvert installation Rock surfacing	USDA-SCS, cited in Weaver and Hagans, 1994
Road Maintenance	$2,205-$3,941		Lower end for roads constructed without BMPs; upper end for roads constructed with BMPs. Costs over 20 years discounted at 4%.	Dissmeyer and Frandsen, 1988
Mechanical Site Preparation	$140/ac	$77/ac -$281/ac	Lower end for disking only; upper end for shear-rake-pile-disk. Southern states.	Dubois et al., 1991
		$75/ac -$180/ac	Lower end for light preparation, including hand; upper end for chemical-mechanical site preparation.	Minnesota, 1991
Regeneration		$84/ac - $355/ac	Lower end for direct seeding; upper end for tree planting with purchased planting stock.	Illinois, 1990
	$50/ac	$48/ac - $60/ac	Lower end for machine planting; upper end for hand planting. Southern states.	Dubois et al., 1991
Revegetation	$22,741		Cost for average sized tract of 1,361 ac; includes seed, fertilizer, mulch. Southern states.	Lickwar, 1989
		$132/ac - $239/ac	Lower end for introduced grasses; upper end for native grasses. Includes seedbed preparation, fertilizer, chemical application, seed, seedlings.	Minnesota, 1991
Prescribed burning	$13/ac	$10/ac - $19/ac	Lower end for windrow burning; upper end for burning after chemical site preparation. Southern states.	Dubois et al., 1991
Pesticide application	$102/ac	$56/ac - $138/ac	Lower end for ground application; upper end for aerial application. Southern states.	Dubois et al., 1991
Fertilizer application	$63/ac	$43/ac - $73/ac	Lower end for ground application; upper end for aerial application. Southern states.	Dubois et al., 1991

Note: All costs in 1998 dollars.

terrain typically being higher than costs for harvesting on flatter terrain) and the regulatory structure of forest practice rules. Compliance in states that have numerous and stringent forest practice regulatory requirements generally costs more than compliance in states where regulatory requirements are fewer or less stringent, or are voluntary. Some states have single regulations that can add significantly to the cost of forest harvesting. An example is the requirement for a detailed forest harvest plan in California. This alone places compliance with forest practices in California in a category by itself.

Table 2-2 summarizes estimations of the overall per-harvest cost of complying with forest practice regulations in different regions and states. Table 2-3 provides cost estimates for implementation of individual management measures in the Southeast and Midwest. The costs, updated to 1998 dollars, have been verified with state and federal forest management agencies and have been found to be representative of actual expenditures. Although most of the cost information came from case studies in the southeastern United States, they are representative of costs incurred nationwide. Costs vary depending on the site-specific nature of the timber harvesting area. Table 2-4 provides estimates of costs for installing individual road construction and erosion control BMPs. Costs are provided by region. Factors that affect implementation costs are mentioned in the *Comments* column.

Other costs, where available, are provided for individual management measures or BMPs within the appropriate discussions in Chapter 3.
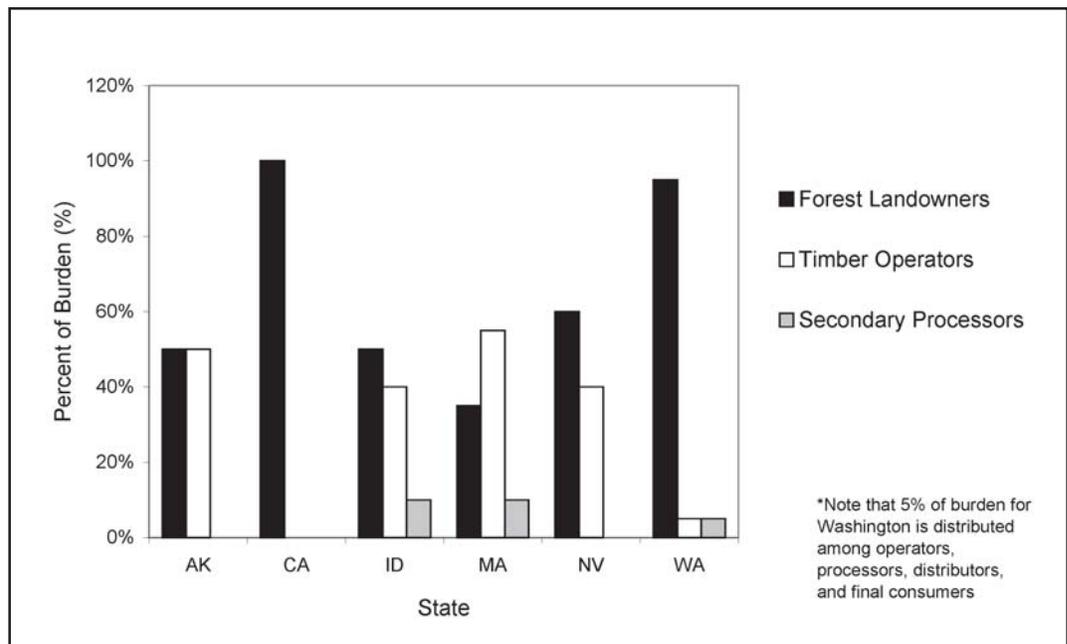
Figure 2-1. **Distribution of the cost of regulatory programs among different groups in representative states (Ellefson et al., 1995).**

Table 2-4. Estimations of Construction and Implementation Costs for Individual BMPs, by Region

BMP	Approximate Construction and Implementation Costs per BMP Installed, by Region							Comments
	Northeast[1]	Southeast[2]	Midwest[3]	Rocky Mountains[4]	Northwest[5]	Southwest[6]	Alaska[7]	
Broad-based dip		$40	$40 - $90	$50 - 60	$25 - 35	$100 - $130	$30 - $40	Depends on the cost of labor, equipment, and terrain (Northwest costs include profit and overhead).
Waterbar		$20 (not including labor)	$60 - $75 (on skid trails)	n/a	$100	$45 - $60	$25 - $35	Cost varies with size and construction material.
Mulch		$71 (ton)	$20 - $80 (ton)	n/a	$1,500(ac) (hydro-mulch)	$400 - $500 (ac)	$80 - $90 (ton)	Cost varies with regional market price and haul distance.
Seed	$1,000 (ac) (hydro-seed)	$1 - $6 (lb)	$0.50 - $10 (lb)	$6 (lb)	$400 - $450 (ac)	$200 - $400 (ac)	$7 - $10 (lb)	Cost varies with species of seed, regional market price, and terrain.
Riprap		n/a	$5 - $10 (yd^3)	$21 (yd^3)	$15 - $30 (yd^3)	n/a	$19 - $37 (yd^3)	Price varies with size of rock used.
Gravel		$6 - $10 (ton)		$35,000-$40,000 (mile, 14' W x 4" D)	$16 - $26 (yd^3)	$30 (yd^3)	$18 - $22 (yd^3)	Cost varies with the size of rock and haul distance.
Culvert		$420	$500 - $2,000	$19 (ft, 18" pipe)	$26 (ft, 24" pipe) $100 (ft, 72" pipe)	$24 (ft, 18" pipe)	$23 (ft, 18" pipe)	Cost varies with size and length of culvert. Costs provided reflect base cost for installation.
Straw Matting		$56 (roll, 7.5' x 120')		n/a	$2 (yd^2)	$1 - $3 (yd^2)	$2.50 (yd^2)	Cost varies with size of matting.
Geotextiles		$378 (700 yd^2)	$2 - $6 (ft)	$8 - $12 (ft)	$1 - $2 (ft)	n/a	$14 (ft)	Woven geotextiles are the only geotextile recommended for road-stream crossings.
Hardwood Mats (pallets)	$120 - $200	$120 - $200	$170 (10' x 12')	$120 - $200	$120 - $200	$120 - 200	$155 (10' x 12')	Cost varies with size.
Turn-outs	$40 - $50	$50 - $70	$50 - $70	$50	$50	$40 - $50	$71	Cost varies with equipment and labor costs.
Silt Fence		$24 (24" H x 100' L)	not commonly used	not commonly used	$1.50 (yd^2)	$4 (ft)	$2 (yd^2)	Cost varies with regional prices and length.
Dust Control	$1,000 (mile, using calcium chloride)				$1,000 - $3,000 (mile, annually)	$190 (ton)		Varies widely with traffic level.
Temporary Bridge		$500 - $20,000	$500 - $15,000	$200 - $25,000	$1,000 - $2,000 (ft)	n/a	$1,250 - $2,500 (ft)	Cost varies widely with quality of materials used, width, and span.
Barge (Alaska)	–	–	–	–	–	–	$1,000 (hr)	Barge transport in southeastern Alaska (Tongass Natl. Forest) is the most common means to deliver material to a site.

Note: All costs are per unit provided (ac = acre; ft = linear foot; hr = hour; lb = pound; yd^2 = square yard; yd^3 = cubic yard; D = depth; H = height; L = length; W = width).
Where units are not provided, cost is per BMP installed.
[1] Schmid, 2000
[2] Holburg, 2000; Marzac, 2000
[3] Hansit, 2000; Gambles, 2000
[4] Taylor, 2000
[5] Dorn, 2000; Hulet, 2000; Wilbrecht, 2000; Yoder, 2000
[6] Leyba, 2000
[7] Jenson, 2000

CHAPTER 3: MANAGEMENT MEASURES

Scope of This Chapter

For the purposes of this guidance, EPA has addressed the activities associated with forestry activities that could affect water quality through nine management measures. A separate management measure is applicable specifically to forested wetlands. The management measures are stated as steps to be taken, guidelines for operations, or goals to be achieved for protecting water quality during the related phases or activities. The following are EPA's forestry management measures:

- Preharvest planning
- Streamside management areas
- Road construction/reconstruction
- Road management
- Timber harvesting
- Site preparation and forest regeneration
- Fire management
- Revegetation of disturbed areas
- Forest chemical management
- Wetland forest management

Numerous BMPs are associated with each management measure. BMPs are specific actions, processes, or technologies that can be used to achieve a management measure. These BMPs are very similar to those recommended by most states. Because of the national scope of this guidance, however, some of the particulars of implementation (such as prescriptions for sizes of pipes, lengths of road at particular slopes, and other such site- or region-specific details) are not included as part of the descriptions of BMPs. Implementation of one or more BMPs is usually necessary to achieve the level of pollution control intended by a single management measure.

Each management measure is addressed in a separate section of this chapter. Each section contains the wording of the management measure, which has not been changed from that in the 1993 CZARA guidance; a description of the management measure's purpose or how it can be used effectively to protect water quality; and information on BMPs that are suitable, either alone or in combination with other BMPs, to achieve the management measure. Where new or improved versions of BMPs have been developed, they are discussed in this guidance. Many of the BMPs were in the 1993 CZARA guidance, and most can be found in state forest practices manuals. For recommendations on widths of streamside management areas, slopes and lengths of culverts, and other criteria for your specific area, consult a state forest practices manual or contact your local forester.

Since the forestry management measures developed for CZARA are for the most part a system of BMPs commonly used and recommended by states and the U.S. Forest Service, many BMPs are already being implemented at many harvest sites and on many forest roads. Where the BMPs in place are inadequate to protect water quality, augmenting them with additional or complementary BMPs might be all that is necessary. Where measures are lacking and water quality is or might become impaired, this guidance can assist in the choice of BMPs suitable to the source of water quality impairment.

Management Measure Effectiveness

States have used a number of approaches for assessing the effectiveness of management measures and BMPs. Florida and South Carolina have assessed their effectiveness using bioassessment techniques and stream habitat assessment. Florida has compared sites adjacent to harvests with non-logged reference sites, and South Carolina has also compared sites upstream from harvests to those downstream from harvests and conditions at the same site before harvests to those after harvests. Maine and Virginia have placed in-stream water quality samplers in streams near forest harvest operations. South Carolina and Washington have used a weight-of-evidence approach, in which a variety of different assessment approaches are used and the conclusion about effectiveness arrived at most by the different approaches is accepted as the overall conclusion. South Carolina has concluded from its weight-of-evidence assessments that on sites with perennial streams, BMP compliance checks, stream habitat assessment, and benthic macroinvertebrate assessments can be used effectively to assess BMP effectiveness.

All of the approaches have produced valuable information about BMP effectiveness. The conclusions from these studies are many:

- BMP assessment monitoring is important for determining that the standards for design and implementation of BMPs are appropriate for the soils and topography where they are to be used.

- One or more BMP assessment approaches, including BMP compliance and an in-stream habitat or macroinvertebrate approach, can help determine whether BMP implementation standards are adequate.

- Once adequate implementation standards have been developed, rigorous BMP compliance checks generally suffice as an indicator of BMP effectiveness. The compliance checks are used to verify that BMPs are being installed properly and in a timely manner, and that they are maintained adequately.

- It is important to assess the effectiveness of BMPs under a variety of site conditions and to tailor implementation standards to different types of soils, slopes, and regional site characteristics if the BMPs are to be effectively applied.

- Application of BMPs per implementation standards during forest harvesting protects water quality in adjacent streams. BMPs protect stream ecology and stream temperature, and they prevent sedimentation.

- When BMPs are not properly applied, they do not adequately protect water quality. Improperly applied BMPs can result in stream sedimentation, changes in stream morphology, increased average water temperatures, wider water temperature fluctuations, and changes to stream ecology.

- Many water quality problems that arise from forest harvesting are associated with improperly applied BMPs or not having used BMPs. The most frequently misapplied or missing BMPs are those for road surface drainage control, erosion control prior to the harvest, stream crossings, and SMAs.

- Some states do not adequately address some water quality problems associated with forest harvesting. BMPs for ephemeral drainages need to be developed and the circumstances under which ephemeral drainages require BMPs needs to be determined. Ephemeral drainages can produce or deliver large quantities of sediment to other streams if left unprotected after a harvest.

- The most important BMPs for protecting stream water quality are properly sized SMAs, properly designed BMPs for erosion control implemented prior to the commencement of road construction and harvesting, properly designed stream crossings, and comprehensive preharvest plans.

Examples of Management Measure Effectiveness

Examples of how BMPs can operate as a system to control nonpoint source pollution are given in a paper that summarizes a national effort by USDA's Forest Service to develop analysis procedures for estimating the economic benefits of soil and water resource management (Dissmeyer and Foster, 1990). The paper focuses on benefits in five areas—timber, forage, fish, enhanced water quality, and road construction and maintenance. The benefits noted from the use of resource management systems are expressed as increased timber production, increased forage on the harvest site, and benefits to other resources from improved soil and water resource management. The following are the examples of the proper implementation of resource management systems provided in Dissmeyer and Foster (1990) and Dissmeyer and Frandsen (1988). Each example begins with a hypothetical situation and then describes how BMPs apply to the situation.

Example 1 focuses on soil and water resource management in road construction and maintenance. In this example, a main haul road is built across problem soils, cutbanks yield excessive surface runoff and erode easily, the runoff volume from the site is sufficient to erode through the road surface and road subgrade, road maintenance (without BMPs installed) is needed every 3 years, and the road is assumed to be used for 20 years. Applying a resource management system to this situation, the following solution was devised: construct the road with midslope terraces in the cutbanks; install water diversions above the cutbanks; and seed, fertilize, and mulch the cutbanks. The total estimated repair costs over 20 years were calculated at $2,137 for materials, labor, and cost of technical assistance. The one-time installation of BMPs, which would eliminate the need for maintenance every 3 years, would cost $1,200. The resulting net present value, or economic benefit to the property owner, of installing the BMPs in this example was calculated as $937 (all cost figures in 1990 dollars).

Example 2 relates to recouping timber growth and yield losses through skid trail rehabilitation. Skid trails and skid roads in harvest areas are areas where sediment is lost, and as a result the timber yield in primary skid trails and on skid roads is in general severely reduced. Soils in skid trails can become severely compacted, limiting water infiltration and thus soil moisture availability and tree root development. Finally, soil nutrients are removed during skidding and during road construction. A resource management system solution to this problem involves using the following BMPs: ripping and tilling the soil,

waterbarring, seeding, fertilizing, and mulching. Using these practices as a system, the net present value of timber volume recovered (based on estimations provided in published studies) would be $210 per acre based on a harvest of shortleaf pine stands and $237 per acre in hardwood stands. Note that the economic returns are positive in high-value shortleaf pine stands and negative in low-value hardwood stands. The study notes, however, that the herbaceous growth from applying a system of resource BMPs in hardwood stands would have positive value for hunting and environmental protection.

Example 3 relates to the effect of site preparation, which can affect sediment production, soil productivity, and timber growth and yields. Poor site preparation practices that compact the soil, remove litter, and remove nutrients adversely affect soil productivity and sediment retention. The study, based on modeling data from independent studies of BMPs used for site preparation, found that site preparation results in economic benefits. Specifically, investing $50 *more* per acre in preparing a site with shearing and windrowing *reduced* future maintenance costs by $129 per acre, compared to chopping and burning.

These examples highlight the economic and ecological advantages of using management measures and BMPs as a system to reduce effects on surface waters and to ensure more rapid site regeneration and healthier timber stands.

3A: PREHARVEST PLANNING

Management Measure for Preharvest Planning

Perform advance planning for forest harvesting that includes the following elements where appropriate:

(1) Identify the area to be harvested including location of water bodies and sensitive areas such as wetlands, threatened or endangered aquatic species habitat areas, or high-erosion-hazard areas (landslide-prone areas) within the harvest unit.

(2) Clearly mark these sensitive areas with paint or flagging tape, or in another highly visible manner, prior to harvest or road construction.

(3) Time the activity for the season or moisture conditions when the least effect occurs.

(4) Consider potential water quality effects and erosion and sedimentation control in the selection of silvicultural and regeneration systems, especially for harvesting and site preparation.

(5) Reduce the risk of occurrence of landslides and severe erosion by identifying high-erosion-hazard areas and avoiding harvesting in such areas to the extent practicable.

(6) Consider additional contributions from harvesting or roads to any known existing water quality impairments or problems in watersheds of concern.

Perform advance planning for forest road systems that includes the following elements where appropriate:

(1) Locate and design road systems to minimize, to the extent practicable, potential sediment generation and delivery to surface waters. Key components are:
  - locate roads, landings, and skid trails to avoid to the extent practicable steep grades and steep hillslope areas, and to decrease the number of stream crossings;
  - avoid to the extent practicable locating new roads and landings in Streamside Management Areas (SMAs); and
  - determine road usage and select the appropriate road standard.

(2) Locate and design temporary and permanent stream crossings to prevent failure and control effects from the road system. Key components are:
  - size and site crossing structures to prevent failure;
  - for fish-bearing streams, design crossings to facilitate fish passage.

(3) Ensure that the design of road prism and the road surface drainage are appropriate to the terrain and that road surface design is consistent with the road drainage structures.

(4) Identify and plan to use road surfacing materials suitable to the intended vehicle use for roads that are planned for all-weather use.

(5) Design road systems to avoid high erosion or landslide hazard areas. Identify these areas and consult a qualified specialist for design of any roads that must be constructed through these areas.

Each state should develop a process (or utilize an existing process) that ensures that the management measures in this chapter are implemented. Such a process should include appropriate notification, compliance audits, or other mechanisms for forestry activities with the potential for significant adverse nonpoint source effects based on the type and size of operation and the presence of stream crossings or SMAs.

Management Measure Description

The objective of this management measure is to ensure that forestry activities, including timber harvesting, site preparation, and associated road construction, are planned with water quality considerations in mind and conducted without significant nonpoint source pollutant delivery to streams or other surface waters. Road system planning is an essential part of this management measure because road construction is the main soil destabilizing activity carried out in forestry, and avoidance is the most cost-effective means of dealing with unstable terrain (Weaver and Hagans, 1994).

A basic tenet of road planning is to minimize the number of road miles constructed in a watershed through basin-wide planning. A second tenet is to locate roads to minimize the risk of water quality impacts. Good road location and design can greatly reduce the sources and transport of sediment. Road systems can be designed to minimize the length and surface area of roads and skid trails, the size and number of landings, and the number of stream crossings, and to locate all of these road system elements as far from surface waters as feasible. Minimizing stream crossings is especially important in sensitive watersheds.

Preharvest planning includes consideration of the potential water quality and habitat effects of the component parts of the harvest, including the harvesting system (e.g., clear-cut or selective cut); the yarding system (e.g., skyline cable or ground skidding); the road system; and postharvest activities such as site preparation. Water quality considerations can most effectively be incorporated into preharvest planning by determining which pollutants are likely to be generated during each of the phases of the harvest and how best to ensure that they are kept out of surface waters. Reviewing Section 2 can help with the task of identifying the pollutants, and Section 3 provides information on the BMPs that will minimize their entry into surface waters.

The water quality effects of yarding can be reduced with thoughtful preharvest planning. Yarding done with ground skidding equipment can cause much more soil disturbance than cable yarding. McMinn (1984) compared a skidder logging system and a cable yarder for their relative effects on soil disturbance (Table 3-1). With the cable yarder, 99 percent of the soil remained undisturbed (the original litter still covered the mineral soil), whereas the amount of soil remaining undisturbed after logging by skidder was only 63 percent. Whether cable yarding, ground skidding, or skyline yarding is best for the particular harvest is based on whether the stand is even-aged or uneven-aged, the terrain, cost, and other factors. Among these other factors should be the need and means to protect water quality.

Table 3-1.   Comparison of the Effect of Conventional Logging System and Cable Miniyarder on Soil in Georgia (McMinn, 1964)

Disturbance Class[a]	Cable Skidder	Miniyarder
Undisturbed	63%	99%
Soil exposed	12%	1%
Soil disturbed	25%	0%

[a] Undisturbed = original duff or litter still covering the mineral soil.
   Exposed = litter and duff scraped away, exposing mineral soil, but no scarification.
   Disturbed = Mineral soil exposed and scarified or dislocated.

Preharvest planning is the time to consider how harvested areas are to be replanted or regenerated to prevent erosion and effects on water bodies after the harvest has occurred. At the same time, it is important to consider other activities that have occurred recently, will coincide with the harvesting, or are scheduled to occur in the watershed where harvesting is to take place, as well as the overall soil, habitat, and water quality conditions of the watershed. Other activities within the watershed that can also stress water systems include land use changes from forest to agriculture, residential development or other construction, and applications of pesticides or herbicides. Cumulative effects on soils, water quality, and habitats from other activities and the proposed forest practices can result in excessive erosion and pollutant transport, and detrimental receiving water effects (Sidle, 1989). Cumulative effects are influenced by forest management activities, natural ecosystem processes, and the distribution of other land uses within a watershed. Forestry operations such as timber harvesting, road construction, and chemical use can increase runoff of nonpoint source pollutants and thereby contribute to preexisting impairments to water quality.

A previously completed cumulative assessment might exist for the area to be harvested, in which case it can be determined whether water quality problems, if any, in the watershed are attributable to the types of pollutants that might be generated by the planned forestry activity. If more pollutants of the same types are likely to be generated as a result of the harvesting activity, adjustments to the harvest plan or use of management practices beyond those normally used might be necessary. For instance, consider selecting harvest units with low sedimentation risk, such as flat ridges or broad valleys; postponing harvesting until existing erosion sources are stabilized; or selecting limited harvest areas using existing roads. The need for additional measures, as well as the appropriate type and extent, is best considered and addressed during the preharvest planning process.

During preharvest planning, it is also particularly important to plan implementation of management practices to be used to control sediment delivery from sources that are characteristically erosion-prone and lead to water quality impairment at stream crossings, landings, road fills on steep slopes, road drainage structures, and roads located close to streams. Constructing roads through high-erosion-hazard areas can lead to serious water quality degradation and should be avoided when possible. Some geographical areas (e.g., the Pacific coast states) tend to have more serious erosion problems (landslides, major gullies, etc.) after road construction than other areas. Factors such as climate, slope steepness, soil and rock characteristics, and local hydrology influence this potential. A person trained to recognize high-erosion hazard areas should be involved with preharvest planning.

Erosion hazard areas are often mapped by public agencies, and these maps are one tool to use in identifying high-erosion-hazard sites. The U.S. Geological Survey has produced geologic hazard maps for some areas. The USDA Natural Resources Conservation Service (NRCS) and Agricultural Farm Service Agency (FSA), as well as state and local agencies, might also have erosion-hazard-area maps.

Benefits of Preharvest Planning

The Virginia Department of Forestry found that preharvest planning is one of the three BMPs that are crucial to water quality protection. The other two are the establishment and use of streamside management areas (SMAs) and properly designed and constructed

stream crossings. Although all BMPs are considered to be important, these three were found to be the most important to preventing water quality degradation.

In a study conducted by Black and Clark (no date), sediment concentrations were compared from stream waters in an unlogged watershed, a watershed where a harvesting operation with thorough preharvest planning had been conducted, and a watershed where a harvesting operation with no preharvest planning had been conducted. Sediment concentrations in the water from the unlogged watershed averaged 4 parts per million (ppm), those in the water from the watershed with the planned logging operation averaged 5 ppm, and those from the watershed with the unplanned harvest averaged 31 ppm (Figure 3-1). Preharvest planning in this study took into consideration road siting and construction techniques, landing siting, yarding techniques, and other BMPs intended to minimize erosion and sediment loss.

Of course, BMPs are effective only when properly designed, constructed, implemented, and maintained. Too often, BMPs are not installed early enough in the process to effectively control nonpoint source pollution, or they are not maintained properly, which can lead to their failure and to sedimentation or other forms of pollution. In general, poor BMP effectiveness can be attributed to one or more of the following:

- A lack of time or willingness to plan timber harvests carefully before cutting begins.
- A lack of skill in or knowledge of designing effective BMPs.
- A lack of equipment needed to implement effective BMPs.
- The belief that BMPs are not an integral part of the timber harvesting process and can be engineered and fitted to a logging site after timber harvesting has been completed.
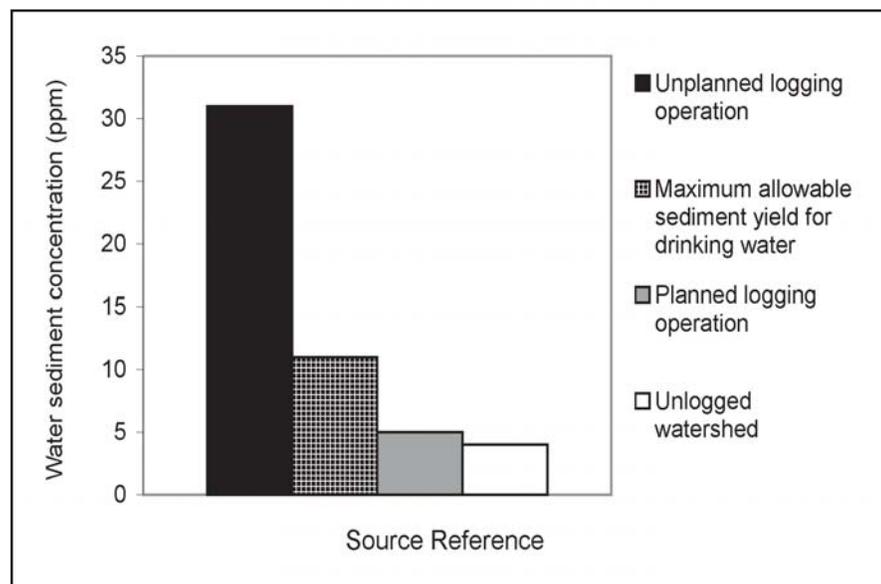
Figure 3-1.   Comparison of sediment concentrations in runoff from various forest conditions to drinking water standard (after Black and Clark, nd).

Best Management Practices

Harvest Planning Practices

◆ *Use topographic maps, aerial photographs, soil surveys, geologic maps, and seasonal precipitation information—as slow long duration precipitation can be as limiting as high intensity short duration rainfall—to augment site reconnaissance to lay out and map harvest units. Identify and mark, as appropriate:*

- Sensitive habitats that need special protection, such as threatened and endangered species nesting areas.
- Streamside management areas.
- Steep slopes, high-erosion-hazard areas, and landslide-prone areas.
- Wetlands.

◆ *In warmer regions, schedule harvest and construction operations during dry periods or seasons. Where weather permits, schedule harvest and construction operations during the winter to take advantage of snow cover and frozen ground conditions.*

◆ *Consider potential water quality and habitat effects when selecting the silvicultural system as even-aged (clear-cut, seed tree, or shelterwood) or uneven-aged (group or individual selection). The yarding system, site preparation method, and any pesticides that will be used can also be considered during preharvest planning. As part of this practice, consider the potential effects from and extent of roads needed for each silvicultural system.*

◆ *In high-erosion-hazard areas, trained specialists (geologist, soil scientist, geotechnical engineer, wild land hydrologist) can identify sites that have high risk of landslides or that might become unstable after harvest. These specialists can recommend specific practices to reduce the likelihood of erosion hazards and protect water quality.*

◆ *Determine what other harvesting activities, chemical applications, or other potentially polluting activities are scheduled to occur in the watershed and, where appropriate, conduct the harvest at a time and in such a manner as to minimize potential cumulative effects.*

Road System Planning Practices

Road Location Practices

◆ *Preplan skid trail and landing locations on stable soils and avoid steep gradients, landslide-prone areas, high-erosion-hazard areas, and poor-drainage areas.*

- Plan to minimize roads, stream crossings, landings, skid trails, and activities on unstable soils and steep slopes.
- Locate landings outside of SMAs and ephemeral drainage areas.
- Locate new roads and skid trails outside of SMAs, except where necessary to cross drainages.

- • Locate roads away from stream channels where road fill extends within 50 to 100 horizontal feet of the annual high water level. (Bankfull stage is also used as a reference point for this.)

◆ *Systematically design transportation systems to minimize total mileage.*

- • Compare layouts for roads, skid trails, landings, and yarding plans, and determine which will result in the least soil disturbance and erosion.

- • Locate landings to minimize skid trail and haul road mileage and disturbance of unstable soils.

◆ *Identify areas that would need the least modification for use as log landings and use them to reduce the potential for soil disturbance. Avoid using areas, such as ephemeral drainages, that could contribute considerably to nonpoint source pollution if high precipitation occurs during the harvest. Use topographic maps and aerial photographs to locate these areas.*

◆ *Plot feasible routes and locations on aerial photographs or topographic maps to assist in the final determination of road locations. Compare the possible road location on-the-ground and proof the layout to ensure that the road follows the contours. Design roads and skid trails to follow the natural topography and contour, minimizing alteration of natural features.*

Proper design can reduce the area of soil exposed by construction activities. Figure 3-2 presents a comparison of road systems. Following the natural topography and contours can reduce the amount of cut and fill needed and consequently reduce both road failure potential and cost. Ridge routes and hillside routes are good locations for ensuring stream protection because they are removed from stream channels and the intervening undisturbed vegetation acts as a sediment barrier. Wide valley bottoms are good routes if stream crossings are few and roads are located outside SMAs.

◆ *Plan the management of existing and future roads and road systems to minimize environmental problems arising from them.*

Roads analysis is an integrated ecological, social, and economic approach to transportation planning addressing both existing and future road systems. The U.S. Forest Service's Roads Analysis procedure, developed by a team of Forest Service scientists and managers, is designed to help national forest managers bring their road systems into balance with current social, economic, and environmental needs. The top priority is to provide road systems that are safe for the public, responsive to public needs, environmentally sound, affordable, and efficient to manage. A roads analysis provides scientific information used to inform decision makers about effects, consequences, options, priorities, and other factors. This information is essential to plan efficiently and manage the forest transportation crisis. The iterative procedure for conducting the roads analysis consists of six steps aimed at producing needed information and maps (USDA Forest Service, 1999):

- • **Step 1**: Set up the analysis. The analysis is designed to produce an overview of the road system. An interdisciplinary team develops a list of information needs and a plan for the analysis.

- • **Step 2**: Describe the situation. The interdisciplinary team describes the existing road system in relation to current forest management plans. Products from this step include a map of the existing road system, descriptions of access needs, and

Plans A, B, and C show three ways to place truck and skid roads on a cutting unit. The comments next to each plan indicate why Plan C is best.

Plan A layout: 2 bridges
                 4 landings
                 3 miles of haul road

Comment: Road and bridge construction costs too high. Skid distance too short. Too much steep downhill skidding. Too many landings on too steep land. Two bridges are unnecessary.

Plan B layout: 1 bridge
                 3 landings
                 3.5 miles of haul road

Comment: Loop road unnecessary. Skid distances too short. Erosion minimized up hill skidding.

Plan C layout: 1 bridge
                 2 landings
                 2 miles of haul road

Comment: Haul road follows high ground. Minimal road construction. Ideal skidding distances. Erosion minimized by uphill skidding. Least number of landings. Only one bridge required.

Figure 3-2.   An example of laying out sample road systems for comparison purposes (Hynson et al., 1982).

information about physical, biological, social, cultural, economic, and political conditions associated with the road system.

- **Step 3**: Identify issues. The interdisciplinary team, in conjunction with the public, identifies important road-related issues and the information needed to address them. The interdisciplinary team also determines data needs associated with analyzing the road system in the context of the important issues, for both existing and future roads. The output from this step includes a summary of key road-related issues, a list of screening questions to evaluate them, a description of the status of relevant available data, and a list of additional data needed to conduct the analysis.

- **Step 4**: Assess benefits, problems, and risks. After identifying the important issues and associated analytical questions, the interdisciplinary team systematically examines the major uses and effects of the road system, including the environmental, social, and economic effects of the existing road system and the values and sensitivities associated with unroaded areas. The output from this step is a synthesis of the benefits, problems, and risks of the current road system and the risks and benefits of building roads into unroaded areas.

- **Step 5**: Describe opportunities and set priorities. The interdisciplinary team identifies management opportunities, establishes priorities, and formulates technical recommendations that respond to the issues and effects. The output from this step includes a map and a descriptive ranking of management options and technical recommendations.

- **Step 6**: Report. The interdisciplinary team then produces a report and maps that portray management opportunities and provide supporting information important for making decisions about the future characteristics of the road system. This information sets the context for the development of proposed actions to improve the road system and for future amendment and revision of forest plans.

◆ *Consider using or upgrading existing roads to minimize the total amount of road construction necessary whenever practical and when less adverse environmental impact would be caused.*

Existing roads should be used where they are in good condition or can be feasibly up-graded, unless using the roads would cause more water quality impacts than building a new road elsewhere (Weaver and Hagans, 1994). When an existing road is available on the side of a drainage opposite the harvest site, consider using it instead of constructing a new road to minimize the amount of soil disturbance due to new road construction. Avoid using existing or previously-used roads, however, if they are likely to create water quality problems, such as if they were constructed next to streams in valleys.

Road Design Practices

◆ *In moderately sloping terrain, plan for road grades of less than 10 percent, with an optimal grade of between 3 percent and 5 percent. In steep terrain, short sections of road at steeper grades can be used if the grade is broken at regular intervals. On steep grades, vary road grades frequently to reduce culvert and road drainage ditch flows, road surface erosion, and concentrated culvert discharges.*

Gentle grades are desirable for proper drainage and economical construction. Steeper grades are acceptable for short distances (200-300 feet), but an increased number of drainage structures might be needed above, on, and below the steeper grade to reduce runoff potential and minimize erosion. Heavy traffic on steep grades can result in surface rutting that renders crowning, outsloping, and insloping ineffective. On sloping terrain, no-grade road sections are difficult to drain properly and are best avoided when possible.

◆ *Design skid trail grades to be 15 percent or less, with steeper grades only for short distances.*

◆ *In designing roads for steep terrain, avoid the use of switchbacks through the use of more favorable locations. Avoid stacking roads above one another in steep terrain by using longer span cable harvest techniques.*

◆ *Avoid locating roads where they will need fills on slopes greater than 60 percent. When necessary to construct roads across slopes that exceed the angle of repose, use full-bench construction and/or engineered bin walls or other stabilizing techniques.*

◆ *Plan to use full-bench construction and remove fill material to a suitable location where constructing road prisms on side slopes greater than 60 percent.*

◆ *Design cut-and-fill slopes to be at stable angles, or less than the normal angle of repose, to minimize erosion and slope failure potential.*

The degree of steepness that can be obtained is determined by the stability of the soil. Figure 3-3 presents recommended stable backslope and fill slope angles for different soil materials.

• Use retaining walls, with properly designed drainage, to reduce and contain excavation and embankment quantities. Vertical banks can be used without retaining walls if the soil is stable and water control structures are adequate.

• Balance excavation and embankments to minimize the need for supplemental building material and to maximize road stability.

• Avoid the use of road fills at drainage crossings as water impoundments unless they have been designed as an earthfill dam (in which case they might be subject to section 404 requirements). These earthfill embankments need outlet controls to allow draining prior to runoff periods and a design that permits flood flows to pass.

◆ *Try to avoid springs wherever possible. However, where they must be crossed, provide drainage structures for springs that flow to roads and that flow continuously for longer than 1 month, rather than allowing road ditches to carry the flow to a drainage culvert.*

Avoiding springs will limit disruptions to the natural hydrology of an area and limit the extent to which roads can become integrated into an area's drainage system. Unmanaged springs can compromise sections of roads and contribute to erosion and sedimentation.
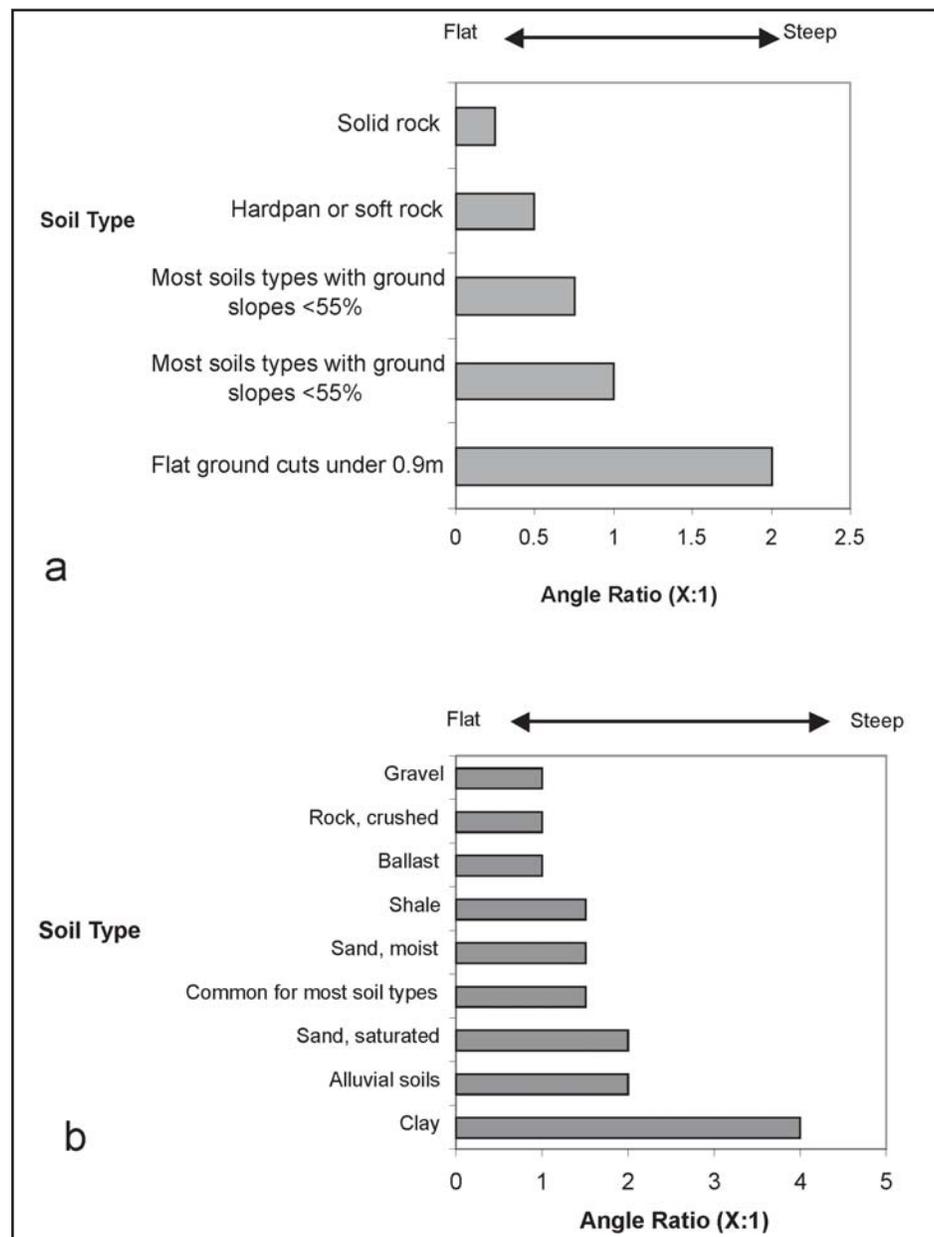
Figure 3-3.   Maximum recommended stable angles for (a) backslopes and (b) fill slopes (after Rothwell, 1978).

◆ *Design roads crossing low-lying areas so that water does not pond on the upslope side of the road.*

- Use overlay construction techniques with suitable nonhazardous materials for roads crossing muskegs.

- Provide cross drains at short intervals to ensure free drainage and avoid ponding, especially in sloping areas.

- Provide adequate cross drainage to maintain natural dispersed hydrologic flows through wet areas.

◆ *Plan water source developments, used for wetting and compacting roadbeds and surfaces, to prevent channel bank and stream bed effects.*

◆ *Design access roads such that they do not provide sediment to the water source.*

Road Surfacing Practices

◆ *Select a road surface material suitable for the intended road use and likelihood of water quality effects.*

The volume and composition of traffic, the desired service life, and the stability and strength of the road foundation (subgrade) material will determine the type of road surfacing needed. Roads that are closer to streams or other surface waters should be considered for a durable, non-erosive surface.

◆ *Where grades increase the potential for surface erosion, design roads with a surface of gravel, grass, wood chips, or crushed rocks.*

◆ *Where a road is to be surfaced, select an appropriately sized aggregate, appropriate percentage of fines, and suitable particle hardness to protect road surfaces from rutting and erosion under heavy truck traffic during wet periods.*

When a road is to be used for only a short time period, consider not surfacing it, and closing it and returning the surface to natural vegetation after use.

Road Stream Crossing Practices

◆ *Lay out roads, skid trails, and harvest units to minimize the number of stream crossings.*

◆ *Design and site stream crossings to cross drainages perpendicular to the streamflow. Design road segments with water turn-outs and broad-based dips to minimize runoff directly entering the stream at the crossing.*

◆ *Locate stream crossings to avoid channel changes and minimize the amount of excavation or fill needed at the crossing. Apply the following criteria to determine the locations of stream crossings:*

- Construct crossings at locations where the streambed has a straight and uniform profile above, at, and below the crossing.

- Locate the crossing so the stream and road alignment are straight in all four directions.

- Cross where the stream is relatively narrow with low banks and firm, rocky soil.

- Avoid deeply cut streambanks and soft, muddy soil.

◆ *Choose stream-crossing structures (bridges, culverts, or fords) with the structural capacity to safely handle expected vehicle loads with the least disturbance to the watercourse.*

◆ *Design culverts and bridges for minimal effect on water quality. Install culverts of a size that is appropriate to pass a design storm. Opening size varies depending on climate, the drainage area upstream of where the stream-crossing structure is to be placed, and the likelihood of plugging with debris.*

Consider the following guidelines for culvert sizing, but consult the state forestry agency and local hydrologists: a 50-year design storm for small diameter culverts and a 100-year design storm for large diameter culverts and bridges. Bridges or arch culverts, which retain the natural stream bottom and slope, are preferred over pipe culverts for streams used for fish migrating or spawning areas (Figure 3-4). The FishXing Web site (http://www.stream.fs.fed.us/fishxing/index.html) provides software and learning systems for fish passage through culverts.

Figure 3-4.   Alternative water crossing structures (Ontario Ministry of Natural Resources, 1988).
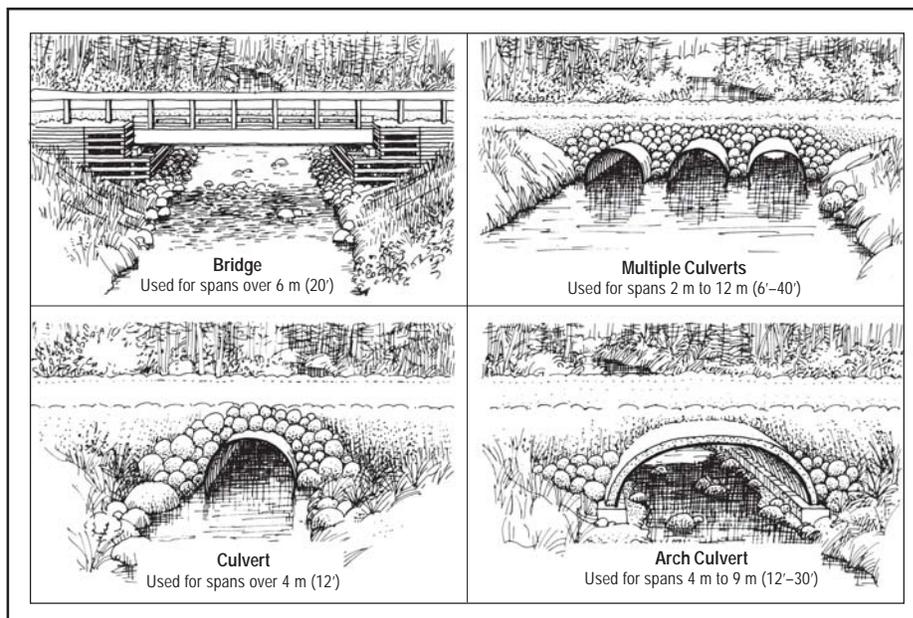
◆ *The use of fords is best limited to areas where the stream bed has a firm rock or gravel bottom (or where the bottom has been armored with stable material), where the approaches are both low and stable enough to support traffic, where fish are not present during low flow, and where the water depth is no more than 3 feet.*

◆ *Design small stream crossings on temporary roads using temporary bridges.*

Temporary bridges usually consist of logs bound together and suspended above the stream, with no part in contact with the stream itself. This prevents stream bank erosion, disturbance of stream bottoms, and excessive turbidity. Provide additional capacity to accommodate debris loading that might lodge in the structure opening and reduce its capacity.

Scheduling Practices

◆ *Plan road construction or improvement to allow sufficient time afterward for disturbed soil and fill material to stabilize prior to use of the road.*

Compact and stabilize roads prior to use. This reduces the amount of maintenance needed during and after harvesting activities.

◆ *To minimize soil disturbance and road damage, plan to suspend operations when soils are highly saturated. This will reduce sediment runoff potential and creation of ruts in the haul road, landings, skid trails, and loading areas, which in turn will prevent possible damage to vehicles. Damage to forested slopes can also be minimized by not operating logging equipment when soils are wet, during wet weather, or when the ground is thawing.*

Preharvest Notification Practices

◆ *Encourage timberland owners and harvesters to submit a preharvest plan to the state for review prior to performing any road work or harvesting.*

States are encouraged to adopt notification mechanisms for harvest planning that integrate and avoid duplicating existing requirements or recommendations for notification, including severance taxes, stream crossing permits, erosion control permits, labor permits, forest practice acts, plans, and so forth. For example, states might recommend that a preharvest plan be submitted by the landowner to a single state or local office. The appropriate state agency might encourage forest landowners to develop a preharvest plan. The plan would address the components of this management measure, including the area to be harvested, any forest roads to be constructed, and the timing of the activity.

Many states currently use some process to ensure implementation of management practices. These processes are typically related to the planning phase of forestry operations and commonly involve some type of notification process. Some states have one or more processes in place that serve as notification mechanisms used to ensure implementation. These state processes are usually associated with forest practices acts, erosion control acts, state dredge and fill or CWA section 404 requirements, timber tax requirements, or state and federal incentive and cost share programs. Some state education and training programs are discussed in Section 2.

It is suggested that notification be encouraged prior to:

- Timber harvesting or commercial timber cutting.
- Road construction or road improvement.
- Stream crossing construction or any work within 50 feet of a watercourse or water body.
- Reforestation.
- Pesticide, herbicide, or fertilizer applications.
- Any work in a wetland.
- Conversion of forestland to a non-forest use.

3B: STREAMSIDE MANAGEMENT AREAS

Management Measure for Streamside Management Areas

Establish and maintain a streamside management area along surface waters, which is sufficiently wide and which includes a sufficient number of canopy species to buffer against detrimental changes in the temperature regime of the water body, to provide bank stability, and to withstand wind damage. Manage the SMA in such a way as to protect against soil disturbance in the SMA and delivery to the stream of sediments and nutrients generated by forestry activities, including harvesting. Manage the SMA canopy species to provide a sustainable source of large woody debris needed for in-stream channel structure and aquatic species habitat.

Management Measure Description

Streamside management areas (SMAs), also commonly referred to as streamside management zones or riparian management areas or zones, are areas of riparian vegetation along streams that receive special management attention because of their value in protecting water quality and habitat. Riparian vegetation is highly beneficial to water quality and aquatic habitat. Riparian areas reduce runoff and trap sediment from upslope areas and may reduce nutrients in runoff (Belt et al., 1992). Canopy species shade surface waters, moderating water temperature and providing detritus that serves as an energy source for streams. Trees in riparian areas are a source of large woody debris (LWD) to surface waters. Riparian areas provide important habitat for aquatic organisms and terrestrial species.

The width of SMAs is determined in one of two ways: (1) a fixed minimum width is recommended or prescribed, or (2) a variable width is determined based on site conditions such as slope (Phillips et al., 2000) (Figure 3-5). SMAs need to be of sufficient width to protect the adjacent water body. A minimum width of 35 to 50 feet is generally recommended for SMAs to be effective. Areas such as intermittent channels, ephemeral channels, and depressions need to be given special consideration when determining SMA boundaries. Channels should be disturbed as little as possible to maximize the effectiveness of an SMA, as disturbance in and adjacent to a SMA can contribute considerably to pollutant runoff volumes. SMAs also need to be able to withstand wind damage or blowdown. For example, a single rank of canopy trees is not likely to withstand blowdown and maintain the functions of an SMA.

Table 3-2 presents North Carolina's recommendations for SMA widths for various types of water bodies dependent on adjacent upland slope. Maine's recommended filter strip widths are dependent on the land slope between the road and the water body (Table 3-3). SMA widths might vary along a stream's course and on opposite sides of the same stream. SMA width is measured along the ground from the streambank on each side of the stream and not from the centerline of the watercourse (Georgia Forestry Commission, 1999).
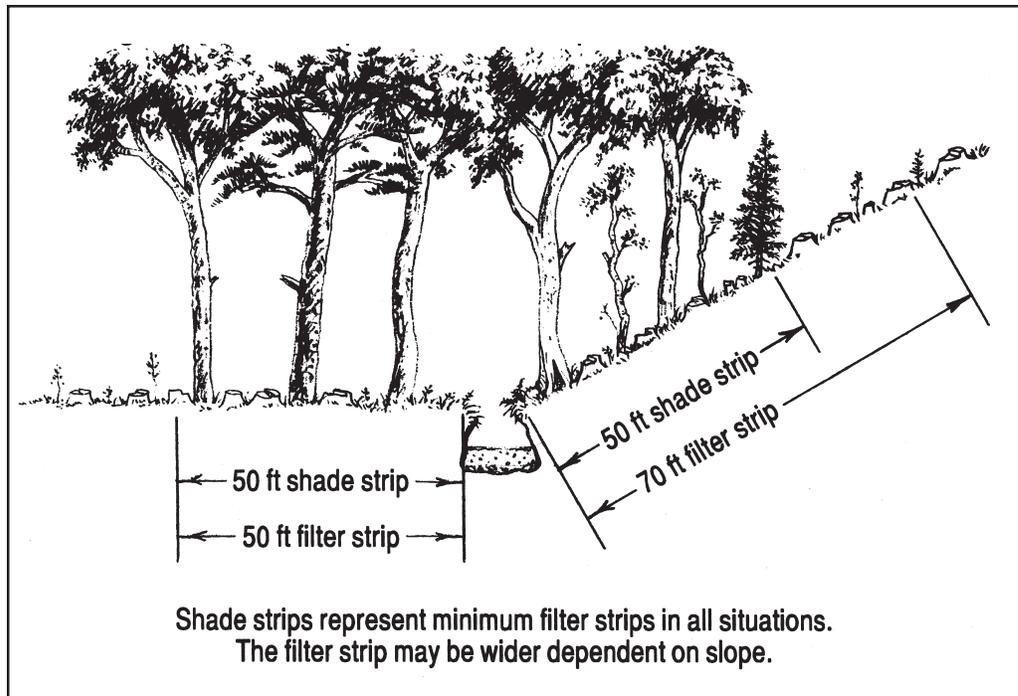
Figure 3-5.   Calculation of slope—an important step in determining SMA width (Georgia Forestry Commission, 1999).

Table 3-2.   Recommended Minimum SMZ Widths (North Carolina Division of Forest Resources, 1989)

Type of Stream or Water Body	Percent Slope of Adjacent Lands				
	0–5	6–10	11–20	21–45	46+
	SMZ Width Each Side (feet)				
Intermittent	50	50	50	50	50
Perennial	50	50	50	50	50
Perennial trout waters	50	66	75	100	125
Public water supplies (Streams and reservoirs)	50	100	150	150	200

Table 3-3.   Recommendations for Filter Strip Widths (Maine Forest Service, 1991)

Slope of Land (%)	Width of Strip (ft along ground)
0	25
10	45
20	65
30	85
40	105
50	125
60	145
70	165

A sufficient number of large trees in an SMA provide for bank stability and a sustainable source of large woody debris. LWD consists of naturally occurring dead and downed woody materials, not to be confused with logging slash or debris. Trees to be maintained or managed in the SMA can provide large woody debris to the stream at a rate that maintains beneficial uses associated with fish habitat and stream structure. Woody debris is added at the site and downstream at a rate that is sustainable over a long time period.

A sufficient number of canopy species are maintained in an SMA also to provide shading to the stream water surface to prevent changes in the temperature regime of the water body and to prevent harmful temperature- or sunlight-related effects on the aquatic biota. If the existing shading conditions for the water body prior to activity are known to be less than optimal for the stream, SMAs can be managed to increase shading of the water body.

Lakeside management areas, or LMAs—the lake and pond equivalent of SMAs—should also be left around lakes and ponds on harvest sites (Minnesota Forest Resources Council, 1999; Wisconsin Department of Natural Resources, 2003). The width of LMAs varies depending on site conditions, as do the recommended widths of SMAs. Topography, hydrology, size of water body, size of adjacent harvest area, harvest method, forest management objectives (e.g., timber production, wildlife), whether the water body contains sensitive fish species, and tree species composition all influence the size and leave-tree recommendations for LMAs.

Generally, LMAs should be as wide as SMAs, or generally between 50 and 100 feet wide, though where sensitive fish species are present in the water body, a wider LMA— up to 200 feet—may be necessary to fully protect water quality.

Other considerations for timber harvesting near lakes and ponds include ensuring that some trees are left on all areas surrounding water bodies all the way to the top of the adjacent slope, and using an extended rotation period within LMAs (as should be done for SMAs) to minimize soil and riparian area disturbance.

To preserve SMA integrity for water quality protection, some states limit the type of harvesting, timing of operations, amount harvested, or reforestation methods used in them. SMAs are managed to use only harvest and forestry methods that prevent soil disturbance in the SMA. Additional operational considerations for SMAs are addressed in subsequent management measures. Practices for SMA applications to wetlands are described in the *Wetlands Forest Management Measure* (Chapter 3, section J).

Benefits of Streamside Management Areas

The effectiveness of SMAs in regulating water temperature depends on the interrelationship between vegetative and stream characteristics. Specifying leave tree and stream shade quantities is an effective way to prevent detrimental temperature changes. An example of a leave tree specification might be Leave trees that provide midsummer and midday shade to the water surface, and preferably a quantity of trees that provide a minimum of 50 percent of the summer midday shade. Shade cover is preferably left distributed evenly within the SMA. If a threat of blowdown exists, leave trees may be clumped and clustered as long as sufficient shade at the reach scale is provided.

Lynch and others (1985) studied the effectiveness of SMAs in controlling suspended sediment and turbidity levels (Table 3-4). A combination of practices were applied,

Table 3-4.   Storm Water Suspended Sediment Delivery for Treatments (Pennsylvania) (Lynch et al., 1985)

Water Year and Treatment	Annual Average Suspended Sediment in mg/L (Range)
1977	
Forested control	1.7 (0.2–8.6)
Clear-cut-herbicide	10.4 (2.3–30.5)
Commercial clear-cut with BMPs[a]	5.9 (0.3–20.9)
1978	
Forested control	5.1 (0.3–33.5)
Clear-cut-herbicide	— [b](1.8–38.0)
Commercial clear-cut with BMPs[a]	9.3 (0.2–76.0)

[a]Buffer strips, skidding in streams prohibited, slash disposal away from streams, skid trail and road layout away from streams.
[b]Data not available

including SMAs and prohibitions on skidding, slash disposal, and roads located in or near streams. Average storm water-suspended sediment and turbidity levels in the area without these practices were very high compared to those of the control and SMA/BMP sites. Table 3-5 presents data on how effective different cutting practices and buffer strips are in preventing debris from entering the stream channel (Froehlich, 1973).

Hall and others (1987) studied the effectiveness of SMAs in protecting streams from temperature increases, large increases in sediment load, and reduced dissolved oxygen (Table 3-6). The value of SMAs for protecting streams from water temperature changes is clear from the 30 ºF maximum daily increase in stream temperature observed during the study. The study also showed that not leaving a SMA can cause sediment increases streams, and more recent research has demonstrated that SMAs might be effective in

Table 3-5.   Average Changes in Total Coarse and Fine Debris of a Stream Channel After Harvesting (Oregon) (Froehlich, 1973)

Cutting Practice	Natural Debris	Material Added in Felling	% Increase
	(tons per hundred feet of channel)		
Conventional tree-felling	8.1	47	570
Cable-assisted directional felling	16	14	112
Conventional tree-felling with buffer strip[a]	12	1.3	14

[a]Buffer strips ranged from 20 to 130 feet wide for different channel segments.

Table 3-6.   Comparison of Effects of Two Methods of Harvesting on Water Quality (Oregon) (Hall et al., 1987)

Watershed	Method	Streamflow	Water Temperature	Sediment	Dissolved Oxygen
Deer Creek	Patch cut with buffer strips (750 acres)	No increase in peak flow	No change	Increases for one year due to periodic road failure	No change
Needle Branch	Clearcut with no stream protection (175 acres)	Small increases	Large changes, daily maximum increase by 30 °F, returning to pre-log temp. within 7 years	Five-fold increase during first winter, returning to near normal the fourth year after harvest	Reduced by logging slash to near zero in some reaches; returned to normal when slash removed

intercepting overland flow and some sediment it contains, but not in intercepting sediment contained in channelized flow (Belt et al., 1992; Keim and Schoenholtz, 1999). Keim and Schoenholtz (1999), in a study on highly erodible soils in Mississippi, found that the primary means by which SMAs reduce sediment delivery to streams is by preventing soil disturbance next to the stream and not by intercepting sediment from upland sources. Finally, the study demonstrated the effect that logging slash placed in streams has in depleting dissolved oxygen as it decomposes.

Hartman and others (1987) compared the physical changes associated with logging using three streamside treatments—leaving a variable-width strip of vegetation along a stream (least intensive); clear cutting to the margin of a stream, but with virtually no instream disturbance (intensive); and clear-cutting to the stream bank with some yarding near the stream and pulling merchantable timber from the stream (most intensive). They performed their study to observe the effect of different SMAs on the supply of woody debris. The volume and stability of large woody debris decreased immediately in the most intensive treatment area, decreased a few years after logging in the careful logging area, and remained stable where streamside trees and other vegetation remained.

The costs associated with SMAs vary according to site conditions. SMAs can be more difficult to lay out on rough terrain or along a stream or river that meanders a lot due to the need to adjust the SMA width appropriately. Also, harvesters or landowners take into account the value of merchantable timber left unharvested because of SMA restrictions. No single SMA width or layout is preferable for all sites in terms of cost. Dykstra and Froelich (1976a) concluded in one study that a 55-foot buffer strip was the least costly on a million-board-foot (mfb) basis, but they cautioned that cost is not the only factor to consider when deciding what type of stream protection to use (Table 3-7).

There are several research papers that focus on the costs of SMA implementation. Lickwar (1989) examined the costs of SMAs as determined by varying slope steepness (Table 3-8) in different regions in the Southeast and compared them to road construction and revegetation practice costs. He found that SMAs are the least expensive practice, in general, and that their cost is approximately the same regardless of slope. The costs associated with use of alternative buffer and filter strips were also analyzed in an Oregon study (Olsen, 1987) (Table 3-9). In that study, increasing the SMA width from 35 feet on each side of a stream to 50 feet reduced the value per acre by $75 (discounted cost) to $103 (undiscounted cost), or an approximate 2 percent increase in harvesting cost per acre (from $3,163 discounted to $5,163 undiscounted). Doubling the SMA width from

Table 3-7.   Average Estimated Logging and Stream Protection Costs per MBF (Oregon) (Dykstra and Froehlich, 1976a)

Cutting Practice	Total Cost		Volume Foregone
	Average	Range	
Conventional felling	$70.98	$62.74–85.74	None
Cable-assisted directional felling (1.43% breakage saved within 200-foot stream)	$74.62	$61.19–89.49	—
Cable-assisted felling (10% breakage saved)	$70.59	$56.00–85.42	—
Buffer strip (55 feet wide)	$66.86	$56.84–79.55	0 - 6 percent
Buffer strip (150 feet wide)	$77.78	$69.70–86.74	6 - 17 percent

Note: All costs updated to 1998 dollars.
[a]Cost estimates for each of 10 areas studied by Dykstra and Froehlich were averaged for this table.

Table 3-8.   Cost Estimates (and Cost as a Percent of Gross Revenues) for Streamside Management Areas (Lickwar, 1989)

Practice Component	Steep Sites[a]	Moderate Sites[b]	Flat Sites[c]
Streamside Management Zones	$2,958 (0.52%)	$3,441 (0.51%)	$3,363 (0.26%)

Note: All costs updated to 1998 dollars.
[a] Based on a 1,148-acre forest and gross harvest revenues of $573,485. Slopes average over 9 percent.
[b] Based on a 1,104-acre forest and gross harvest revenues of $678,947. Slopes ranged from 4 percent to 8 percent.
[c] Based on a 1,832-acre forest and gross harvest revenues of $1,290,641. Slopes ranged from 0 percent to 3 percent.

Table 3-9.   Cost Effects of Three Alternative Buffer Strips (Oregon): Case Study Results with 640-acre Base (36 mbf/acre) (Olsen, 1987)

	Scenario		
	I	II	III
Average buffer width (feet on each side)	35	50	70
Percent conifers removed	100	60	25
Percent reclassified Class II streams[a]	0	20	80
Harvesting restrictions	Current	New	New
Road Construction			
New miles	2.09	2.14	3.06
Road and landing acres	10.9	11.1	15.9
Cost total (1000's)	$96.00	$102.00	$197.00
Cost/acre	$149.00	$160.00	$307.00
Harvesting Activities[b]			
mmbf harvested	22.681	22.265	20.277
Acres harvested	638.3	635.5	633.1
Cost total (1000's)	$3,104.00	$3,101.00	$2,842.00
Cost/acre	$4,841.00	$4,835.00	$4,432.00
Cost/mbf	$136.87	$139.26	$140.17
Inaccessible Area and Volume			
Percent area in buffers	1.3	3.9	14.0
mmbf left in buffers	0.000	0.313	2.214
Acres unloggable	1.44	4.32	6.72
mmbf lost to roads and landings	0.202	0.205	0.295
Undiscounted Costs (1000's)			
Road cost	$96.00	$102.00	$197.00
Harvesting cost	$3,104.00	$3,101.00	$2,842.00
Value of volume foregone[c]	$38.00	$101.00	$413.00
Total	$3,238.00	$3,304.00	$3,451.00
Cost/acre	$5,060.00	$5,163.00	$5,393.00
Reduced dollar value/acre	—	$103.00	$323.00
Discounted Costs			
Cost with 4% discount rate (1000's)	$2,023.00	$2,071.00	$2,195.00
Cost/acre	$3,162.00	$3,237.00	$3,431.00
Reduced value/acre	—	$75.00	$269.00

Note: mmbf = millon board feet; mbf = thousand board feet.
     1986 dollars.
[a] Generally, only Class I streams are buffered.
[b] Includes felling, landing construction and setup, yarding, loading, and hauling.
[c] Volume foregone x net revenue ($150/mbf).

35 to 70 feet on each side of a stream reduced the dollar value per acre by approximately 3 times, adding approximately 8 percent to the discounted harvesting costs.

According to the Vermont Agency of Natural Resources, adequately sized SMAs are the best means to protect water quality (VANR, 1998). The agency conducted habitat assessments and bioassessments on stream segments above and below harvest sites and before and after harvesting and determined that SMAs are particularly important for protecting small headwater streams and ephemeral stream channels. The Virginia Department of Forestry also monitored BMP implementation and effectiveness and determined that although improvement was needed in meeting minimum standards of implementation, properly implemented SMAs (together with stream crossings and preharvest plans) are crucial to protecting water quality.

The Oregon Department of Forestry similarly found that application of a riparian rule (passed in 1987) results in stream protection that generally maintains pre-operation vegetative conditions.

Where SMAs were found to be ineffective or less effective than possible, the Virginia Department of Forestry discovered that in some cases this was the result of careless timber harvesting in the SMAs, a lack of adequately sized SMAs on adjacent intermittent streams, or gaps in SMAs caused by cutting in them.

Of course, BMPs are effective only when properly designed and constructed. In general, poor BMP effectiveness can be attributed to one or more of the following:

- A lack of time or willingness to plan timber harvests carefully before cutting begins.
- A lack of skill in or knowledge of designing effective BMPs.
- A lack of equipment needed to implement BMPs effectively.
- The belief that BMPs are not an integral part of the timber harvesting process and can be engineered and fitted to a logging site after timber harvesting has been completed.
- A lack of timely implementation and maintenance of BMPs.

Best Management Practices

◆ *Minimize disturbances that would expose the mineral soil of the SMA forest floor. Do not operate skidders or other heavy machinery in the SMA.*

◆ *Locate all landings, portable sawmills, and roads outside the SMA.*

◆ *Restrict mechanical site preparation in the SMA, and encourage natural revegetation, seeding, and hand planting.*

◆ *Limit pesticide and fertilizer usage in the SMA. Establish buffers for pesticide application for all flowing streams.*

◆ *Directionally fell trees away from streams to prevent excessive quantities of logging slash and organic debris from entering the water body. Remove slash and debris unless consultation with a fisheries biologist indicates that it should be left in the stream for large woody debris.*

There is no "correct" amount of organic debris that streams should have. Streams have natural amounts of organic debris (e.g., fallen leaves, twigs, limbs, and trees), but the

amount varies with season, tree falls, storms, and so forth. Aquatic organisms are adapted to the annual (and longer) range of the quantities of organic debris in the stream. As discussed in Chapter 2, large woody debris, or LWD, alters sediment and water routing and, thereby, affects channel morphology, provides structure and complexity to aquatic and terrestrial organism habitats, and is a source of nutrients for aquatic organisms. Periodic variations in the influx of sediment and LWD also contribute to habitat heterogeneity that is reflected in diverse aquatic communities. When areas upslope from a stream are changed enough that the quantity of organic debris that reaches a stream is significantly changed (i.e., so much that it is too little or too much for the stream's dynamics and the aquatic organisms), it can be detrimental to the aquatic system and be considered a water quality problem. Removing trees from near the stream edge, harvesting older trees on upslope areas, and burning that removes forest floor litter could all reduce inputs of organic debris to the aquatic system and adversely affect stream ecology.

Retaining SMAs along streams is one step to take to ensure that the streams are provided with sufficient inputs of organic debris. Leaving slash and other logging debris in a stream could exceed the natural high limit of organic debris inputs for the stream's ecology and adversely affecting the stream. Removing felled material from streams on a site where changes have occurred that will reduce inputs of organic debris in the future could leave the stream with less organic debris than the stream ecology is adapted to. Maintaining stream water quality—which includes habitat diversity for aquatic life support—does not necessarily imply reducing inputs of woody debris to a stream, therefore, but rather means not altering the aquatic system to a degree in either direction (too much or too little) that stream ecology is adversely affected. A fisheries biologist will be able to help with decisions on what sizes and quantities of woody debris, if any, should be left in a stream to mimic natural conditions. Table 3-10 compares the goals of two types of LWD projects. Further information on the role and importance of LWD in streams and on placing LWD in streams can be obtained from the U.S. Army Corps of Engineers' Ecosystem Management and Restoration Research Program (EMRRP). A paper issued under the program, *Streambank habitat enhancement with large woody debris* (Fischenich and Morrow, 2000), can be found on the Web at http://el.erdc.usace.army.mil/elpubs/pdf/sr13.pdf.

◆ *Apply harvesting restrictions in the SMA to maintain its integrity.*

Vegetation, including trees, should be left in the SMA to achieve the desired objective for the area, such as maintain shading and bank stability and to provide adequate woody debris to create habitat diversity and provide nutrients to surface waters. This provision for leaving residual trees might be specified in various ways. For example, the Maine Forestry Service specifies that no more than 40 percent of the total volume of timber 6 inches diameter breast height (DBH) and greater be removed in a 10-year period, and that the trees removed be reasonably distributed within the SMA. Florida recommends leaving a volume equal to or exceeding one-half the volume of a fully stocked stand. The number of residual trees varies inversely with their average diameter. A shading specification that is independent of the volume of timber might be necessary for streams where temperature changes could alter aquatic habitat.

Table 3-10. Goals of Two Main Types of LWD Projects (Fischenich and Morrow, 2000)

	Category 1	Category 2
LWD Project Goals	Improve habitat by increasing LWD quantities in a stream	Alter flows to improve aquatic habitat

3C: ROAD CONSTRUCTION/RECONSTRUCTION

Management Measure for Road Construction/Reconstruction

(1) Follow preharvest planning (as described under the Management Measure for Preharvest Planning) when constructing or reconstructing the roadway.

(2) Follow designs planned under the Management Measure for Preharvest Planning for road surfacing and shaping.

(3) Install road drainage structures according to designs planned under the Management Measure for Preharvest Planning and regional storm return period and installation specifications. Match these drainage structures with terrain features and with road surface and prism designs.

(4) Guard against the production of sediment when installing stream crossings.

(5) Protect surface waters from slash and debris material from roadway clearing.

(6) Use straw bales, silt fences, mulching, or other favorable practices on disturbed soils on unstable cuts, fills, etc.

(7) Avoid constructing new roads in streamside management areas to the extent practicable.

Management Measure Description

Road construction is one of the largest potential sources of forest activity-produced sediment (Megahan, 1980), and road and drainage crossing construction practices that minimize sediment delivery to surface waters are essential for protecting water quality. Water quality degradation resulting from forest roads is mostly attributable to sediment loss during road construction, erosion that occurs within a few years after road construction, soil loss from heavy road use, and road failure during storm events that exceed the road's design capacity. An early study of erosion from road construction concluded that the amount of sediment produced by road construction is directly related to the percent of area occupied by roads, whether a road is given a protective surface, and the amount of protection provided to loose soils on back slopes and fill slopes (King, 1984) (Table 3-11). Best management practices related to these aspects of road construction, and for stream crossing construction, are the subject of this management measure. Erosion and water quality degradation are also problems associated with older, unmaintained roads, and BMPs for road maintenance are the subject of the next management measure.

General Road Construction Considerations

Road design and construction that are tailored to the topography and soils and that take into consideration the overall drainage pattern in the watershed where the road is being constructed can prevent road-related water quality problems. Lack of adequate consideration of watershed and site characteristics, road system design, and construction techniques appropriate to site circumstances can result in mass soil movements, extensive surface erosion, and severe sedimentation in nearby water bodies. The effect that a forest

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Table 3-11. Effects of Several Road Construction Treatments on Sediment Yield in Idaho (King, 1984)

Watershed Area (acres)	Area in Roads (percent)	Treatment	Increase of Annual Sediment Yield[a] (percent)
207	3.9	Unsurfaced roads; Untreated cut slope; Untreated fill slope	156
161	2.6	Unsurfaced roads; Untreated cut slope dry seeded	130
364	3.7	Surfaced roads; Cut and fill slopes straw mulched and seeded	93
154	1.8	Surfaced roads; Filter windrowed; Cut and fill slopes straw mulched and seeded	53
70	3.0	Surfaced roads; Filter windrowed; Cut and fill slopes hydro-mulched and seeded	25
213	4.3	Surfaced roads; Filter windrowed; Cut and fill slopes hydro-mulched and seeded	19

[a] Measured in debris basins.

road network has on stream networks largely depends on the extent to which the road and stream networks are interconnected. Road networks can be hydrologically connected to stream networks where road surface runoff is delivered directly to stream channels at stream crossings or via ditches or gullies that direct flow off of the road and then to a stream, and where road cuts transform subsurface flow into surface flow in road ditches or on road surfaces that delivers sediment and water to streams much more quickly than without a road present and increases the risk of mass wasting (Jones and Grant, 1996; Montgomery, 1994; Wemple et al., 1996). The combined effects of these drainage network connections are increased sedimentation and peak flows that are higher and arrive more quickly after storms. This in turn can lead to increased instream erosion and stream channel changes. This effect is strongest in small watersheds (Jones et al., In press).

Site characteristics are first considered during preharvest planning, and it is important to review the harvesting plan at the harvest site before construction begins to verify assumptions made during planning. On-site verification of information from topographic maps, soil maps, and aerial photos is necessary to ensure that locations where roads are to be cut into slopes or built on steep slopes or where skid trails, landings, and equipment maintenance areas are to be located are appropriate to the use. If an on-site visit indicates that changes to road, skid trail, or landing locations can reduce the risk of erosion, the project manager can make these changes prior to construction, and in some cases as the project progresses.

Road drainage features tailored to the site and its conditions prevent water from pooling or collecting on road surfaces and thereby prevent saturation of the road surface, which can lead to rutting, road slumping, and channel washout. It is especially important to ensure that road drainage structures are well constructed and designed for use during logging operations because the heavy vehicle use during harvesting creates a high potential for the contribution of large quantities of sediment to runoff.

Some roads are temporary or seasonal use roads, and their construction should not generally involve the high level of disturbance generated by the construction of permanent, high-standard roads. However, temporary or low-standard roads still need to be constructed and maintained to prevent erosion and sedimentation, and many of the BMPs discussed for this management measure are applicable to temporary road construction.

In a study in three headwater watersheds in the mountains of central Idaho, 70 percent of sediment deposition from roads constructed on the watersheds, where the slope ranged from 15 to 40 percent, occurred during the first year after construction, and one-fourth of this deposition occurred during road construction (Ketcheson and Megahan, 1996). In this study, sediment usually traveled less than 100 meters (m) from its source. The distance that sediment traveled varied depending on its source: the distance traveled from fills, rock drains, berm drains, and landings was between 4 m and 20 m, while that from cross drains was 50 m. The maximum travel distance from some cross drains was more than 250 m. Cross drains have a larger source area from which runoff is collected, including the road prism and upslope watershed area, and this accounted for more sediment being deposited than from all other sources combined. These findings highlight the importance of road placement, design, and construction in relation to watercourse location and the installation of BMPs to control runoff sedimentation from roads.

Based on the findings of studies such as this, it is clear that erosion control practices need to be applied while a road is being constructed, when soils are most susceptible to erosion, to minimize soil loss to water bodies. Since sedimentation from roads often does not occur incrementally and continuously, but in pulses during large rainstorms, it is important that road, drainage structure, and stream crossing design take into consideration a sufficiently large design storm that has a good chance of occurring during the life of the project. Such a storm might be the 10-year, 25-year, 50-year, or even 100-year, 12- to 24-hour return period storm. Sedimentation cannot be completely prevented during or after road construction, but the process is certainly exacerbated if the road construction and design are inappropriate for the site conditions or if the road drainage or stream crossing structures are insufficient.

Several common practices minimize erosion during road construction. In general, it is recommended that forest roads be constructed as a single lane for minimum width and outsloped with minimal cut-and-fill, where conditions are suitable (Weaver and Hagans, 1984). These roads should cause the least disturbance and have lower maintenance costs. Figure 3-6 illustrates various erosion and sediment control practices. Aspects of road construction addressed by the BMPs discussed under this management measure are introduced below. Further information is provided in the discussions of the individual BMPs.

Road Surface Shape and Composition

The shape of a road is an important component of runoff control. Terminology related to road construction and road shape is illustrated in Figure 3-7. Road drainage and runoff control are obtained by shaping the road surface to be insloping, outsloping, or crowned (Figure 3-8). Road surfaces need to have and maintain one of these shapes at all points to ensure good drainage (Moll et al., 1997). Insloping roads can be particularly effective where soils are highly erodible and directing runoff directly to the fill slope would be detrimental. Outsloped roads tend to dissipate runoff more than insloped roads, which concentrate runoff at cross drain locations, and are useful where erosion of the backfill or

Earth cuts sloped to a stable angle of repose will encourage natural erosion control with vegetation.

Check dams across roadside ditches will slow down water velocities and prevent erosion on steep grades.

Rip rap in the ditch bottom and on the fill slopes at culverts will prevent erosion problems.

A diversion berm is used to divert flow into a cross-culvert or off the right of way into the bush.

Sediment traps are dug to collect sediment and prevent its movement further downstream.

The most economical erosion control method is to retain existing vegetation and organic material.

The most economical sediment control method is to use the forest floor litter as a filter to trap sediment.

Slash debris pushed into the soil controls erosion and sediment by reducing flow velocities.

Revegetation is encouraged with stable slopes, retaining organic material and seeding.

Silt fences are a short term measure to trap sediment during construction until vegetation is established.

Rock or boulder rip rap prevents bank erosion and scour under abutments or piers.

Protection or enhancement of fish spawning beds requires particular attention when crossing a rapids.

GORDON GRICE '88

Figure 3-6.   Mitigation techniques used for controlling erosion and sediment to protect water quality and fish habitat (Ontario MNR, 1988).
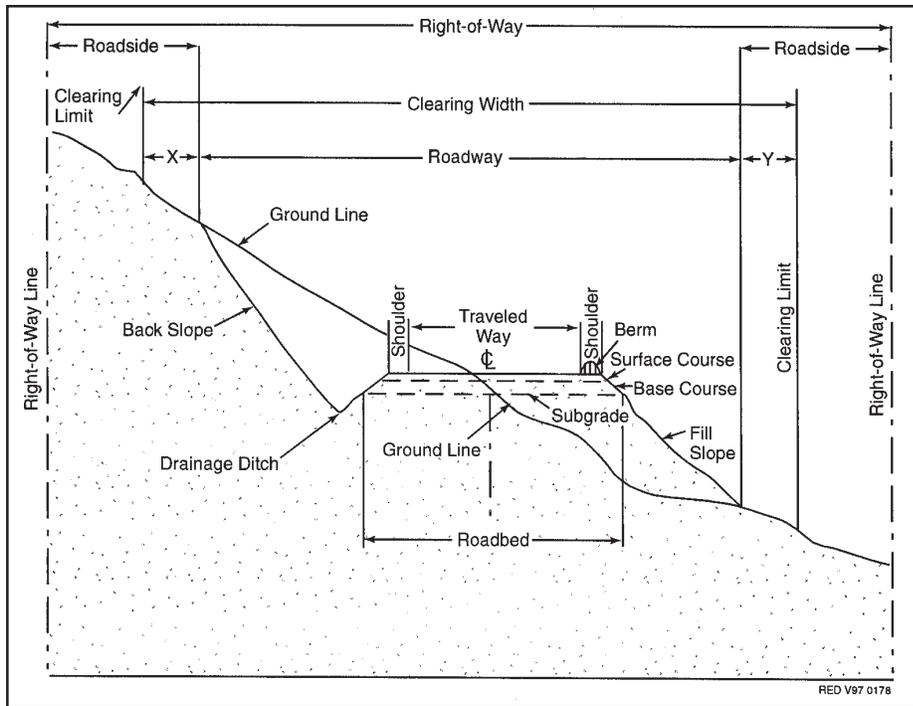
Figure 3-7.   Illustration of road structure terms (Moll et al., 1987).
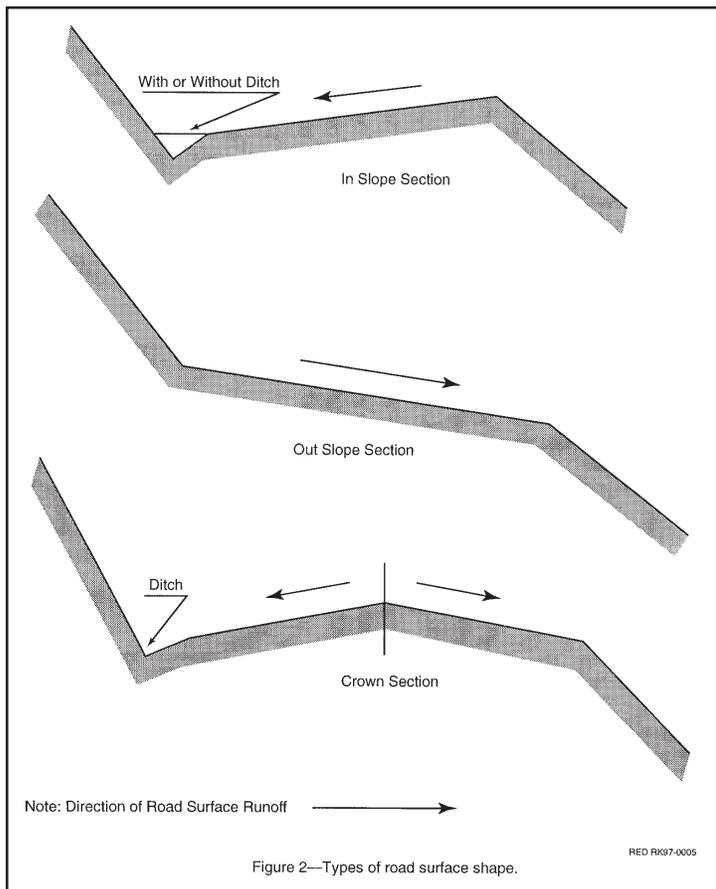
Figure 3-8.   Types of road surface shape (Moll et al., 1997).

Sediment Runoff Distance and Quantity Vary with Source

Seventy percent of sediment deposition from roads constructed on three headwater watersheds in the mountains of central Idaho, where the slope ranged from 15 to 40 percent, occurred during the first year after construction, and on-fourth of this occurred during road construction.

Sediment generally traveled less than 100 m from its source. Average sediment travel distances from fills, rock drains, berm drains, and landings were between 4 m and 20 m, while that from cross drains was 50 m. The maximum travel distance from some cross drains was more than 250 m.

The larger source area for runoff from cross drains, including he road prism and upslope watershed areas, accounts for more sediment deposited form them and for the sediment from them traveling farther than from other sources.

(Source: Ketcheson and Megahan, 1996)

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ditch soil might be a problem. Crowned roads are particularly suited to two-lane roads and to steep single-lane roads that have frequent cross drains or ditches and ditch relief culverts (Moll et al., 1997). Crowns, inslopes, and outslopes will quickly lose effectiveness if not maintained frequently, due to micro-ruts created by traffic when the road surface is damp or wet.

The composition of a road surface can be chosen to effectively control erosion from the road surface and slopes. It is important to choose a road surface that is suitable to the topography, slope, aspect, soils, and intended use. Small, temporary, dry season roads can be left unsurfaced and decommissioned after use to minimize their impact to water quality. Roads that will be used more intensively or for long periods can have road surfaces formed from native material, aggregates, asphalt, or other suitable materials. Any of these surface compositions can be shaped in one of the ways discussed above. Surface protection of the roadbed and cut-and-fill slopes with a suitable material can

- Minimize soil losses during storms
- Reduce frost heave erosion production
- Restrain downslope movement of soil slumps
- Minimize erosion from softened roadbeds

Numerous studies have been conducted and have demonstrated the potential of a suitable road surface composition to control erosion and sedimentation from forest roads. Swift (1985) found that applying 20 centimeters (cm) of crushed rock to forest roads in the southern Appalachian mountains yielded sediment runoff of 0.06 ton/acre/inch of rainfall, a significant reduction from the 1.475 ton/acre/inch of rainfall yielded by a road surface covered by only 5 cm of crushed rock (Figure 3-9). In another study in the Appalachian mountains, Kochenderfer and Helvey (1984) demonstrated that using 1-inch crusher-run gravel or 3-inch clean gravel reduced erosion from road surfaces to less than one-half of that from 3-inch crusher-run gravel, and to only 12 percent of the erosion rate measured from an ungraveled road surface (Table 3-12). In a more recent study (Johnson and Bronsdon, 1995), a surface of bituminous oil or 15 to 20 cm of gravel reduced erosion rates by as much as 96 percent below that measured from unsurfaced roads (Figure 3-10). In the same study, logging slash left on roads was also found to provide a protective layer and reduced erosion by 75 to 87 percent compared to unsurfaced roads.

Properly shaping a road surface (i.e., insloped, outsloped, or crowned) might not suffice to control drainage adequately, and drainage structures in addition to the relief culverts on insloped and crowned roads might be necessary for drainage control (Moll et al., 1997). Structures such as broad-based dips, turnouts, and cross drains can be used under such conditions, and these BMPs are further discussed below. The proper choice of drainage structure, in combination with the chosen surface shape, and effective installation of the

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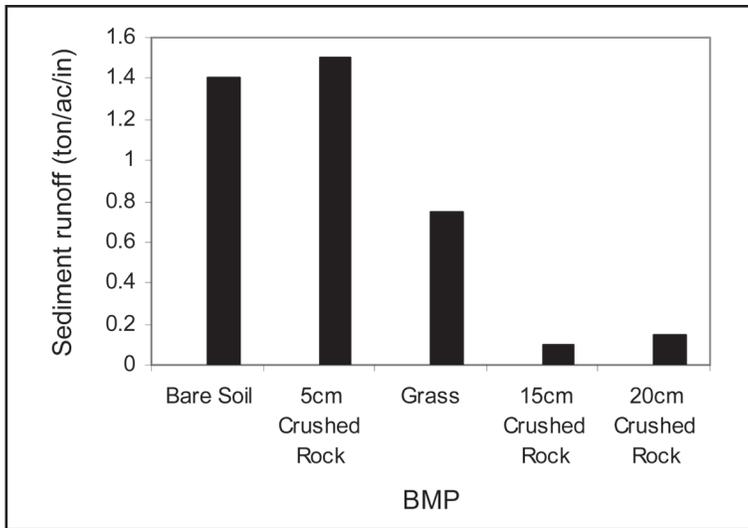
Figure 3-9. Comparison of sedimentation rates (as tons of sediment in runoff per acre per inch of rainfall) from different forest road surfaces (after Swift, 1984).

Table 3-12. Effectiveness of Road Surface Treatments in Controlling Soil Losses in West Virginia (adapted from Kechenderfer and Helvey, 1984)

Surface Treatment	Average Annual Soil Losses (tons/acre)[a]
Ungraveled	44.4
3-inch crusher-run gravel	11.4
1-inch crusher-run gravel	5.5
3-inch clean gravel	5.4

[a] Six measurements taken over a 2-year period.
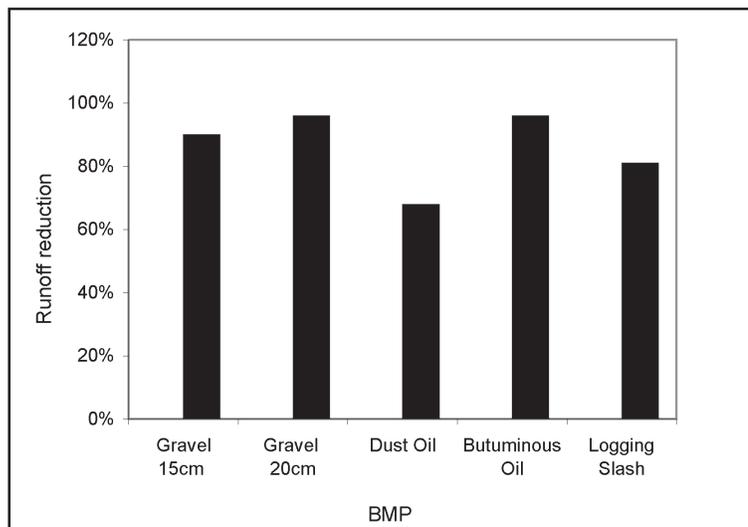
Figure 3-10. Percent of reduction in sediment runoff from a forest road surface with different treatments. Percent reduction in erosion is the amount below that observed on an untreated road (after Johnson and Bronsdon, 1995).

drainage structures is crucial to minimizing erosion from roads and sedimentation in water bodies. Improper or insufficient installation of road drainage structures is the cause of many road failures, whereas proper installation of the correct structure can reduce erosion potential, extend the useful life of a road, and decrease the need for road maintenance.

Slope Stabilization

Road cuts and fills can be a large source of sediment once a logging road is constructed. Stabilizing back slopes and fill slopes as they are constructed is an important process in minimizing erosion from these areas. Combined with graveling or otherwise surfacing the road, establishing grass or using another form of slope stabilization can significantly reduce soil loss from road construction. If constructing on an unstable slope is necessary, as it sometimes is, consider consulting with an engineering geologist or geotechnical engineer for recommended construction methods and to develop plans for the specific road segment. Unstable slopes that threaten water quality should always be considered unsuitable for road building (Weaver and Hagans, 1984).
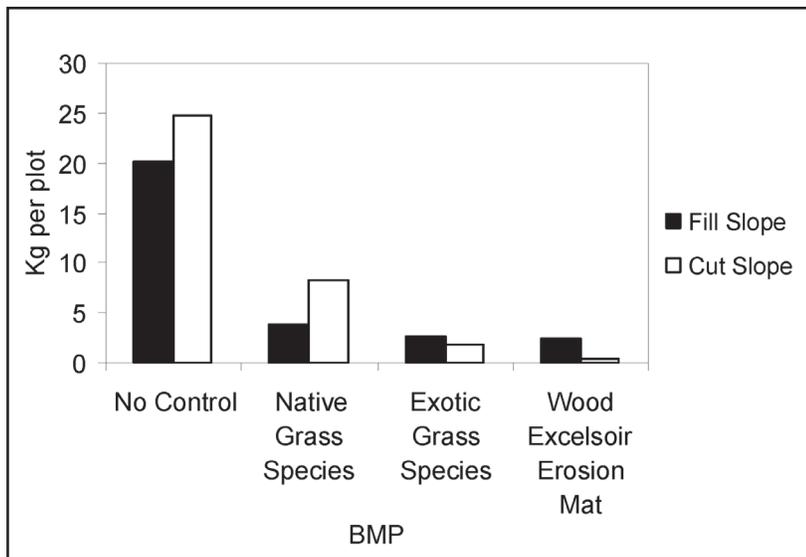
Figure 3-11. **Sediment yield from plots using various forms of ground covering. Sediment yield is per plot area over a 6-month period; plots measured 1.5 m x 3.1 m (after Grace et al., 1998).**

Planting grass on cut-and-fill slopes of new roads can effectively reduce erosion, and placing forest floor litter or brush barriers on downslopes in combination with establishing grass is also an effective means to reduce downslope sediment transport (Tables 3-13 and 3-14). Grass-covered fill is generally more effective than mulched fill in reducing soil erosion from newly constructed roads because of the roots that hold the soil in place, which are lacking with any other covering placed on the soil. Because grass needs some time to establish itself, a combination of straw mulch with netting to hold it in place can be used to cover a seeded area and effectively reduce erosion during the period while grass is growing. The mulch and netting provide immediate erosion control and promote growth of the grass. Figure 3-11 shows the results of a study conducted by Grace and others (1998) to demonstrate the erosion control capacities of different cut-and-fill slope stabilization BMPs on forest roads. The results of several studies on different types of slope stabilization BMPs are summarized in Table 3-15.

Table 3-13. **Reduction in the Number of Sediment Deposits More Than 20 Feet Long by Grass and Forest Debris (Swift, 1986)**

Type of Soil Protection	Degree of Soil Protection	Number of Deposits per 1,000 Feet of Road
Grassed fill, litter and brush burned	Low	13.9
Bare fill, forest litter		9.9
Mulched fill, forest litter	↕	8.1
Grassed fill, forest litter, no brush barrier		6.9
Grassed fill, forest litter, brush barrier	High	4.5

Table 3-14.   Comparison of Downslope Movement of Sediment from Roads for Various Roadway and Slope Conditions (Swift, 1986)

Comparisons	Sites (no.)	Mean Slope (%)	Distance (feet) Mean	Distance (feet) Max	Distance (feet) Min
All sites	88	46	71	314	2
Barrier[a]					
Brush barriers	26	46	47	156	3
No brush barrier	62	47	81	314	2
Drainage[b]					
Culvert	21	40	80	314	30
Outsloped without culvert	56	47	63	287	2
Unfinished roadbed with berm	11	57	95	310	25
Grass fill and forest litter[c]	46	40	45	148	2
With brush barrier	16	39	34	78	3
With culvert	4	20	37	43	30
Without culvert	12	45	32	78	3
Without brush barrier	30	41	51	148	2
With culvert	7	37	58	87	30
Without culvert	23	42	49	148	2

[a] Examined the effectiveness of leaving brush barriers in place below road fills, rather than removing brush barriers.
[b] Compared roads where storm water was concentrated at a culvert pipe to outsloped roads without a culvert. The berm was constructed on an unfinished roadbed to prevent downslope drainage.
[c] Compared effectiveness of brush barriers versus drainage (culvert) systems.

Table 3-15.   Effectiveness of Surface Erosion Control on Forest Roads (adapted from Megahan, 1980, 1987)

Stabilization Measure	Portion of Road Treated	Percent Decrease in Erosion[a]	Reference
Hydro-mulch, straw mulch, and dry seeding[b]	Fill slope	24 to 58	King, 1984
Tree planting	Fill slope	50	Megahan, 1974b
Wood chip mulch	Fill slope	61	Ohlander, 1964
Straw mulch	Fill slope	72	Bethlahmy and Kidd, 1966
Excelsior mulch	Fill slope	92	Burroughs and King, 1985
Paper netting	Fill slope	93	Ohlander, 1964
Asphalt-straw mulch	Fill slope	97	Ohlander, 1964
Straw mulch, netting, and planted trees	Fill slope	98	Megahan, 1974b
Straw mulch and netting	Fill slope	99	Bethlahmy and Kidd, 1966
Straw mulch	Cut slope	32 to 47	King, 1984
Terracing	Cut slope	86	Unpublished data[c]
Straw mulch	Cut slope	97	Dyrness, 1970
Wood chip mulch	Road fills	61	Bethlahmy and Kidd, 1966
Straw mulch	Road fills	72	Ohlander, 1964
Grass and legume seeding	Road cuts	71	Dyrness, 1970
Gravel surface	Surface	70	Burroughs and King, 1985
Dust oil	Surface	85	Burroughs and King, 1985
Bituminous surfacing	Surface	99	Burroughs and King, 1985

[a] Percent decrease in erosion compared to similar, untreated sites.
[b] No difference in erosion reduction between these three treatments.
[c] Intermountain Forest and Range Experiment Station, Forestry Sciences Laboratory, Boise, ID, nd.

Road Construction, Fish Habitat, Stream Crossings, and Fish Passage

Chapter 2 discusses how road construction and road use can cause sediment to be delivered to streams, and it reviews the water quality and fish passage problems associated with sediment and stream crossings. The quality of surface waters to support early life stages of fish can be degraded by nonpoint source pollution from forestry activities as well. Salmonids and other fish that nest on stream bottoms are very susceptible to sediment pollution due to the settling of sediment that can smother nests and deplete the oxygen available to the eggs. The eggs, buried 1 to 3 feet deep in the gravel redd, rely on a steady flow of clean, cold water to bring oxygen and remove waste products. In coastal streams, eggs hatch in a month or so, depending on water temperatures and species of fish. Eggs hatch into alevin and remain in the gravel another 30 days or so, living on the nutrients in their yolk sacs. As they develop into fry, the yolk gets used up, and fry emerge through spaces in the gravel to begin life in the stream. During the 60-day period when the eggs and alevin are in the gravel, any shifts of the stream bottom can kill them.

Recent studies in streams on the Olympic Peninsula in Washington found that if more than 13 percent fine sediment (< 0.85 mm) intruded into the redd, no steelhead or coho salmon eggs survived (McHenry et al., 1994). Chinook salmon are the most susceptible to increased fine sediment, followed by coho salmon, steelhead, and cutthroat trout, respectively (Lotspeich and Everest, 1983). The different tolerances to fine sediment is due to the different head diameters of the fry of the species.

The predominant source of sediment from logging is from the construction and maintenance of access roads.

The redd is a depression in the gravel streambed where the eggs are laid, and the depression creates a Venturi effect, drawing water down into the gravel. If the water in the stream above is full of fine sediment, the sediment is drawn down into the redd and smother the eggs.

In a healthy stream, young salmon and trout hide in the interstitial spaces between cobbles and boulders to avoid predation. In streams that become extremely cold in winter, young steelhead may actually burrow into the streambed and spend the winter in flowing water down within the gravel. The area of the stream where flowing water extends down into the gravel is also extremely important for aquatic invertebrates, which supply most of the food for young salmon, steelhead, and cutthroat trout. If fine sediment is clogging interstitial spaces between streambed gravel, juvenile salmonids lose their source of cover and food.

During the year coho salmon spend in freshwater, they prefer pools. High sediment concentrations in the water can cause pools to fill with sediment and reduce or destroy essential coho rearing habitat. Case studies in southwest Oregon showed that streams damaged by logging can also have significant problems with mortality of salmon eggs and alevin (Nawa and Frissell, 1993). When streams are affected by high sediment deposition, these formerly productive low-gradient reaches become wide and shallow and recovery of fish habitat can take decades (Frissell, 1992).

A fishway is any structure or modification to a natural or artificial structure for the purpose of fish passage. Five common conditions at stream crossing culverts create migration barriers (WADOE, 1999):

- Excess drop at culvert outlet

- High velocity within culvert barrel
- Inadequate depth within culvert barrel
- Turbulence within the culvert
- Debris accumulation at culvert inlet

Figure 3-12 illustrates four of these conditions. Barriers to fish passage can be complete, partial, or temporal. Complete barriers block the use of the upper watershed, often the most productive spawning habitat in the watershed for migratory species of fish. Partial barriers block smaller or weaker fish of a population. Culverts are therefore designed to accommodate smaller or weaker individuals of target species, including juvenile fish. Temporal barriers block migration during some part of the year. Fish passage can be provided in streams that have wide ranges of flow by providing multiple culverts (Figure 3-13). They can delay some fish from arriving at upstream locations, which for some fish (anadromous salmonids that survive a limited amount of time in fresh water) can cause limited distribution or mortality (WADOE, 1999). The FishXing Web site (http://www.stream.fs.fed.us/fishxing/index.html) provides software and learning systems for fish passage through culverts.

Figure 1. Culvert conditions that block fish passage (after Evans and Johnston 1974).

A. Velocity too great,
B. Flow in thin stream over bottom,
C. No resting pool below culvert,
D. Jump too high.
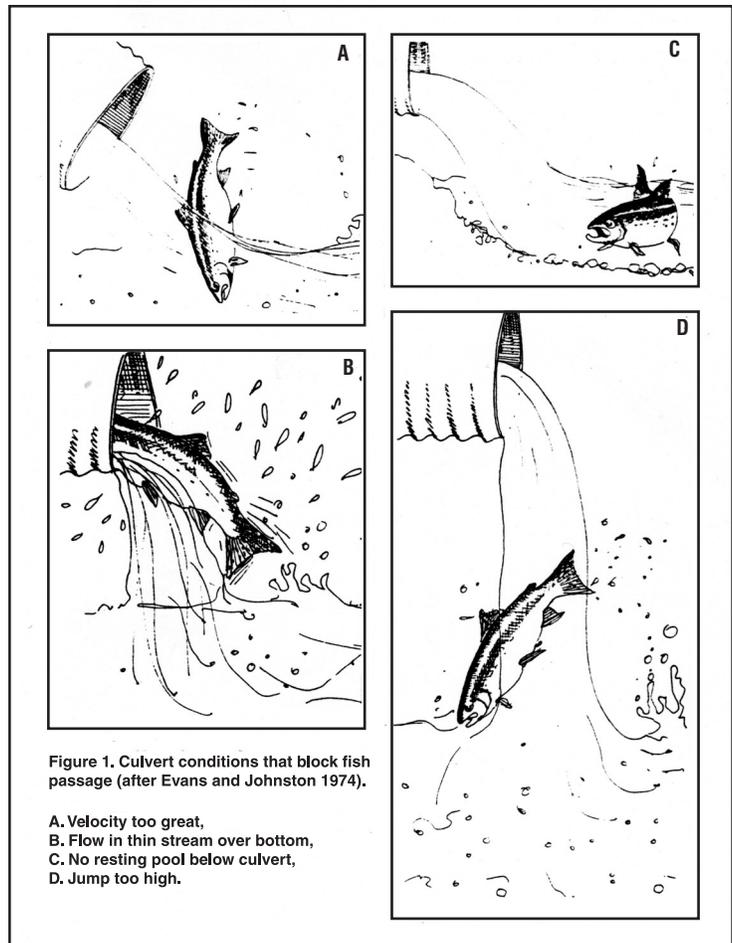
Figure 3-12.   Culvert conditions that block fish passage (Yee and Roelofs, 1980).
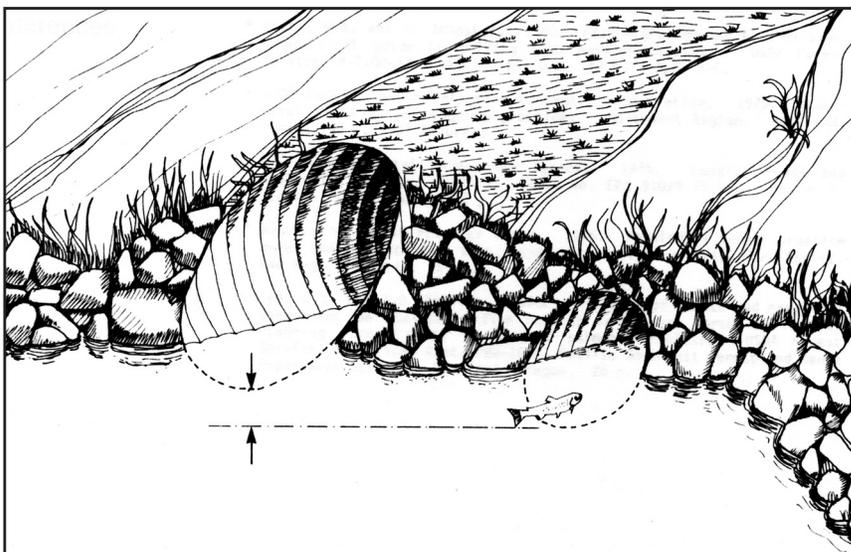
Figure 3-13.   Multiple culverts for fish passage in streams that have a wide range of flows (Hyson et al., 1982).

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Stream Crossing Considerations

- Whether fish use the channel at the crossing site

- Whether the crossing will be temporary or permanent

- The type of vehicles that will use the crossing

- The slope, configuration, and stability of the natural hillslopes on either side of the channel

- The slope of the channel bed

- The orientation of the stream to the proposed road

- The expected 50- and 100-year flood discharge

- The amount and type of sediment and woody debris that is in transport within the channel

- The installation and subsequent maintenance costs for the crossing

- The expected frequency of use

- Permits and other legal requirements

(Source: Weaver and Hagans, 1984)

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Barriers at culverts can result from improper initial design or installation, or they can be the result of channel degradation that leaves culvert bottoms elevated above the downstream channel. Changes in hydrology due to an extensive road network can be a primary reason for channel degradation, and older culverts that might have been adequate when installed can become inadequate for fish passage when channel degradation or land use changes cause changes in stream channel hydrology (Baker and Votapka, 1990; WADOE, 1999). When such changes occur in a watershed, inspect culverts and, if necessary, replaced them with ones that meet actual specifications.

Other problems at culverts include their not providing the roughness and variability of the adjacent stream channel bottom, which can create short distances of increased water velocity and turbulence (WADOE, 1999). These problems create barriers to the upstream migration of juvenile fish. Fish will not travel upstream under high water velocity conditions (Barber and Downs, 1996).

Water velocity in culverts is a complex issue, involving the length of the culvert in relation to fish capabilities, depth of water, icing and debris flows, and design flows in relation to fish migration upstream or downstream. The size and species of fish passing through a culvert and the magnitude, duration, frequency, and seasonal relationship of the flow to the timing of fish movement have to be considered in setting guidelines for culvert design to meet fish passage requirements (Ashton and Carlson, 1984; Baker and Votapka, 1990).

The addition of baffles to a culvert to affect water velocity and turbulence is not generally recommended because of the regular cleaning that becomes necessary. In addition, it has been found that turbulence at the edge of a baffled culvert actually creates a blockage to fish passage, and in higher-velocity culverts passage success can be higher in smooth pipe (Bates, 1994; Powers, 1996).

Countersunk culverts are recommended where fish passage is desired. Installation of multiple, parallel culverts in place of a larger single culvert is discouraged except in special cases, such as to permit fish passage where flows vary widely (see Figure 3-9). Countersunk culverts allow for natural downstream transport of sediment and a natural stream bottom within the culvert (White, 1996).

Wetland Road Considerations

Sedimentation is also a concern when considering road construction through wetlands. Because of the fragility of these ecosystems, where an alternative route exists, avoid putting a forest access road through a wetland. If it's necessary to traverse a wetland,

implement the BMPs suggested by the state. In addition, if road construction or maintenance involves a discharge of dredged or fill material into wetlands or other waters of the United States, section 404(f) requires the application of specific BMPs designed to protect the aquatic environment. (More information on wetlands and forestry, including a list of the aforementioned BMPs, is provided in Chapter 3, section J.)

Benefits of Road Construction Practices

Many states have found roads to consistently be sources of sediment discharge to streams. The Vermont Agency of Natural Resources assessed BMP implementation and effectiveness and found that roads were consistently the most problematic with respect to proper BMP implementation. Drainage ditches, culverts, and stream crossings were most frequently the points of origin of stream sedimentation. The Virginia Department of Forestry also found that water control structures on roads are often inadequately used and applied. The Department found that water bars, rolling dips, and broad-based dips were usually installed improperly. Water bars, for instance, were built using fill only, rather than by cutting into the road bed and then using fill material to shape the bar. These structures were often placed too infrequently and too far apart as the road grade increased, and in some cases they were installed backwards, being angled uphill with the outlet pointing upslope.

The Montana Department of Natural Resources and Conservation, Forestry Division, also monitored BMP implementation and effectiveness and similarly found that the most frequent departures from BMP implementation standards and sources of effects were associated with providing adequate road surface drainage, routing road drainage through adequate filtration zones before the runoff entered a stream, maintaining erosion control structures, and providing energy dissipaters at drainage structure outlets. The division also found that high-risk BMPs were more frequently not applied properly, and water quality effects from them were common.

The Virginia Department of Forestry assessed BMP implementation and effectiveness in 1994 and concluded from the study that although improvement was needed in meeting minimum standards of BMP implementation, properly implemented stream crossings (as well as SMAs and preharvest plans) are crucial to protecting water quality. Where not implemented properly, stream crossings are less effective than they could be. Improper sizing, placement, and installation of culverts are the causes of most failures. Culverts often were found to be too short for the intended roadbed width, and consequently they became clogged or buried. Some culverts were placed improperly, and without correction could have been rendered ineffective or swept away by storm water cutting through fill material.

In general, poor BMP effectiveness can be due to many factors, including the following:

- A lack of time or willingness to plan timber harvests carefully before cutting begins.
- A lack of skill in or knowledge of designing effective BMPs.
- A lack of equipment needed to implement effective BMPs.
- The belief that BMPs are not an integral part of the timber harvesting process and can be engineered and fitted to a logging site after timber harvesting has been completed.
- A lack of timely implementation and maintenance of BMPs.

Road Construction and Stream Crossing BMP Costs

Costs of forestry BMPs for water quality protection are difficult to specify because the need for and design of BMPs varies from site to site with changes in topography, soil, and proximity to water, among other factors. However, with respect to road construction BMPs, some generalizations can be made. In a study of the costs of various forestry practices in the southeastern United States, practices associated with road construction were generally found to be the most expensive, regardless of terrain, and the costs for broad-based dips and water bars increased as slope increased (Lickwar, 1989) (Table 3-16). The proximity of roads to watercourses also increases the cost of road construction because of the increased need to prevent sediment runoff from reaching the surface waters.

Unit cost comparisons for road surfacing practices (Swift, 1984a) revealed that grass is the least expensive alternative at $272 per kilometer of road (1998 dollars) (Table 3-17). Initial material costs alone, however, are misleading because a durable road surface can endure several years of use, whereas a grassed or thinly graveled surface will generally need regular maintenance and resurfacing. Grass and thin gravel coverings are also likely to result in more erosion and sedimentation. Table 3-18 compares the cost of using a single BMP (dry seeding alone) versus using multiple BMPs (seeding in conjunction with plastic netting) to control erosion (Megahan, 1987).

Table 3-16.   Cost Estimates (and Cost as a Percent of Gross Revenues) for Road Construction (Lickwar, 1989)

Practice Component	Location					
	Steep Sites[a]		Moderate Sites[b]		Flat Sites[c]	
Stream crossings	$45	(0.01%)	$185	(0.03%)	$4,303	(0.33%)
Broad-based dips	$16,550	(2.88%)	$10,101	(1.49%)	$4,649	(0.36%)
Water bars	$12,225	(2.13%)	$6,371	(0.94%)	$2,999	(0.24%)
Added road costs	$5,725	(1.00%)	Not provided		Not provided	

Note: All costs updated to 1998 dollars.
[a] Based on a 1,148-acre forest and gross harvest revenues of $399,685. Slopes average over 9 percent.
[b] Based on a 1,104-acre forest and gross harvest revenues of $473,182. Slopes ranged from 4 percent to 8 percent.
[c] Based on a 1,832-acre forest and gross harvest revenues of $899,491. Slopes ranged from 0 percent to 3 percent.

Table 3-17.   Cost of Gravel and Grass Road Surfaces (North Carolina, West Virginia) (Swift, 1984a)

Surface	Quantity/km	Unit Cost	Total Cost/km
Grass	28 kg Ky-31 14 kg rye 405 kg 10-10-10 900 kg lime Labor and equipment	$1.32/kg $1.03/kg $0.189/kg $0.052/kg $97.49/km	$36.90 $14.50 $76.89 $46.59 $97.49
Crushed rock (5 cm)[a]	425 ton	$7.34/ton	$3,120
Crushed rock (15 cm)[a]	1,275 ton	$7.34/ton	$9,361
Large stone (20 cm)[a]	1,690 ton	$8.22/ton	$13,893

Note: All costs updated to 1998 dollars.
[a] Values in parentheses are thickness or depth of surfacing material.

Table 3-18.   Costs of Erosion Control Measures in Idaho (Megahan, 1987)

Measure	Cost ($/acre)
Dry seeding	$178
Plastic netting placed over seeded area	$8,124

Best Management Practices

Road Surface Construction Practices

◆ Follow the design developed during preharvest planning to minimize erosion by properly timing and limiting ground disturbance operations.

Verify with site visits that information used during preharvest planning to develop road layout and surfacing designs is accurate. Make any changes to road and road surface construction designs that are necessary based on new information obtained during these site visits.

◆ *During road construction, operate equipment to minimize unintentional movement of excavated material downslope.*

◆ *Properly dispose of organic debris generated during road construction.*

  • Stack usable materials such as timber, pulpwood, and firewood in suitable locations and use them to the extent possible. Organic debris can be used as mulch for erosion control, piled and burned, chipped, scattered, place in windrows, or removed to designated sites. Slash can be useful if placed as windrows along the base of the fill slope. A windrow is created by piling logging debris and unmerchantable woody vegetation in rows on the contour of the land. Arranged in this manner, the slash material provides a barrier to overland flow, prevents the concentration of runoff, and reduces erosion.

  • Don't use organic debris as fill material for road construction since the organic material eventually decomposes and causes fill failure.

  • Perform any work in the stream channel by hand to the extent practicable. Machinery can be used in the SMA as long as the desired SMA objective is not compromised.

◆ *Prevent slash from entering streams and promptly remove slash that accidentally enters streams to prevent problems related to slash accumulation.*

To the extent possible, prevent slash from entering streams. If allowed to stay in streams, it can cause flow or fish passage problems, or dissolved oxygen depression as it decomposes. Leave natural debris in stream channels, and remove only that slash that is contributed during road construction or harvesting. Large woody debris is an important source of energy for aquatic organisms, especially in smaller headwater streams, and it creates habitat diversity important to aquatic invertebrates and young fish. It is important, therefore, to inspect streams before any work is done near them and to attempt to leave them in a condition similar to that prior to the work.

◆ *Compact the road base at the proper moisture content, surfacing, and grading to give the designed road surface drainage shaping.*

The predominant source of sediment associated with forest harvesting is the construction and maintenance of access roads, which contribute as much as 90 percent of the total eroded sediments (Appelbloom et al., 1998). The annual production of sediment from roads can be as high as 100 tons per hectare (40.5 tons per acre) of road surface or more (Grayson et al., 1993; Kockenderfer and Helvey, 1984). Management practices, including gravel surfacing, proper road maintenance, and proper drainage control, can reduce

sediment loss. Gravel surfacing has to be of a sufficient depth (e.g., 15–20 cm). Improperly maintained roads can produce up to 50 percent more sediment than properly maintained roads. Since roads can produce large quantities of sediment even when they are well maintained, careful consideration of their placement and management is extremely important to minimizing their effects on water quality.

◆ *When soil moisture is high, promptly suspend earthwork operations and weatherproof the partially completed work.*

Regulating traffic on logging roads during unfavorable weather is an important phase of erosion control. Construction and logging under these conditions destroy drainage structures, plug up culverts, and cause excessive rutting, thereby increasing the amount and the cost of maintenance.

◆ *Consider geotextiles for use on any section of road requiring aggregate material layers for surfacing.*

Geotextile is a synthetic permeable textile material used with soil, rock, or any other geotechnical engineering-related materials (Wiest, 1998). Also known as geosynthetics, geotextiles are associated with high-standard all-season roads, but can also be used in low-standard logging roads. Geotextiles have three primary functions: drainage (filtration), soil separation (confinement), and soil reinforcement (load distribution). These functions are performed separately or simultaneously, but not all functions are provided by each type of geotextile, so use care when making a purchase. Geotextiles reduce the amount of aggregate needed, thus reducing the cost of the road (Wiest, 1998).

The location of a geotextile along a forest road does not affect installation procedures. When installing geotextiles, proper procedure includes the following steps:

- Clear the subgrade of sharp objects, stumps, and debris.
- Grade the surface to provide proper drainage and cross-slope shaping.
- Unroll the geotextile on the subgrade. The amount of overlap depends on the load-bearing capacity of the subgrade, and varies from 1.5 to 3 feet. Sewing may be necessary if the geotextile is to provide reinforcement.
- Place and compact the aggregate fill. Depth of the aggregate is determined by subgrade strength and the anticipated wheel loading (usually between 9 and 24 inches). It might be necessary to back-dump the aggregate onto the geotextile and spread with a dozer or grader. The rock is feathered out, since pushing it onto the site produces an uneven distribution of the aggregate. Spread the aggregate in the same direction as the geotextile overlap to avoid separation.
- Compact the aggregate by conventional methods.

Streambanks and other slopes with light wave action can be stabilized by placing the revetment material directly on top of the geotextile. Installing the geotextile underneath the revetment material prevents the occurrence of scour which normally takes place along streambanks behind BMPs such as rip-rap. To ensure that the geotextile stays in place, toe it in at the top and bottom.

Geotextiles extend the service life of roads, increase their load-carrying capacity, and reduce the incidence of ruts. These benefits are realized due to the textiles separating aggregate structural layers from subgrade soils while allowing the passage of water.

◆ *Protect access points to the site that lead from a paved public right-of-way with stone, wood chips, corduroy logs, wooden mats, or other material to prevent soil or mud from being tracked onto the paved road.*

This practice prevents tracking of sediment onto roadways, thereby preventing the subsequent washoff of that sediment during storm events. When necessary, clean truck wheels to remove sediment before entering a public right-of-way.

◆ *Use pioneer roads to reduce the amount of area disturbed and ensure the stability of the area involved.*

Pioneer roads are temporary access ways used to facilitate construction equipment access when building permanent roads. Confine pioneer roads to the construction limits of the surveyed permanent roadway, and it is important that pioneer roads be fitted with temporary drainage structures to prevent erosion, sedimentation, and road deterioration.

◆ *If the use of borrow or gravel pits is needed during forest road construction, locate rock quarries, gravel pits, and borrow pits outside SMAs and above the 50-year flood level of any waters to minimize the adverse effects caused by the resulting sedimentation. Avoid excavating below the water table.*

Gravel mining directly from streams causes a multitude of effects, including destruction of fish spawning sites, turbidity, and sedimentation. During the construction and use of rock quarries, gravel pits, or borrow pits, either divert runoff water onto the forest floor or pass it through one or more settling basins. Revegetate and reclaim rock quarries, gravel pits, spoil disposal areas, and borrow pits upon abandonment.

Road Surface Drainage Practices

◆ *Install surface drainage controls at intervals that remove storm water from the roadbed before the flow gains enough volume and velocity to erode the surface. Avoid discharge onto fill slopes unless the fill slope has been adequately protected. Route discharge from drainage structures onto the forest floor so that water disperses and infiltrates. Methods of road surface drainage include the following:*

• *Broad-based dips.* A broad-based dip is a gentle roll in the centerline profile of a road that is designed to be a relatively permanent and self-maintaining water diversion structure that can be traversed by any vehicle (Figure 3-14). Outslope dips 3 percent to divert storm water off the roadbed and onto the forest floor, where transported soil can be trapped by forest litter. Use broad-based dips on roads having a gradient of 10 percent or less because on steeper grades they can be difficult for loaded trucks to traverse

Numbers for illustrative purposes only. Dimensions will vary.
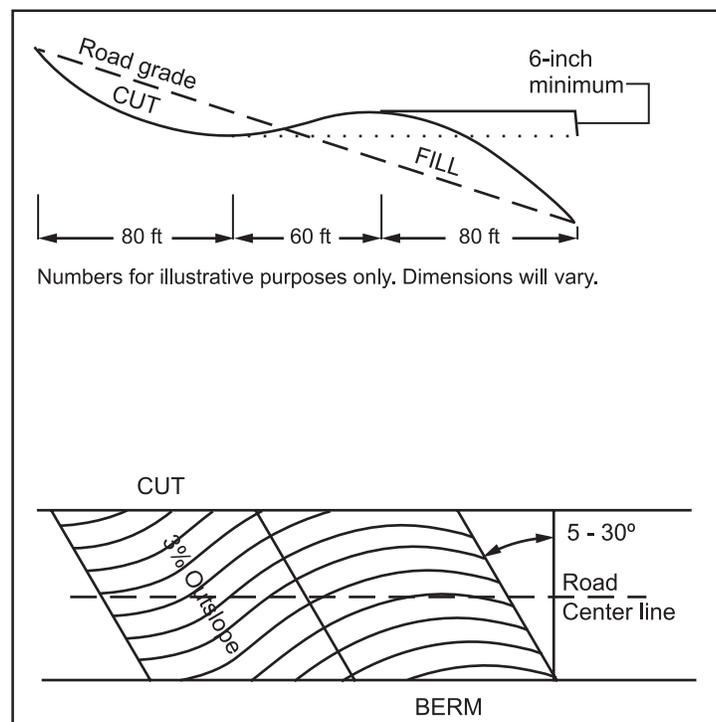
Figure 3-14.   Broad-based dip installation. A broad-based dip is a portion of road sloped to carry water from the inside edge to the outside onto natural ground (Minnesota DNR, 1995; Montana State University, 1990).

(Kochenderfer, 1995). Dips can be difficult to construct on very rocky sections of roads as well.

• *Road outsloping, Insloping, Crowning, and Grading.* Water accumulation on road surfaces can be minimized by grading and insloping or outsloping roadbeds (Figure 3-15). This minimizes erosion and the potential for road failure. Outsloping involves grading a road so that the entire width of the road slopes down the hill it is cut into, and it is appropriate when fill slopes are stable and drainage won't flow directly into stream channels. Outsloping the roadbed keeps water from flowing next to and undermining the cutbank, and it is intended to spill water off the road in small volumes along its length. Give the width of the road a 2 to 3 percent outslope.

In addition to outsloping the roadbed, construct a short broad-based dip to turn water off the surface. The effectiveness of outsloping is limited by roadbed rutting during wet conditions. Providing a berm on the outside edge of an outsloped road during construction, and until loose fill material is protected by vegetation, can eliminate erosion of the fill. A continuous berm (i.e., a low mound of soil or gravel built along the edge of a road) along a roadside can reduce total sediment loss by an average of 99 percent over a standard graded soil road surface (Applebloom et al., 1998). Berms need to have openings provided to allow water to drain off the road surface at appropriate locations where a suitable infiltration or sediment trap site is reached (Swift and Burns, 1999). Construct berms high enough to contain the storm water, and wide enough and with a coarse material to prevent their erosion. Berms are also installed over culvert crossings to prevent runoff from draining directly into streams. A graveled road surface or a grassed strip on the edge of the driving surface can reduce total loss of sediment from roads by up to 60 percent over a standard graded soil road surface. Also, natural berms can form along the edge of older roadbeds or at

Figure 3-15. Typical road profiles for drainage and stability. Choice of cross section depends on drainage needs, soil stability, slope, and expected traffic volume. Dashed lines indicate natural land contour and solid lines indicate constructed road (Wiest, 1998).

drainage locations on constructed berms over time and block drainage. Proper maintenance, therefore, is necessary.

Insloped roads carry road surface water to a ditch along the cutbank. Ditch gradients of between 2 and 8 percent usually perform best. Slopes greater than 8 percent give runoff waters too much momentum and enough erosive force to carry excessive sediment and debris for long distances, and slopes of less than 2 percent tend to cause water to drain too slowly and do not provide the runoff with enough energy to move accumulated debris with it. The ditch grade also depends on the soil type—nearer to 2 percent on less stable soils and nearer to 8 percent on stable soils.

A crowned road surface is a combination of both an outsloped and insloped surface with the high point (crown) at the center of the road (Moll et al., 1997). The crowned road provides drainage to both sides of the roadway, and a drainage ditch is usually placed next to the road on the insloped side. Properly spaced and sized culverts then direct the runoff to an appropriate grassed buffer, detention basin, or other sediment control structure.

- *Relief culverts*. Relief culverts move water from an inside ditch to the outside edge of a road for dispersion. The culverts should protrude from both ends at least 1 foot beyond the fill and be armored at inlets to prevent undercutting and at outlets to prevent erosion of fill or cut slopes (Figure 3-16).

Figure 3-16.   Design and installation of relief culvert (Vermont DFPR, 1987).

Where the slope on the cutslope above a culvert is steep, as is often the case because of the need to cut into the slope to accommodate the culvert opening, soil erosion above culverts and culvert plugging might be a problem. Installing a riser pipe on the inlet end of a culvert with holes or slits cut at a proper height to allow water to enter (which depends on the amount of soil eroding and flow in the ditch) can prevent plugging while allowing runoff drainage. A ditch dam will reinforce the entrance of water into the culvert through the riser holes (Firth, 1992).

- *Open-top or pole culverts.* Open-top or pole culverts are temporary drainage structures that are most useful for intercepting runoff flowing down road surfaces (Figure 3-17). They can also be used as a substitute for pipe culverts on roads of smaller operations, if properly built and maintained, but don't use them for handling intermittent or live streams. Place open-top culverts at angles across a road to provide gradient to the culvert and to ensure that no two wheels of a vehicle hit it at once. For an open-top culvert to function properly, careful installation and regular maintenance are necessary. Open-top culverts are recommended for ongoing operations only and are best removed upon completion of forestry activities (Wiest, 1998). These culverts generally slope below the perpendicular to the road at 10 to 45 degrees. Additional maintenance can be necessary as the angle approaches 10 degrees because at this angle debris tends to accumulate; an angle of 30 to 45 degrees is usually recommended (Wiest, 1998).

Figure 3-17. **Details of installation of open-top and pole culverts (Wiest, 1998; Vermont DFPR, 1987).**

Figure 3-18. **Grading and spacing of road turnouts (Georgia Forestry Commission, 1999).**

Open-top culverts constructed of 8-inch or 10-inch pipe are useful as a supplemental means of runoff control on steep sections of roads where broad-based dips are difficult to install and difficult for trucks to traverse (Kockenderfer, 1995). They are also useful on excessively rocky sections of roads where broad-based dips are difficult to construct. Rectangular openings spaced evenly along the top of a piece of pipe direct runoff into the pipe, and unbroken spacings between the openings provide structural integrity. The culverts can be installed by hand and can be removed and used elsewhere when a road is decommissioned. Their trenches are shallower than those for pole culverts. Discharges from all types of culverts can be controlled using plastic corrugated culvert piping cut in half or, where something that blends in with the surroundings is desired, with riprap (Kockenderfer, 1995). Diversions or in-ditch dams can be placed in ditches to ensure that flow in ditches is directed into culverts and it does not bypass culverts and continue to gain momentum and erosive force.

*   *Ditches and turnouts.* Use ditches only where necessary to discharge water to vegetated areas via turnouts (Figure 3-18). Turnouts should be used wherever there is an adequate, safe outlet site where the water can infiltrate. In most cases, the less water a ditch carries and the more frequently water is discharged, the better. Construct wide, gently sloping ditches, especially in areas with highly erodible soils. Slow the velocity of water by installing check dams, rock dams that intercept water flow, along the ditch or lining the ditch with rocks. Check dams also trap sediment and need to be

inspected for sediment build-up. Additionally, stabilize ditches with rock and/or vegetation and protect outfalls with rock, brush barriers, live vegetation, or other means. Roadside ditches need to be large enough to carry runoff from moderate storms. A standard ditch used on secondary logging roads is a triangular section 45 cm deep, 90 cm wide on the roadway side, and 30 cm wide on the cutbank side. The minimum ditch gradient is 0.5 percent, and 2 percent is preferred to ensure good drainage. Runoff is diverted frequently to prevent erosion or overflow.

◆ *Install turnouts, wing ditches, and dips to disperse runoff and reduce the amount of road surface drainage that flows directly into watercourses.*

◆ *Install appropriate sediment control structures to trap suspended sediment transported by runoff and prevent its discharge into the aquatic environment.*

Methods to trap sediment include the following:

• *Sediment traps*. Sediment traps are used downstream of erodible soil sites, such as cuts and fills, to keep sediment from flowing downstream and entering water bodies (Figure 3-19) (Ontario MNR, 1990). They are located close to the source of sediment and preferably in a low area. Use them for drainage areas of less than 5 acres. Size sediment traps so that the expected sediment runoff fills them at about the time that the disturbed area reestablishes vegetation. If sediment accumulates beyond this time, periodic cleaning becomes necessary. Sediment traps are most effective at removing large sediment particles.

• *Brush barriers*. Brush barriers are slash materials piled at the toe slope of a road or at the outlets of culverts, turnouts, dips, and water bars. Install brush barriers at the toes of fills if the fills are located within 150 feet of a defined stream channel. Brush barriers must have good contact with the ground and be constructed approximately on the contour if they are to be effective in minimizing sediment runoff. Figure 3-20 shows the use of a brush barrier at the toe of fill. Proper installation is important because if the brush barrier is not firmly anchored and embedded in the slope, brush material can be ineffective for sediment removal and can detach to block ditches or culverts. In addition to use as brush barriers, slash can be spread over exposed mineral soils to reduce the effect of precipitation events and surface flow.

• *Silt fences*. Silt fences are temporary barriers used to intercept sediment-laden runoff from small areas. They act as a strainer: silt and sand are trapped on the surface of the fence while water passes through. They usually consist of woven geotextile filter fabric or
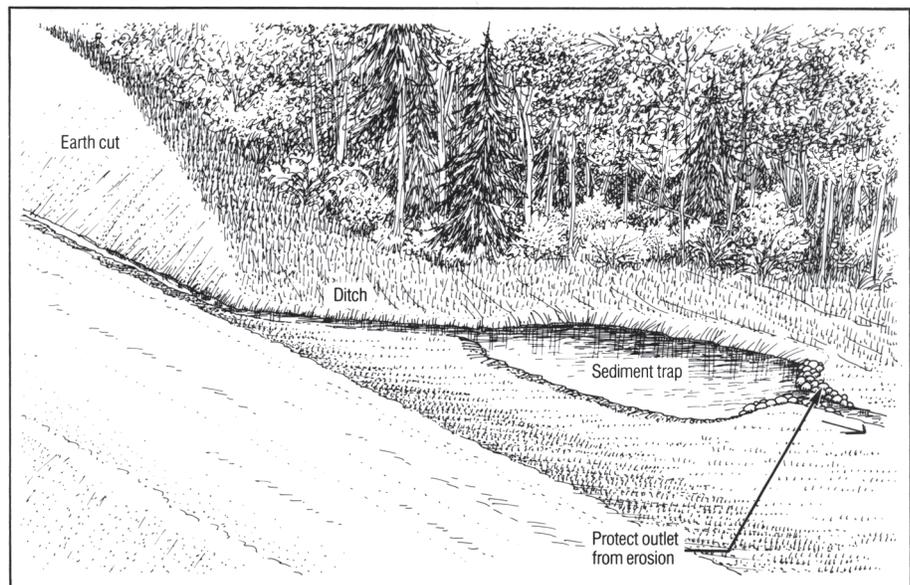
Figure 3-19.   Sediment trap constructed to collect runoff from ditch along cutslope (Ontario MNR, 1990).
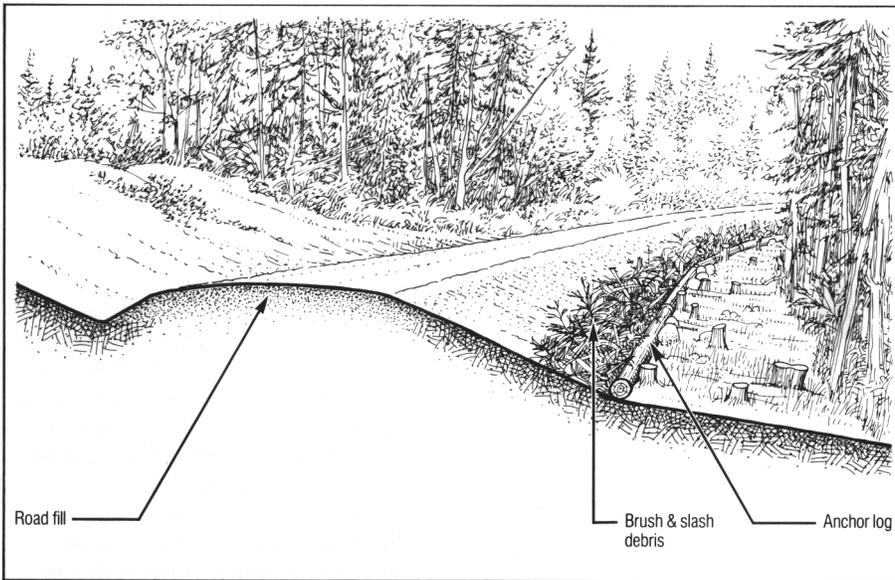
Figure 3-20. **Brush barrier placed at toe of fill to intercept runoff and sediment (Ontario MNR, 1990).**

straw bales. Install silt fences before earthmoving operations and place them as much along the contour as possible (Figure 3-21).

*   *Filter strips.* Sediment control is achieved by providing a filter or buffer strip between streams and construction activities to use the natural filtering capabilities of the forest floor and litter (Figure 3-22). The Streamside Management Area management measure recommends the presence of a filter or buffer strip around all water bodies. Filter strips are effective at trapping sediment only when the runoff entering them is dispersed. Concentrated flows, such as from culverts, ditches, gullies, etc., entering filter strips will tend to cut a path through the filter strip and render it ineffective.

Foresters with the USDA Forest Service working in the Allegheny National Forest in Pennsylvania inspected numerous roads and streams to determine the minimum length of filter strip between the two that was necessary for preventing sediment from reaching the streams (USDA-FS, 1994, 1995). They found that no matter what the slope, filter strips 100 feet in length were the minimum necessary to prevent sedimentation; in more than a few instances, filter strips as long as 200 feet were necessary. In a test of filtering capacities of roadside erosion control techniques in Tuskegee National Forest in Macon County, Alabama, sediment fences retained 29 percent of runoff sediment and vegetative strips
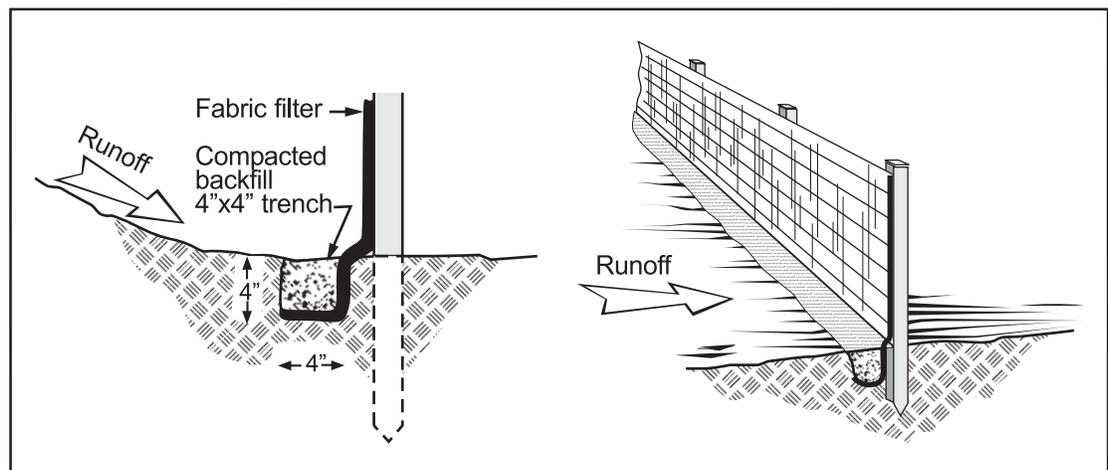
Figure 3-21. **Silt fence installation (Wisconsin DNR, 1989).**

retained 13.5 percent. Sediment below riprap increased by 10 percent, indicating that riprap has no ability to filter sediment from runoff.

These findings illustrate the importance of both using guidelines developed for the area where the harvest is to occur and inspecting points where runoff is concentrated (e.g., culvert outlets, turnouts) to see if sedimentation controls are sufficient to protect streams. Slope, type of vegetation, ground litter, and nature of flow (channelized or overland) combine to determine how effective filter strips are, and how wide they must be. If sedimentation is found to be occurring despite having installed BMPs according to specifications additional sediment control BMPs might be needed.
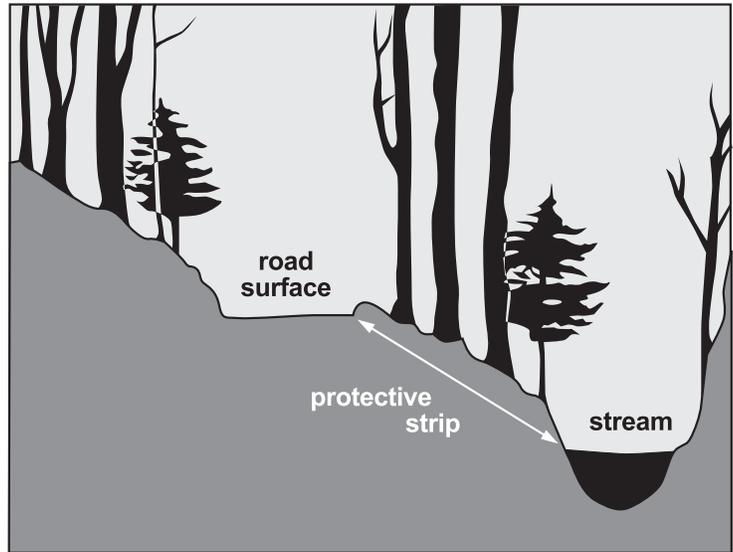
Figure 3-22. **Protective filter strip maintained between road and stream to trap sediment and provide shade and streambank stability (Vermont DFPR, 1987).**

Road Slope Stabilization Practices

◆ *Visit locations where roads are to be constructed on steep slopes or cut into hillsides to verify that these are the most favorable locations for the roads.*

Aerial photos and topographic and soil maps can inaccurately represent actual conditions, especially if these media are more than a few years old. Visiting a location where roads are to be cut into slopes or built on steep slopes or where skid trails, landings, and equipment maintenance areas are to be located is valuable for verifying that the information used during planning is accurate. Such visits can also help in determining whether roads can be located to pose less risk of erosion than the risk associated with the locations originally chosen.

◆ *Use straw bales, straw mulch, grass seeding, hydromulch, and other erosion control and revegetation techniques to stabilize slopes and minimize erosion (Figure 3-23). Straw bales and straw mulch are temporary measures used to protect freshly disturbed soils and are effective when implemented and maintained until adequate vegetation has established to prevent erosion.*

◆ *Compact the fill to minimize erosion and ensure road stability.*

During construction, fills or embankments are built up by gradual layering. Compact the entire surface of each layer with a tractor or other construction equipment. If the road is to be grassed, do not compact the final layer in order to provide an acceptable seedbed.

◆ *Revegetate or stabilize disturbed areas, especially at stream crossings.*

Cutbanks and fill slopes along forest roads are often difficult to revegetate. Properly condition slopes to provide a seedbed, including rolling embankments and scarifying cut slopes. The rough soil surfaces provide niches in which seeds can lodge and germinate. Seed as soon as it is feasible after the soil has been disturbed, preferably before it rains. Early grassing and spreading of brush or erosion-resisting fabrics on exposed soils at stream crossings are imperative. See the Revegetation of Disturbed Areas management measure for a more detailed discussion.

Stream Crossing Practices

◆ *Based on information obtained from site visits, make any alterations to the harvesting plan that are necessary or prudent to protect surface waters from sedimentation or other forms of pollution and to ensure the adequacy of fish passage.*

After preharvest planning has been completed with the aid of aerial photos and/or topographic maps, site visits can be conducted to verify the information used to determine the locations of stream crossings. Photos and maps record the landscape at a moment in time, and changes might have occurred since these media were created. Land use

Figure 3-23. Details of hay bale installation, used to prevent sediment from skid trails and roads from entering surface waters (Georgia Forestry Commission, 1999; Vermont DFPR, 1987).

changes in the upper portion of the watershed in which harvesting occurs could have altered streamflow, which in turn might have modified stream corridor characteristics. As a result, alternative stream crossing locations might have to be found. Slopes might be inaccurately represented on topographic maps, and therefore stream crossing approaches or roads near streams might have to be relocated to avoid steep grades, or the width of SMAs might have to be increased. Land use changes in the watershed that increase streamflow or changes in weather patterns (such as numerous recent years of above-average rainfall) that affect streamflow characteristics might call for larger culverts than those originally intended or a switch from fords to culverts or from culverts to temporary bridges to ensure that fish can pass and that stream crossings can adequately handle streamflow. Refer to *Fish Passage Practices* later in this section for further information on constructing stream crossings that ensure adequate fish passage.

◆ *Construct stream crossings to minimize erosion and sedimentation.*

Erosion and sedimentation can be minimized by avoiding any operation of machinery in water bodies. It is especially important to not work in or adjacent to live streams and water channels during periods of high streamflow, intense rainfall, or migratory fish spawning.

Avoid stream crossings whenever practical alternatives are available. When it is necessary to construct stream crossings, install as few of them as possible, select their locations carefully, and select the most appropriate type of stream crossing for the particular site (Blinn et al., 1999). Use existing stream crossings whenever this would affect water quality less than

constructing a new one. Make crossings at the narrowest practical portion of a stream and, if possible, cross at a right angle to the stream. Crossing at right angles reduces the potential for sediment to be carried down the road and deposited into the stream during a rain event. If the right angle crossing is too long it is likely to be ineffective. Crossing at right angles is not always practical, particularly in gentle topography. Gentle topography does not accelerate runoff into streams as steep angles do. If there is a gentle grade to a stream, the installation of water turnouts and a broad-based dip on each side of the crossing might suffice. This diverts the majority of the water that is runoff down the road. Avoid sags in grades on stream crossings, as they can cause road runoff to enter the stream (Swift and Burns, 1999). Road grade, whether up or down, should be maintained over the length of the crossing and the runoff diverted from the road at the first feasible location after the crossing.

Diverting a stream from its natural course is a potential problem when any stream crossing is constructed. When the capacity of a culvert under a stream crossing is too small or a culvert becomes plugged, flow is diverted around the culvert (Furniss et al., 1997). The stream might maintain its natural course (flow across the road parallel to the culvert), or, if the road has an inclining grade across the stream crossing in the direction of streamflow or it slopes downward away from a stream crossing in at least one direction, flow is diverted along the road for a distance until it reaches a low point, flows out of the road, and finds a new course to rejoin the original stream course. If left unchecked, such unintentional diversion can result in very large amounts of erosion and sedimentation and long-term adverse effects to roads and aquatic habitats. Stream diversion can also be caused by accumulations of snow and ice on the road that direct water out of the channel. Diversion potential is greatest on outsloped roads that redirect stream water down a road instead of across it (Best et al., 1995).

Stream diversion is best avoided by properly sizing culverts based on streamflow, constructing crossings such that their grade rises away from the crossing at each approach, inspecting stream crossings regularly after their construction, and maintaining roads and stream crossings properly (Bohn, 1998). Eliminating the potential for stream diversion by properly planning, installing, and maintaining roads and stream crossings is, in the long term, much less expensive and straightforward than attempting to correct improper design and installation after a stream crossing fails (Furniss et al., 1997).

◆ *Install a stream crossing that is appropriate to the situation and conditions.*

Determining the stream classification and the type of road to be constructed (e.g., temporary, seasonal, or permanent all-weather) is the first step in defining the type of stream crossing to be installed (Weaver, 1994). Design stream crossings to minimize effect on water quality, to handle peak runoff from flood waters, and to allow for adequate fish passage (where fish could be seasonally present). There are three basic subcategories of both permanent and temporary stream crossings: (1) bridges, (2) fords, and (3) culverts.

• *Bridges*. Temporary or portable bridges are being used increasingly because they can be installed and removed with minimal site disturbance or water quality effect and reused (Figure 3-24) (Taylor et al., 1999). Temporary stream crossings can be constructed of polyvinyl chloride and high-density polyethylene pipe bundles, and portable bridges are often constructed of steel (Blinn et al., 1999; Taylor et al., 1999). Approaches on weak soils can be protected with logs, wood mats, wood panels, or expanded metal grating placed over a woven geotextile.
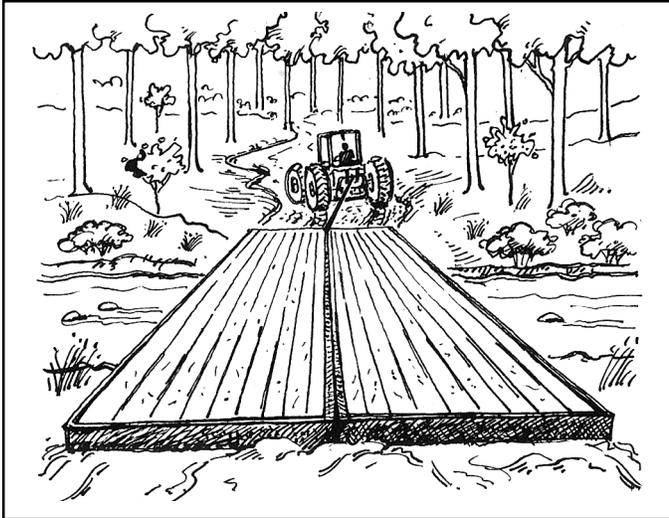
Figure 3-24. **Portable bridge for temporary stream crossing (Indiana DNR, 1998).**

- *Fords*. A ford is a low-water crossings that uses existing or constructed stream bottoms to support vehicles when crossing a stream (Figure 3-25). A ford is an appropriate stream crossing structure under the following circumstances (Wiest, 1998):

  – The streambed has a firm rock or coarse gravel bottom, and the approaches are low and stable enough to support traffic.

  – Traffic volume is low.

  – Water depth is less than 3 feet.

  – Ford will not prevent fish migration.

If log, coarse gravel, or gabion is used to create a driving surface at a stream ford, install the crossing flush with the streambed to minimize erosion and to allow fish passage. Stabilize approaches to the ford using nonerodible material that extends at least 50 feet from the ford on both sides of the stream crossing.
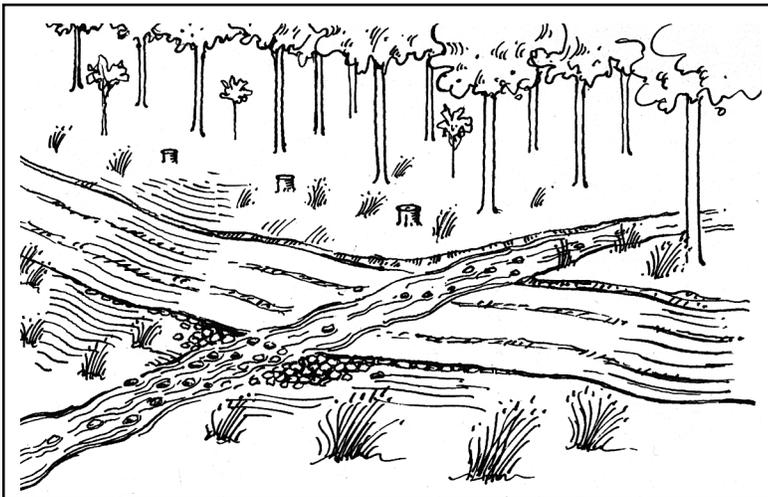
Figure 3-25. **A stream ford. Hard and stable approaches to a ford are necessary (Indiana DNR, 1998).**

The following is a common procedure for crossing a small stream where a streambed is not armored with bedrock or an otherwise stable foundation:

  – Place several inches of rock down on the streambed. The rock size depends on actual costs, haul distance, and how much is to be installed. Normally, 2 feet or more of rock is installed.

  – Place geotextiles over the rock. Geotextile costs approximately $550 per 1,000 square yards.

  – Spread out approximately 1 foot of gravel. The amount and size of gravel varies with the conditions of the stream crossing.

Unless they are very large, stream fords are often the least expensive stream crossing to construct (Taylor et al., 1999). However, they can have greater effects on water quality than other crossings because sediment is introduced during construction and vehicle crossings. They also permit sediment-laden runoff to flow downslope directly into a stream unless adequate runoff diversions are installed.

- *Stream Crossing Culverts*. Stream crossing culverts are placed on roads where a semi-permanent or permanent stream crossing is necessary and to minimize interference with streamflow and stream ecology. Culverts often need outlet and

inlet protection to keep water from scouring away supporting material and to keep debris from plugging the culvert. Firmly anchor culverts and compact the earth at least halfway up the side of the pipe to prevent water from leaking around it (Figure 3-26). Energy dissipaters, such as riprap and slash, can be useful for this if installed at culvert outlets. If riprap is used for inlet protection, a layer of geotextile should be placed behind the riprap to prevent erosion. Culvert spacing depends on rainfall intensity, drainage area, topography, and amount of forest cover. Most state forestry departments can provide recommendations for culvert pipe diameters.

According to Murphy and Miller (1997), culverts should be able to handle large flows—at least the 50-year flood. The larger the drainage area leading to a culvert and the steeper the topography, the larger the culvert needs to be to adequately handle the storm flow. If culverts are not properly sized for site-specific factors, culvert blowouts and overtopping can occur. Improper culvert sizing and spacing in Breitenbush, Oregon, led to severe road damage after a storm, and the estimated cost for the additional culverts that would have properly drained the watershed was $23,500, or 21 percent of the estimated $110,000 that was necessary to restore the road after the storm (Copstead et al., 1998).

If possible, install arch culverts (Figure 3-4) to avoid disturbance to the stream bottom, or place culverts within the natural streambed (Figure 3-27). Place the inlet on or below the streambed to minimize flooding upstream and to facilitate fish passage. Align large culverts with the natural course and gradient of the stream unless the inlet condition can be improved and the erosion potential reduced with some channel improvement. Use energy dissipators at the downstream end of the culverts to reduce the erosion energy of emerging water.

- Design stream crossings to fail during very large storm events.

Stream crossings cannot be designed for the largest possible storm that could occur, and rarely but eventually many streams will carry flows that exceed even the largest stream crossings along it. If stream crossings are not designed to fail under such circumstances, major erosion can result. One of the most important aspects of designing a stream crossing for failure is to design the path that excessive stream flow will
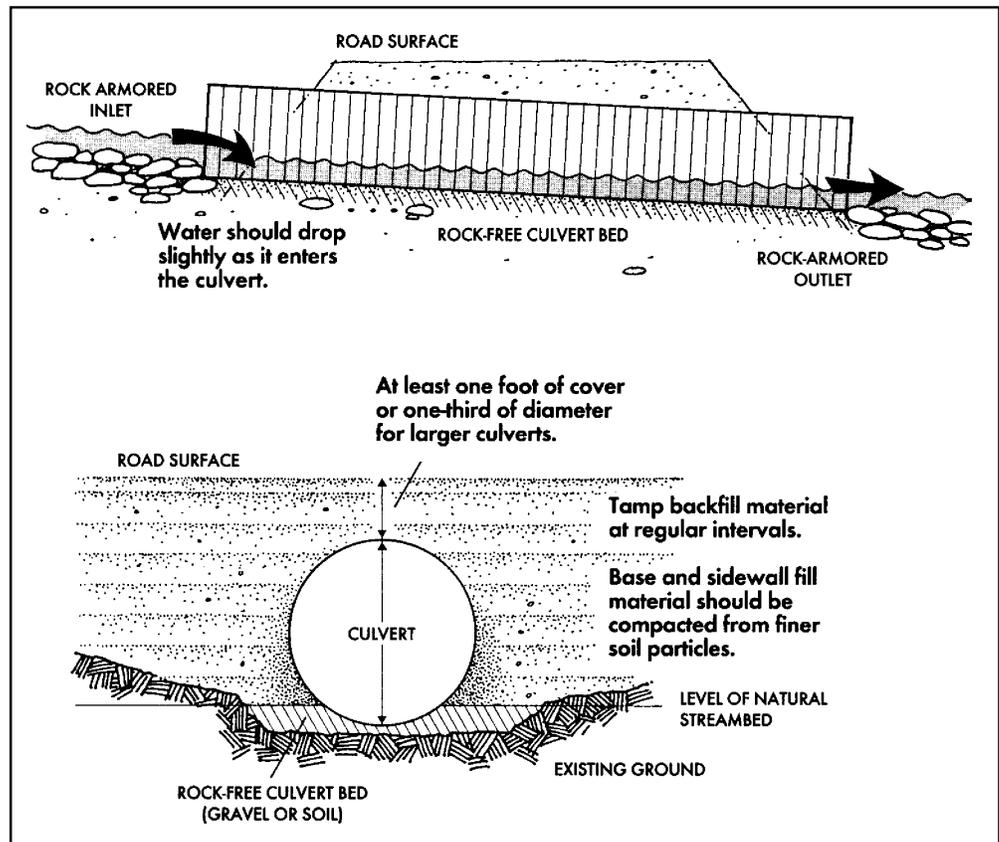
Figure 3-26.   Design and installation of pipe culvert at stream crossing (Montana State University, 1991).
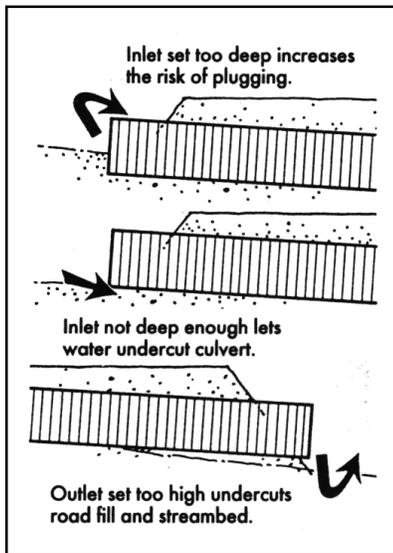
Figure 3-27. Proper installation of culvert in the stream is critical to preventing plugging or undercutting (Montana State University, 1991).

follow (Furniss et al., 1997). Maximize the likelihood that the excessive flow will follow the natural course of the stream. The following are means to achieve this objective (Furniss et al., 1998):

– Locate stream crossings where the road grade rises away from the crossing at each approach.

– Create a rolling grade where a stream is crossed on a climbing road to prevent overflow from flowing down the road.

– Design stream crossings with the least amount fill possible and construct fills with coarse material.

◆ *Construct bridges and install culverts during periods when streamflow is low.*

◆ *Do not perform excavation for a bridge or a large culvert in flowing water. Divert the water around the work site during construction with a cofferdam or stream diversion.*

Isolating the work site from the flow of water is necessary to minimize the release of soil into the watercourse and to ensure a satisfactory installation in a dry environment. Minimize environmental effects by limiting the duration of construction and by establishing limits on the quantity of surface area disturbed and the equipment to be used. Also, operate when disturbance can most easily be controlled, and use erosion and sediment controls such as silt fences and sediment catch basins. Only use diversions where constructing the stream crossing structure without diverting the stream would result in instream disturbance greater than the disturbance from diverting the stream. Figure 3-28 portrays a procedure for installing a large culvert when excavation in the channel of the stream would cause sedimentation and increase turbidity.

◆ *Protect embankments with mulch, riprap, masonry headwalls, or other retaining structures.*

Some form of reinforcement along stream banks at road stream crossings can reduce sediment loss from these sites (Table 3-19). Soft protection, such as mulch or forest debris, or hard protection, such as gravel or riprap, can be used to protect these vulnerable locations.

◆ *Construct ice bridges in streams with low flow rates, thick ice, or dry channels during winter. Ice bridges might not be appropriate on large water bodies or areas prone to high spring flows.*

Ice bridges can provide acceptable temporary access across streams during winter. Ice bridges are made by pushing and packing snow into streams and applying water to freeze the snow (Figure 3-29). Their use is limited to winter under continuous freezing conditions. A permit might be necessary before an ice bridge crossing can be built, and operators can check this with the appropriate state agency prior to ice bridge construction.

The Minnesota Extension Service (1998) suggests the following when building an ice bridge:

• Choose a period when night temperatures are below 0 °F.
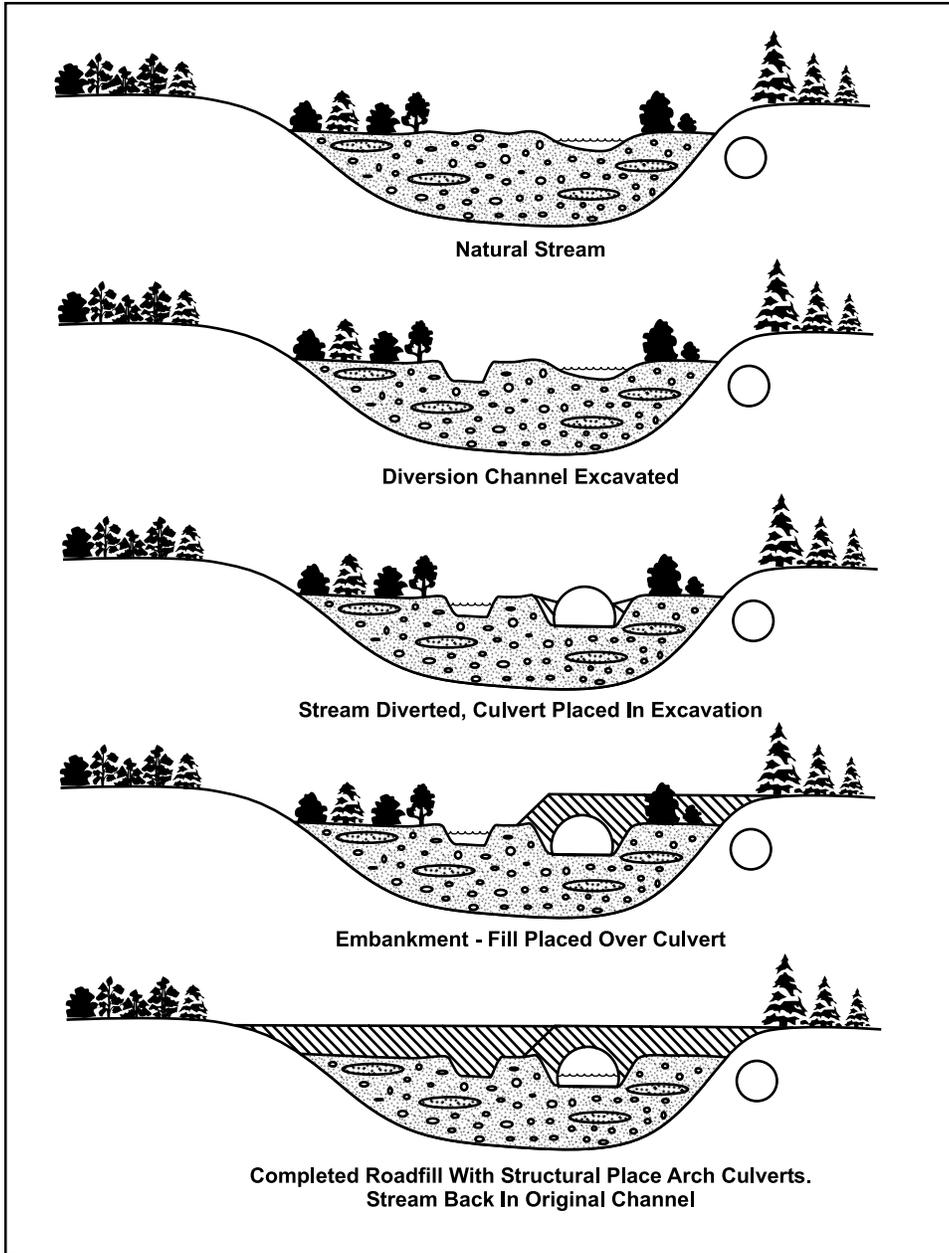
Figure 3-28. **Procedure for installing culvert when excavation in channel section of stream could cause sediment movement and increase turbidity (Hynson et al., 1982).**

Table 3-19. **Sediment Loss Reduction from Reinforcement at Road Stream Crossings (Rothwell, 1983)**

Quantity of Sediment Lost	Embankment Reinforcement with Mulch	No Reinforcement
	566 kg/day/ha	2,297 kg/day/ha
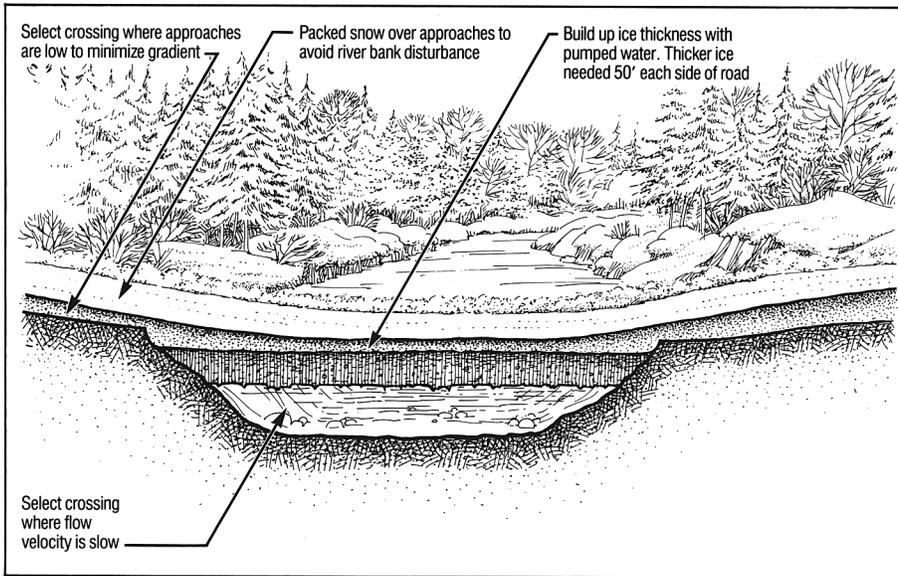
Figure 3-29.   **Details of ice bridge construction for temporary stream crossing in winter (Ontario MNR, 1990).**

- Make the approaches to the ice bridge nearly level or level.

- Don't add brush or other vegetation to the ice bridge. Doing so weakens the structure and can create a dam when the bridge melts.

- Let the surface freeze; then repeat the construction process until the crossing is of the desired thickness and width.

- Make the bridge thick enough to permit a level approach.

- Also, make the ice thick enough to support the weight and speed of anticipated traffic.

- Inspect the bridge often, because weather and water flow can affect its strength.

Properly constructed winter roads have provisions for adequate drainage during winter weather warmups, and for the spring thaw. If a winter thaw occurs, expect to temporarily shut down road travel. The thaw creates working conditions similar to a wet weather event and causes erosion, severe soil compaction, rutting, and possibly vehicle damage.

Fish Passage Practices

◆ *On streams with spawning areas, avoid construction during egg incubation periods.*

◆ *Design and construct stream crossings for fish passage according to site-specific information on stream characteristics and the fish populations in the stream where the passage is to be installed.*

The types of structures recommended for use on forest roads as fish passage structures are listed below in order of preference (WADOE, 1999). The choice and design of each is determined by a number of factors, including sensitivity of the site to critical fish habitats, engineering specifications, cost, and availability of materials.

1. Bridges—permanent, semipermanent, and temporary

2. Bottomless culverts or log culverts

3. Embedded metal culverts

4. Nonembedded culverts

5. Baffled culverts

Baffled culverts are the most complicated type of fish passage and are the most difficult to design and construct.

To ensure safe fish passage can be provided without resulting in unacceptable effects on existing fisheries habitat values, consider physical, hydrological, and biological factors to determine whether a structure is acceptable for a site. Review the harvest plan and, based on actual site conditions, make any changes necessary to ensure adequate fish passage. Streamflow, bottom substrate, approach slopes, and soil types on either side of the stream are some details from the harvest plan to verified at the site prior to constructing stream crossings and installing culverts. The minimum site data for any proposed bridge or major culvert include

- Cross section showing the high water mark and profile of water crossing.
- Description of water body bed materials.
- Presence or absence of and depth to bedrock.
- Water velocity and direction.
- Bankfull width and depth.
- Bottom channel width.
- Channel topography, including gradient for the site and reach.
- Assessment of natural sediment and debris loading and any other condition that might influence the choice, design, and location of a structure.
- Existing improvements and resource values that might influence the structure.

Minimum biological data for successful stream crossing design include

- Species of fish that you'll want to safely pass
- Size of fish that will pass (life stage)
- Time of year in which fish passage occurs
- High and low design passage flows

The success of any fish passage structure depends very much on channel adjustments that occur after construction of the stream crossing, so it is important to survey far enough upstream and downstream to account for any possible channel conditions that might affect the design and placement of the structure.

3D: ROAD MANAGEMENT

Management Measure for Road Management

(1) Avoid using roads where possible for timber hauling or heavy traffic during wet or thaw periods on roads not designed and constructed for these conditions.

(2) Evaluate the future need for a road and close roads that will not be needed. Leave closed roads and drainage channels in a stable condition to withstand storms.

(3) Remove drainage crossings and culverts if there is a reasonable risk of plugging or failure from lack of maintenance.

(4) Following completion of harvesting, close and stabilize temporary spur roads and seasonal roads to control and direct water away from the roadway. Remove all temporary stream crossings.

(5) Inspect roads to determine the need for structural maintenance. Conduct maintenance practices, when conditions warrant, including cleaning and replacement of deteriorated structures and erosion controls, grading or seeding of road surfaces, and, in extreme cases, slope stabilization or removal of road fills where necessary to maintain structural integrity.

(6) Conduct maintenance activities, such as dust abatement, so that chemical contaminants or pollutants are not introduced into surface waters to the extent practicable.

(7) Properly maintain permanent stream crossings and associated fills and approaches to reduce the likelihood (a) that stream overflow will divert onto roads and (b) that fill erosion will occur if the drainage structures become obstructed.

Management Measure Description

The objective of this management measure is to ensure the management of existing roads to maintain their stability and utility; to minimize erosion, polluted runoff from roads and road structures, and sedimentation in water bodies; and to ensure that roads no longer needed are properly closed and decommissioned so they pose minimal risk to water quality.

Roads that are actively maintained reduce the potential for erosion to occur. Road drainage structures, road fills in stream channels, and road fills on steep slopes are of greatest concern with respect to water quality protection in road management. Roads actively used for timber hauling usually need the most maintenance, and mainline roads typically need more maintenance than spur roads. Regular road use by heavy trucks, especially at stream crossings, creates a chronic source of sediment runoff to streams (Murphy and Miller, 1997). It is important to inspect and repair roads prior to heavy use, especially during wet or thawing ground conditions (Weaver and Hagans, 1984). Use of roads during wet or thaw periods can result in excessive sediment loading to water bodies when road surfaces become deeply rutted and drainage becomes impaired. The first rule of maintaining a stable road surface is to minimize hauling and grading during wet weather conditions, especially if the road is unsurfaced (Weaver and Hagans, 1984).

Sound planning, design, and construction measures often reduce road maintenance needs after construction. Roads constructed with a minimum width in stable terrain, and with frequent grade reversals or dips, need minimum maintenance. Unfortunately, older roads remain one of the greatest sources of sediment from managed forestlands. After harvesting is complete, roads are often forgotten, and erosion problems might go unnoticed until after severe resource damage has occurred.

Routine maintenance of road dips and road surfaces and quick response to drainage problems can significantly reduce road deterioration and prevent the creation of ruts that could channelize runoff (Ontario Ministry of Natural Resources, 1988; Oregon Department of Forestry 1981). Roads and drainage structures on all roads, including decommissioned roads for as long as water quality effects might result from them, should be inspected annually, at a minimum, prior to the beginning of the rainy season (Weaver and Hagans, 1984). Also inspect and perform emergency maintenance during and following peak storms.

In some locations, problems associated with altered surface drainage and diversion of water from natural channels results in serious gully erosion or landslides. In western Oregon, 41 out of the 104 landslides reported on private and state forestlands during the winter of 1989-90 were associated with older (built before 1984) forest roads. These landslides were related to both road drainage and original construction problems. Smaller erosion features, such as gullies and deep ruts, are far more common than landslides and very often are related to poor road drainage.

Sedimentation from roads can be reduced significantly if drainage structures are maintained to function properly. Culverts and ditches that are kept free of debris are less likely to restrict water flow and fish passage. Routinely cleaning these structures can minimize clogging and prevent flooding, gullying, and washout (Kochenderfer, 1970). Fish passage was discussed in the last management measure as an issue of proper sizing and installation of culverts and other stream crossings, and it is equally important to inspect culverts, fords, and bridges on a regular basis to ensure that debris and sediment do not accumulate and prevent fish migration. Undercutting of culvert entrances or exits can create vertical barriers to fish passage, and debris buildup at the entrances of culverts or at trash racks can prevent fish migration. If roads are no longer in use or won't be needed in the foreseeable future, removing drainage crossings and culverts where there is a risk of plugging or failure from lack of maintenance is a precautionary measure. Where a road will be used in the future, it is usually more economical to periodically maintain crossing and drainage structures than not to do so and to have to make extensive repairs after failure.

Road Reconstruction

Road reconstruction provides the opportunity to upgrade and improve substandard and old roads that are no longer used. After an on-site inspection of the entire route and consideration of the economic and environmental costs of the reconstruction, a decision about reopening a road can be made. Reconstruction might be economically feasible for a particular road but could entail unacceptable environmental costs. Roads where stream crossings have been washed out or short, steep sections of road have been entirely lost to progressive erosion or landsliding are examples of roads where the environmental costs of reconstruction might be too high (Weaver, 1994). In such cases, it might be possible to

lessen the environmental damage incurred in reconstruction by rerouting the road around problem areas with a section of new road. Factor overall project costs into the economic and environmental costs of any rerouting to determine its feasibility, and do all road reconstruction in a manner consistent with the Management Measure for Road Construction.

Washed-out stream crossings are the most common obstacle to effective road reconstruction. Initial improper sizing of drainage structures or their not being installed or maintained properly results in erosion at stream crossings. When reconstructing stream crossings, it is important to follow the same design and installation procedures as are used for new crossings.

Road Decommissioning

Proper closure, decommissioning, and obliteration are essential to preventing erosion and sedimentation on roads and skid trails that are no longer needed or that have been abandoned (Swift and Burns, 1999). Road closure involves preventing access by placing gates or other obstructions (such as mounds or earth) at road access points while maintaining the road for future use. Roads that will no longer be used or that have remained unused for many years may be decommissioned and obliterated. Decommissioning typically involves stabilizing fills, removing stream crossings and culverts, recontouring slopes, reestablishing original drainage patterns, and revegetating disturbed areas (Harr and Nichols, 1993; Kochenderfer, 1970; Rothwell, 1978). Revegetating disturbed areas protects the soil from rainfall and binds the soil, thereby reducing erosion and sedimentation and the potential for mass wasting in the future. Because closed roads and trails are rarely inspected, it is important to leave them in as stable a condition as possible to prevent erosion that could become a large problem before any damage is noticed (Rothwell, 1978).

Road decommissioning can significantly reduce water quality effects from unused roads, and road closure and decommissioning can help realize many objectives and purposes (Harr and Nichols, 1993; Moll, 1996):

- Eliminate or discourage access to roads to reduce maintenance expenditures.
- Eliminate the potential for drainage structure failure and stream diversion.
- Reduce soil loss, embankment washout, mass wasting, failures, slides, slumps, sedimentation, turbidity, and damage to fish habitat.
- Provide cover and organic matter to soil, and improve the quality of wildlife and fish habitat.
- Enhance the visual qualities of road corridors and disturbed areas.
- Attempt to restore the natural pre-road hydrology to the site.

Benefits of Road Management

Proper road maintenance has definite economic benefits. In one comparison of road maintenance costs over time, maintenance costs on a road where BMPs were not installed initially were 44 percent higher than costs on a road where BMPs were installed initially (Dissmeyer and Frandsen, 1988) (Table 3-20).

Table 3-20.   Comparison of Road Repair Costs for a 20-Year Period With and Without BMPs[a] (Dissmeyer and Frandsen, 1988)

Maintenance Costs Without BMPs		Costs of BMP Installation	
Equipment	$365	Labor to construct terraces and water diversions	$780
Materials (gravel)	122		
Work supervision	0	Materials to revegetate	120
Repair cost per 3 years	527	Cost of technical assistance	300
Total cost over 20 years [b]	$2,137	Total cost over 20 years	$1,200
IRR: 11.2%			
PNV: $937			
B/C ratio: 1.78 to 1.00 for road BMP installation versus reconstruction/repair.			

[a] BMPs include construction of terraces and water diversions, and seeding.
[b] Discounted at 4%.

In another economic study, the costs of various revegetation treatments and associated technical services (e.g., planning and reviewing the project in the field) were compared to the benefits over time of the initial planning and BMP installation (Dissmeyer and Foster, 1987) (Table 3-21). Savings resulted from avoiding problem soils, wet areas, and unstable slopes, and the analysis demonstrated that including soil and water resource management (i.e., revegetating and technical services) in road planning and construction is more economical over the long term.

As part of the Fisher Creek Watershed Improvement Project, Rygh (1990) examined the costs of ripping and scarification using different techniques and specifically compared the relative advantages of using track hoes for ripping and scarification versus using large tractor-mounted rippers. Track hoes were found to be preferable to tractor-mounted rippers for a variety of reasons, including the following:

Table 3-21.   Analysis of Costs and Benefits of Watershed Treatments Associated with Roads (SE United States) (Dissmeyer and Foster, 1987)

	Treatment[a]		
	Seed Without Mulch	Seed With Mulch	Hydroseed With Mulch
<u>Costs</u>			
Cost per kilometer ($)	511	816	1,006
Cost per kilometer for soil and water technical services ($)	89	89	89
Total cost of watershed treatment ($)	600	905	1,095
<u>Benefits</u>[b]			
Savings in construction costs ($/km)	446	446	446
Savings in annual maintenance costs ($/km)	267	267	267
Benefit/cost (10-year period)	4.4:1	2.9:1	2.4:1

Note: All costs updated to 1998 dollars.
[a] Treatments included fertilization and liming where needed.
[b] Cost savings were associated with soil and water resource management in the location and construction of forest roads by avoiding problem soils, wet areas, and unstable slopes. Maintenance cost savings were derived from revegetating cut and fill slopes, which reduced erosion, prolonging the time taken to fill ditch lines with sediment and reducing the frequency of ditch line reconstruction.
Source: Adapted by Dissmeyer and Foster from West, S., and B.R. Thomas, 1982. Effects of Skid Roads on Diameter, Height, and Volume Growth in Douglas-Fir. *Soil Sci. Soc. Am. J.*, 45:629–632.

- A reduction in furrows and resulting concentrated runoff caused by tractors
- Improved control over the extent of scarification
- Increased versatility and maneuverability of track hoes
- Cost savings

The study concluded that the cost of ripping with track hoes ranged from $406 to $506 per mile compared to $686 per mile for ripping with D7 or D8 tractors (1998 dollars) (Table 3-22).

Road decommissioning, however, can be expensive. The estimated cost for small roads with gentle terrain and few stream crossings is approximately $22,500; for larger roads with greater slope and larger and more stream crossings, the cost can equal or exceed $282,000 (1998 dollars) (Glasgow, 1993).

Table 3-22.   Comparative Costs of Reclamation of Roads and Removal of Stream Crossing Structures (ID) (Rygh, 1990)

Method	Cost (dollars/mile)
Ripping/scarification	
Ripping with D7 or D8 tractor	$686
Scarifying with D8-mounted brush blade	$1,053
Scarification to 6-inch depth and installation of water bars with track hoe	$2,086
Ripping and slash scattering with track hoe	$549–$823
Ripping, slash scattering, and water bar installation with track hoe	$1,013
Ripping with track hoe	$406–$506

Best Management Practices

Road Maintenance Practices

◆ *Blade and reshape the road to conserve existing surface material; to retain the original, crowned, self-draining cross section; and to prevent or remove berms (except those designed for slope protection) and other irregularities that retard normal surface runoff.*

Ruts and potholes can weaken road subgrade materials by channeling runoff and allowing standing water to persist. Erosion from forest roads is a process associated with their location, construction, and use, and erosion begins with the development of ruts and the erosion of fine material from the road surface (Johnson and Bronsdon, 1995). Severe rutting on a road can cause drivers to seek routes around the ruts and lead to traffic's moving closer to riparian areas and stream channels, essentially widening a road and magnifying the problem (Phillips, 1997). Natural berms can develop on regularly used roads at undesirable locations and can trap runoff on the road instead of allowing it to drain off at design locations. Natural berms can also develop from improper road grading or gradual entrenchment of the road below the surrounding terrain (Swift and Burns, 1999). If serious road degradation due to rutting or other causes has occurred, the road can be regraded, and periodic regrading of roads is usually necessary to fill in wheel ruts and

reshape roads. Regrading a road removes ruts, but it exposes more fine sediment that continues to erode for some months after grading until a protective, coarser layer on the road surface is developed. Serious rutting can indicate the need for a more durable surface.

◆ *Maintain road surfaces by mowing, patching, or resurfacing as necessary.*

Annual roadbed mowing and periodic trimming of encroaching vegetation is usually sufficient for grassed roadbeds carrying fewer than 20 to 30 vehicle trips per month.

◆ *Clear road inlet and outlet ditches, catch basins, culverts, and road-crossing structures of obstructions as necessary.*

Avoid undercutting back slopes when cleaning silt and debris from roadside ditches. Minimize machine cleaning of ditches during wet weather. Do not disturb vegetation when removing debris or slide blockage from ditches. The outlet edges of broad-based dips need to be cleaned of trapped sediment to eliminate mud holes and prevent the bypass of storm water. The frequency of cleaning depends on traffic load.

Clear stream-crossing structures and their inlets of debris, slides, rocks, and other materials before and after any heavy runoff period. Surveys by Copstead and Johansen (1998) of the roads in the Detroit Ranger District after storm damage showed that plugged culverts accounted for a greater percentage of damage to the roads than any other cause (Figure 3-30). Culverts were plugged by stream bedload and woody debris. Many times a small branch caught in the culvert inlet caused stream bedload to accumulate, eventually burying the inlet. Undersized culverts accounted for 81 percent of the plugged culverts.

Although regular cleaning of road ditches and culvert inlets and outlets is important, there are circumstances under which leaving accumulated debris in ditches is sometimes called for to help prevent erosion. Some debris might be left in ditches simply to interrupt the free flow of runoff down the ditch, thus reducing the velocity of the runoff and erosion as well.

During road construction, the cut slope is often undercut to provide the design flow capacity in roadside ditches or to provide room for culvert inlets, and undercut slopes are usually unstable. Especially above culvert inlets, soil erosion on the cut slope can lead to high maintenance costs. If, based on experience gained after the road is constructed, the flow in the ditch is less than it was designed for, leaving the accumulated debris in the ditch can help stabilize the cut slope above it. If debris has to be cleared out of a portion of ditch that repeatedly fills with sediment to provide sufficient volume for runoff flow, an option is to build a permanent or temporary passage under the accumulated debris and leave the debris to help stabilize the slope above the ditch. A temporary underpass can be
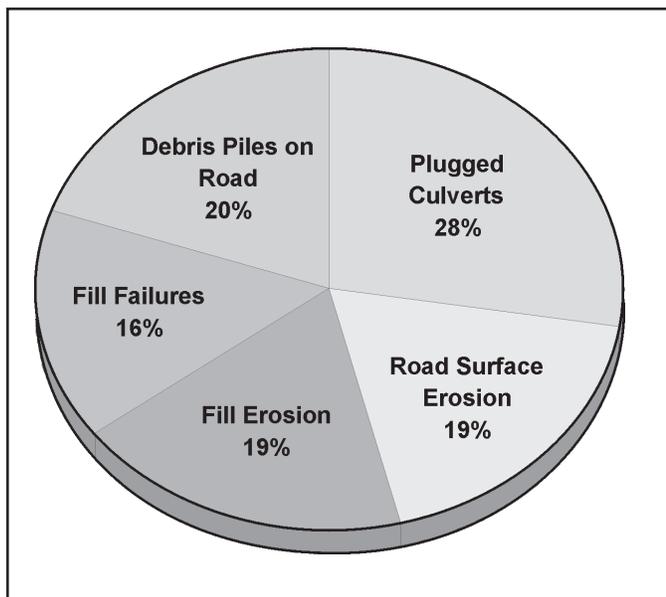
Figure 3-30. Road-related storm damage by type in the Detroit Ranger District (Copstead and Johansen, 1998).

constructed of two logs placed parallel with a gap between them and a third log on top. A permanent underpass can be constructed much like a culvert (Firth, 1992).

◆ *Remove any debris that enters surface waters from a winter road or skid trail located over surface waters before a thaw.*

◆ *Return the spring following a harvest and build erosion barriers on any skid trails that are steep enough to erode.*

◆ *Abate dust problems during dry summer periods.*

Excessive road dust during the summer is a condition that can threaten water quality. Dust can deliver large quantities of fine sediment to nearby stream channels. This fine material can be especially damaging to fish and fish habitat. Seasonal summer roads need almost the same amount of maintenance as permanent roads.

Dust control methods such as applying dust oil and watering during dry summer conditions are almost always necessary during an intensive dry season to prevent excessive loss of surface materials.

Wet and Winter Road Practices

◆ *Before winter, inspect and prepare all permanent, seasonal, and temporary roads for the winter months.*

Winterizing consists of maintenance and erosion control work needed to drain the road surface (Weaver, 1994). Clean trash barriers, culvert inlet basins, and pipe inlets of floatable debris and sediment accumulations. Clean ditches that are partially or entirely plugged with soil and debris, and trim and remove heavy concentrations of vegetation that impede flow. Gate and close seasonal and temporary roads to nonessential traffic.

Surface runoff problems caused by winter use of a bermed, unsurfaced road can cause rutting. The ruts collect runoff and cause additional erosion of the road. Lack of waterbars or rolling dips, together with the graded berm along the outside edge of the road, keep surface runoff on the roadbed. Annual grading can produce an outside berm of soil and rock that can be graded back onto the road surface.

Winter is a popular time to harvest wetlands or areas that are not accessible during wet periods, and road structures that will have to be maintained during the winter can be marked prior to snowfall. Snow accumulation could otherwise hide the BMPs.

◆ *On woodland roads "daylight" or remove trees to a width that permits full sunlight to reach the ground.*

The objective of road "daylighting" is to have sunlight dry the road so that it is less susceptible to erosion and damage from vehicle traffic. Daylighting also promotes the establishment of protective vegetative cover on road fillslopes and cutslopes and vegetation for wildlife. Vegetation clearing to promote daylighting needs to be managed so that slope integrity is not compromised. Daylighting should also be coordinated with wildlife specialists so that openings that might be detrimental to certain wildlife species, such as neotropical migratory birds, are not created.

Stream Crossing and Drainage Structure Practices

◆ *When temporary stream crossings are no longer needed, and as soon as possible upon completion of operations, remove culverts and log crossings to maintain adequate streamflow. Restore channels to pre-project size and shape by removing all fill materials used in the temporary crossing.*

Failure or plugging of abandoned temporary crossing structures can result in greatly increased sedimentation and turbidity in the stream, as well as channel blowout.

◆ *Replace open-top culverts with cross drains (water bars, dips, or ditches) to control and divert runoff from road surfaces.*

Open-top culverts are for temporary drainage of ongoing operations. It is important to replace them with more permanent drainage structures to ensure adequate drainage and reduce erosion potential prior to establishment of vegetation on the roadbed. It is recommended that open-top culverts be used for ongoing operations only and that they be removed upon completion of activities (Wiest, 1998).

◆ *During and after logging activities, ensure that all culverts and ditches are open and functional.*

Culvert plugging is common in woodland streams (Flanagan and Furniss, 1997). The risk of culvert plugging is greatest where small culverts have been installed on wide streams. Channel width controls the size of debris that can be transported in a stream, and culverts with a diameter that is less than the width of the stream are prone to block and accumulate woody debris. Another configuration that leads to debris trapping is increasing channel width toward a culvert inlet. Woody debris, transported in a lengthwise position down a stream, can rotate to a position perpendicular to the channel where the channel widens and block the culvert inlet. Hand, shovel, and chainsaw work can remedy almost all culvert maintenance needs (Weaver and Hagans, 1984). Heavy machinery and equipment is usually unnecessary to keep culverts clean.

Where culvert and ditch plugging is a problem, assess the cause of the problem and develop a strategy to correct it (see Roads Analysis in the Management Measure for Preharvest Planning, subsection 3A). Corrective measures might include installation of a new culvert, trimming dead wood from overhanging vegetation, or performing regularly scheduled maintenance.

Road Decommissioning, Obliteration, and Closure Practices

◆ *Decommission or obliterate roads that are no longer needed (see Road Decommissioning in this section).*

When a road is not needed for harvesting, forest management activities, or recreation, it can be decommissioned. Effective decommissioning reduces actual and potential erosion from the road and saves maintenance costs. Typically, a road is decommissioned by removing temporary stream crossings, installing water bars to minimize erosive surface runoff flows, and planting stream crossings and the road surface with vegetation to retail soil. If decommissioning is properly done, an area previously occupied by a forest road blends into the surrounding landscape naturally, erodes no more than an undisturbed site,

and provides wildlife habitat. Decommissioned roads are generally left in a state such that they can be opened and used again in the future should the need arise.

More than 120 miles of roads have been decommissioned in the Targhee National Forest in Idaho (USDA-FS, 1997). Roads in riparian areas were particularly targeted for decommissioning. Decommissioning the roads involved seeding with grasses and adding water bars to prevent erosion. In the Lake Tahoe Basin, existing road surfaces are ripped to a depth of 12 to 18 inches, the surface is seeded, and pine needle mulch is spread on top to prevent erosion and encourage good establishment of vegetation. The road prism and drainage features are left in place to prevent erosion and soil runoff while the vegetation establishes itself. Roads decommissioned by the U.S. Forest Service in Region 8 are similarly seeded to create linear wildlife open areas that provide forage and edge vegetation. The U.S. Forest Service in Region 4, where the Targhee National Forest is located, found that public acceptance of the road decommissioning was enhanced by adding turnarounds and parking areas at the closure gates.

Road obliteration goes further than road decommissioning by returning a forest road to its natural drainage characteristics and topography to the extent possible. It is a suitable goal for roads that will not be used in the future. Road obliteration aims to eliminate alterations in drainage patterns created by a road system and the potential for drainage structure failure and stream diversion, and to reestablish drainage connectivity that might have been interrupted by the presence of the road (Moll, 1996).

Stabilizing areas disturbed by road construction and use is another major goal of road obliteration. Disturbed slopes, road cuts and fills, and areas to which drainage will be directed after the obliteration is terminated are areas that need to be stabilized. In some cases, artificial means to stabilize slopes might be necessary until vegetation has become established.

Road obliteration can lead to improvements in fisheries habitat where sediment runoff from old forest roads enters streams. The practice was used in a watershed in northwest Washington as part of watershed rehabilitation to improve fisheries habitats and water quality and to reduce flood hazards. On unused, 30- to 40-year-old, largely impassable roads and landings, fills were stabilized, stream crossings were removed, slopes were recontoured, and drainage patterns were reestablished at an average cost of $3,950 per kilometer (with a range of $1,500 to $7,500 per kilometer) (1998 dollars). Costs were lowest where little earthmoving was involved, more where a lot of brush had to be cleared away and sidecast material had to be pulled upslope, and highest where fills were removed at stream crossings and landings. Afterward, however, the obliterated roads and landings sustained much less damage from storms than unused roads that were not obliterated (Harr and Nichols, 1993).

Road obliteration in the Redwood National Park demonstrated that the following measures are effective for restoring hydrology and habitat (Belous, 1984, cited in NCASI, 2000): stream crossing removal, road outsloping, straw mulch placement, tree planting on road alignments and stream crossings, and waterbars. Soil decompaction and terrain recontouring wee found to be important first steps in successful road obliteration. Topsoil replacement significantly aided vegetation establishment.

◆　*Wherever possible, completely close roads to travel and restrict access by unauthorized persons by using gates or other barriers (Figure 3-31).*
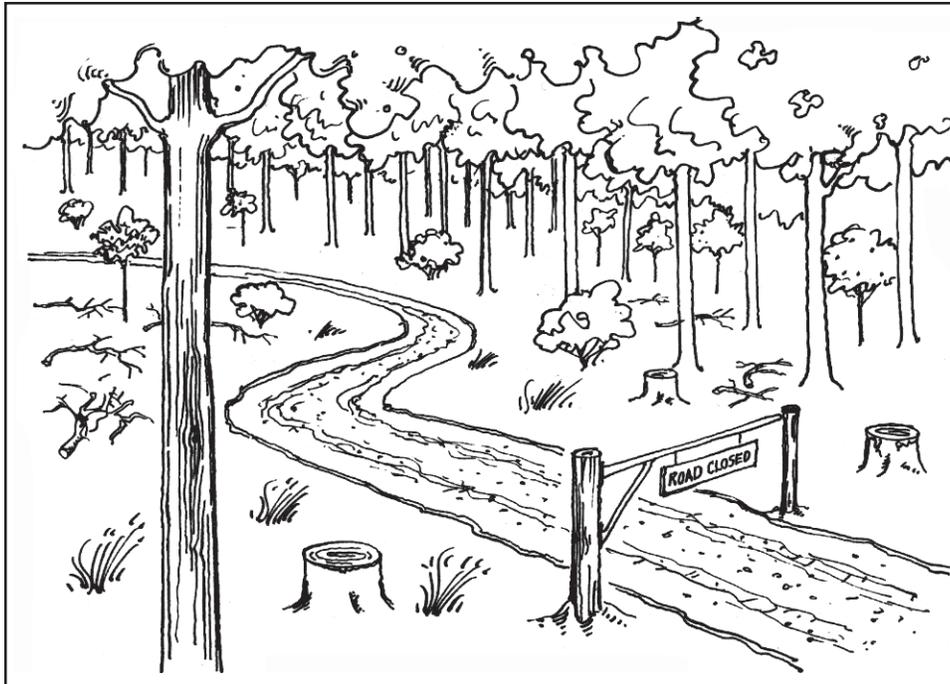
Figure 3-31.   Install visible traffic barriers where appropriate to prevent off-road vehicle and other undesired disturbance to recently stabilized roads (Indiana DNR, 1998).

Closing a road that is not needed in the immediate future for harvesting or other forestry purposes can minimize use that could create erosive conditions and the need for continual maintenance. Closed roads should be decommissioned or maintained regularly. Access to roads at entry points can be restricted using rocks, logs, slash piles, or other on-site materials; planted trees; fences, gates; guardrails; or concrete barriers. Complete obliteration of a road access point can be accomplished by recontouring and removing all drainage structures, bridges, and other road features. Traffic entry should be regulated where restricting access with such barriers is not feasible.

◆   *Convert closed forest access roads into recreation trails.*

An unused forest access road can be converted to recreational use for off-road vehicles, horseback riding, mountain biking, and hiking. All of these activities, however, create the potential for road or trail damage, and regular maintenance of stream crossings, waterbars, and other drainage structures is necessary to ensure that sediment runoff from the road does not threaten water quality. The frequency and type of maintenance depends on the type and intensity of recreational use allowed on the road. Trails need the same kinds of runoff control measures as roads, and regular trail maintenance is as important as regular road maintenance (Figure 3-32).

◆   *Install or regrade water bars on roads that will be closed to vehicle traffic and that lack an adequate system of broad-based dips (Figure 3-33).*

Water bars help to minimize the volume of water flowing over exposed areas and remove water to areas where it will not cause erosion. Water bar spacing

Figure 3-32.   Construct trails using the same drainage structures as closed forest roads (Indiana DNR, 1998).

depends on soil type and slope. Table 3-23 presents the Oregon Department of Forestry's suggested guidelines for water bar spacing. In other states with different climates, topographies, and soil types, recommended spacing might differ from these guidelines; contact the state forestry department for assistance. Divert water flow off the water bar onto rocks, slash, vegetation, duff, or other less erodible material and avoid diverting it directly to streams or bare areas. Outslope closed road surfaces to disperse runoff and prevent closed roads from routing water to streams.

◆ *Revegetate disturbed surfaces to provide erosion control and stabilize the road surface and banks.*

Refer to the Management Measure for Revegetation of Disturbed Areas for a more detailed discussion of this practice.

◆ *Periodically inspect closed roads to ensure that vegetational stabilization measures are operating as planned and that drainage structures are operational. Conduct reseeding and drainage structure maintenance as needed.*
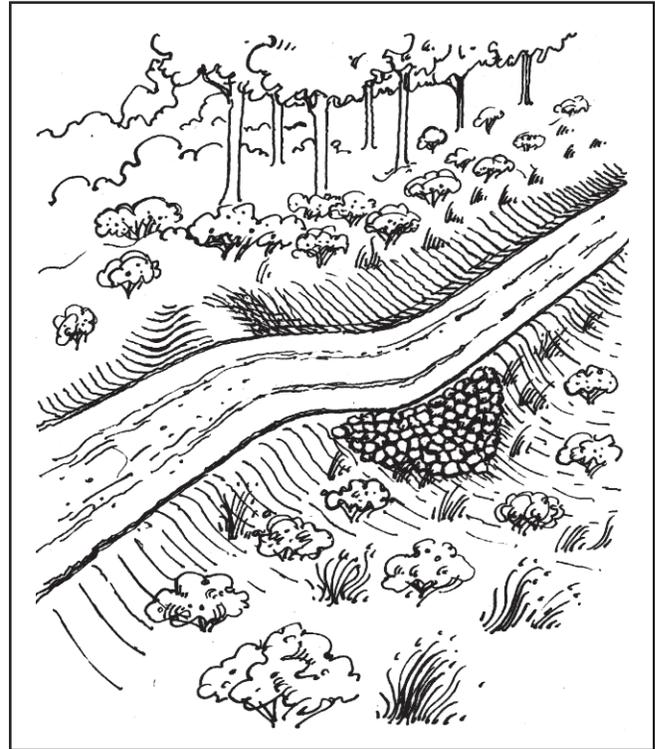
Figure 3-33. Broad-based dips reduce the potential for erosion (Indiana DNR, 1998).

Table 3-23. Example of Recommended Water Bar Spacing by Soil Type and Slope (Oregon Department of Forestry, 1979a)

Road Grade (percent)	Soil Type		
	Granitic or Sandy	Shale or Gravel	Clay
2	900	1,000	1,000
4	600	1,000	800
6	500	1,000	600
8	400	900	500
10	300	800	400
12	200	700	400
15	150	500	300
20	150	300	200
25+	100	200	150

Note: Distances (in feet) are approximate and are varied to take advantage of natural features.
Recommendations of spacing will vary with soil type, climate, and topography. Consult your state forester.

3E: TIMBER HARVESTING

Timber Harvesting Management Measure

The timber harvesting management measure consists of implementing the following:

(1) Follow layouts for timber harvesting operations determined under the Preharvest Planning Management Measure, subject to adjustments made based on preharvest on-site inspections.

(2) Install landing drainage structures to avoid sedimentation to the extent practicable. Disperse landing drainage over sideslopes.

(3) Construct landings away from steep slopes and reduce the likelihood of fill slope failures. Protect landing surfaces used during wet periods. Locate landings outside streamside management areas.

(4) Protect stream channels and significant ephemeral drainages from logging debris and slash material.

(5) Use appropriate areas for petroleum storage, draining, and dispensing, and vehicle maintenance. Establish procedures to contain and treat spills that could occur during these activities. Recycle or properly dispose of all waste materials.

For cable yarding:

(1) Limit yarding corridor gouge or soil plowing by properly locating cable yarding landings.

(2) Locate corridors for streamside management areas according to the guidelines of the Management Measure for Streamside Management Areas.

For groundskidding:

(1) To the extent practicable, do not operate groundskidding equipment within streamside management areas except at stream crossings. In streamside management areas, fell and endline trees in a manner that avoids sedimentation.

(2) Use improved stream crossings for skid trails that cross flowing drainages. Construct skid trails to disperse runoff and with adequate drainage structures.

(3) On steep slopes, use cable systems rather than groundskidding where groundskidding could cause excessive sedimentation.

Management Measure Description

The goal of this management measure is to minimize the likelihood of water quality effects resulting from timber harvesting. This goal can be accomplished by taking precautions to control erosion and sedimentation during harvesting operations and by storing, handling, and disposing of petroleum products and vehicle maintenance products in an environmentally safe manner.

Reducing effects on soils and water quality from harvesting begins in the preharvest planning stage, when a system of roads, landings, and skid trails is planned. Preharvest planning, as described in the Preharvest Planning Management Measure, is performed to minimize the amount of disturbed area, which makes it easier to rehabilitate the site after

the operation is complete; locate roads on stable soils to minimize erosion and at a safe distance from streams; build stream crossings at the locations where they cause the least amount of instream disturbance and hydrological change; and limit disturbance to sensitive areas. Thoroughly review the Preharvest Planning Management Measure before incorporating the practices in this management measure into a harvesting plan. The practices in that management measure can serve as a guide for reducing soil disturbance and water quality effects during harvesting. Having a harvesting plan reviewed by a professional forester before starting any aspect of harvesting or road building is strongly recommended. The forester might be able to offer ideas specific to the planned harvest on how environmental damage and operational costs can be reduced.

Do an additional review of the harvesting plan in conjunction with a site visit to verify that the information used during planning is still valid. Aerial photos and topographic and soil maps can inaccurately represent actual conditions, especially if these media are more than a few years old. Before construction begins, verify that the soils and slopes where landings and skid trails are to be located are suitable to the use and that equipment maintenance or chemical handling areas are appropriately located. As the harvest progresses, make any alterations to the harvesting plan necessary to protect soils and water quality.

Conducting a harvest with attention paid to the potential for soil disturbance from the operation can result in significantly less water quality impairment than conducting a harvest with little or no attention paid to the potential for environmental damage. For instance, skid trails that are parallel to the slope of the land have far more potential to yield sediment-laden runoff than skid roads that run along the contour. Similarly, practices that minimize soil compaction on and prevent or disperse runoff from landings and loading decks can be implemented to reduce the potential for sediment-laden runoff and to minimize sediment delivery to surface waters. Incorporating these and other erosion reduction practices into a harvesting plan, conducting an on-site inspection during the planning stage before harvesting or road construction begins to ensure that the practices chosen are appropriate to the site, and properly implementing and maintaining the practices can significantly decrease water quality effects.

Spill prevention and containment procedures are necessary to prevent petroleum products from entering surface waters. Chemicals and petroleum products spilled in harvest areas can be transported great distances if they enter areas of concentrated runoff, and therefore can adversely affect water quality far from where they are spilled. Designating appropriate areas for the storage and handling of petroleum products and protecting these areas from precipitation can minimize the water quality effects that could result from spills or leakage.

Many studies have evaluated and compared the effects of different timber harvest techniques on soil loss (erosion), soil compaction, and overall ground disturbance associated with various harvesting techniques. The data presented in Tables 3-24 through 3-28 were compiled from many studies conducted throughout the United States and Canada. Some of the data presented in the table should be considered as older data that were based on operations conducted prior to current understanding and concern for water quality protection. The studies examined different harvesting systems (e.g., clear-cuts, selective harvesting) using a variety of techniques (e.g., cable yarding, skidding). Local factors such as climate, soil type, and topography affected the results of each study. The major

Table 3-24. Soil Disturbance from Roads for Alternative Methods of Timber Harvesting (Megahan, 1980)

Logging System (State)	Percent of Logged Area Bared			Reference
	Roads	Skid Roads and Landings	Total	
Tractor:				
Tractor — clear-cut (BC)	30.0	—	30.0	Smith, 1979
Tractor — selection (CA)	2.7	5.7	8.4	Rice, 1961
Tractor — selection (ID)	2.2	6.8	9.0	Haupt and Kidd, 1965
Tractor — group selection (ID)	1.0	6.7	7.7	Haupt and Kidd, 1965
Tractor and helicopter — fire salvage (WA)	4.5	0.4	4.9	Klock, 1975
Tractor and cable — fire salvage (WA)	16.9	—	16.9	Klock, 1975
Ground Cable:				
Jammer — group selection (ID)	25–30	—	25–30	Megahan and Kidd, 1972
Jammer — clear-cut (BC)	8.0	—	8.0	Smith, 1979
High-lead — clear-cut (BC)	14.0	—	14.0	Smith, 1979
High-lead — clear-cut (OR)	6.2	3.6	9.8	Silen and Gratkowski, 1953
High-lead — clear-cut (OR)	3.0	1.0	4.0	Brown and Krygier, 1971
High-lead — clear-cut (OR)	6.0	1.0	7.0	Brown and Krygier, 1971
High-lead — clear-cut (OR)	6.0	—	6.0	Fredriksen, 1970
Skyline:				
Skyline — clear-cut (OR)	2.0	—	2.0	Binkley, 1965
Skyline — clear-cut (BC)	1.0	—	1.0	Smith, 1979
Aerial:				
Helicopter — clear-cut	1.2	—	1.2	Binkley[a]

[a] Estimated by Virgil W. Binkley, Pacific Northwest Region, USDA Forest Service, Portland, OR, nd.

conclusions of these studies regarding the relative effects of different timber harvesting techniques on soil erosion, summarized below, are shared among the studies and enable cross-geographic comparison:

- Aerial and skyline cable techniques are far less damaging than other yarding techniques.
- Tractor, jammer, and high-lead cable methods result in significantly more soil disturbance and compaction than skyline and aerial techniques.
- Skyline yarding serves far more area per mile of road than skidding.

Although skidding can be damaging, areas disturbed by skidding operations can be rehabilitated without a net economic loss to the landowner. An analysis of the costs and benefits of rehabilitating skid trails in the southeastern United States by planting different species of trees indicated that the benefit/cost ratios of using shortleaf pine, hardwood pine, and hardwoods were 5.1:1, 2.8:1, and 1.3:1, respectively. Shortleaf pine yielded the highest benefit for costs incurred (Dissmeyer and Foster, 1986).

Table 3-25. Soil Disturbance from Logging by Alternative Harvesting Methods (Megahan, 1980)

Method of Harvest	Location	Disturbance (%)	Reference
Tractor:			
Tractor — clear-cut	E. WA	29.4	Wooldridge, 1960
Tractor — clear-cut	W. WA	26.1	Steinbrenner and Gessel, 1955
Tractor — fire salvage	E. WA	36.2	Klock,[a] 1975
Tractor on snow — fire salvage	E. WA	9.9	Klock,[a] 1975
Tractor — clear-cut	BC	7.0	Smith, 1979
Tractor — selection	E. WA, OR	15.5	Garrison and Rummel, 1951
Ground Cable:			
Cable - selection	E. WA, OR	20.9	Garrison and Rummel, 1951
High-lead — fire salvage	E. WA	32.0	Klock,[a] 1975
High-lead — clear-cut	W. OR	14.1	Dyrness, 1965
High-lead — clear-cut	W. OR	12.1	Ruth, 1967
High-lead — clear-cut	BC	6.0	Smith, 1979
Jammer — clear-cut	BC	5.0	Smith, 1979
Grapple — clear-cut	BC	1.0	Smith, 1979
Skyline:			
Skyline — clear-cut	W. OR	12.1	Dyrness, 1965
Skyline — clear-cut	E. WA	11.1	Wooldridge, 1960
Skyline — clear-cut	BC	7.0	Smith, 1979
Skyline — clear-cut	W. OR	6.4	Ruth, 1967
Skyline — fire salvage	E. WA	2.8	Klock,[a] 1975
Balloon — clear-cut	W. OR	6.0	Dyrness[b]
Aerial:			
Helicopter — fire salvage	E. WA	0.7	Klock,[a] 1975
Helicopter — clear-cut	ID	5.0	Clayton (in press)

[a] Disturbance shown is classified as severe.
[b] C.T. Dyrness, unpublished data on file, Pacific Northwest Forest and Range Experiment Station, Corvallis, OR, nd.

Benefits of Timber Harvesting Practices

After a 1994 study of BMP implementation and effectiveness, the Virginia Department of Forestry concluded that harvesters often failed to seed bare soil with adequate ground cover. The department determined that ground cover of 70 percent or more is effective, while many sites studied had ground cover on only 0 to 35 percent of bare soil. The Vermont Agency of Natural Resources (1998) also studied the effectiveness of erosion control BMPs and concluded that the construction and proper placement of such BMPs before harvesting is essential for protecting water quality. The Agency also found that regularly maintaining BMPs increased the longevity of their effectiveness.

In general, poor BMP effectiveness can be due to many factors, including

- A lack of time or willingness to plan timber harvests carefully before cutting begins.
- A lack of skill in or knowledge of designing effective BMPs.

Table 3-26. Relative Effects of Four Yarding Methods on Soil Disturbance and Compaction in Pacific Northwest Clear-cuts (OR, WA, ID) (Sidle, 1980)

Yarding Method	Bare Soil (%)	Compacted Soil (%)	Water Quality Effects
Tractor	35	26	Greater
High-lead	15	9	
Skyline	12	3	
Balloon	6	2	Lesser

Table 3-27. Percent of Land Area Affected by Logging Operations (Southwest MS) (after Miller and Sirois, 1986)

Operational Area	Cable Skyline (% Land Affected)	Groundskidding (% Land Affected)	Water Quality Effects
Cable corridors or skid trails	9.2	21.4	Greater
Landings	4.1	6.4	
Spur roads	2.6	3.5	Lesser
Water Quality Effects	Lesser	Greater	

Table 3-28. Skidding/Yarding Method Comparison (after Patric, 1980)

Harvesting System	Acres Served per Mile of Road	Water Quality Effects
Wheeled skidder	20	Greater
Jammer	31	
High-lead	40	
Skyline	80	Lesser

- A lack of equipment needed to implement effective BMPs.

- The belief that BMPs are not an integral part of the timber harvesting process and can be engineered and fitted to a logging site after timber harvesting has been completed.

- A lack of timely BMP maintenance.

Best Management Practices

Harvesting Practices

◆ *Based on information obtained from site visits, make any alterations to the harvesting plan that are necessary or prudent to protect soils from erosion and surface waters from sedimentation or other forms of pollution.*

◆ *Fell trees away from watercourses whenever possible, keeping logging debris from the channel, except where debris placement is specifically prescribed for fish or wildlife habitat.*

◆ *Immediately remove any tree accidentally felled in a waterway.*

◆ *Remove unwanted slash from water bodies and place it above the normal high water line or flood level to prevent downstream transport.*

As discussed in Chapter 2 and in Chapter 3, section B, *Streamside Management Areas*, streams have natural amounts of organic debris (e.g., fallen leaves, twigs, limbs, and trees), and the amount varies with season, tree falls, storms, and so forth. Aquatic organisms are adapted to the presence of and variability in the quantity of organic debris in streams. Large woody debris, or LWD, affects channel morphology, provides structure and complexity to aquatic and terrestrial organism habitats, and is a source of nutrients for aquatic organisms. When the quantity of LWD and organic debris in general that reaches a stream is changed, either to too much or too little, it can be detrimental to the aquatic system's ecology and ability to support life. Removing excessive slash from a stream helps maintain water flow and avoids the addition of excessive nutrients. In instances where the addition of organic debris—especially LWD—to a stream is desirable, an appropriate amount may be left in stream channels or on stream banks. Slash left in streams adds nutrients, regulates stream temperature, and traps fine sediments where these effects are desirable (Jackson, 2000). Consult with a fisheries biologist or the state forestry or ecology department for specific guidance for your area.

Leave pieces of large woody debris in place during stream cleaning to preserve channel integrity and maintain stream productivity. Indiscriminate removal of large woody debris can adversely affect channel stability. Figure 3-34 presents one way to determine debris stability. State forestry or ecology departments can help with such determinations for particular regions and stream types.

> *Where desirable, leave slash on the harvest site and distribute it to provide good ground cover and minimize erosion after the timber harvest.*

Leaving slash on disturbed soils can help reduce erosion until new vegetative growth is established. The quantity of slash to leave depends on the erodibility of the soil, though leaving an amount that provides 40 to 60 percent ground cover for soils that have low to high erodibility, respectively, is recommended. Leaving slash on the ground significantly reduces erosion potential. It also keeps the nutrients contained in the slash material on the site for incorporation into the soil and new vegetative growth.

Practices for Landings

◆ *Make landings no larger than necessary to safely and efficiently store logs and load trucks.*

◆ *Install drainage and erosion control structures as necessary.*

A slight slope on landings facilitates drainage. Also, adequate drainage on approach roads prevents road drainage water from entering the landing area.

◆ *Do not exceed a 5 percent slope on landing surfaces and shape them to promote efficient drainage.*

◆ *Do not exceed 40 percent slope on landing fills and do not incorporate woody or organic debris into fills.*

◆ *If landings are to be used during wet periods, protect the surfaces with a suitable material such as a wooden mat or gravel.*

◆ *Install drainage struc-
tures–such as water bars,
culverts, and ditches–on
landings to avoid sedi-
mentation. Disperse
landing drainage over
side slopes. Provide
filtration or settling if
water is concentrated in a
ditch.*

◆ *Upon completion of a
harvest, clean up, re-
grade, and revegetate
landings.*

- Upon abandonment,
minimize erosion on
landings by adequately
ditching or mulching
with forest litter.

- Establish a herbaceous
cover on areas that will
be used again in re-
peated cutting cycles,
and restock landings
that will not be reused.

- If necessary, install
water bars for drainage
control.

**Figure 3-34. General large woody debris stability guide based on Salmon Creek, Washing-
ton (after Bilby, 1984).**

- Landings should be
ripped to break up compacted soil layers and allow water infiltration. This will also
aid in the establishment of new vegetation.

- Runoff on and from landings should be dispersed with waterbars or dips.

◆ *Locate landings for cable yarding where slope profiles provide favorable deflection
conditions so that yarding equipment does not cause yarding corridor gouge or soil
plowing, which can concentrate drainage or cause slope instability.*

◆ *Locate cable yarding corridors for streamside management areas according to the
Streamside Management Areas management measure. Avoid disturbing major chan-
nel banks in SMAs with yarded logs.*

Ground Skidding Practices

◆ *Skid uphill to log landings whenever possible. Skid with ends of logs raised to reduce
rutting and gouging.*

This practice disperses water on skid trails away from the landing. Skidding uphill lets
water from trails flow onto progressively less-disturbed areas as it moves downslope,
reducing erosion hazard. Skidding downhill concentrates surface runoff on lower slopes

along skid trails, resulting in significant erosion and sedimentation hazard. If skidding downhill, provide adequate drainage on approach trails so that drainage does not enter the landing.

◆ *Skid along the contour (perpendicular to the slope), and avoid skidding on slopes greater than 40 percent.*

Following the contour reduces soil erosion and encourages revegetation. If skidding has to be done parallel to the slope, skid uphill, taking care to break the grade periodically.

Avoid skid trail layouts that concentrate runoff into draws, ephemeral drainages, or watercourses and avoid skidding up or down ephemeral drainages. Use endlining to winch logs out of SMAs or directionally fell trees so tops extend out of SMAs and trees can be skidded without operating equipment in SMAs. In SMAs, endline trees carefully to avoid soil plowing or gouge.

Suspend ground skidding during wet periods, when excessive rutting and churning of the soil begins, or when runoff from skid trails is turbid and no longer infiltrates within a short distance from the skid trail. Further limitation of ground skidding of logs, or use of cable yarding, might be needed on slopes where there are sensitive soils and/or during wet periods.

Retire skid trails by installing water bars or other erosion control and drainage devices, removing culverts, and revegetating.

- After logging, obliterate and stabilize all skid trails by mulching and reseeding.
- Build cross drains on abandoned skid trails to protect stream channels or side slopes in addition to mulching and seeding.
- Restore stream channels by removing temporary skid trail crossings.
- Distribute logging slash throughout skid trails to supplement water bars and seeding to reduce erosion on skid trails.

Cable Yarding Practices

◆ *Use cabling systems or other systems when ground skidding would expose excess mineral soil and induce erosion and sedimentation.*

- Use high-lead cable or skyline cable systems on slopes greater than 40 percent.
- To avoid soil disturbance from sidewash, use high-lead cable yarding on average-profile slopes of less than 15 percent.

◆ *Avoid cable yarding in or across watercourses.*

When cable yarding across streams cannot be avoided, use full suspension to minimize damage to channel banks and vegetation in the SMA. Cut or clear cableways across SMAs where SMAs must be crossed. This will reduce the damage to trees remaining and prevent trees next to the stream channel from being uprooted.

◆ *Yard logs uphill rather than downhill.*

When yarding uphill, log decks are placed on ridges or hilltops rather than in low-lying areas. This approach results in less soil disturbance for two reasons: (1) lifting the logs

reduces their weight on the ground and thus the amount of friction and ground scouring, and (2) yard trails radiate outward from the elevated position of the log deck, dispersing runoff in numerous directions from the deck.

Downhill yarding does the opposite. The full weight of the logs is transferred to the ground, and runoff from all of the yard trails is directed downslope to the log deck, concentrating the erosive effect of rain. If yarding uphill is not possible, soil disturbance can be minimized during downhill yarding by suspending logs from a pulley system so that the logs are lifted partially or completely off the ground.

The amount of soil disturbance caused by yarding depends on the slope of the area, the volume yarded, the size of the logs, and the logging system. Megahan (1980) ranked yarding techniques (from greatest effect to lowest effect) based on percent area disturbed as follows: tractor (21 percent average), ground cable (21 percent, one study), high-lead (16 percent average), skyline (8 percent average), jammer in clear-cut (5 percent, one study), and aerial techniques (4 percent average). Aerial and skyline cable techniques are far less damaging than other yarding techniques.

The amount of road needed for different yarding techniques varies considerably (Sidle, 1980). Skyline techniques use the least amount of road area, with only 2 to 3.5 percent of the land area in roads. Tractor and single-drum jammer techniques use the greatest amount of road area (10 to 15 percent and 18 to 24 percent of total area, respectively). High-lead cable techniques fall in the middle, with 6 to 10 percent of the land used for roads. Compared to the skyline and aerial techniques, tractor, jammer, and high-lead cable methods result in significantly higher amounts of disturbed soil (Megahan, 1980). Figure 3-35 shows a typical cable yarding operation (OSHA, 1999).
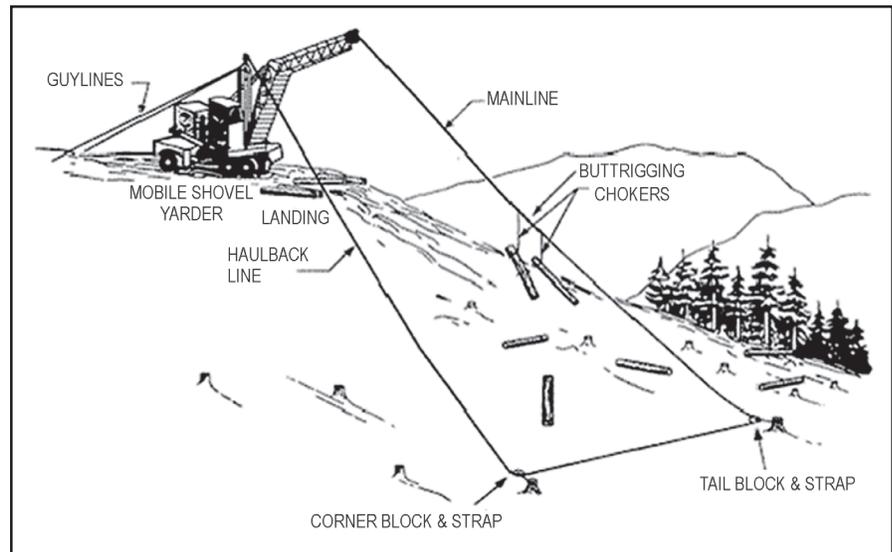
Figure 3-35.   Typical cable yarding operation (OSHA, 1999).

Other Yarding Methods

◆ *Horse logging*

Horse logging can be a viable alternative to mechanized logging for small harvests or for sensitive environmental areas of a larger harvest. Horses give a lot of control for logging in partial cuts because logs are cut to log length, not left at tree length, and this improves maneuverability around trees that are left in place. This maneuverability combined with the narrower path needed by horses compared to a skidder means that fewer trees have to be removed solely for access. Soil is compacted and disturbed less with horse logging than with a skidder because a horse weighs about 1,600 pounds compared to a rubber-tired skidder that weighs about 10,000 pounds.

◆   *Helicopter yarding*

Helicopter yarding is a practical and environmentally friendly alternative yarding approach for use on public and private timberlands where other yarding systems would be physically, economically, or environmentally infeasible. According to the Helicopter Logging Association (1998), the benefits of helicopter timber harvesting include:

• Minimum damage is caused to the following:

  – The soil layer. Very little vehicular traffic is associated with the method.

  – Water resources. There is a negligible increase in stream turbidity compared to conventional yarding methods.

  – Riparian areas.

  – Wildlife habitat.

• Damage to retained trees is reduced. Fewer trees are felled per acre and ground-based skidders are absent.

• Road density is lower. A combined helicopter and tractor logging approach can reduce road density by approximately half compared to conventional tractor methods. Environmental damage is thus reduced, and forest access points are fewer.

◆   *Shovel harvesting.*

Shovel harvesting is more widely used in the coastal areas of the Pacific Northwest and the wetland areas of the Southeast than in other parts of the United States (Aust, Virginia Tech, personal communication, 2000). The process of shovel harvesting involves a shovel logger moving in lines parallel to a road, picking up logs that have been felled by a logger and lifting debris out of gullies as it moves forward. The shoveler starts at the nearest access point and moves logs until they are within reach of a road, where they can be retrieved (Figure 3-36) (Humboldt State University, 1999).

Shovel logging is considered an environmentally friendly means to harvest timber. Operations require fewer people and fewer access roads, produce no skid trails, reduce ground disturbance in environmentally sensitive areas such as wetlands, and disturb SMAs less than any conventional logging method. Table 3-29 compares the costs of various yarding methods.

◆   *Balloon harvesting.*

Balloon harvesting involves using hot air or helium balloons to remove logs from a harvest site for loading on trucks (Figure 3-37). Because the logs are lifted off the ground and taken to a log landing, they are not dragged up or down a slope and disturbance to the

Figure 3-36.   Common pattern of shovel logging operations (Humboldt State University, 1999)

Table 3-29.   Costs Associated with Various Methods of Yarding

Yarding Method	Cost Range
Cable Yarding	$90 to $135/ac, depending on yarding distance, crew size, and size of landing. • Clear-cutting costs $50 to $60/mbf • Thinning costs $200/mbf
Helicopter Yarding	$3,000 to $3,500/hr; or $180 to $300/mbf $175 to $285/mbf
Shovel Harvesting	$25.00 to $83.84/hr

ground is reduced. In areas where road construction is expensive, balloon harvesting can save money and protect the environment because of the smaller number of roads and skid trails needed. The environmental benefits realized from balloon harvesting are similar to those associated with helicopter yarding. Additionally, balloon harvesting permits access to wet sites such as wetlands and steep slopes where ground skidding would not be feasible because of the potential for environmental damage or the cost of road construction (Aust, Virginia Tech, personal communication, 2000).
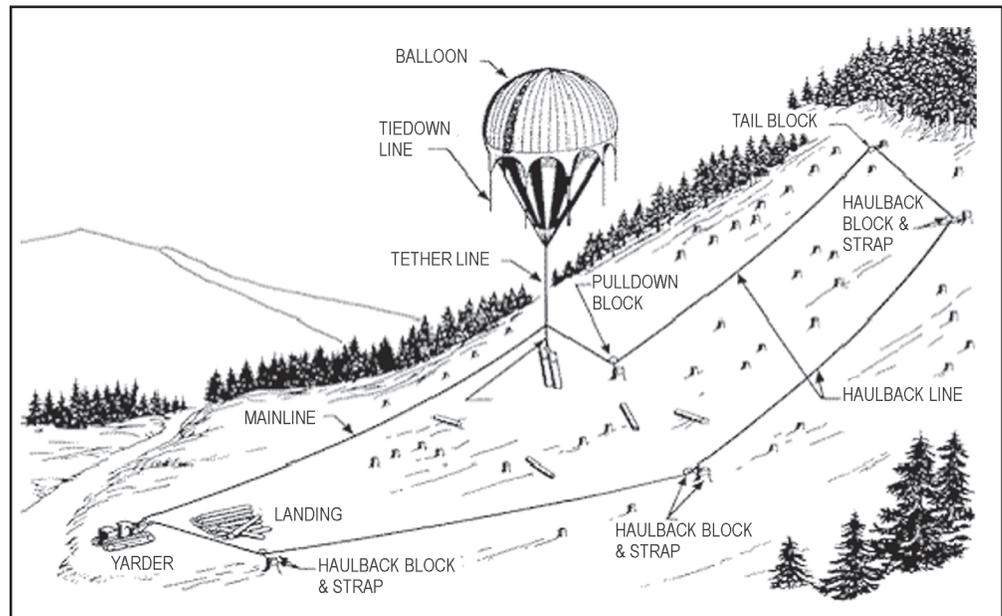
Figure 3-37.   Balloon harvesting practices on a steep slope (OSHA, 1999).

Winter Harvesting

Winter harvesting is a component of several state timber removal programs. In winter frozen ground provides conditions that do not exist during other times of the year for timber harvest activities and an opportunity for low-impact logging (Logan and Clinch, 1991). Areas where winter road construction and harvesting are particularly advantageous include wetlands (see Chapter 3, section J, Management Measure for Wetlands Forest Management of this document for a discussion of BMPs specifically for wetland harvesting), sensitive riparian areas, and sites where erosion and soil compaction would be expected to be a serious problem during nonfrozen conditions.

BMP guidelines for warmer months apply during winter harvesting as well. Additional practices that can be implemented to ensure the protection of water quality include the following (Logan and Clinch, 1991; North Dakota Forestry Service, 1999):

◆ *Consult with operators experienced in winter logging techniques.*

◆ *Compact skid trail snow before skidding logs.*

Compacting the snow prevents damage to soils that are still wet or not completely frozen.

◆ *Avoid steeper areas where frozen skid trails may be subject to erosion the following spring.*

◆ *Before felling in wet, unfrozen soil areas, use tractors or skidders to compact the snow on skid trails. Avoid steep areas where frozen skid trails might be subject to erosion the following spring.*

Petroleum Management Practices

◆ *Service equipment where spilled fuel or oil will not reach watercourses, and drain all petroleum products and radiator water into containers.*

◆ *Dispose of wastes and containers in accordance with proper waste disposal procedures.*

Do not leave waste oil, filters, grease cartridges, and other petroleum-contaminated materials as refuse in the forest.

◆ *Take precautions to prevent leakage and spills.*

Ensure that fuel trucks and pickup-mounted fuel tanks do not have leaks. Use and maintain seepage pits or other confinement measures to prevent diesel oil, fuel oil, or other liquids from running into streams or important aquifers, and use drip collectors on oil-transporting vehicles.

◆ *Develop a spill contingency plan that provides for immediate spill containment and cleanup, and notification of proper authorities.*

Have materials for absorbing spills easily accessible, and collect wastes for proper disposal.

3F: SITE PREPARATION AND FOREST REGENERATION

Management Measure for Site Preparation and Forest Regeneration

Confine on-site potential NPS pollution and erosion resulting from site preparation and the regeneration of forest stands. The components of the management measure for site preparation and regeneration are:

(1) Select a method of site preparation and regeneration suitable for the site conditions.

(2) Conduct mechanical tree planting and ground-disturbing site preparation activities on the contour of sloping terrain.

(3) Do not conduct mechanical site preparation and mechanical tree planting in streamside management areas.

(4) Protect surface waters from logging debris and slash material.

(5) Suspend operations during wet periods if equipment used begins to cause excessive soil disturbance that will increase erosion.

(6) Locate windrows at a safe distance from drainages and SMAs to control movement of the material during high-runoff conditions.

(7) Conduct bedding operations in high-water-table areas during dry periods of the year. Conduct bedding in sloping areas on the contour.

(8) Protect small ephemeral drainages when conducting mechanical tree planting.

Management Measure Description

Regeneration of harvested forestlands is important not only in terms of restocking a valuable resource, but also in terms of minimizing erosion and runoff from disturbed soils that could degrade water quality. Vegetative cover on disturbed soils reduces raindrop impact and slows storm runoff, and the roots of vegetation stabilize soils by holding them in place and aiding their aggregation. Both of these factors decrease erosion.

Harvesters and landowners can follow certain practices to protect the soil and aid tree regeneration. For instance, leaving the forest floor litter layer intact during site preparation operations minimizes soil disturbance and detachment, maintains infiltration, and slows runoff. These factors in turn reduce erosion and sedimentation after site preparation is completed. It is especially important to leave the forest floor litter layer intact in areas that have steep slopes, or erodible soils, or where the prepared site is located near a water body, all of which increase the risk of erosion, landslides, and degraded water quality. Site preparation methods such as herbicide application and prescribed burning cause less disturbance to the soil surface than mechanical practices and can be considered where

mechanical site preparation could pose a threat to water quality. Drum chopping, a form of mechanical site preparation, normally results in less soil exposure than other mechanical methods. The intensity of a prescribed burn in part determines whether use of the method will pose a threat to water quality.

Natural regeneration, hand planting, and direct seeding are other methods that can be used to minimize soil disturbance, especially on steep slopes with erodible soils. Mechanical planting with machines that scrape or plow the soil surface can produce erosion rills, increasing surface runoff and erosion and decreasing site productivity.

Data in Figures 3-38 to 3-42 compare sediment loss or erosion rates for numerous site preparation methods. Many of the data are site-specific, so site characteristics and experimental conditions are mentioned (when available) in the text below and regional locations are noted on the figures.

Ballard (2000) reviewed the effects of forest management on forest soils. Mechanical site preparation, he noted, both has benefits and causes problems. Nutrient depletion is one adverse effect. A study in northern British Columbia concluded that 500 kg N/ha were removed on a large area that had been bladed, raked, and piled for burning. Conducting research on intensively-managed loblolly pine plantations in the Piedmont region of North Carolina, Piatek and Allen (2000) found the following nutrient removal rates from sites that received different methods of site preparation: Shear-pile-disk, 591 kg N/ha and 34 kg P/ha; stem-only harvest, 57 kg N/ha and 5 kg P/ha; chop and burn, 46 kg N/ha and 0 kg P/ha. Piatek and Allen (2000) also found that the nutrients removed during site preparation had no observable effect on foliage production when measured 15 years after planting on the site.

Beasley (1979) studied the relative soil disturbance effects of site preparation following clear-cutting on three small watersheds in the hilly northern coastal plain of Mississippi and Arkansas (Figure 3-38). Slopes in the three watersheds were mostly 30 percent or more. One site was single drum-chopped and burned; another was sheared and windrowed (windrows were burned); and a third was sheared, windrowed, and bedded to contour. The control watershed was instrumented and left uncut. Soil exposure was 37 percent on the chopped site, 53 percent on the sheared and windrowed site, and 69 percent on the bedded site. A temporary cover crop of clover was sown after site preparation to protect the soil from rainfall impact and erosion. Increases in soil erosion and sediment production were similar for all three treatments in the first year after site preparation. Decreases in these processes were noted during the second year on all sites. During the second year,
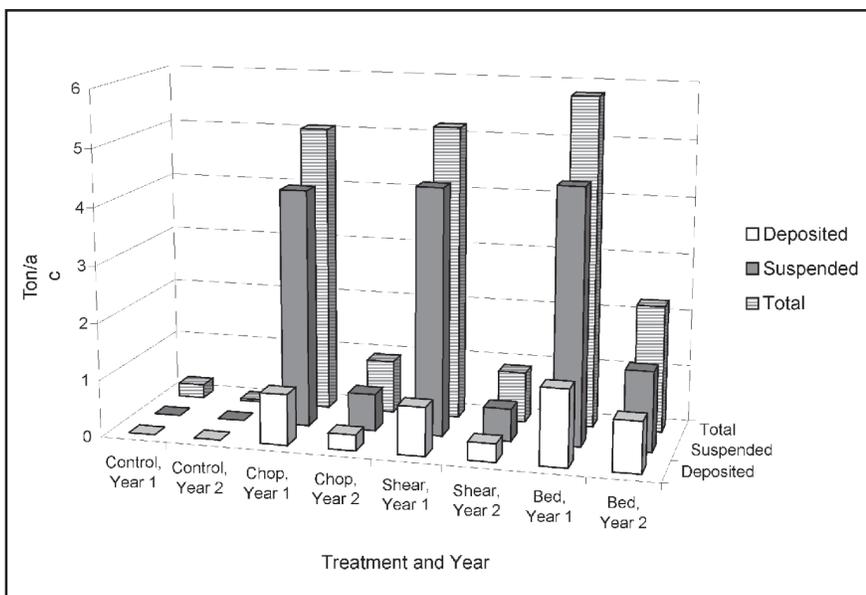
Figure 3-38. Deposited, suspended, and total sediment losses in experimental watersheds during water years 1976 and 1977 for various site preparation techniques (Mississippi, Arkansas) (after Beasley, 1979).

the clover and other vegetation covered 85 to 95 percent of the surface of each site and effectively decreased sediment production.

Golden and others (1984) summarized studies on erosion rates from site preparation (Figure 3-39). The rates reflect soil movement measured at the bottom of a slope, not the quantity of sediment actually reaching streams. Therefore, the numbers estimate the worst-case erosion if a stream is located directly at the toe of a slope with no intervening vegetation. Rates are averages for 3- to 4-year recovery periods.

Dissmeyer (1980) showed that discing produced more than twice the erosion rate of any other method (Figure 3-40). Bulldozing, shearing, and sometimes grazing were associated with relatively high rates of erosion, and chopping or chopping and burning produced moderate erosion rates. Logging also produced moderate erosion rates in this study when the effect of skid and spur roads was included. The lowest rate of erosion was associated with burning.

Figure 3-39. Predicted erosion rates using various site preparation techniques for physiographic regions in the southeastern United States (after Golden et al., 1984). Numbers in parentheses indicate number of predictions for the region.

Beasley and Granillo (1985) compared storm flow and sediment losses from mechanically and chemically prepared sites in southwest Arkansas over a 4-year period. Mechanical preparation (clear-cutting followed by shearing, windrowing, and replanting with pine seedlings) increased sediment losses in the first 2 years after treatment. A subsequent decline in sediment losses in the mechanically prepared watersheds was attributed to rapid growth of ground cover. Windrowing brush into ephemeral drainages and leaving it unburned effectively minimized soil losses by trapping sediment on the site and reducing channel scouring. Chemical site preparation (using herbicides) had no significant effect on sediment losses.

Figure 3-40. Erosion rates for site preparation practices in selected land resource areas in the Southeast (after Dissmeyer, 1980). Numbers in parentheses indicate the number of sites in the region.

Figure 3-41. Sediment loss (kg/ha) in stormflow by site treatment from January 1, to August 31, 1981 (TX) (after Blackburn et al., 1982).

Blackburn and others (1982) studied water quality changes associated with two site preparation methods in Texas. Figure 3-41 shows that shearing and windrowing (which exposed 59 percent of the soil) produced 400 times more sediment loading than chopping (which exposed 16 percent of the soil) during site preparation in this study. The authors also found that total nitrogen losses from sheared and windrowed watersheds were nearly 20 times greater than those from undisturbed watersheds and three times greater than those from chopped watersheds (Figure 3-42).

Mechanical Site Preparation in Wetlands

Under certain circumstances, a permit is needed for mechanical forestry site preparation activities when used for the establishment of pine plantations in the Southeast. EPA and the U.S. Army Corps of Engineers recently issued a memorandum to clarify the applicability of forested wetlands BMPs to these circumstances. Refer to the Wetlands Forest Management Measure for a discussion of permitting requirements in forested wetlands.

Figure 3-42. Nutrient loss (kg/ha) in stormflow by site treatment from January 1 to August 31, 1981 (TX) (after Blackburn et al., 1982).

Benefits of Site Preparation Practices

Three studies summarized here compare the costs and benefits of different site preparation methods. Dissmeyer and Foster (1987) estimated the long-term costs and benefits of light and heavy site preparation in the Southeast. They concluded that light site preparation would yield more wood production and a higher internal rate of return on investment (Table 3-30). Heavy site preparation methods involve a greater initial investment than light site preparation methods but did not yield more wood per unit area.

Table 3-30. **Analysis of Two Management Schedules Comparing Cost and Site Productivity in the Southeast (Dissmeyer and Foster, 1987)**

Year	Silviculture Treatment	Light Site Preparation[a]		Heavy Site Preparation[b]	
		Investment Per Hectare[c]	Wood Produced M³/ha	Investment Per Hectare[c]	Wood Produced M³/ha
1984	Site Prep/Tree Planting	$297		$420	
1999	Thinning	$252	64.2 pulpwood	$180	46.0 pulpwood
2010	Thinning	$256	22.3 saw timber 33.3 pulpwood	$331	5.3 saw timber 22.0 pulpwood
2020	Final Harvest	$2,422	133.5 saw timber 15.2 pulpwood	$2,071	112.3 saw timber 22.0 pulpwood
Present Net Value (at 4%)		$623		$304	
Internal Rate of Return		12.4%[d]		10.1%	

[a] Light site preparation includes chop and light burn or chop with herbicides, and reduces soil exposure and erosion.
[b] Heavy site preparation includes bulldozing or windrowing or shearing and windrowing, and increases erosion and sediment yields over those for light site preparation.
[c] 1984 dollars.
[d] Based on 4% inflation rate assumed.
Source: Adapted from Patterson, 1984. Dollars in Your Dirt. Alabama's Treasured Forests. Spring: 20-21

Dissmeyer (1986) analyzed the economic benefits of controlling erosion during site preparation. Site preparation methods that increased soil exposure, displacement, and compaction increased site preparation costs and erosion from the site prepared (Table 3-31) and decreased timber production. Using light site preparation techniques such as a single chop and burn reduced erosion, increased timber production on the site, and cost less per unit area treated than more intensive site preparation methods. Heavy site preparation techniques such as shearing and windrowing removed nutrients, compacted soil, increased erosion and site preparation costs, and resulted in a lower present net value of timber.

The U.S. Forest Service (1987) examined the costs of three alternatives to slash treatment: (1) broadcast burn and protection of streamside management zones, (2) yarding of unmerchantable material (YUM) of 15 inches in diameter or more, and (3) YUM of

Table 3-31. **Site Preparation Comparison (VA, SC, NC) (Dissmeyer, 1986)**

Treatment	Treatment Cost ($/acre)	Erosion Index[a]
No site preparation	$59	1.0
Burn only	$67	1.1
Single chop and burn	$119	2.3
Double chop and burn	$178	3.0
Single shear and burn	$216	4.3
Shear twice and burn	$253	5.1
Rootrake and disk and burn	$253	16.0
Rootrake and burn	$253	16.0

Note: All costs updated to 1998 dollars
[a] The index is an expression of relative erosion potential resulting from each treatment.

8 inches in diameter or more (Table 3-32). The two YUM alternatives cost approximately $625-$1,180/acre, in comparison to broadcast burning at $1,300/acre (1998 dollars). In addition, the YUM alternatives protected highly erodible soils from direct rainfall and runoff effects, reduced fire hazards, resulted in meeting air and water quality standards, and allowed for the rapid establishment of seedlings on clear-cut areas.

Table 3-32.   Comparison of Costs for Yarding Unmerchantable Material (YUM) vs. Broadcast Burning (OR) (USDA-FS, 1987)

Activity	Broadcast Burn and Protect SMA	YUM 15" in Diameter and No Burn	YUM 8" in Diameter and No Burn
Broadcast burn	$502/acre	N/A	N/A
SMA protection	$646/acre	N/A	N/A
YUM, fell hardwood, lop and scatter	N/A	$438/acre	$1,004/acre
Planting cost	$143/acre	$187/acre	$172/acre
Totals	$1,291/acre	$624/acre	$1,177/acre

Note: All costs updated to 1998 dollars.

Best Management Practices

Site Preparation Practices

◆ *Do not conduct mechanical site preparation, except for drum chopping, on slopes greater than 30 percent.*

On sloping terrain greater than 10 percent, or on highly erosive soils, operate mechanical site preparation equipment on the contour.

◆ *Do not conduct mechanical site preparation in SMAs.*

◆ *Do not place slash in perennial or intermittent drainages, and remove any slash that accidentally enters drainages.*

Slash can clog the channel and cause alterations in drainage configuration and increases in sedimentation. Extra organic material can lower the dissolved oxygen content of the stream. Slash also allows silt to accumulate in the drainage and to be carried into the stream during storm events.

◆ *Provide SMAs of sufficient width to protect streams from sedimentation by the 10-year storm.*

◆ *Locate windrows a safe distance from drainages to avoid material movement into the drainages during high-runoff conditions.*

Locating windrows above the 50-year floodplain usually prevents windrowed material from entering floodwaters.

◆ *Avoid mechanical site preparation operations during periods of saturated soil conditions, which might cause rutting and accelerate soil erosion.*

◆ *Minimize soil movement when shearing, piling, or raking.*

◆ *Minimize incorporation of soil material into windrows and piles during their construction.*

This can be accomplished by using a rake or, if using a blade is unavoidable, keeping the blade above the soil surface and removing only the slash. This helps retain nutrient-rich topsoil, which promotes rapid site recovery and tree growth and increases the effectiveness of the windrow in minimizing sedimentation.

Forest Regeneration Practices

◆ *Distribute seedlings evenly across the site.*

◆ *Order seedlings well in advance of planting time to ensure their availability.*

◆ *Hand plant highly erodible sites, steep slopes, and lands adjacent to stream channels (SMAs).*

◆ *Operate planting machines along the contour to avoid ditch formation.*

  • Ensure that soil conditions (slope, moisture conditions, etc.) are suitable for machine operation.

  • Close slits or drilling furrows periodically to avoid channeling flow.

3G: Fire Management

Management Measure for Fire Management

Prescribe fire for hazardous fuel reduction and control or suppression of wildfire in a manner that reduces potential nonpoint source pollution of surface waters:

(1) Prescribed fire should not cause excessive sedimentation due to the combined effect of partial or full removal of canopy and removal of ground fuels, litter layer and duff.

(2) Prescriptions for wildland fire use should protect against excessive erosion or sedimentation to the extent practicable.

(3) All bladed firelines, for prescribed fire and wildfire, should be stabilized with water bars and/or other appropriate techniques if needed to control excessive sedimentation or erosion of the fireline.

(4) Wildfire suppression and rehabilitation should consider possible NPS pollution of watercourses, while recognizing the safety and operational priorities of fighting wildfires.

Management Measure Description

The goal of this management measure is to minimize nonpoint source pollution and erosion resulting from prescribed fire used for site preparation, fuel hazard reduction, and activities associated with wildfire control or suppression. Studies have shown that prescribed burning, if carefully planned and done using appropriate BMPs, has no significant effect on water quality (South Carolina Forestry Commission, 2000).

Prescribed burning reduces hazardous fuels. Where tree species are ecologically dependent on fire for regeneration or maintenance of healthy stands, fire is an essential forest management tool. Particularly in the interior west and much of the south, ecosystems developed in the presence of frequently-occurring, low-intensity ground fires. Returning these stands to a structure that more closely resembles that which occurred under these frequent fire regimes requires the use of prescribed fire. Because fire suppression has contributed to increased levels of fuels, wildland fires occurring in these areas burn quite hot and consume a lot of material (live and dead).

The severity of burning and the proportion of the watershed burned are the major factors that affect the influence of prescribed burning on streamflow and water quality. Fires that burn severely on steep slopes close to streams and that remove most of the forest floor and litter down to the mineral soil are most likely to adversely affect water quality. The amount of erosion following a fire depends on

- The amount of ground cover remaining on the soil
- The steepness of the slope
- The time, amount, and intensity of subsequent rainfall
- The severity of fire
- The erodibility of the soil and soil type

- How rapidly a site revegetates
- The type of vegetation

Periodic, low-intensity prescribed fires usually have little effect on water quality, and revegetation of burned areas reduces sediment yield from prescribed burning and wildfires.

Cost of Prescribed Burning

Costs associated with prescribed fire depend on the size of the fire crew, the amount of heavy equipment needed at the site to control the burn, the areal extent and intensity of the burn, and the topography of the area being burned. Table 3-33 provides a range of costs associated with prescribed burning (Hansit, personal communication, 2000; Holburg, personal communication, 2000).

Table 3-33.   **Range of Prescribed Fire Costs**

Topography	Crew Cost[a]	Heavy Equipment Cost[a]
Mountainous	$50 to $100 per acre	$200 to $400 per acre
Flat land	$3 to $60 per acre	$75 to $300 per acre

[a] Hansit, personal communication, 2000; Holburg, personal communication, 2000.

Best Management Practices

Prescribed Fire Practices

◆ *Plan burning to take into account weather, time of year, and fuel conditions so that these help achieve the desired results and minimize effects on water quality.*

Evaluate ground conditions to control the pattern and timing of the burn.

◆ *Execute the prescribed burn with an agency-qualified crew and burn boss.*

◆ *Do not conduct intense prescribed fire for site preparation in the SMA.*

◆ *Do not pile and burn for slash removal purposes in the SMA.*

◆ *Avoid construction of fire lines in the SMA.*

◆ *Avoid conditions that require extensive blading of fire lines by heavy equipment when planning burns.*

◆ *Use handlines, firebreaks, and hose lays to minimize blading of fire lines.*

◆ *Avoid burning on steep slopes in high-erosion-hazard areas or areas that have highly erodible soils.*

Prescribed Fire in Wetlands

◆ *Whenever possible, conduct burns in wetlands in a manner that does not completely remove the organic layer of the forest floor.*

Prescribed burns conducted in wetlands have the potential to be the most severe due to the increased fuels available. Conduct the fire to minimize the potential to increase surface runoff and soil erosion.

◆ *When conducting prescribed fire to regenerate fire-dependent species, such as aspen, minimize consumption of the organic layer and openings in the vegetation to that which is necessary to obtain adequate regeneration.*

◆ *Do not construct firelines that could drain wetlands.*

◆ *Avoid intense burning.*

Intense burning can accelerate erosion by consuming more organic cover than desired.

Wildfire Practices

Wildfire can change erosion rates on the burned area in two ways. First, fire eliminates vegetative soil cover. Second, chemical changes in the soil following fire may create an increased resistance to water infiltration in the upper soil layer, and this can increase surface runoff and sheet erosion (Elliot et al., 1998). The magnitude of these effects depends on how hot a fire burns, slope, vegetation type, and soil resistance to erosion. Erosion following fire is greatest where a fire has burned most severely and the fire is followed by a strong storm, a year of moderately high rainfall, or a spring with a large volume of snowmelt.

◆ *Whenever possible leave a 300-foot buffer on both sides of a waterway when using aerially applied fire retardants. If necessary to apply retardant within the 300-foot zone, used the application method that will most accurately keep the retardant from entering the stream.*

The U.S. Forest Service will stop purchasing fire retardant chemicals that contain sodium ferrocyanide. A recent study revealed that mixtures with the chemical can decompose to produce amounts of cyanide that exceed EPA water quality guidelines for freshwater organisms.

◆ *Do not clean application equipment in watercourses or locations that drain into watercourses.*

◆ *Close water wells and temporary water catchments excavated for wildfire-suppression activities as soon as practical following fire control.*

◆ *During wildfire emergencies, firelines, road construction, and stream crossings are unrestricted by BMPs when necessary for health and safety of firefighters and the public and protection of resources from greater damage due to wildfire. However, use BMPs whenever possible and begin remediation as soon as possible after the emergency is controlled.*

Fireline Practices

Fireline construction is an integral part of both wildfire suppression and preparation for prescribed burning. Because of the possibility of water quality degradation following fireline construction, however, precautions are necessary to ensure that water quality is not impaired when firelines are constructed (Florida Department of Agriculture and Consumer Services, 1993). Fireline construction involves removing all organic material to expose mineral soil, and this can result in excessive erosion and water quality degradation. In wetland systems, firelines can function as drainage corridors, resulting in excessive drainage and converting a wetland to a non-wetland system. Implementation of one or more of the following practices can minimize water quality effects from fireline construction.

◆ *Use natural or in-place barriers (e.g., roads, streams, and lakes) to minimize the need for fireline construction in situations where artificial construction of firelines could result in excessive erosion and sedimentation.*

◆ *Avoid placing firelines through sensitive areas such as wetlands, marshes, prairies, and savannas unless absolutely necessary.*

◆ *When crossing water bodies with plowing equipment, raise the plow to prevent connecting the fireline directly to the water body. Water bodies can be used as firelines to avoid unnecessarily disturbing riparian zones.*

◆ *Construct firelines with the minimum disturbance possible that still allows for safe and effective firefighting, for instance handline rather than cat line when possible.*

◆ *Construct firelines in a manner that minimizes erosion and sedimentation and prevents runoff from directly entering watercourses.*

◆ *Avoid constructing firelines in SMAs. When necessary to construct line in SMAs, use appropriate strategies following direction in Land Management Plans for protection of resources*

◆ *Minimize construction of fireline straight up and down hill. Balance location of fireline with potential for larger fire consuming greater amounts of material.*

The following minimum impact suppression techniques (MIST) for firelines are recommended to minimize water quality impacts (http://www.nps.gov/crmo/firemp/crmofmp_aj.htm).

• Minimize fireline construction by taking advantage of natural barriers, rock outcrops, trails, roads, streams, and other existing fuel breaks.

• Construct firelines to be as narrow as necessary to halt the spread of the fire and place then to avoid impacts to water resources.

• Leave unburned material within the final line.

• Minimize clearing and scraping.

• Flag the route to the fire from the nearest trail or road to minimize off-road travel and soil disturbance.

Fireline Rehabilitation

◆ *Where possible, use alternatives to plowed lines such as harrowing, foam lines, wet lines, or permanent grass.*

◆ *Get cover on the site as soon as possible after the fire is out to maintain erosion control measures on firelines.*

◆ *Revegetate firelines with native species.*

◆ *Install grades, ditches, and water bars as soon as it is safe to begin rehabilitation work.*

◆ *Install water bars on any fireline running up and down the slope, and direct runoff onto a filter strip or sideslope, not into a drainage.*

3H: REVEGETATION OF DISTURBED AREAS

Management Measure for Revegetation of Disturbed Areas

Reduce erosion and sedimentation by rapid revegetation of areas disturbed by harvesting operations or road construction:

(1) Revegetate disturbed areas (using seeding or planting) promptly after completion of the earth-disturbing activity. Local growing conditions will dictate the timing for establishment of vegetative cover.

(2) Use mixes of species and treatments developed and tailored for successful vegetation establishment for the region or area.

(3) Concentrate revegetation efforts initially on priority areas such as disturbed areas in SMAs or the steepest areas of disturbance (e.g., on roads, landings, or skid trails) near drainages.

Management Measure Description

Revegetating disturbed areas restabilizes the soil in these areas, reduces erosion, and helps to prevent sediment and pollutants associated with sediment (such as phosphorus and nitrogen) from entering into nearby surface waters. Vegetation controls soil erosion by dissipating the impact force of raindrops, reducing the velocity of surface runoff, trapping dry sediment and preventing it from moving farther downslope, stabilizing the soil with roots, and contributing organic matter to the soil, which increases soil infiltration rates.

Nutrient and soil losses to streams and lakes are reduced by revegetating harvested, burned, or other disturbed areas. In some cases, planting early to establish erosion protection quickly and then again later to provide more permanent protection is necessary and advisable to prevent excessive erosion.

Good ground cover is key to reducing erosion. Good ground cover is defined as living plants within 5 feet of the ground and litter or duff with a depth of 2 inches or more (Kuehn and Cobourn, 1989).

Benefits and Costs of Revegetation Practices

The effectiveness of revegetation for controlling erosion, particularly on steep slopes and road fills, depends on protecting the slope until vegetative growth can take hold and grow enough to serve as a soil stabilizer. Straw mulch and netting are common ways to protect a newly seeded and fertilized slope. Adding straw mulch can reduce erosion by one-eighth to one-half. Adding netting with mulch can reduce erosion by nearly 100 percent to negligible levels (Figure 3-43) (Bethlahmy and Kidd, 1966).

Megahan (1987) estimated that the cost of seeding with plastic netting placed over the seeded area (approximately $8,200 per acre) is almost 50 times more than the cost of dry

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Group A: seed, fertilizer
Group B: seed, mulch, fertilizer
Group C: seed, fertilizer, mulch, netting
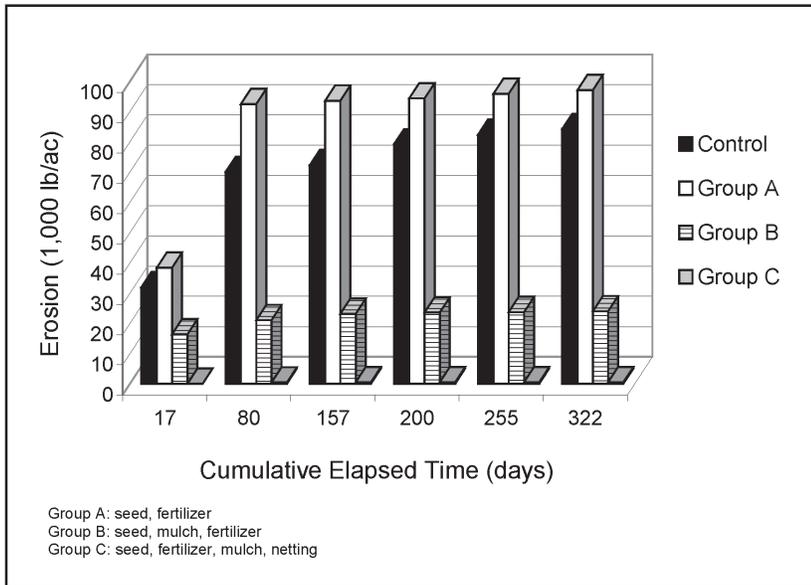
Figure 3-43. Comparison of the effectiveness of seed, fertilizer, mulch, and netting in controlling cumulative erosion from treated plots on a steep road fill in Idaho (after Bethlahmy and Kidd, 1966).

seeding alone (approximately $180 per acre). Other cost estimates related to practices for forest regeneration are presented in Tables 3-34 to 3-36. Dubensky (1991) estimated the economic effect of regeneration practices on the overall cost of a harvesting operation (Table 3-34). Lickwar (1989) compared revegetation costs for disturbed areas of various slope gradients in the Southeast (Table 3-35). Minnesota's Stewardship Incentives Program estimated the costs of reestablishing permanent vegetation with native and introduced grasses (Table 3-36).

Table 3-34. Economic Effect of Implementation of Proposed Management Measures on Road Construction and Maintenance (Dubensky, 1991)[a]

Management Practice	Increased Cost
Fiber for road and landing construction/maintenance	$5.00/ton
Ripping, shaping, and seeding log decks	$214/deck
Seeding firelines or rough logging roads	$24/100 ft
Construction and seeding of water bars	$15 each
Construction of rolling dips on roads	$24 each

All costs updated to 1998 dollars
[a] Public comment information provided by the American Paper Institute and the National Forest Products Association.

Table 3-35. Cost Estimates (and Cost as a Percent of Gross Revenues) for Seed, Fertilizer, and Mulch (1987 Dollars) (Lickwar, 1989)

Practice Component	Steep Sites[a]		Moderate Sites[b]		Flat Sites[c]	
Seed, fertilizer, and mulch	$19,950	(3.41%)	$18,438	(2.72%)	$17,590	(1.36%)

Note: All costs updated to 1998 dollars.
[a] Based on a 1,148-acre forest and gross harvest revenues of $399,685. Slopes average over 9 percent.
[b] Based on a 1,104-acre forest and gross harvest revenues of $473,182. Slopes ranged from 4 percent to 8 percent.
[c] Based on a 1,832-acre forest and gross harvest revenues of $899,491. Slopes ranged from 0 percent to 3 percent.

Table 3-36.   Estimated Costs for Revegetation (1991 Costs) (Minnesota DNR, 1991)

Practice	Total Cost[a]
Establishment of permanent vegetative cover (includes seedbed preparation, fertilizer, chemicals and application, seed, and seeding as prescribed in the plan)	
Introduced grasses	$96/acre
Native grasses	$176/acre

Note: All costs updated to 1998 dollars.
[a] The costs shown represent the total cost of the practice. Calculations were made by dividing the maximum Federal cost share by 0.75 to obtain the total cost.

Best Management Practices

◆ *Use mixtures of seeds adapted to the site, and avoid the use of invasive species. Choose annuals to allow natural revegetation of native understory plants, and select species that have adequate soil-binding properties.*

The selection of appropriate grasses and legumes is important for vegetation establishment. Grasses vary as to climatic adaptability, soil chemistry, and plant growth characteristics. USDA Natural Resources Conservation Service technical guides at the statewide level are excellent sources of information about seeding mixtures and planting prescriptions. The U.S. Forest Service, state foresters, and county extension agents can also provide helpful suggestions.

Using native species is both important and practical, and plenty of hardy native species are usually available. Nonnative species can outcompete and eliminate native vegetation, and the use of nonnative species often results in increased maintenance activities and expense.

Seeding rates (e.g., pounds per 1,000 square feet) are generally recommended for individual seed varieties and seed mixtures. Following such recommendations usually provides adequate cover and soil protection, whereas overseeding can create seedling overcrowding and subsequent failure.

◆ *On steep slopes, use native woody plants planted in rows, cordons, or wattles.*

These species may be established more effectively than grass and are preferable for binding soils.

◆ *Seed as soon as practicable after soil disturbance, preferably before rain, to increase the chance of successful vegetation establishment.*

Timing depends on the species to be planted and the schedule of operations, which determines when protection is needed.

◆ *Mulch as needed to hold seed, retard rainfall impact, and preserve soil moisture.*

Critical, first-year mulch applications provide the necessary ground cover to curb erosion and aid plant establishment. Various materials, including straw, bark, and wood chips, can be used to temporarily stabilize fill slopes and other disturbed areas and to improve conditions for germination immediately after construction. In most cases, mulching is done together with seeding and planting to establish stable banks. Both the type and the

240 & 375 t/a stone(a)
135 t/a stone(a)
7 t/a woodchips(a)
4 t/a woodchips
60 t/a stone
2.3 t/a straw
70 t/a gravel
15 t/a stone(a)
2 t/a woodchips(a)
2 t/a Portland cement
No mulch(a)

Soil Loss (ton/acre)

(a) Based on one replication. Other treatments based on average of two replications.
t/a = ton per acre
Soil Type: 6" silt loam topsoil underlain by compacted calcareous till.
Slopes: Uniform 20 percent
Rainfall Rate: Simulated rainfall at rate of 2.5"/hr for 1 hr the first day, followed by two 30-minute applications the second day.

Figure 3-44. Soil losses from a 35-foot-long slope (after Hynson et al., 1972).

amount of mulch applied vary considerably between regions and depend on the extent of the erosion potential and the available materials (Hynson et al., 1982). Figure 3-44 summarizes the effectiveness of various types of mulch (including Portland cement) for reducing erosion.

◆ *Fertilize according to site-specific conditions.*

Fertilization is often necessary for successful grass establishment because road construction commonly results in the removal or burial of fertile topsoil. To determine fertilizer formulations, it is best to compare available nitrogen, phosphorus, potassium, and sulphur in the soils to be treated with the requirements of the species to be sown. It might be necessary to refertilize periodically after vegetation establishment to maintain growth and erosion control capabilities. Fertilizer and other chemical management techniques are covered in depth in section 3I of the document.

◆ *Use biosolids as an alternative to commercial fertilizers.*

Biosolids is the name given to the solid material remaining after raw sewage has been treated. Biosolids can be used for forest regeneration efforts as a viable alternative to using commercial fertilizers. Biosolids are rich in nitrogen, as well as other nutrients essential for plant growth, including phosphorus, zinc, boron, manganese, and chromium (King County, Washington, 1999). The nutrients in biosolids are mostly in an organic form, so the biosolids act like a slow-release fertilizer, releasing only 15-20 percent of their nutrients during the first year after an application (Meyers, 1998). They also have a high content of organic matter, which increases soil infiltration rates and helps improve the ability of the soil to retain water, making it available for trees during dry periods. Biosolids can increase the growth rate of trees growing on relatively infertile soils to match that of trees growing on fertile soils.

Biosolids that are applied to the forest are delivered to the forest as a semisolid product with a content of approximately 20 percent solids and 80 percent water. The biosolids can be dispersed using a device that propels them aerially over an area, or they can be applied using a high-pressure hose. From a single point, they can be spread to a 250-foot radius or more across young tree growth and to a 60-foot radius in thinned timber stands.

The application rate (in ton/acre) of biosolids can be determined based on the nitrogen content of the biosolids. Specific amounts of nitrogen can be specified for each area to be treated based on soil testing and the nutrient requirements of the species involved. In the Northwest, application rates vary from 3 dry ton/acre of biosolids for timber to 7 dry ton/acre for young plantations, which corresponds to 150 to 350 pounds of plant-available nitrogen per acre (King County, Washington, 1999).

Streams and other water bodies are protected during biosolids applications by 33-foot buffer areas that are not fertilized. States regulate the use and application of biosolids, and obtaining a permit is usually necessary before biosolids may be used.

The potential for long-term effects from metals and pathogens in biosolids has been raised as a concern, but biosolids that meet EPA and state standards pose very little environmental threat (USEPA, 1994).

◆ *Protect seeded areas from grazing and vehicle damage until plants are well established.*

◆ *Inspect all seeded areas for failures, and make necessary repairs and reseed within the planting season.*

◆ *During non-growing seasons, apply interim surface stabilization methods to control surface erosion.*

Possible methods include mulching (without seeding) and installation of commercially produced matting and blankets. Alternative methods for planting and seeding include hand operations, the use of a wide variety of mechanical seeders, and hydroseeding.

3I: FOREST CHEMICAL MANAGEMENT

Forest Chemical Management

Use chemicals when necessary for forest management in accordance with the following to reduce nonpoint source pollution effects due to the movement of forest chemicals off-site during and after application:

(1) Conduct applications by skilled and, where required, licensed applicators according to the registered use, with special consideration given to effects to nearby surface waters.

(2) Carefully prescribe the type and amount of pesticides appropriate for the insect, fungus, or herbaceous species.

(3) Prior to applications of pesticides and fertilizers, inspect the mixing and loading process and the calibration of equipment, and identify the appropriate weather conditions, the spray area, and buffer areas for surface waters.

(4) Establish and identify buffer areas for surface waters. (This is especially important for aerial applications.)

(5) Immediately report accidental spills of pesticides or fertilizers into surface waters to the appropriate state agency. Develop an effective spill contingency plan to contain spills.

Management Measure Description

Chemicals used in forest management are generally pesticides (insecticides, herbicides, and fungicides) and fertilizers. Since pesticides can be toxic, they have to be mixed, transported, loaded, and applied correctly and their containers disposed of properly to prevent potential nonpoint source pollution. Since fertilizers can also be toxic or can shift the ecosystem's energy dynamics, depending on the exposure and concentration, it is important that they be handled and applied properly.

Pesticides and fertilizers are occasionally used in forestry to reduce mortality of and favor desired tree species and improve forest production. Many forest stands or sites never receive chemical treatment, and for those that do receive treatment, typically no more than two or three applications are made during an entire tree rotation (40 to 120 years).

Even though few applications are made, forestry chemicals can enter surface waters and precautions can be taken to prevent water contamination.

A number of studies conducted before 1990 demonstrate the importance of following current state and federal guidelines for forest chemical applications for protecting surface waters and groundwater. Norris and others (1991) compiled information from multiple studies that evaluated the peak concentrations of herbicides, insecticides, and fertilizers in soils, lakes, and streams (see Table 3-37). These studies were conducted from 1967 to 1987. Norris (1968) found that application of 2,4-D to marshy areas led to higher-than-normal levels of stream contamination. When ephemeral streams were treated, residue

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levels of hexazinone and picloram greatly increased with storm-generated flow. Glyphosate was aerially applied (3.3 kg/hectare) to an 8-hectare forest ecosystem in the Oregon Coast Range. The study area contained two ponds and a small perennial stream. All were unbuffered and received direct application of the herbicide. Glyphosate residues were detected for 55 days after application with peak stream concentrations of 0.27 mg/L. It was demonstrated that the concentration of insecticides in streams was significantly greater when the chemicals were applied without a buffer strip to protect the watercourse. When streams were unbuffered, the peak concentrations of malathion ranged from 0.037 to 0.042 mg/L. When buffers were provided, however, the concentrations of malathion

Table 3-37. Peak Concentrations of Forest Chemicals in Soils, Lakes, and Streams After Application (Norris et al., 1991)

Chemicals[a] and System[b]	Application Rate (kg/hectare)	Concentration (mg/L or mg/kg*) Peak	Subsequent	Time Interval[c]	Time to Non-detection	Source[d]
		Herbicides				
2,4-D	2.24	0.001-0.13			1-168 h[e]	17
Marsh	2.24	0.09				17,18
2,4-D BE						
Built pond	23.0					1
Water		3.0	1.0	85 d		
			0.2	180 d		
Sediment		8.0*	4.0*	13+ d		
			0.4–0.6*	82–182 d		
Aquatic plants			206*	7 d		
			8*	82 d	182 d	
2,4-D AS						
Reservoir		3.6	0	13 d		7
Picloram						
Runoff		0.078				19
Runoff		0.038				23
Ephemeral stream	2.8	0.32		157 d	915 d	9
Stream	0.37					3
Hexazinone						
Stream (GA)	1.68	0.044		3–4 m		11
Forest (GA)	1.68					14
Litter		0.177*	<0.01*	60+ d		
Soil		0.108*	<0.01*	90 d		
Ephemeral stream		0.514		3 d		
Perennial stream		0.442		3 d		
Atrazine						
Stream	3.0	0.42	0.02	17 d		16
Built ponds						10
Water		0.50	0.05	14 d		
			0.005	56 d		
Sediments		0.50*	0.9*	4 d		
		0.50*	0.25*	56 d		
Triclopyr						
Pasture (OR)	3.34	0.095*	0.09	5.5 h		20
Glyphosate						
Water	3.3	0.27	<0.01	3 d		15
Dalapon						
Field irrigation water		0.023–3.65	<0.01	Sev h		5

Table 3-37.   (continued)

Chemicals[a] and System[b]	Application Rate (kg/hectare)	Concentration (mg/L or mg/kg*) Peak	Concentration (mg/L or mg/kg*) Subsequent	Time Interval[c]	Time to Non-detection	Source[d]
Insecticides						
Malathion						
Streams	0.91					24
Unbuffered		0.037–0.042				
Buffered		0–0.017				
Carbaryl						
Streams & ponds (E)		0–0.03				24
Streams, unbuffered (PNW)		0.005–0.011			48 h	24
Water	0.84	0.026–0.042				8
Brooks with buffer	0.84	0.001–0.008				22
Rivers with buffer	0.84	0.000–0.002				22
Streams, unbuffered	0.84	0.016				22
Ponds	0.84					6
Water		0.254			100-400 d	
Sediment		<0.01–5.0*[f]				
Acephate						
Streams		0.003–0.961		1 d		4
Pond sediment & fish	0.56	0.113–0.135	0.013-0.065	14 d		21
Fertilizers						
Urea	224					
Urea-N						
Forest stream (OR)		0.39	0.39	48 h		12
Dollar Cr (WA)		44.4				13
NH_4^+-N						
Forest stream (OR)		<0.10				12
Tahuya Cr (WA)		1.4				13
NO_3^+-N						
Forest stream (OR)		0.168				12
Elochoman R (WA)		4.0				13

[a] 2,4-D BE = 2,4-D butoxyethanol ester; 2,4-D AS = 2,4-D amine salt + ester.

[b] E = eastern USA; Cr = Creek; GA = Georgia; PNW = Pacific Northwest; OR = Oregon; R = River; WA = Washington; buffer = wooded riparian strip.

[c] d = day; h = hours; m = months; sev h = several hours. Intervals are times from application to measurement of peak or subsequent concentration, whichever is the last measurement indicated.

[d] 1 = Birmingham and Colman (1985); 2 = Bocsor and O'Connor (1975); 3 = Davis et al. (1968); 4 = Flavell et al. (1977); 5 = Frank et al. (1970); 6 = Gibbs et al. (1984); 7 = Hoeppel and Westerdahl (1983); 8 = Hulbert (1978); 9 = Johnsen (1980); 10 = Maier-Bode (1972); 11 = Mayack et al. (1982); 12 = Moore (1970); 13 = Moore (1975b); 14 = Neary et al. (1983); 15 = Newton et al. (1984); 16 = M. Newton (Oregon State University, personal communication, 1967); 17 = Norris (1967); 18 = Norris (1968); 19 = Norris (1969); 20 = Norris et al. (1987); 21 = Rabeni and Stanley (1979); 22 = Stanley and Trial (1980); 23 = Suffling et al. (1974); 24 = Tracy et al. (1977).

[e] Normally less than 48 h.

[f] One extreme case: 23.8 mg/kg peak concentration, 16 months to nondetection.

were reduced to levels that ranged from undetectable to 0.017 mg/L. The peak concentrations of carbaryl ranged from 0.000 to 0.0008 mg/L when watercourses were protected with a buffer, but they increased to 0.016 mg/L when watercourses were unbuffered.

Moore (1971), as cited in Norris et al. (1991), compared nitrogen loss from a watershed treated with 224 kg urea-N per hectare to nitrogen loss from an untreated watershed. The study demonstrated that the loss of nitrogen from the fertilized watershed was 28.02 kg/hectare whereas the loss of nitrogen from the unfertilized watershed was only 2.15 kg/hectare (Table 3-38).

Table 3-38.   Nitrogen Losses from Two Subwatersheds in the Umpqua Experimental Watershed (OR) (Norris et al., 1991)

Loss Locus or Statistic	Urea-N	NH₃-N	NO₃-N	Total
	Absolute loss (kg/hectare)			
Watershed 2 (treated)	0.65	0.28	27.09	28.02
Watershed 4 (untreated)	0.02	0.06	2.07	2.15
Net loss (2-4)	0.63	0.22	25.02	25.87
	Proportional loss			
Percent of total	2.44	0.85	96.71	100.00

Riekerk and others (1989) found that the greatest risk to water quality from pesticide application in forestry operations occurred from aerial application because of drift, wash-off, and erosion processes. They found that aerial applications of herbicides resulted in surface runoff concentrations roughly 3.5 times greater than those for application on the ground.

The Riekerk and others (1989) study results also suggested that tree injection application methods would be considered the least hazardous for water pollution, but would also be the most labor-intensive. Hand application of herbicides usually poses little or no threat to water quality in areas where there is no potential for herbicides to wash into water-courses through gullies. Providing buffer areas around streams and water bodies can effectively eliminate adverse water quality effects from forestry chemicals.

Megahan (1980) summarized data on changes in water quality following the fertilization of various forest stands with urea. The major observations from this research are summarized below:

- Increases in the concentration of urea-N ranged from very low to a maximum of 44 ppm, with the highest concentrations attributed to direct application to water surfaces.

- Higher concentrations occurred in areas where buffer strips were not left beside stream banks.

- Chemical concentrations of urea and its by-products tended to be relatively short-lived due to transport downstream, assimilation by aquatic organisms, or adsorption by stream sediments.

Based on his review, Megahan concluded that the effects of fertilizer application in forested areas could be significantly reduced by avoiding application techniques that could result in direct deposition into the water body and by maintaining a buffer area along the stream bank. Other researchers have presented information supporting Megahan's conclusions (Hetherington, 1985; Malueg et al., 1972).

Cost of Forest Chemical Applications

The cost of chemical management depends on the method of application (Table 3-39). Generally, chemicals are applied by hand, from an airplane or helicopter (aerial spray), or mechanically. When forest chemicals are applied mechanically, it is most common to use a boom sprayer.

Table 3-39. Average Costs for Chemical Management (Hansit, 2000; Holburg, 2000)

Application Practice	Average Cost
Hand application	$100/acre
Aerial application	$55–$70/acre

Best Management Practices

◆ *For aerial spray applications, mark and maintain a buffer area of appropriate width around all watercourses and water bodies to avoid drift or accidental application of chemicals directly to surface waters (Figure 3-45).*

Buffer width is determined by taking into considerations the altitude of application, weather conditions, and drop size distribution (Ice and Teske, 2000). Careful and precise marking of application areas for aerial applications helps avoid accidental contamination of open waters.

Models are available to help the forest manager calculate pesticide application details. The Spray Drift Task Force, in collaboration with EPA and USDA, co-developed AgDRIFT, a new model, to provide estimates of spray drift deposition under different pesticide application and meteorological conditions (see www.agdrift.com). The Forest Service Cramer-Barry-Grim (FSCBG) spray dispersion model analyzes data on aircraft,
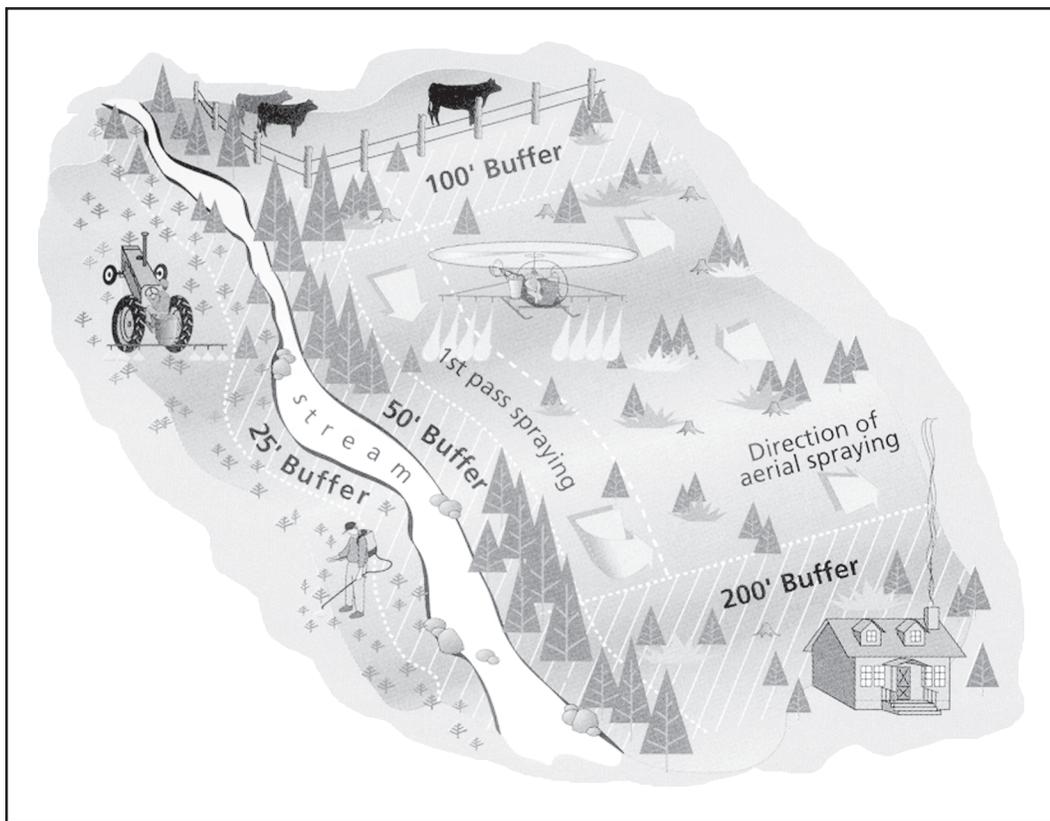
Figure 3-45. Establish buffer zones of appropriate width during aerial applications of forest chemicals to protect water quality, people, and animals (Washington State DNR, 1997).

meteorology, pesticides, and target areas to predict deposition and drift (see www.fs.fed.us/foresthealth/technology). A personal computer version of the model is available that combines and implements mathematical models to assist forest managers in planning and implementing aerial spray operations.

◆ *Apply pesticides and fertilizers during favorable atmospheric conditions.*

Do not apply pesticides when wind conditions increase the likelihood of significant drift. It is also best to avoid pesticide application when temperatures are high or relative humidity is low because these conditions influence the rate of evaporation and enhance losses of volatile pesticides.

◆ *Ensure that pesticide users abide by the current pesticide label, which might specify whether users be trained and certified in the proper use of the pesticide; allowable use rates; safe handling, storage, and disposal requirements; and whether the pesticide may be used only under the provisions of an approved State Pesticide Management Plan.*

Consistency between management measures and practices for pesticides and those in the approved State Pesticide Management Plan helps ensure consistency in the method and means of use.

◆ *Locate mixing and loading areas, and clean all mixing and loading equipment thoroughly after each use, where pesticide residues will not enter streams or other water bodies.*

◆ *Dispose of pesticide wastes and containers according to state and federal laws.*

◆ *Take precautions to prevent leaks and spills.*

◆ *Develop a spill contingency plan that provides for immediate spill containment and cleanup, and notification of proper authorities.*

Maintain an adequate spill and cleaning kit that includes the following:

- Detergent or soap.
- Hand cleaner and water.
- Activated charcoal, adsorptive clay, vermiculite, kitty litter, sawdust, or other adsorptive materials.
- Lime or bleach to neutralize pesticides in emergency situations.
- Tools such as a shovel, broom, and dustpan and containers for disposal.
- Proper protective clothing.

◆ *Apply slow-release fertilizers when possible.*

This practice reduces potential nutrient leaching to groundwater, and it increases the availability of nutrients for plant uptake.

◆ *Apply fertilizers during maximum plant uptake periods to minimize leaching.*

◆ *Base fertilizer type and application rate on soil and/or foliar analysis.*

Conduct foliar analysis approximately once per year to diagnose nutrient toxicities or deficiencies and to determine the correct fertilization program to follow. Foliar analysis is

the process whereby leaves from trees are dried, ground, and chemically analyzed for their nutrient content. Compare the results of foliar analysis to available nitrogen, phosphorus, potassium, and sulphur in the soils to be treated and to the requirements of the species.

◆ *Consider the use of pesticides as only one part of an overall program to control pest problems.*

Integrated Pest Management (IPM) strategies have been developed to control forest pests without total reliance on chemical pesticides. The IPM approach uses all available techniques, including chemical and nonchemical. An extensive knowledge of both the pest and the ecology of the affected environment is necessary for IPM to be effective.

◆ *Base selection of pesticide on site factors and pesticide characteristics.*

These factors include vegetation height, target pest, adsorption (attachment) to soil organic matter, persistence or half-life, toxicity, and type of formulation.

◆ *Check all application equipment carefully, particularly for leaking hoses and connections and plugged or worn nozzles. Calibrate spray equipment periodically to achieve uniform pesticide distribution and rate.*

◆ *Always use pesticides in accordance with label instructions, and adhere to all federal and state policies and regulations governing pesticide use.*

3J: WETLANDS FOREST MANAGEMENT

Management Measure for Wetlands Forest Management

Plan, operate, and manage normal, ongoing forestry activities (including harvesting; road design, construction, and maintenance; site preparation and regeneration; and chemical management) to adequately protect the aquatic functions of forested wetlands.

Management Measure Description

Forested wetlands provide many beneficial functions that need to be protected. Among these are floodflow alteration, sediment trapping, nutrient retention and removal, provision of important habitat for fish and wildlife, and provision of timber products. The extent of wetlands (including forested wetlands) in the continental United States has declined greatly in the past 40 years because of conversion to other land uses. There are currently approximately 100 million acres of wetlands in the 48 contiguous states, or about one-half of their extent at the time of European settlement. Although the rate of wetlands loss has slowed in recent years, the United States continues to sustain a net loss of approximately 58,000 acres per year. Forestry activities are the third leading cause of wetlands loss–behind urban development and agriculture–and accounted for 23 percent of wetland losses from 1986 to 1997 (Dahl, 2000). Given the historic and ongoing losses, it is critical that additional effects to wetlands be avoided and minimized to the maximum extent possible.

Potential effects of forestry operations in wetlands include the following:

- Loss and/or degradation due to discharges of dredged or fill material.
- Sediment production from road construction and use and equipment operation resulting in wetlands filling.
- Drainage alteration as a result of improper road construction and ditching. An excellent discussion of the relationship between forest roads and drainage is contained in the U.S. Forest Service document Water/Road Interaction Technology Series (USDA-FS, 1998b).
- Stream obstruction caused by failure to remove logging debris.
- Soil compaction caused by operation of logging vehicles during flooding periods or wet weather. Skid trails, haul roads, and log landings are areas where compaction is most severe.
- Contamination from improper application or use of pesticides.
- Loss of integrity of whole wetland landscapes (and the functions they serve) as a cumulative effect of incremental losses of small wetland tracts.

Potential adverse effects associated with road construction and maintenance in forested wetlands are alteration of drainage and flow patterns, increased erosion and sedimentation, habitat loss and degradation, and damage to existing timber stands. In an effort to prevent these potential adverse effects, section 404 of the Clean Water Act requires the use of appropriate BMPs for road construction and maintenance in wetlands so that flow and circulation patterns and chemical and biological characteristics are not impaired (see text below).

Harvest planning and selection of the right harvest system are essential in achieving the management objectives of timber production, ensuring stand establishment, and avoiding adverse effects on water quality and wetland functions and values. The potential effects of reproduction methods and cutting practices on wetlands include changes in water quality, water quantity, temperature, nutrient cycling, and aquatic habitat. Streams can also become blocked with logging debris if SMAs are not properly maintained or if appropriate practices are not employed in SMAs.

Site preparation includes but is not limited to the use of prescribed fire, chemicals, and/or mechanical site preparation. Extensive site preparation on bottoms where frequent flooding occurs can cause excessive erosion and stream sedimentation. The degree of acceptable site preparation is governed by the amount and frequency of flooding, soil type, and species suitability and is dependent on the regeneration method used.

Forestry in Wetlands: Section 404

Section 404 establishes a program that regulates the discharge of dredged or fill material into waters of the United States, including wetlands. The Corps and EPA jointly administer the program. The Corps administers the day-to-day program, including permit decisions and jurisdictional determinations; develops policy and guidance; and enforces Section 404 provisions. EPA develops and interprets environmental criteria used in evaluating permit applications; determines the scope of geographic jurisdiction; and approves and oversees state assumption. EPA also identifies activities that are exempt, enforces Section 404 provisions, and has the authority to elevate and/or veto Corps permit decisions. In addition, the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, and state resource agencies have important advisory roles.

Section 404(f) exempts normal forestry activities (for example, bedding, seeding, harvesting, and minor drainage) that are part of an established, ongoing forestry operation. A forest operation ceases to be "established" when the area in which it was conducted has been converted to another use or has lain idle so long that modifications to the hydrological regime are necessary to resume operations (40 CFR Part 232.3(c)(1)(ii)(B)). This exemption does not apply to activities that represent a new use of the wetland and that would result in a reduction in reach or impairment of flow or circulation of waters of the United States, including wetlands. In addition, Section 404(f) provides an exemption of discharges of dredged or fill material for the purpose of constructing or maintaining forest roads, where such roads are constructed or maintained in accordance with BMPs to assure that the flow and circulation patterns and chemical and biological characteristics of the navigable waters are not impaired, that the reach of the navigable waters is not reduced, and that any adverse effect on the aquatic environment will be otherwise minimized. Following are the section 404(f) regulations pertaining to forestry activities, including the BMPs for forest road construction or maintenance.

Code of Federal Regulations, Title 40, section 232.3: Activities Not Requiring a Section 404 Permit

Except as specified in paragraphs (a) and (b) of this section, any discharge of dredged or fill material that may result from any of the activities described in paragraph (c) of this section is not prohibited by or otherwise subject to regulation under this part.

(a) If any discharge of dredged or fill material resulting from the activities listed in paragraph (c) of this section contains any toxic pollutant listed under section 307 of the Act, such discharge shall be subject to any applicable toxic effluent standard or prohibition, and shall require a section 404 permit.

(b) Any discharge of dredged or fill material into waters of the United States incidental to any of the activities identified in paragraph (c) of this section must have a permit if it is part of an activity whose purpose is to convert an area of the waters of the United States into a use to which it was not previously subject, where the flow or circulation of waters of the United States may be impaired or the reach of such waters reduced. Where the proposed discharge will result in significant discernible alterations to flow or circulation, the presumption is that flow or circulation may be impaired by such alteration.

Note: For example, a permit will be required for the conversion of a cypress swamp to some other use or the conversion of a wetland from silvicultural to agricultural use when there is a discharge of dredged or fill material into waters of the United States in conjunction with construction of dikes, drainage ditches or other works or structures used to effect such conversion. A conversion of section 404 wetland to a non-wetland is a change in use of an area of waters of the U.S. A discharge which elevates the bottom of waters of the United States without converting it to dry land does not thereby reduce the reach of, but may alter the flow or circulation of, waters of the United States.

(c) The following activities are exempt from section 404 permit requirements, except as specified in paragraphs (a) and (b) of this section:

* * *

(6) Construction or maintenance of farm roads, forest roads, or temporary roads for moving mining equipment, where such roads are constructed and maintained in accordance with best management practices (BMPs) to assure that flow and circulation patterns and chemical and biological characteristics of waters of the United States are not impaired, that the reach of the waters of the United States is not reduced, and that any adverse effect on the aquatic environment will be otherwise minimized. The BMPs which must be applied to satisfy this provision include the following baseline provisions:

   (i) Permanent roads (for farming or forestry activities), temporary access roads (for mining, forestry, or farm purposes) and skid trails (for logging) in waters of the United States shall be held to the minimum feasible number, width, and total length consistent with the purpose of specific farming, silvicultural or mining operations, and local topographic and climatic conditions;

   (ii) All roads, temporary or permanent, shall be located sufficiently far from streams or other water bodies (except for portions of such roads which must cross water bodies) to minimize discharges of dredged or fill material into waters of the United States;

(iii) The road fill shall be bridged, culverted, or otherwise designed to prevent the restriction of expected flood flows;

(iv) The fill shall be properly stabilized and maintained to prevent erosion during and following construction;

(v) Discharges of dredged or fill material into waters of the United States to construct a road fill shall be made in a manner that minimizes the encroachment of trucks, tractors, bulldozers, or other heavy equipment within the waters of the United States (including adjacent wetlands) that lie outside the lateral boundaries of the fill itself;

(vi) In designing, constructing, and maintaining roads, vegetative disturbance in the waters of the United States shall be kept to a minimum;

(vii) The design, construction and maintenance of the road crossing shall not disrupt the migration or other movement of those species of aquatic life inhabiting the water body;

(viii) Borrow material shall be taken from upland sources whenever feasible;

(ix) The discharge shall not take, or jeopardize the continued existence of, a threatened or endangered species as defined under the Endangered Species Act, or adversely modify or destroy the critical habitat of such species;

(x) Discharges into breeding and nesting areas for migratory waterfowl, spawning areas, and wetlands shall be avoided if practical alternatives exist;

(xi) The discharge shall not be located in the proximity of a public water supply intake;

(xii) The discharge shall not occur in areas of concentrated shellfish production;

(xiii) The discharge shall not occur in a component of the National Wild and Scenic River System;

(xiv) The discharge of material shall consist of suitable material free from toxic pollutants in toxic amounts; and

(xv) All temporary fills shall be removed in their entirety and the area restored to its original elevation.

Best Management Practices

Wetland Harvesting Practices

◆ *Conduct forest harvesting according to preharvest planning designs and locations.*

Planning and close supervision of harvesting operations are needed to protect site integrity and enhance regeneration. Harvesting without regard to season, soil type, or type of equipment can damage the site productivity; retard regeneration; cause excessive rutting, churning, and puddling of saturated soils; and increase erosion and sedimentation of streams. Harvesting without regard to other activities occurring in the watershed can cause unacceptable cumulative effects.

◆ *Establish a streamside management area (SMA) adjacent to natural perennial streams, lakes, ponds, and other standing water in the forested wetland following the components of the SMA management measure.*

◆ *Select the harvesting method to minimize soil disturbance and hydrologic effects on the wetland.*

In seasonally flooded wetlands, a guideline is to use conventional skidder logging that employs equipment with low-ground-pressure tires, cable logging, or aerial logging. Comparisons of cable logging and helicopter logging have concluded that helicopter operations cause less site disturbance, are more economical, and provide greater yield. Table 3-40 presents one set of harvesting system recommendations by type of forested wetland (Florida Division of Forestry, 1988). Another alternative is to conduct harvesting during winter months when the ground is frozen (see below).

◆ *Use ultrawide, high-flotation tires on logging trucks and skidders to reduce soil compaction and erosion.*

Using dual-tired skidders and high-floatation tires for log hauling reduces soil damage, soil compaction, surface runoff, and sedimentation (Aust et al., 1994).

◆ *When ground skidding, use low-ground-pressure tires or tracked machines and confine skidding to a few primary skid trails to minimize site disturbance, soil compaction, and rutting. Adjust tire pressure on skidders during wet weather or when conducting forested wetland harvesting (Aust, Virginia Polytechnic Institute and State University, personal communication, 1999).*

Table 3-40. Recommended Harvesting Systems by Forested Wetland Site[a] (Florida Department of Agriculture and Consumer Services, 1988)

Site Type	Conventional	Conventional with Controlled Access[b]	Cable or Aerial	Barge or High Flotation Boom
Flowing Water				
Mineral Soil				
Alluvial River Bottom	B	A	C	C
Organic Soil				
Black River Bottom	B	A	C	C
Branch Bottom	A[c]	B	C	C
Cypress Strand	B	A	A	A
Muck Swamp	C	A	A	A
Nonflowing Water				
Mineral Soil				
Wet Hammock	B	A	C	C
Organic Soil				
Cypress Dome	B	A	A	A
Peat Swamp	C	A	A	A

Note: A = recommended; B = recommended when dry; C = not recommended.
[a] Recommendations include cost considerations
[b] Preplanned and designated skid trails and access roads.
[c] Log from the hill (high ground).

Research conducted by Randy Foltz of the Intermountain Research Station in the Lowell Ranger District of the Willamette National Forest, Oregon (1994), addressed the use of variable tire pressure as a BMP for forest roads. His study showed that by reducing the tire pressure on logging trucks from their highway inflation of 90 psi to between 30 and 70 psi, sediment runoff was reduced on average by 67 percent. The percentage reduction in sediment runoff was directly correlated with the rainfall quantity and traffic volume.

◆ *When soils become saturated, suspend ground skidding harvesting operations. Use of ground skidding equipment during excessively wet periods can result in unnecessary site disturbance and equipment damage.*

Wetland Road Design and Construction Practices

◆ *Locate, design, and construct forest roads according to preharvest planning.*

Forestry activities in wetlands are often subject to municipal, county, state, and federal regulations. Therefore, sufficient time should be set aside to obtain all necessary permits.

Improperly located, designed, or constructed forest roads can cause changes in hydrology, accelerate erosion, reduce or degrade fisheries habitat, and destroy or damage existing stands of timber.

◆ *Use temporary roads in forested wetlands.*

A temporary road in a wetland needs to provide adequate cross-road drainage at all natural drainageways. Temporary drainage structures include culverts, bridges, and porous material such as corduroy or chunkwood.

Construct permanent roads only to serve large and frequently used areas, as approaches to watercourse crossings, or to provide access for long-term fire protection. Use the mini-mum design standard necessary for reasonable safety and the anticipated traffic volume. Various temporary wetland crossing options are compared in Table 3-41.

Blade the surface of a wetland to be as flat as possible prior to constructing a temporary road (Hislop and Moll, 1996, cited in Blinn et al., 1998). Do not disturb the root mat in any wetland that has grass mounds or other uneven vegetation. Any temporary wetland crossing is enhanced by using a root or slash mat to provide additional support to the equipment.

◆ *Construct fill roads only when absolutely necessary for access since fill roads have the potential to restrict natural flow patterns.*

Where construction of fill roads is necessary, use a permeable fill material (such as gravel or crushed rock) for at least the first layer of fill. The use of pervious materials helps maintain the natural flow regimes of subsurface water. Figure 3-46 demonstrates the different effects of impervious and pervious road fills on wetland hydrology. Permeable fill material is not a substitute for using bridges where needed or for installing adequately spaced culverts at all natural drainageways. Use this practice in conjunction with cross drainage structures to ensure that natural wetland flows are maintained (i.e., so that fill does not become clogged by sediment and obstruct flows).

◆ *Provide adequate cross drainage to maintain the natural surface and subsurface flow of the wetland.*

Table 3-41.   Temporary Wetland Crossing Options (Blinn, 1996)

Crossing Option	Description	Application	Cost
Wood Mats	Individual cants that are strung together using two 3/16-inch galvanized steel cables to make a single-layer crossing.	Wet mineral or sandy soils or existing road beds. Wood mats are not recommended for undisturbed peat or very weak clay soils. They require a relatively level surface with grades up to 4 percent, a fairly straight alignment, and no cross slope.	Approximately $170 to initially construct a 10' x 12' mat
Wood Planks/ Panels	Wood planks or panels are constructed using lumber planking to create a two-layer crossing. Parallel runners are laid down on each side where the vehicle's tires will pass and then lumber is nailed perpendicular to these runners.	Most wetland soils, if sized properly. The surface width needed depends on the soil strength. Wood plank crossings require a relatively level surface with grades up to 4 percent, a fairly straight alignment, and no cross slope.	Approximately $150 to initially construct an 8' x 12' wood plank
Wood Pallets	Wood-pallet crossing mats are sturdy, commercially available, multilayered variation of a three-layer wood pallet (used for shipping or storage) that has been designed specifically for traffic.	Most wetland soils, if sized appropriately. The require a relatively level surface with grades up to 4 percent, a fairly straight alignment, and no cross slope. Most appropriate for hauling or forwarding operations.	Approximately $350 for a commercial 8' x 16' pallet
Bridge Decking	The decking of a timber bridge can be used to cross a small wetland area.	Most wetland soils, if sized properly. Easy to install and remove. Require a relatively level ground surface.	Approximately $6,000 for a 30' x 12' bridge
Expanded Metal Grating	Metal grating is relatively light and the surface is rough enough to provide some traction. Built by hand-placing the grating sections in the wheel paths.	Most shallow wetland soils, sandy soils, or on an existing road. It is not recommended for undisturbed peat or very weak clay soils. Performance is enhanced where there is an adequate root or slash mat to provide additional support.	Approximately $100 for a 4' x 8' grate
PVC or HDPE Pipe and Plastic Road	A PVC and HDPE pipe mat is constructed using 4-inch diameter PVC or HDPE pipes that are tightly connected using galvanized steel cables. Plastic roads are similar to pipe mats except that they are not built to ease the transition of tires between the firm soil and the road.	Most wetland soils, if sized properly. Mat width needed depends on soil strength. Require a relatively level surface with grades up to 4 percent, a fairly straight alignment, and no cross slope.	Approximately $200 for a 4' x 12' pipe mat. Plastic road that is 8' x 40' costs approximately $2,000

Table 3-41.   (continued)

Crossing Option	Description	Application	Cost
Tire Mats	A tire mat or panel of tires created by interconnecting tire sidewalls with corrosion-resistant fasteners. Tire threads are also used in some designs. Mats of varying length and width can be created.	Most wet mineral soils with different designs for distinct soils and situations. Tire mats require a relatively level surface with grades up to 5 percent, a fairly straight alignment, and no cross slope.	Approximately $300 for a 5' x 10' mat
Corduroy	Corduroy is a crossing made of brush, small logs cut from low-value and noncommercial trees on-site, or mill slabs that are laid perpendicular or parallel to the direction of travel.	Most wetland soils. Corduroy crossings require a relatively level surface with grades up to 4 percent, a fairly straight alignment, and no cross slope.	Low
Pole Rails	When attempting to support skidding or forwarding machinery equipped with high flotation or dual tires, one or more straight hardwood poles cut from on-site trees can be laid parallel to the direction of travel below each wheel.	Skidding and felling machinery equipped with wide, high-flotation tires and used across small mineral soil wetlands. Should only be used on relatively level surface with grades up to 4 percent, a fairly straight alignment, and no cross slope.	Low
Wood Aggregate	Wood particles ranging in size from chips to chunks can provide cohesion and support on soft soils. Wood aggregate is used in the same way as gravel, except that it is lighter and temporary due to natural deterioration.	The traffic capability of most wet soils can be improved substantially with the application of wood aggregate. Can be used on a variety of grades, alignments, and cross slopes.	Competitive with local sources of gravel fill.
Equipment with Wide Tires, Duals, Bodies, or Tire Tracks	These mobility options provide a method for increasing the contact area between the equipment and the soil so that the machine's weight is spread over a larger surface area.	Many wetland soils. Performance is enhanced in areas where there is adequate root or slash mat to provide additional support to the equipment.	Wide tires may cost more than $4,000 each, tire tracks may cost approximately $7,000 for a set of two tracks.
Central Tire Inflation (CTI)	CTI is a low-ground-pressure option currently for use on hauling vehicles only, but will likely be available on other equipment in the future.	Many wetland soils. The reduced tire pressure, when used with radial ply tires, results in a larger tire "footprint," which reduces the vehicle pressure applied to the ground.	Cost depends on the number of axles retrofitted. 18 axles = $16,000

This can be accomplished through adequate sizing and spacing of water crossing structures, proper choice of the type of crossing structure, and installation of drainage structures at a depth adequate to pass subsurface flow. Designed and constructed according to these considerations helps ensure that bridges, culverts, and other structures do not perceptibly diminish or increase the duration, direction, or magnitude of the minimum, peak, or mean flow of water on either side of the structure.

◆ *Construct roads at natural ground level to minimize the potential to restrict flowing water.*

Float the access road fill on the natural root mat. If the consequences of the natural root mats' failing are serious, use reinforcement materials such as geotextile fabric, geo-grid mats, or log corduroy. Figure 3-47 depicts a cross section of the practice of floating the road. Protect the root mat beneath the roadway from equipment damage by diverting through traffic to the edge of the right-of-way, shear-blading stumps instead of grubbing, and using special wide-pad equipment. Also, protect the root mat from damage or puncture by using fill material that does not contain large rocks or boulders.

◆ *Discharges of dredged or fill material into wetlands or other waters of the United States must comply with CWA section 404 (see text above).*

(a) Impervious roadfill section

(b) Pervious roadfill section

Figure 3-46. Comparison of impervious (a) and pervious (b) roadfill sections. Impervious roadfill consolidates natural material and restricts groundwater flow. Pervious roadfill allows movement of groundwater through it and minimizes flow changes (adapted from Thronson, 1979).

Practices for Crossing Wetlands in Winter

Winter provides an opportunity to cross wetlands with little effect. Roads are often constructed across wetlands in winter to take advantage of frozen ground.
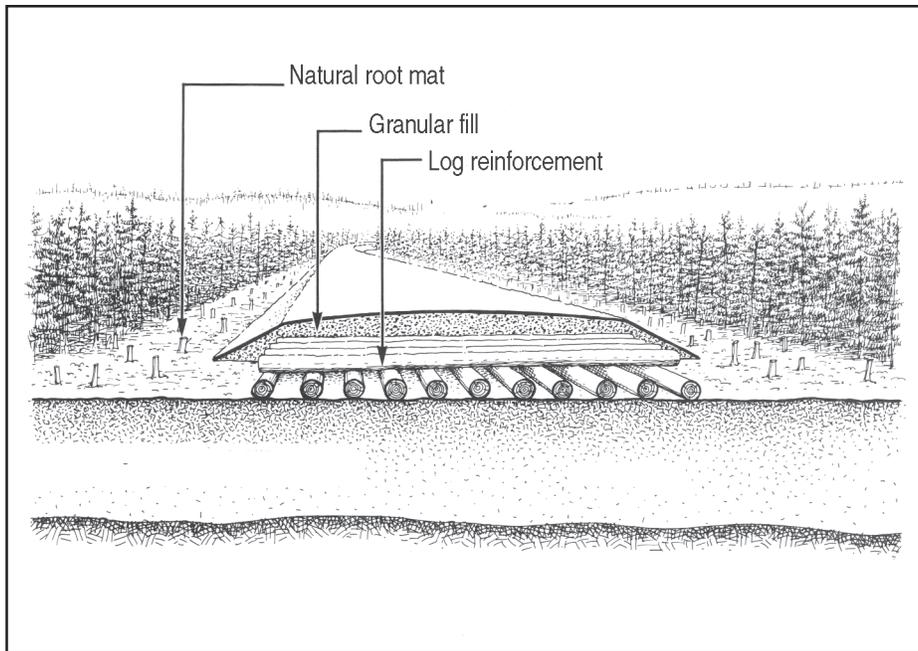
Figure 3-47. Elements of a road crossing through a swamp wetland, cross section (Ontario MNR, 1990).

◆ *The following are recommendations for crossing wetlands in winter, for all wetland types (Minnesota Division of Forestry, 1995):*

 • If permanent structures are to be used, follow BMP installation guidelines for permanent roads.

 • Select the shortest practical route to minimize potential problems with drifting snow and crossing of open water.

 • Avoid crossing open water or active springs. If crossing is unavoidable, temporary crossings are preferred over permanent crossings. These can be ice bridges, temporarily installed bridges, or timber mats.

 • Avoid using soil fill.

 • Install structures that block water flow so that they can be easily removed prior to the spring thaw. Remove these structures during a winter thaw.

 • Use planking, timber mats, or other support alternatives to improve the capability of the road to support heavy traffic. If removal would cause more damage than leaving them in place, these structures can be left as permanent sections on frozen roads. Avoid clearing practices that result in berms of soil or organic material, which can disrupt normal water flow in wetlands.

 • Do not operate machinery during a winter thaw. Resume operations only when conditions are adequate to support equipment.

 • Remove temporary fills and structures to the extent practical when no longer needed.

 • Install buffer strips near open water.

 • Anchor temporary structures at one end only to allow them to move aside during high-water flows.

◆ *To avoid excessive damage, equipment operations are best avoided on any portion of a road where ruts are deeper than 6 inches below the water surface for a continuous distance of more than 100 yards (Wiest, 1998).*

Wetland Site Preparation and Regeneration Practices

◆ *Select a regeneration method that meets the site characteristics and management objectives.*

Choice of regeneration method has a major influence on the stand composition and structure and on the forestry practices to be applied over the life of the stand. Natural regeneration may be achieved by clear-cutting the existing stand and relying on regeneration from seed from adjacent stands, the cut trees, or stumps and from root sprouts (coppice). Successful regeneration depends on recognizing the site type and its characteristics, evaluating the stocking and species composition in relation to stand age and site capability, planning regeneration options, and using sound harvesting methods. Schedule harvest during the dormant season to take advantage of seed sources and to favor coppice regeneration. Harvest trees at a stump height of 12 inches or less when practical to encourage vigorous coppice regeneration. Artificial regeneration may be accomplished by planting of seedlings or direct seeding. Table 3-42 presents an example of regeneration system recommendations (Georgia Forestry Association, 1990).

◆ *Conduct mechanized site preparation and planting of sloping areas on the contour.*

◆ *To reduce disturbance, conduct bedding operations in high-water-table areas during dry periods of the year.*

The degree of acceptable site preparation depends on the amount and frequency of flooding, the soil type, and the species suitability.

◆ *Minimize soil degradation by limiting operations on saturated soils.*

Wetland Fire Management Practices

Site preparation burns in wetlands are often the most severe (hottest) and have the most potential to increase surface runoff and soil erosion.

Table 3-42.   Recommended Regeneration Systems by Forested Wetland Type (Georgia Forestry Association, 1990)

Type	Natural Regeneration				Artificial Regeneration		
	Clear-cut	Group Selection	Shelter Wood	Seed[a] Tree	Mechanical Site Prep.[b]	Plant	Direct Seed
Flood Plains, Terraces, Bottomland							
Black River	A	B	B	C	D	C	C
Red River	A	B	B	C	D	B	B
Branch Bottoms	A	B	B	C	D	C	C
Piedmont Bottoms	A	B	B	C	D	B	B
Muck Swamps	A	C	C	C	D	C	C
Wet Flats							
Pine Hammocks & Savannahs	A	B	B	B	A	A	B
Pocosins or Bays	A	C	B	B	B	B	B
Cypress Strands	A	C	C	C	D	C	C
Cypress Domes: Peat Swamps							
Peat Swamps	A	C	C	C	C	C	C
Cypress Domes	A	C	C	C	D	C	C
Gulfs, Coves, Lower Slopes	A	B	B	C	C	B	C

Note: A = highly effective; B = effective; C = less effective; D = not recommended.
[a] Seed tree cuts are not recommended on first terraces of floodplains, terraces, and bottomland.
[b] Mechanical site preparation to convert wetlands to pine plantation is regulated by Section 404 of the Clean Water Act and a permit may be required for site preparation to convert some of the wetlands identified in the table, i.e., floodplains, bottomlands, pocosins, bays, cypress stands, peat swamps, cypress domes.

◆ *Conduct site preparation burns in a manner such that they do not completely remove the organic layer from the forest floor.*

◆ *Do not construct firelines for site preparation that will drain wetlands.*

Chemical Management Practices

◆ *Where feasible and applicable, apply herbicides by injection to individual stems.*

◆ *For chemical and aerial fertilizer applications, maintain and mark a buffer area around all surface water to avoid drift or accidental direct application.*

Avoid application of pesticides with toxicity to aquatic life, especially aerial applications. Aerial applications generally require a buffer from water, agricultural lands, and homes. Motorized ground applications require a buffer from water. The first pass of each application is be made parallel to the buffer zone. A buffer is not necessary for hand applications; however, hand-applied forest chemicals have to be applied to specific targets, and chemicals need to be prevented from entering the water. Before any application of a chemical, consult state laws and regulations for chemical application for proper buffer establishment. Have a person licensed in chemical application perform all work (Washington State DNR, 1997).

◆ *Apply slow-release fertilizers when possible.*

This practice reduces the potential of the nutrients leaching to groundwater, and it increases the availability of nutrients for plant uptake.

◆ *Apply fertilizers when leaching will be minimized.*

◆ *Base fertilizer type and application rate on soil and/or foliar analysis.*

To determine fertilizer formulations, it is best to compare available nitrogen, phosphorus, potassium, and sulphur in the soils to be treated with the requirements of the species to be sown.

EPA and Corps of Engineers Memorandum to the Field

Mechanical Site Preparation Activities and CWA Section 404

Under certain circumstances, a CWA section 404 permit is required for mechanical silvicultural site preparation activities in wetlands. In 1995, EPA and the U.S. Army Corps of Engineers issued a memorandum to clarify the applicability of section 404 to mechanical silvicultural site preparation activities in the Southeast.

The memorandum (particularly the descriptions of wetlands, activities, and BMPs in the memorandum) focuses on the southeastern United States. However, the guidance in the memorandum is generally applicable when addressing mechanical silvicultural site preparation activities in wetlands elsewhere in the country.

The memorandum clarifies the applicability of forested wetlands BMPs to silvicultural site preparation activities for the establishment of pine plantations in the Southeast. Mechanical silvicultural site preparation activities conducted in accordance with the

BMPs discussed below, which are designed to minimize effects to the aquatic ecosystem, will not require a Clean Water Act section 404 permit. These BMPs further recognize that certain wetlands should not be subject to unpermitted mechanical silvicultural site preparation activities because of the adverse nature of potential effects associated with these activities on these sites.

EPA and the Corps will continue to work closely with state forestry agencies to promote the implementation of consistent and effective BMPs that facilitate sound silvicultural practices. In those states where no BMPs specific to mechanical silvicultural site preparation activities in forested wetlands are currently in place, EPA and the Corps will coordinate with those states to develop BMPs. In the interim, mechanical silvicultural site preparation activities conducted in accordance with the memorandum will not require a section 404 permit.

Circumstances in Which Mechanical Site Preparation Activities Require a Section 404 Permit

Mechanical silvicultural site preparation activities can have measurable and significant effects on aquatic ecosystems when conducted in wetlands that are permanently flooded, intermittently exposed, or semipermanently flooded, and in certain additional wetland communities that exhibit aquatic functions and values that are more susceptible to effects from these activities. For the wetland types identified below, mechanical silvicultural site preparation activities require a permit so that individual proposals can be evaluated on a case-by-case basis for site preparation and potential associated environmental effects.

A permit will be required in the following areas unless they have been so altered through past practices (including the installation and continuous maintenance of water management structures) as to no longer exhibit the distinguishing characteristics described below (see *Circumstances in which Mechanical Silvicultural Site Preparation Activities Do Not Require a Permit* below). Of course, discharges incidental to activities in any wetlands that convert waters of the United States to non-waters always require authorization under Clean Water Act section 404.

Permanently flooded wetlands, intermittently exposed wetlands, and semipermanently flooded wetlands. Permanently flooded wetland systems are characterized by water that covers the land surface throughout the year in all years. Intermittently exposed wetlands are characterized by surface water that is present throughout the year except in years of extreme drought. Semipermanently flooded wetlands are characterized by surface water that persists throughout the growing season in most years and, even when surface water is absent, a water table usually at or very near the land surface. Examples of these wetlands include cypress-gum swamps, muck and peat swamps, and cypress strands/domes.

Riverine bottomland hardwood wetlands. These are seasonally flooded (or wetter) bottomland hardwood wetlands within the first or second bottoms of the floodplains of river systems. Site-specific characteristics of hydrology, soils, and vegetation and the presence of the alluvial features mentioned in the memorandum determine the boundary of riverine bottomland hardwood wetlands. National Wetlands Inventory maps provide a useful reference for the general location of these wetlands on the landscape.

White cedar swamps. These wetlands are greater than 1 acre in headwaters and greater than 5 acres elsewhere. They are underlain by peat of greater than 1 meter and vegetated

by natural white cedar representing more than 50 percent of the basal area, where the total basal area for all tree species is 60 square feet or greater.

Carolina bay wetlands. These are oriented, elliptical depressions with a sand rim that are either underlain by clay-based soils and vegetated by cypress or underlain by peat of greater than 0.5 meter and typically vegetated with an overstory of red, sweet, and loblolly bays.

Nonriverine forest wetlands. The wetlands in this group are rare, high-quality wet forests, with mature vegetation, located on the Southeastern Coastal Plain. Their hydrology is dominated by high water tables. Two forest community types fall into this group: (1) nonriverine wet hardwood forests, poorly drained mineral soil interstream flats (comprising 10 or more contiguous acres), typically on the margins of large peatland areas, seasonally flooded or saturated by high water tables, with vegetation dominated (greater than 50 percent of basal area per acre) by swamp chestnut oak, cherrybark oak, or laurel oak alone or in combination, and (2) nonriverine swamp forests, very poorly drained flats (comprising 5 or more contiguous acres), with organic soils or mineral soils with high organic content, seasonally to frequently flooded or saturated by high water tables, with vegetation dominated by bald cypress, pond cypress, swamp tupelo, water tupelo, or Atlantic white cedar alone or in combination.

Low pocosin wetlands. These are the central, deepest parts of domed peatlands on poorly drained interstream flats, underlain by peat soils greater than 1 meter, typically vegetated by a dense layer of short shrubs.

Wet marl forests. These are hardwood forest wetlands underlain with poorly drained, marl-derived, high-pH soils.

Tidal freshwater marshes. These wetlands are regularly or irregularly flooded by fresh water. They have dense herbaceous vegetation and occur on the margins of estuaries or drowned rivers or creeks.

Maritime grasslands, shrub swamps, and swamp forests. These are barrier island wetlands in dune swales and flats, underlain by wet mucky or sandy soils. They are vegetated by wetland herbs, shrubs, and trees.

Circumstances in Which Mechanical Site Preparation Activities Do Not Require a Section 404 Permit

Mechanical silvicultural site preparation activities in wetlands that are seasonally flooded, intermittently flooded, temporarily flooded, or saturated or are in existing pine plantations and other silvicultural sites (except as listed above) do not require a permit if conducted according to the BMPs listed below in *Best Management Practices*. Of course, silvicultural practices conducted in uplands never require a Clean Water Act section 404 permit (see *Code of Federal Regulations* text above).

Seasonally flooded wetlands are characterized by surface water that is present for extended periods, especially early in the growing season, but is absent by the end of the season in most years. (When surface water is absent, the water table is often near the surface.) Intermittently flooded wetland systems are characterized by substrate that is usually exposed and the presence of surface water for variable periods without detectable seasonable periodicity. Temporarily flooded wetlands are characterized by surface water

that is present for brief periods during the growing season, but also by a water table that usually lies well below the soil surface for most of the season. Saturated wetlands are characterized by substrate that is saturated to the surface for extended periods during the growing season, but also by the absence of surface water most of the time. Examples typical of these wetlands include pine flatwoods, pond pine woodlands, and wet flats (e.g., certain pine/hardwood forests).

Best Management Practices

The BMPs below are from a joint EPA and Corps of Engineers *Memorandum to the Field* (see below) on the application of BMPs to mechanical silvicultural site preparation activities for the establishment of pine plantations in the Southeast. The guidance is, however, generally applicable to mechanical silvicultural site preparation activities in wetlands elsewhere in the country. Every state in the Southeast has developed BMPs for forestry to protect water quality, and most have also developed specific BMPs for forested wetlands.

The BMPs listed here are the minimum to be applied for mechanical silvicultural site preparation activities in forested wetlands where these activities do not require a permit (see *Memorandum to the Field* below). In circumstances where a permit is required, BMPs specifically required for the individual operation will be detailed in the permit.

The BMPs below were developed because silvicultural practices have the potential to result in effects on an aquatic ecosystem. Mechanical silvicultural site preparation activities have the potential to cause effects such as soil compaction, turbidity, erosion, and hydrologic modifications if the activities are not effectively controlled by BMPs.

◆ *Position shear blades or rakes at or near the soil surface and windrow, pile, and otherwise move logs and logging debris by methods that minimize dragging or pushing through the soil to minimize soil disturbance associated with shearing, raking, and moving trees, stumps, brush, and other unwanted vegetation.*

◆ *Conduct activities in such a manner as to avoid excessive soil compaction and maintain soil tilth.*

◆ *Arrange windrows in such a manner as to limit erosion, overland flow, and runoff.*

◆ *Prevent disposal or storage of logs or logging debris in SMAs.*

◆ *Maintain the natural contour of the site and ensure that activities do not immediately or gradually convert the wetland to a non-wetland.*

◆ *Conduct activities with appropriate water management mechanisms to minimize off-site water quality effects.*

The full text of the memorandum is available on the Internet at <http://www.epa.gov/owow/wetlands/guidance/silv2.html>.

CHAPTER 4:
USING MANAGEMENT MEASURES TO PREVENT AND SOLVE NONPOINT SOURCE POLLUTION PROBLEMS IN WATERSHEDS

Management measures and associated management practices applied at harvest sites and along roads provide essential control of erosion and sedimentation, and it is important that all management measures and management practices applicable to a harvest site or road be applied to limit as much as possible the amount of soil erosion and the potential for water pollution that can result from forest harvesting activities.

The watershed perspective enables the practitioner to go beyond the effects from a single harvest area or individual road to consider all activities occurring within the watershed that could affect water resources. Each activity can have its own effect on water quality, and the watershed perspective views the effects due to harvesting and road construction within the context of the overall effects of forestry activities together with other activities such as recreational uses and conversions of land use. It is the collective effects of all of these activities that determine how water quality is affected, and these cumulative effects on water quality wouldn't normally be recognized if the effects arising from individual harvesting activities are considered alone.

Research has determined that the use of BMPs on forestland results in smaller increases in nutrients and suspended sediment load after logging than when BMPs are not used. This points to the need for a watershed approach to water quality management, and such an approach within the context of forest harvesting and road construction and use implies, at a minimum, the following:

- Applying management measures and management practices that are appropriate not only to the harvest site, but that take into consideration the current state of water quality in receiving waters, given all that is happening in the watershed, and the effect that forestry activities could have.

- The foreseeable future needs to be considered as well. Some effects of harvesting and road building can last beyond the duration of a harvest or the completion of road construction, and if other activities that could effect water quality are planned in the watershed in the timeframe during which those effects are expected to continue, mitigation of these long-term effects might be necessary.

- Maintenance of older roads built with outdated management practices (those dating from the 1950s to the mid-1970s), which can be significant sources of sediment, is an essential part of forested watershed management. Long-term management plans

for forest roads include their inventory, maintenance, and closure; and closure of unused, unneeded, and high-erosion-risk roads.

The EPA Watershed Approach

Watersheds are areas of land that drain to a single stream or other water resource. Watersheds are defined solely by drainage areas and not by land ownership or political boundaries.

Since 1991, the USEPA has promoted the watershed protection approach as a holistic framework for addressing complex pollution problems such as those from nonpoint sources. The watershed protection approach is a comprehensive planning process that considers all natural resources in the watershed, as well as social, cultural, and economic factors. The process tailors workable solutions to ecosystem needs through participation and leadership of stakeholders.

Although watershed approaches may vary in terms of specific objectives, priorities, elements, timing, and resources, all should be based on the following guiding principles.

- *Partnerships*. People affected by management decisions are involved throughout and help shape key decisions. Cooperative partnerships among federal, state, and local agencies and non-governmental organizations with interests in the watershed are formed. This approach ensures that environmental objectives are well integrated with those for economic stability and other social/cultural goals of the area. It also builds support for action among those individuals who are economically dependent upon the natural resources of the area.

- *Geographic focus*. Resource management activities are coordinated and directed within specific geographic areas, usually defined by watershed boundaries, areas overlaying or recharging groundwater, or a combination of both.

- *Sound management techniques based on strong science and data*. Collectively, watershed stakeholders employ sound scientific data, tools, and techniques in an iterative decision-making process. Typically, this includes:
  - Assessment and characterization of the natural resources in the watershed and the people who depend upon them.
  - Goal setting and identification of environmental objectives based on the condition or vulnerability of resources and the needs of the aquatic ecosystem and the people.
  - Identification of priority problems.
  - Development of specific management options and action plans.
  - Implementation, evaluation, and revision of plans as needed.

Operating and coordinating programs on a watershed basis makes good sense for environmental, financial, social, and administrative reasons. For example, by jointly reviewing the results of assessment efforts for drinking water protection, pollution control, fish and wildlife habitat protection, and other resource protection programs, managers from all levels of government can better understand the cumulative effects of various human activities and determine the most critical problems within each watershed. Using this information to set priorities for action allows public and private managers from all levels to allocate limited financial and human resources to address the most critical needs.

Establishing environmental indicators helps guide activities toward solving those high-priority problems and measuring success.

The final result of the watershed planning process is a plan that is a clear description of resource problems. Goals to be attained, and identification of sources for technical, educational, and funding assistance needed. The successful plan provides a basis for seeking support and for maximizing the benefits of that support.

Cumulative Effects

The watershed approach is a useful mechanism for managing the resources within a defined geographical boundary, and it provides a basis for cumulative effects assessment as well. Though it is not a formal analytical framework for the evaluation of cumulative effects, the watershed approach shares with cumulative effects assessment (CEA) a consideration of all relevant activities and influences. Furthermore, a watershed is a natural geographic boundary for the analysis of cumulative effects on water quality because the influences of upstream activities can create a cumulative effect on down-stream water quality.

Definition

Current environmental regulations provide at least two definitions of cumulative effects (CEs):

> Cumulative effect is the effect on the environment which results from the incremental effect of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (federal or non-federal) undertakes such other actions. Cumulative effects can result from individually minor but collectively significant actions taking place over a period of time (40 CFR 1508.7).

> Cumulative effects are the changes in an aquatic ecosystem that are attributable to the collective effect of a number of individual discharges of dredged or fill material. Although the effect of a particular discharge may constitute a minor change in itself, the cumulative effect of numerous such piecemeal changes can result in a major impairment of the water resources and interfere with the productivity and water quality of existing aquatic ecosystems (40 CFR 230.11).

CEs can be very difficult to quantify and assess, and they are best understood by focusing on the mechanisms by which watershed processes are affected (Reid, 1993). Watershed processes are affected when a land use activity causes a change in the production and transport of one or more watershed products (water, sediment, organic material, chemicals, or heat). Most land use activities affect only one of four aspects of the environment—vegetation, soils, topography, or chemicals—and other watershed changes result from initial effects on these. Understanding CEs within a watershed context involves: (1) understanding how specific land uses affect vegetation, soils, topography, or chemicals; (2) determining to what extent these changes affect watershed processes; and (3) understanding how changes to vegetation, soils, topography, chemicals, and watershed processes affect particular resources and values.

Cumulative effects can be additive or synergistic (MacDonald, 2000). Additive effects are those in which each land use activity creates a discrete effect on an individual resource or

value and the total effect is the sum of the individual effects. Synergistic effects are those in which the combined effect of individual activities on a resource or value are greater than the sum of their individual effects. Synergistic effects can occur through the interaction of different chemicals or types of effects on a single resource. Many times with synergistic effects, each effect is analyzed and determined to individually not be detrimental to a particular resource, but the combined or cumulative effect of the three activities do create a significant impact on a resource.

Assessment of CEs should also take into account whether they are on-site or off-site. On-site CEs can occur if a change persists long enough for later activities to affect the same resource or for the effects of off-site activities to be transported to the site of the change. The temporal dimension of on-site CEs is important to their assessment, while the spatial dimension is limited to the original site of the effect. Off-site CEs occur when a land use activity causes a change in a watershed process such that effects are created at a location other than where the original land use activity occurred. Off-site CEs occur when watershed processes are altered long enough for the off-site effects to accumulate over time; when watershed processes are affected at multiple sites in a watershed and the watershed products that are affected are transported to the same site, or when an off-site effect interacts with an on-site effect. Both the temporal and spatial dimension of off-site CEs are important to consider when analyzing them.

The Importance of Considering and Analyzing Cumulative Effects

Cumulative effects are of concern with respect to forest roads; forest road construction, use, and maintenance; and forest harvesting because the changes that can occur in watershed processes following these activities can persist for many years. This persistence increases the potential for cumulative effects to occur.

Traditionally, effect assessment has evaluated the likely effects of single actions on the environment. But single areas and ecosystems are often affected by more than single actions or projects. The collective effect of numerous small actions can cause serious degradation, though the effects of each small action by itself might be undetectable. Even after an area or ecosystem has been degraded, an analysis of the effects of an additional action might conclude that there would be only minor or no significant effect. An analysis of the additive effect of the single additional action—the cumulative effects—however, might conclude that the action could be detrimental (USEPA, 1992). Cumulative effects analysis also differs from many types of traditional environmental assessment in the need to predict the consequences of "reasonably foreseeable future actions."

The importance of cumulative effects assessment, then, lies in the difference between traditional effect assessment and cumulative effects assessment. Traditional effect assessment is performed with respect to the proposed disturbance, whereas cumulative effects assessment is performed with respect to valued environmental functions (USEPA, 1992). An assessment of an action might have little to no detectable significant effect in terms of pollutant additions or habitat loss, as determined by traditional effect assessment, but might have a clearly disturbing effect on ecosystem functioning as determined by cumulative effects assessment. As more habitat is lost or fragmented and pollutants are generated, environmental stewardship demands that we pay more attention to the collective effects of our actions on ecosystems and their functioning and place less stress on the absolute quantities of pollutants that are generated or habitat lost as a result of each action. Cumulative effects assessment is the means to do this.

Problems in Cumulative Effects Analysis

Cumulative effects analysis, as conceived, is a powerful approach to assessing the overall effect of our actions on the environment and of managing those actions such that species and ecosystems continue to function properly. Unfortunately, many practical problems are associated with performing a cumulative effects analysis, including the following:

- Because total maximum daily load (TMDL) assessments calculate all point source and non-point source pollution for a watershed, a TMDL is essentially a cumulative effects analysis. Agencies responsible for implementing TMDL's have been hesitant to do so because of limitations in personnel, water quality data, and understanding of watershed dynamics. There is also a lack of available methodologies for tracking pollutants such as clean sediment (MacDonald, 2000).

- Ecosystems are complex and our knowledge of their workings is still limited, yet cumulative effects assessment involves identification of the ecosystem components of relevance that will be the focus of the cumulative effects analysis (Berg et al., 1996).

- The boundaries for cumulative effects assessment might be different from those relevant to other analyses, such as nonpoint source pollution or TMDL assessment. A single watershed might be appropriate for assessing nonpoint source pollution, but many watersheds might be involved in cumulative effects analysis for effects on forest conservation (Berg et al., 1996).

- Current guidelines published by the CEQ (1997) do not explicitly address natural processes, spatial variability, and temporal variability within project areas. Natural variability and rates of recovery can affect prediction and detection of cumulative impacts (MacDonald, 2000).

- Effects from individual projects often last for no longer than one human generation, whereas the time frame for changes in ecosystem processes that are the focus of cumulative effects assessment is typically an order of magnitude longer (Berg et al., 1996).

- The effects of most management activities diminish over time, and so then does the magnitude of possible cumulative effects. This leads to a problem of temporal scale related to determining the magnitude of human-induced cumulative effects relative to natural variability over a long time lag (MacDonald, 1997).

- The scale of cumulative effects analysis is very different from that used for traditional effect assessment, and effects due to individual projects might be undetectable using the analytical methods necessary for cumulative effects assessment. For instance, patterns on the landscape, such as whether 10,000 hectares are contiguous or not, are relevant for cumulative effects analysis; a small clear-cut, important at the local scale, might not appear in an analysis at a scale of thousands of hectares (Berg et al., 1996).

- When working at the scale necessary for cumulative effects assessment, areas that contain fragmented jurisdictions with multiple-agency oversight, differences in regulatory structure between jurisdictions and agencies, and conflicting interests and mandates are involved (Berg et al., 1996).

- To adequately assess the future consequences of multiple perturbations in a watershed, the status of ecosystem recovery from past perturbations must be estimated.

Complexity of the analysis increases because recovery times for various components in a system are not necessarily identical, and knowledge is often inadequate to quantify recovery rates. For instance, "recovery" of stream flow magnitude and rate after timber harvest is largely a function of the rate of revegetation of the watershed. Sediment produced by roads associated with the timber harvest will typically take much longer to move through stream channels and "recover" to pre-road levels. Understanding of both types of recovery is needed and they cannot be substituted for each other.

Within the context of forestry activities and forested watersheds, the following difficulties are encountered when attempting to assess cumulative effects (Reid, 1993):

- The effects of forest management activities on streamflow has been studied extensively, yet it remains difficult to determine what effects a management activity will have on a stream because hydrologic response varies greatly with basin size, flow magnitude, season, climate, geology, and type and intensity of forest management activity. The results of studies done in one basin are therefore difficult to extrapolate to other basins. It can be important to determine whether forestry activities will have effects on watershed processes because of the potential consequences if the effects are substantial enough, but such a determination can be costly. It can also be costly, however, to take measures to prevent watershed effects from forestry activities when such effects might not materialize.

- Variability in storm intensity and runoff processes limit the ability to detect human-induced effects on streamflow. Even with years of monitoring data, it can be difficult to distinguish between human-induced effects and natural variability in watershed processes. The process of determining cause and effect is complicated by the fact that different activities can cause similar responses and one activity might not always elicit the same response.

- The dynamics of natural forest communities must be understood to interpret or predict the effects of changes, and natural disturbance frequencies, patterns, characteristics, recovery rates; these are not well understood. Monitoring would be a useful tool to increase our understanding of these dynamics, but the sequences of changes that can lead to CEs, or the combinations of changes that can lead to CEs are varied and can take long periods of time to take effect (e.g., 50 years). Monitoring these effects is often not possible due to the time frame involved.

- If a system responds incrementally, changes can be easily identified; but many changes, such as landslides or floods, do not occur incrementally. Instead, changes, such as loss of vegetation water storage and increased soil compaction, might be relatively benign and accumulate until some event, such as a 50-year storm, triggers a substantial response. These thresholds at which substantial and important CEs occur often cannot be predicted, and knowledge of them is based on studying them after they occur.

- The rate of recovery from land use depends on the type of land use and on the watershed processes that are affected.

Approaches to Cumulative Effects Analysis

Four general approaches for predicting cumulative effects include the use of analytical models, assessments of previous management activities, use of a collection of procedures that address specific anticipated impacts, and use of a checklist to indicate what cumulative effects might be expected to occur because of a land use activity. Models can be used to predict changes to physical or biological aspects of a watershed, or to predict the magnitude of change in a watershed process or characteristic that might trigger a particular type of impact (Reid, 1993). Models are useful because the cumulative effects of repeated timber harvests in a watershed could be estimated or monitored experimentally only in a study lasting several centuries (Ziemer and Lisle, 1991). While modeling does represent a simplification of nature and depends on a modeler's skill, modeling results can represent average conditions and explore the effects of large spatial and temporal scales. They can also be useful for conducting "what if" analyses, where the effects of different sequences of harvesting or precipitation events, for example, are explored. This characteristic of models contrasts sharply with monitoring studies, in which the unique sequence of events that occurs during a monitoring distorts the results.

Many models have been developed for specific locations and cannot easily be applied to other areas. The limitations of the models are stated in user's guides or instructions for use, but the models, nevertheless, are often put into general use regardless of whether the assumptions of the model are valid for a particular application or whether the methods of the model have been tested and validated (Reid, 1993). Many models are meant to be used to predict particular impacts, yet their methods are used to test for the likelihood of a variety of other possible impacts for which the method was not developed. Used properly, however, models can shed light on the importance of processes and variables to watershed behavior and treatment effects, but have limited value for precisely predicting watershed behavior (Reid, 1993). A large amount of data generally is required for modeling, and its acquisition can involve intensive monitoring. Data analysis also can be complex, and these factors have kept the use of models very limited (MacDonald, 1997).

Slightly less complicated than modeling would be an analysis involving a broad-scale assessment of previous management activities. Such a method would use one or more management indices to assess the relative likelihood of a cumulative effect, rather than explicitly modeling cause-and-effect (MacDonald, 1997). The EPA Synoptic Approach and the *Washington State Watershed Analysis Method* (described below) are examples of this level of analysis.

Another approach for assessing cumulative effects consists of a collection of procedures used to evaluate a variety of impacts. A relevant subset of impacts is generally considered. This approach provides flexibility in determining what impacts will be considered, but it provides no guidance on determining which impacts should be evaluated (Reid, 1993). The *Water Resources Evaluation of Non-point Silvicultural Sources* (WRENSS) (described below) method is an example of a procedure-based approach.

A third general approach consists of a checklist of items to consider during an assessment. A checklist provides guidance in determining what impacts to evaluate but does not provide methods for doing so (Reid, 1993). Checklists are useful for (1) identifying which issues to look at in more detail, (2) helping to ensure that a range of issues are considered, (3) providing a simple means to address the issue of cumulative effects assessment. Disadvantages associated with checklists include the strictly qualitative

nature of the assessments, their lack of repeatability, and their lack of documentation (MacDonald, 1997). The California Department of Forestry questionnaire (described below) is an example of a checklist assessment method.

Each approach has its strengths and weaknesses, and a workable approach should be a combination of these separate approaches. For example, a checklist or expert system could be used to guide users through a decision tree to identify the impacts to be considered, and then a set of procedures could be selected to address them (Reid, 1993). Modeling could be employed to assess the sensitivities of the watershed to various treatment scenarios.

Five techniques that have been developed for assessing cumulative effects are described below.

1. EPA The Synoptic Approach

The Synoptic Approach was developed by EPA for the evaluation of cumulative effects on wetlands for section 404 permit review. It does not provide a precise, quantitative assessment of cumulative effects, but is used to rate cumulative effects on resources of interest (Berg et al., 1996). The Synoptic Approach has two major steps—definition of the synoptic indices and selection of landscape indicators.

Synoptic Indices

Four synoptic indices are used for assessing cumulative effects and relative risk—function, value, functional loss, and replacement potential. The function index refers to the total amount of a particular function a wetland provides within a landscape subunit without consideration of the ecological or social benefits of that function. Landscape elements function within landscapes through physical, chemical, and biological processes to provide habitat, cleanse water, prevent flooding, and perform other functions. The value index refers to the value of ecological functions with respect to public welfare. Tangible benefits (e.g., hunting, camping, timber, carbon dioxide sequestration) and intangible benefits (e.g., aesthetic, existence value) can both be included, as well as future value as the future benefit of the functions performed. Note that the value index does not represent economic value since market factors are not considered. The functional loss index represents cumulative effects on a particular valued function that have occurred within a landscape subunit. A complete loss, where an ecosystem element is changed into something else entirely, is a conversion. A partial loss, where ecosystem element type is the same but functioning is altered, is degradation. In the course of a cumulative effects assessment, future loss is considered per the Council on Environmental Quality's regulations (40 CFR 1508.7). Functional loss depends on the characteristics of a particular effect, including the type of effect; its magnitude, timing, and duration; and ecosystem resistance, or the sensitivity of the ecosystem element to disturbance. The replacement potential index represents the ability to replace an ecosystem element and its valued functions. Functional replacement through ecological restoration or natural recovery are both considered. Protection of ecosystem elements and functions is critical for risk reduction if their replacement potential is judged to be low (USEPA, 1992).

Landscape Indicators

Landscape indicators are first-order approximations that represent some particular synoptic index. Quantifying specific synoptic indices for large landscape subunits would be difficult if not impossible, so the Synoptic Approach uses landscape indicators of actual functions, values, and effects (USEPA, 1992).

As an example, a particular management concern might be nonpoint source sediment loading to streams. Nonpoint source sediment loading would then be the synoptic index used in the Synoptic Approach. Since it would be difficult to quantify this over a large area, total area harvested might be chosen as a landscape indicator for forest harvesting. Total harvested area would be the data used to determine cumulative nonpoint source sediment loading effects on the area of concern.

The Synoptic Approach is an ecologically based framework in which locally relevant information and best professional judgment are combined to address cumulative effects. It is not, however, meant to be used to assess the cumulative effects of specific actions. Rather, it is really meant to be used to augment site-specific review processes and to improve best professional judgment. It is probably most effectively used at extremely large landscape scales, such as the state level (Berg et al., 1996). The approach is valuable because it is flexible enough to cover a broad spectrum of management objectives and constraints—the specific synoptic indices and landscape indicators used in an application can be chosen based on the particular goals and constraints of the assessment—and it certainly need not be limited to assessing effects on wetlands. The process allows managers to weigh the need for precision against the constraints of time, money, and information (USEPA, 1992).

2. Washington State Watershed Analysis

The Washington State Watershed Analysis method is used to develop forest plans for individual watersheds based on current scientific understanding of the significant links between physical and biological processes and management activities. The first step in use of the method is screening a watershed to qualitatively define and assess areas of sensitivity to environmental change within the watershed. If any area is found to be sensitive, then the area and the causal mechanism must be addressed by a management plan appropriate to the problem. The management plan will define more precisely the potential effects of management actions and management alternatives. The method uses separate assessment modules for mass wasting, surface erosion, hydrologic change, riparian function, stream channel assessment, fish habitat, water supply/public works, and routing through the fluvial system (Berg et al., 1996).

The Washington State Watershed Analysis process is a collaborative one that involves both scientists and managers, and its products generally are area-specific management prescriptions and monitoring recommendations (Berg et al., 1996).

3. Water Resources Evaluation of Nonpoint Silvicultural Sources (WRENSS)

The WRENSS is a process-based approach to evaluating timber management impacts (Reid, 1993). It consists of a series of procedures for evaluating separate impacts, though it is not intended specifically to address CEs. The original focus of the method was water

quality and consideration of the effects of timber management and roads. While its procedures do not address resources other than water quality, it would be possible to add additional methods to evaluate impacts on particular resources and to assess the effects of other land uses. Use of the method can be complex and time consuming.

The method is based on computer simulation modeling that delivers graphs and tables as results that are used to estimate changes in evapotranspiration, flow duration, and soil moisture from different logging plans. Temperature changes are incorporated using a separate model, the Brown model, and sediment modules include methods for estimating surface erosion, ditch erosion, landsliding, earthflow activity, sediment yield, and channel stability.

Application of the method to CE analysis would require the identification of likely environmental changes generated by a project, likely downstream impacts, and the mechanisms generating them.

4. California Department of Forestry Questionnaire

The California Department of Forestry and Fire Protection developed a questionnaire for use by registered professional foresters to assess potential cumulative watershed effects (CWE) from timber management. Completion of the questionnaire involves a four-step process: (1) perform a resource inventory in the assessment area; (2) judge whether the planned timber operation is likely to produce changes to each of those resources; (3) identify the effects of past or future projects; and (4) judge whether significant cumulative effects are likely from the proposed operation. Onsite and downstream beneficial uses, existing channel conditions, and adverse effects from past projects are identified and listed during the first step. The area for analysis is one of manageable size relative to the timber harvest—usually an order 3 or 4 watershed. During the assessment, the user rates the magnitude of a variety of potential effects from the proposed and future projects, and combined past, present, and future projects. The assessment serves as an indicator of need for further review.

Responding to the questionnaire relies on the qualitative observations and professional judgment of the person filling out the forms. The questionnaire is designed to be used within the time constraints of the development of timber harvest plans and serves primarily as a checklist to be certain that all important issues have been considered. Its strength lies in its flexibility: the checklist can be easily altered to accommodate a wide variety of situations and harvesting conditions.

The California Department of Forestry questionnaire addresses a wide variety of uses and effects and includes many that are not related to water quality, e.g., recreational, aesthetic, biological, and traffic uses and values, but it provides only qualitative results. The questionnaire is the only CWE evaluation method that uses an assessment of more than one type of effect from more than one type of mechanism, and it is one of few that incorporates an evaluation of effects that accumulate due to past, present, and future actions (Berg et al., 1996).

5. Phased Approach to Cumulative Effects Assessment

MacDonald (2000), put forth a conceptual process for assessing cumulative effects. The process is an attempt to overcome some of the problems with other approaches to cumulative effects analysis (CEA), including problems in defining key issues, specifying the

appropriate spatial and temporal scales, and determining the numerous interactions and indirect effects to analyze. The assessment is broken down into three phases: scoping, analysis, and management.

- The scoping phase is further broken down into steps in which the issues, resources, time scale, spatial scale, risk, and assessment effort are identified for the cumulative effects analysis. The analysis phase is likewise subdivided into five substeps.

- In the analysis phase researchers identify and analyze cause-and-effect mechanisms; natural variability and resource condition; past, present and future activities; relative impacts of past, present and future activities; and validity and sensitivity of the overall cumulative effects analysis.

- The management phase identifies possibilities for mitigation and restoration, as well as key data gaps and monitoring needs.

Figure 4-1 illustrates MacDonald's process for assessing cumulative effects.

Scoping Phase

Identify issues and resources, time scale, spatial scale, magnitude of risks to resources, and level of effort.

Identify key cause-effect relationships.

Analysis Phase

Estimate natural variability and resource conditions.

Identify past, present, and future activities and their relative impacts.

Predict cumulative effects and evaluate their validity.

Management Phase

Assess the need to modify activities, to mitigate their impacts, for additional planning, and for restoration activities.

Identify date gaps, and monitoring needs.

Figure 4-1. **Representation of MacDonald's process for assessing cumulative effects (after MacDonald, 2000).**

The President's Council on Environmental Quality (CEQ) published guidelines for performing CEA (CEQ, 1997). The CEQ methodology is broken down into three groups of steps that are designed to be integrated into three components of an environmental impact assessment (EIA). The EIA components relevant to CEA are scoping, describing the affected environment, and determining the environmental consequences.

- In the scoping component of an EIA, the CEA steps are to identify significant issues and define assessment goals; establish spatial boundaries of the CEA; establish temporal scale of the CEA; and identify other activities that affect natural and human communities.

- The affected environment component of the EA should incorporate the following CEA steps: characterize the resources, ecosystems and human communities and their resilience to stress; define stresses and regulatory thresholds for measuring stresses; and define baseline conditions for the area defined in the CEA.

- The environmental consequences component of the EIA should identify CEA cause-and-effect relationships between human activities and resources; determine the significance of cumulative effects; develop alternatives to minimize or mitigate significant cumulative effects; monitor cumulative effects and adapt management accordingly.

CEQ lists seven primary methods to develop baseline data and analytical models for cumulative effects analysis (CEA):

- Questionnaires, interviews, and panels to gather initial information
- Checklists to review important activities that may contribute to cumulative effects
- Matrices to tally cumulative effects
- Networks and system diagrams to qualitatively analyze effects of multiple activities on multiple resources in the analysis
- Modeling to quantify the cause-and-effect relationships within the CEA
- Trends analysis to use baseline data to extrapolate future cumulative effects
- Overlay mapping (GIS) to perform spatial analysis and identify areas of high and low impact.

Appendices to the CEQ report provide examples of each method and how it is might be used in CEA. The report is available on the World Wide Web at <http://ceq.eh.doe.gov/nepa/ccenepa/ccenepa.htm>.

The MacDonald (2000) and CEQ (1997) guidelines share many similar components. The spatial and temporal boundaries of the CEA are defined first, along with the resources that will be impacted by cumulative effects. Detailed analysis of cause-and-effect relationships follows, and baseline data is developed to describe present conditions. Both methods include monitoring and mitigation steps toward the end of the process. MacDonald's framework differs from the CEQ methodology by including natural variability in systems, consideration of past and future activities, sensitivity analysis of predictive models, and an up-front determination on the level of effort that is appropriate for the assessment. MacDonald's refinements help address some of the hurdles to CEA implementation that have hampered past efforts.

Forest Watershed Management: An Example

The Umatilla National Forest, located in the Blue Mountains of southeast Washington and northeast Oregon, covers l.4 million acres of diverse landscapes and plant communities (USDA-FS, 1999). The forest has some mountainous terrain, but mostly consists of V-shaped valleys separated by narrow ridges or plateaus. The landscape also includes heavily timbered slopes, grassland ridges and benches, and bold granite outcroppings. Elevations range from 1,600 to 8,000 feet above sea level.

The Forest is administered by the Forest Supervisors Office in Pendleton, Oregon, along with four Ranger Districts located in Pomeroy and Walla Walla, Washington, and Ukiah and Heppner, Oregon. The actual on the ground management of the forest resources is accomplished at the Ranger District level by the District Ranger and staff, while the Forest Supervisor oversees management and administration. The Forest is challenged daily with protecting both the productivity and the aesthetic values of the land. Managing to provide many resources, benefiting many people "for the long run" is the key principle guiding the Umatilla Management Team.

Because water from the Blue Mountains is important for so many uses, proper management of the watersheds in the Umatilla National Forest is strongly emphasized. The goals of the watershed management program are as follows:

- To maintain streams that are cold, clean, and free of excessive sediments and human-caused pollution.
- To keep stream banks, channels, wetlands, and adjacent floodplains healthy.
- To restore damaged lands to their previous, productive condition.
- To maintain near-natural amounts of runoff water.

The Umatilla National Forest Plan includes important direction for achieving these goals. The plan envisions a basic three-point program for managing forest watersheds:

1. Inventory Basic Watershed Resources

Proper management of a forest watershed demands a good understanding of basic components—soil, water, climate, and vegetation. Managers at the Umatilla National Forest upgrade the resource information base for the forest by conducting the following inventories and surveys:

- Soil
- Water
- Fishery resources
- Potential watershed improvement projects
- Riparian zones (areas adjacent to streams and lakes)

These watershed surveys provide vital information for improving the management of surface water resources.

2. Apply Best Management Practices

The Umatilla National Forest has developed "best management practices"—policies, standards, and methods of operation designed to reduce harmful effects on water while

still allowing use of other resources. Maintaining stream surface shading to prevent fish-bearing waters from overheating during the summer is an example of general practices applied throughout the forest. Others are developed specifically for a particular activity.

Forest managers work together in the project planning stages to identify the nature and risk of potential hazards to water resources. As a result, projects can be modified to avoid problem areas and reduce water resource damage.

The forest's watershed management program emphasizes the prevention of problems before they occur. However, it is sometimes necessary to treat watershed problems resulting from past practices. Such treatments might include restoring wet meadows, recontouring gullied lands, or stabilizing eroding stream banks.

Recently, a program to control and treat the acidic wastewater draining into a forest stream where salmon and steelhead spawn was begun in the Umatilla National Forest. These wastes, produced by abandoned gold mines, are now treated in man-made bogs, where toxic metals and other harmful substances are filtered out. Initial results have shown a dramatic recovery in water quality.

3. Monitor and Analyze Results

An extensive water-monitoring program has been developed for the Umatilla National Forest. It measures success in achieving the goal of maintaining healthy and abundant water resources. Monitoring stations are strategically placed at forest management projects to measure

- Stream flow
- Water temperature
- Suspended sediment and turbidity
- Shape and condition of stream channels and riparian areas
- Precipitation, snow pack and other climatic factors
- The soil's ability to infiltrate and hold precipitation
- Physical, chemical and biological components of water quality

These measurements provide a better understanding of how management activities affect water resources and whether our efforts are effective in maintaining high water quality.

CHAPTER 5: MONITORING AND TRACKING TECHNIQUES

This chapter discusses monitoring the implementation and effectiveness of forestry management measures. For the most part, such monitoring is done either for research purposes or to assess compliance with regulatory requirements or recommendations. Therefore, it is usually the domain of universities or government agencies and this chapter is directed primarily at state agencies responsible for compliance with forestry regulations, nonpoint source pollution control regulations, or voluntary forest practice programs. Owners and managers of large forestland tracts are encouraged to work with state officials to develop a means of monitoring the implementation of BMPs on their lands to assess whether they are installed and maintained adequately so that they will protect water quality effectively, regardless of whether the state's program mandates forest practice implementation or encourages voluntary implementation.

Overview

Designing and legally implementing a state program of management practices for forest harvests and forest road construction cannot protect water quality unless the BMPs are implemented by those who actually harvest the timber or manage the land to be harvested. Monitoring the implementation of BMPs is a crucial element of any BMP program. Monitoring provides feedback on whether management practices are implemented per the specifications required or recommended by state and federal governments, on how the forestry practice program is received by harvesters and landowners, and on forestry practice design and use standards and specifications so they can be refined to be more useful and more effective.

Many states have implemented programs to monitor the implementation of forestry practices at harvest sites in conjunction with the passage of forest practice legislation or after a state has established a set of forestry practice recommendations. The end of this chapter provides information about some of these programs. Fewer states monitor the effectiveness of management practices at protecting water quality as part of their BMP implementation monitoring programs. However, even a limited amount of effectiveness monitoring, such as under controlled conditions during experimental harvests, is important to ensure that BMP design specifications and standards are adequate to protect water quality and soils. Once it is determined that BMPs that are installed according to standards and specifications are actually effective, it can be acceptable to monitor only the implementation of BMPs to ensure that they are properly installed, the assumption being that if they are installed adequately, then they effectively protect water quality and forest resources. Such an approach is often necessary because of the difficulty and cost in measuring water quality directly and confounding factors such as upstream pollution sources. Without the initial information that adequately installed BMPs are effective,

though, little can be said about the degree of water quality and forest resource protection attained by adequately installing BMPs.

Monitoring Program Fundamentals

The most fundamental step in the development of a monitoring plan is to define the goals and objectives, or purpose, of the monitoring program. In general, monitoring goals are broad statements such as "to measure changes in fish spawning habitat" or "to measure nutrient loading to streams adjacent to harvest sites." Monitoring programs can be grouped according to the following general statements of purpose or expected outcomes:

- Describe status and trend
- Describe and rank existing and emerging problems
- Design management and regulatory programs
- Evaluate program effectiveness
- Respond to emergencies
- Evaluate the implementation of best management practices
- Evaluate the effectiveness of best management practices
- Validate a proposed water quality model
- Perform research

Unlike monitoring goals, monitoring objectives are more specific statements that can be used to add detail, including geographic scale, measurement variables, sampling methods, and sample size, to the monitoring design. Detailed monitoring program objectives enable the designer of the program to define precisely what data will be gathered in order to meet the management goals. Vague or inaccurate statements of objectives lead to program designs that provide too little or too much data, thereby either failing to meet management needs or costing too much.

Numerous guidance documents have been developed, or are in development, to assist resource managers in developing and implementing monitoring programs that address all aspects of monitoring design. Appendix A in *Monitoring Guidance for Determining the Effectiveness of Nonpoint Source Controls* (USEPA, 1997) presents a review of more than 40 monitoring guidances for both point and nonpoint source pollution. These guidances discuss virtually every aspect of nonpoint source pollution monitoring, including monitoring program design and objectives, sample types and sampling methods, chemical and physical water quality variables, biological monitoring, data analysis and management, and quality assurance and quality control.

Once the monitoring goals and objectives have been established, existing data and constraints are considered. A thorough review of literature pertaining to water quality studies previously conducted in the geographic region of interest can help determine whether existing data provide sufficient information to address the monitoring goals and what data gaps exist.

Identification of project constraints address financial, staffing, and temporal elements. Clear and detailed information is obtained on the time frame within which management decisions need to be made, the amounts and types of data that is to be collected, the level of effort needed to collect the necessary data, and equipment and personnel needed to

conduct the monitoring. From this information it can be determined whether available personnel and budget are sufficient to implement or expand the monitoring program.

As with monitoring program design, the level of monitoring that will be conducted is largely determined when goals and objectives are set for a monitoring program, although there is some flexibility for achieving most monitoring objectives.

The overall scale of a monitoring program has two components—a temporal scale and a geographic scale. The temporal scale is the amount of time required to accomplish the program objectives. It can vary from an afternoon to many years. The geographic scale can also vary from quite small, such as plots along a single stream reach, to very large, such as an entire river basin. The temporal and geographic scales, like a program's design and monitoring level, are primarily determined by the program's objectives.

If the main objective is to determine the current biological condition of a stream, sampling at a few stations in a stream reach over 1 or 2 days might suffice. Similarly, if the monitoring objective is to determine the presence or absence of a nonpoint source effect, a synoptic survey might be conducted in a few select locations. If the objective is to determine the effectiveness of a watershed forest management program for improving water quality conditions in streams, however, monitoring subwatersheds for 5 years or longer might be necessary. If the objective is to calibrate or verify a model, very intensive sampling might be necessary.

Depending on the objectives of the monitoring program, it might be necessary to monitor only the water body with the water quality problem or it might be necessary to include areas that have contributed to the problem in the past, areas containing suspected sources of the problem, or a combination of these areas. A monitoring program conducted on a watershed scale will include a decision about the watershed's size. The effective size of a watershed is influenced by drainage patterns, stream order, stream permanence, climate, number of landowners in the area, homogeneity of land uses, watershed geology, and geomorphology. Each factor is important because each has an influence on stream characteristics, although no direct relationship exists.

There is no formula for determining appropriate geographic and temporal scales for any particular monitoring program. Rather, once the objectives of the monitoring program have been determined, a combined analysis of them and any background information on the water quality problem(s) being addressed will make it clear what overall monitoring scale is necessary to reach the objectives.

Other factors that can be considered to determine appropriate temporal and geographic scales include the type of water resource being monitored and the complexity of the nonpoint source problem. Some of the constraints mentioned earlier, such as the availability of resources (staff and money) and the time frame within which managers need monitoring information, will also contribute to determination of the scale of the monitoring program.

For additional details regarding nonpoint source monitoring techniques, including chemical and biological monitoring, refer to *Monitoring Guidance for Determining the Effectiveness of Nonpoint Source Controls* (USEPA, 1997). This technical document focuses on monitoring to evaluate the effectiveness of management practices, but also includes approximately 300 references and summaries of more than 40 other monitoring

guides. In addition, Chapter 8 of EPA's management measures guidance for section 6217 contains a detailed discussion of monitoring (USEPA, 1993).

Monitoring BMP Implementation

The implementation of management measures and BMPs should be tracked to determine the extent to which the measures are implemented on harvest sites or throughout a watershed. Data on BMP implementation and trends in BMP implementation can be used to address the following goals:

- Determine the extent to which BMPs are implemented in accordance with relevant standards and specifications.
- Determine whether there has been a change from previous years in the extent to which BMPs are being implemented.
- Establish a baseline from which decisions can be made regarding the need for additional incentives for implementation of BMPs.
- Determine the extent to which BMPs are properly maintained and operated.
- Measure the success of voluntary BMP implementation programs.
- Determine how and why BMP use varies from one geographic area to another.
- Support workload and costing analyses for landowner assistance or regulatory programs.

Methods to assess the implementation of management measures are a key focus of the technical assistance to be provided by EPA and NOAA under CZARA section 6217.

Implementation assessments can be done on several scales. Site-specific assessments can be used to assess individual management practices or management measures, and watershed assessments can be used to look at the cumulative effects of implementing multiple management measures. With regard to "site-specific" assessments, it is important to assess individual management practices at the appropriate scale for the practice of interest. For example, to assess the implementation of management measures or management practices for forest roads at harvest sites, only the roads at timber harvesting sites would need to be inspected. In this example, the scale would be a timber harvest area and the sites would be active and inactive roads at the harvest areas. To assess implementation of management measures and practices at streamside management areas, the proper scale might be a harvest area larger than 10 acres and the sites could be areas encompassed by buffer areas for 200-meter stretches of stream. For site preparation and forest regeneration, the scale and site might be an entire harvest site. Site-specific measurements can then be used to extrapolate to a watershed or statewide assessment.

Sampling design, approaches to conducting the evaluation, data analysis techniques, and ways to present evaluation results are described in EPA's *Techniques for Tracking, Evaluating, and Reporting the Implementation of Nonpoint Source Control Measures—Forestry* (USEPA, 1997a), from which much of the text for this chapter has been borrowed. Chapter 8 of EPA's management measures guidance for section 6217 contains a detailed discussion of techniques and procedures to assess implementation, operation, and maintenance of management measures (USEPA, 1993).

Monitoring BMP Effectiveness

By tracking management measures and water quality simultaneously, analysts gain the information necessary to evaluate the performance of the management measures implemented. Management measure tracking provides information on whether pollution controls are being implemented, operated, and maintained adequately. Only with such information is it possible to draw conclusions from water quality monitoring data about the effectiveness of management practices.

A major challenge in attempting to relate implementation of management measures to water quality changes is determining the appropriate land management attributes to track. For example, simply counting the number of management measures implemented in a watershed has little chance of being useful in statistical analyses to relate water quality to land treatment since the count only remotely relates (i.e., a mechanism is lacking) to the measured water quality parameter (e.g., cobble embeddedness). Land treatment monitoring that relates directly to the pollutants or effects monitored at the water quality station is most useful. For example, the spacing of water bars relative to slope might be a more useful parameter to track than the number of miles of road constructed. Since the effect of management measures on water quality might not be immediate or implementation might not be sustained, information on other relevant watershed activities (e.g., urbanization, wildfire frequency and extent) is essential for the final analysis.

Management practice effectiveness has not been well documented on a watershed scale, particularly for watersheds with mixed land uses. Studies of management practice effectiveness have been done at the plot and field scales where specific treatments are used and compared to a control situation. Extrapolations from these data and studies using nonpoint source pollution models constitute most of the information available on a watershed scale. Actual data collection and management practice effectiveness determination on a watershed scale is more complex and, because of natural variability, it requires long periods of monitoring before management practice implementation so that a statistical minimum detectable change level can be established. The minimum detectable change is the minimum measurable change in a water quality parameter over time that is statistically significant, and it is a function of statistical tests, the number of samples taken per year, the number of years of monitoring, and the variates and covariates used in the analyses. Dissmeyer (1994) provides detailed information on monitoring forestry BMPs to evaluate their effectiveness in meeting water quality goals. An approach for watershed monitoring of management practice effectiveness, and the problems associated with the approach and with such studies in general, is discussed in Park and others (1994).

Appropriately collected water quality information can be evaluated with trend analysis to determine whether pollutant loads have been reduced or whether water quality has improved. Valid statistical associations drawn between implementation and water quality data can be used to indicate the following:

- Whether management measures have been successful in improving water quality in a watershed or recharge area.
- The need for additional management measures to meet water quality objectives in the watershed or recharge area.

Greater detail regarding methods to evaluate the effectiveness of land treatment efforts is provided in EPA's nonpoint source monitoring guidance (USEPA, 1997) and management measures guidance for section 6217 (USEPA, 1993).

Importance of BMP Monitoring

Researchers with the U.S. Forest Service reviewed state BMP implementation and monitoring programs and the results from those programs in 1994. At the time, twenty-one states were assessing BMP effectiveness. They found that the states had generally concluded that carefully developed and applied BMPs can prevent serious deterioration of water quality, and that most water quality problems were associated with poor BMP implementation. Water quality monitoring was determined to be essential to understanding the relationship between land disturbance and water quality, as it leads to improved understanding of the interaction of soils and topography with BMP implementation. BMP guidelines can be reassessed continually to make them more cost effective, and the more they can be specified, used, monitored, and fine tuned for specific circumstances, the more cost-effectively they can be used to protect water quality.

Quality Assurance and Quality Control

Quality assurance (QA) and quality control (QC) are commonly thought of as procedures used in the laboratory to ensure that all analytical measurements made are accurate. But QA and QC extend beyond the laboratory and are essential components of all phases and all activities within each phase of a nonpoint source monitoring project.

Definitions of Quality Assurance and Quality Control

Quality assurance is an integrated management system designed to ensure that a product or service meets defined standards of quality with a stated level of confidence. Quality assurance activities involve planning quality control, quality assessment, reporting, and quality improvement.

*Quality contro*l is the overall system of technical activities designed to measure quality and limit error in a product or service. A quality control program manages quality so that data meet the needs of the user as expressed in a quality assurance project plan.

Quality control procedures include the collection and analysis of blank, duplicate, and spiked samples and standard reference materials to ensure the integrity of analyses, as well as regular inspection of equipment to ensure it is operating properly. Quality assurance activities are more managerial in nature and include assignment of roles and responsibilities to project staff, staff training, development of data quality objectives, data validation, and laboratory audits. Such procedures and activities are planned and executed by diverse organizations through carefully designed quality management programs that reflect the importance of the work and the degree of confidence needed in the quality of the results.

Importance of Quality Assurance and Quality Control Programs

Although the value of a QA/QC program might seem questionable while a project is under way, its value will be quite clear after a project is completed. If the objectives of

the project were used to design an appropriate data collection and analysis plan, all QA/QC procedures were followed for all project activities, and accurate and complete records were kept throughout the project, the data and information collected from the project should be adequate to support a choice from among alternative courses of action. In addition, the course of action chosen should be defensible based on the data and information collected. Development and implementation of a QA/QC program can require up to 10 to 20 percent of project resources (Cross-Smiecinski and Stetzenback, 1994), but this cost can be recaptured in lower overall costs due to the project's being well planned and executed. Likely problems are anticipated and accounted for before they arise, eliminating the need to spend countless hours and dollars resampling, reanalyzing data, or mentally reconstructing portions of the project to determine where an error was introduced. QA/QC procedures and activities are cost-effective measures used to determine how to allocate project energies and resources toward improving the quality of research and the usefulness of project results.

EPA Quality Policy

EPA has established a QA/QC program to ensure that data used in research and monitoring projects are of known and documented quality to satisfy project objectives. The use of different methodologies, lack of data comparability, unknown data quality, and poor coordination of sampling and analysis efforts can delay the progress of a project or render the data and information collected from it insufficient for decision making. QA/QC practices are best used as an integral part of the development, design, and implementation of a nonpoint source monitoring project to minimize or eliminate these problems.

Additional information on QA/QC can be found in Chapter 5 of EPA's nonpoint source monitoring guide (USEPA, 1997) and in EPA documents on QA/QC.

Review of State Management Practice Monitoring Programs

Objectives of the Audits

In general, state audits of harvest sites or other types of forestry operations have as their primary objectives to assess compliance with BMP implementation guidelines and/or the effectiveness of BMPs at preventing soil erosion and protecting water quality. Additionally, because the process of collecting BMP implementation and effectiveness information lends itself well to the collection of related information that can be quite useful to a state forestry department, states also collect information that will help them to

- Identify problem areas where additional landowner training and education is needed to improve BMP implementation.
- Determine which BMP implementation standards and specifications need revision.
- Identify necessary improvements in the BMP monitoring program.

Information on landowner training is easily gathered during the audits if the landowner on whose property a harvest was done is present during the audit or contacted as part of the audit. Landowners can be contacted before the audit in most instances to obtain permission to enter their property, and they can be asked to be present either during the

audit, when they can perhaps offer valuable information about the harvest, or after an audit during a discussion of the results.

Analysis of BMP implementation standards and specifications can be done effectively during an audit, or during an analysis of audit results after an annual audit has been completed, by comparing the implementation and effectiveness information gathered during the audit with state implementation specifications. For example, specifications may call for a recommended maximum distance between culverts on forest roads of a given slope. During the audits it might be noticed that, even where these specifications have been adhered to, erosion is unacceptable. It may then be recommended to lower the maximum distance, or it might be noticed that excessive erosion is related to a particular soil type, and a shorter distance might be recommended where this soil type occurs.

Audits can provide valuable information about the monitoring program, too. It might be discovered during the course of audits that instances of particular types of effects to soils or water resources are increasing over the years. Or it might be recognized that certain forestry operations (e.g., prescribed burning or site preparation) might not be accounted for in the audits adequately enough to draw conclusions about effects to water resources. Information collected during the audits can be used to adjust the monitoring program to actual information needs.

Audits conducted by some states serve specific objectives beyond assessments of BMP implementation and effectiveness. A good example is South Carolina, which has designed the data collection aspect of its BMP implementation survey to permit the state to determine the effect of a number of variables on compliance with BMP standards. The variables investigated include

- Physiographic region in which the harvest occurred
- Occurrence of a stream on the harvest site
- Percent slope at the harvest site
- Type of terrain at the harvest site
- Category to which the landowner belonged
- Use of cost share assistance for the harvest
- Landowner's familiarity with state BMPs
- Use of a site preparation contract
- Written requirement for the use of BMPs
- Involvement of a forester in the prescription and supervision of site preparation
- Size of the area being site-prepared for reforestation

Criteria Used to Choose the Audit Sites

States use a number of criteria to select sites for inclusion in BMP audits. Generally, the criteria exclude from the audits those sites where BMPs of interest would not likely have been used, where the types of effects of interest (e.g., impacts to water quality) would be difficult to detect or nonexistent, and sites where detecting whether BMPs had been implemented would be difficult due to changes in site characteristics since their implementation. Other criteria ensure that sites from different topographic or vegetative community areas or administrative jurisdictions (e.g., counties or state forest service regions) are included in the audits.

The use of criteria result in a biased sample of audit sites, and thus the conclusions from the audits cannot be used to draw conclusions about all harvest sites in a state. But complete random sampling of harvest sites would limit the usefulness of the results more than biasing the selection of sites by the use of criteria. Not limiting the sites chosen for the audits would result in the inclusion of sites where harvests had occurred many years previously and physical evidence of BMP implementation would be undetectable, sites in areas where BMPs of interest (such as those related to SMAs) would not have been used, and would possibly result in not including portions of the state of interest to the state forestry agency. Therefore, it is important to use criteria to ensure that audit sites provide the information of interest.

The following are some of the criteria used in state audits.

Geographic Distribution

Generally, an entire state is included in an audit by choosing a minimum number of sites per county. A minimum of one site per county is a common criterion, though if timber harvesting is limited to certain areas, a state might include only those counties in which timber was harvested during the time period of interest (see second criterion). The geographical distribution of audit sites might be related to the quantity of timber harvested in a county by ensuring that the latter is proportional to the number of sites chosen for the county. Depending on the purpose of the audit, some other potential site selection criteria are

- Sites within a specific watershed.
- The geographic distribution of audit sites reflects the distribution of timber harvest ownership group.
- All physiographic regions of the state are represented.

Time Since Harvest

The timber harvest or other management activity of interest (e.g., site preparation, road construction) is to have occurred within a specific period of time, typically 1 to 2 years, prior to the audit. There are two good reasons to conduct audits as soon as possible after a harvest. First, the longer the delay between a harvest and an audit, the more difficult it will be to determine the adequacy of BMP implementation. With the passage of time natural vegetation growth can hide evidence of the adequacy of soil conservation measures, storms can obliterate evidence of the adequacy of erosion control methods, and the like. Second, most erosion and sedimentation caused by a harvest activity occurs during and shortly after the harvest, and the longer the time between a harvest and an audit of the harvest, the less likely it is that the audit results will be able to help correct BMP implementation problems and, therefore, minimize water quality impacts. Ideally, BMP implementation and effectiveness audits should occur during harvest-related activity.

Minimum Size

Audit sites are generally no less than 5 to 10 acres, which ensures that BMP use would have been called for. A minimum volume of harvested timber is another way of ensuring the same.

Proximity to Watercourse

Most states insist that harvest sites have a stream (perennial or intermittent), lake, wetland, or pond of a certain size on or near them. The criterion might be that the watercourse is on the audit site, especially if a primary goal of the audit is to assess implementation of SMA rules or guidelines, or within 200 to 500 feet of the audit site if water quality effects of harvest operations are of particular concern. States that are interested in overall BMP implementation might not care that audit sites be associated with surface waters.

Representation of Ownership

Inclusion of all ownership groups (private nonindustrial, industrial, federal, state, and local) can be a criterion for choosing sites, though generally audit sites are not specifically chosen to represent the ownership groups. If all ownership groups are to be included, states might use this criterion only if a minimum number of sites per ownership group is not reached using the other criteria. When this happens, sites from the over-represented ownership group or groups are randomly deselected and sites from the under-represented group are randomly selected from those of the desired ownership group.

Randomness

Although, as stated above, simple randomness is not an overriding concern in the design of BMP audits, many states do ensure that once the criteria are met, sites are then selected randomly, resulting in a stratified random sampling design.

Audit Focus: BMP Implementation and BMP Effectiveness

Surveys are geared toward investigating either BMP implementation or BMP effectiveness or both of these. The nature of the forestry activity at any given site that is investigated determines which BMPs are appropriate for implementation at the site or required to be used, depending on whether BMP use is mandatory or voluntary. Sites are generally rated based on the BMPs that should have been used at the site. If a timber harvest plan was prepared prior to the harvest, or a road construction plan prepared prior to construction of a road and BMPs were included in the plan(s), then the survey might investigate whether the BMPs included in the plan were actually implemented.

Number of Sites Investigated

The number of sites investigated varies widely and depends on survey design, amount of silviculture activity in the state, and availability of resources (staff and money). If the results of the survey are to be analyzed statistically, then the number of sites investigated must be sufficient for this purpose. See EPA's *Techniques for Tracking, Evaluating, and Reporting the Implementation of Nonpoint Source Control Measures—Forestry* (USEPA, 1997a) for guidance on selecting a sufficient number of sites for statistical analysis purposes. A difficulty for many states is ensuring that the number of harvest sites inspected is adequate to draw meaningful conclusions about overall BMP implementation. The number of sites harvested within the audit timeframe (e.g., 2 years if the audit includes sites harvested within the 2 years prior to the audit) is often not known. Many states do not require preharvest notification, or that a landowner inform the state department of forestry that a harvest will occur and where it will occur. Without this

information, a state cannot know with certainty what percentage of harvest sites are included in an audit and finding sites to audit can be a difficult, costly, time-consuming task. Even if a state has a policy of voluntary implementation of its forestry BMPs or guidelines, simply requiring that landowners report to the state department of forestry when and where a harvest will occur and the acreage to be harvested, the state's ability to audit BMP implementation in a timely manner, track BMP implementation trends, assist landowners with proper BMP implementation, and maintain accurate statistics about forestry activity in the state can be greatly improved.

Number of BMPs Evaluated

The number of BMPs investigated at each site varies depending on the objectives of the survey and the number and types of BMPs recommended or required by the state. Surveys that target specific types of operations or locations, such as road construction or SMAs, generally involve investigations of fewer BMPs than surveys to assess the use of BMPs for all aspects of forest harvesting, from temporary road construction to site preparation for reforestation.

Composition of the Investigation Teams

An investigation "team" can range from one person to a team of 5 to 7 people with different specialties. Again, the composition of the survey team depends on the objectives of the survey. If BMP implementation is the only thing being investigated, then a state forester alone might be capable of conducting the survey. If, on the other hand, soil characteristics, erosion hazard, improvements in road construction techniques, water quality effects, or other more complex issues are also being investigated, then a team of individuals that represent the appropriate disciplines is generally used.

When one person conducts the surveys, generally the person is a state forester who is familiar with BMP standards for both implementation and effectiveness. When teams are used for the surveys, the state forester is accompanied by one or more specialists that represent fields such as watershed science, soil science, wildlife biology, hydrology, fisheries, and road engineering. Separate organizations might also be represented, such as environmental or conservation organizations and the logging industry. Where possible, the survey team is accompanied by the landowner on whose property the survey is being conducted, the logger who conducted the harvest, and the state forester who prepared the harvest plan, if applicable. Examples of who might be included on an audit "team" are

- A county or state forester
- A watershed specialist
- A forestry industry representative
- A member of the environmental community
- A nonindustrial private landowner
- A member of a local or regional planning and development board
- A wildlife biologist
- A hydrologist
- A soil conservationist or soil scientist
- A fisheries biology

- A road engineer
- A logging professional

BMP Implementation and Effectiveness Rating Systems

The implementation of individual BMPs is rated in one of two ways. A scale of implementation, usually from 0 to 5 or 0 to 3, is used to rate not only whether a BMP was implemented but also the quality of implementation. Alternatively, BMPs are rated simply as having been implemented, not implemented, or not applicable to the particular site.

Generally, all BMPs applicable to a site are rated individually and the site then receives an overall BMP implementation rating. The latter rating might be made using one of the two rating systems mentioned above or using a 3-tiered rating system of excellent, adequate, or inadequate. The overall site rating is usually derived as an average of the individual BMP ratings at the site. Low ratings for overall BMP implementation—for example zero to two on a 0-to-5 scale, zero on a 0-to-3 scale, and inadequate on a 3-tiered rating system—are indications that follow-up with the landowner or harvester is necessary or that further education and training might be helpful.

Even when only BMP implementation is being assessed, BMP effectiveness is often rated on a qualitative basis as an onsite assessment of whether, in the case of a low score or inadequate BMP implementation, there was a resultant risk to water quality. Risks to water quality are generally rated as simply being present or not. If it is apparent that water quality was affected by inadequate BMP implementation, this is also noted.

When more than one team is responsible for the assessments and where teams are composed of many people, assessment training or a mock assessment is performed prior to the actual assessments to establish a degree of consistency in the ratings among members and teams. Assessments of adequacy of BMP implementation and risk to water quality can involve many subjective judgements, and going through a mock assessment prior to the actual assessments gives all team members a chance to discuss what constitutes adequate or proper implementation for the different BMPs. In addition, in many states, after a site assessment and while the assessment team is still on the site the team gathers to discuss the ratings of the individual team members and to arrive at an overall site rating. If any discrepancies or differences of opinion cannot be settled through discussion alone, the individual BMPs are revisited.

Audit Results

Successful implementation of BMPs by landowners and harvesters, as indicated by audits with high compliance rates, depends on many factors, such as whether a state's BMP program is mandatory or voluntary, how long a state has had a BMP program, how long a state has been monitoring BMP implementation, and the effectiveness of a state's education and training outreach program for BMP implementation.

Results of many state audits for BMP implementation and effectiveness indicate that BMPs are being implemented and, where implemented, they are effective in protecting soil from erosion and water quality. Results are generally reported in one of two ways: an overall compliance rate, in which all ratings for compliance with individual BMPs or groups of BMPs are averaged into a single number, and compliance rates for individual

BMPs or groups of BMPs. A group of BMPs might be all those required for SMAs, for instance.

An overall compliance rate can be misleading because it is essentially an average of averages. That is, an overall compliance rate is generally obtained by averaging the compliance ratings for separate groups of BMPs, and then those averages are averaged. Instances where such a rating would be misleading include where most groups of BMPs are rated to have high compliance while one important group of BMPs, say those for SMAs or stream crossings, has a much lower compliance rate. The compliance information for the latter group is lost in the overall compliance rating. Of course, a low overall compliance rating, caused by low compliance ratings for many groups of BMPs, can hide a high compliance rating for another group of BMPs as well. Similarly, a single or a few high or low ratings for individual BMPs within a group of BMPs can be hidden by averaging together the compliance ratings for a whole group of BMPs. Generally, states gain far more information useful to them and to the public for improving and reporting BMP compliance if ratings for individual BMPs are kept separate. Trend analyses for implementation of individual BMPs are also much more meaningful than reports of changes in overall compliance for BMPs from one audit to the next. Of course, it is very important to keep data relevant to the effectiveness of individual BMPs, such as that on the slopes of roads where failure occurs or the amount of cover retained in SMAs where sediment reaches streams, separate for each BMP so that improvements can be made to state BMP specifications.

EPA Recommendations for Forestry Practice Audits

Implement a preharvest notification system to assist in selecting an adequate and unbiased sampling population of harvest sites, to reduce the cost of site selection, and to help determine, prior to a site visit, that selected sites meet many of the selection criteria such as time since harvest and size of harvest.

If feasible, conduct audits soon after harvests are completed so that improvements can be made to BMPs found to be inadequately implemented and the water quality impacts of those BMPs can be minimized.

Ensure that harvest sites are chosen randomly. Stratification based on desired characteristics of sites is perfectly acceptable, but if this is done then sampling within the strata must be random to ensure the validity of results.

If the geographic extent of an audit includes a critical watershed, create a separate statistically valid sample population for the watershed and do not group information from harvests within the watershed with information from other harvests. It is important to maintain separate information for watersheds that have been designated "critical" and to sample them separately if the information obtained is to be related to and useful for programs instituted to protect the watersheds.

Have a clearly defined process for or means of determining whether a BMP implementation is acceptable or not. Audits may be conducted with teams of experts or by individuals working at different harvest sites. The subjectivity of BMP ratings can be reduced and their objectivity increased by clearly defining what standards and quality of implementation constitute each rating level in the rating scale being used. Auditors well trained to recognize these standards and quality criteria will provide the most objective, consistent, meaningful, and comparable ratings.

Ensure that BMP implementation according to state standards reflects protection of water quality by collecting data that is sufficient to determine the effectiveness of BMPs under specific circumstances, such as different soil types, topographies, and rainfall patterns. Modify state standards if the data collected indicate that existing standards are insufficient under certain circumstances.

If forest practice implementation or effectiveness ratings are to be grouped for reporting purposes, maintain separate groupings for functionally different BMPs. For instance, create separate group ratings for road erosion BMPs, stream crossing BMPs, SMA BMPs, etc., so that an average compliance rating will not hide important information about which BMPs are not being implemented adequately.

Volunteer Water Monitoring

The information presented below is available from the USEPA Web site (http://www.epa.gov/owow/monitoring/volunteer/startmon.html) and as a published brochure (United States Environmental Protection Agency; Office of Water (4503F), Washington, DC 20460; EPA 841-B-98-002; July 1998).

Volunteer water monitoring is monitoring done by local citizens rather than agency personnel. In every state, volunteers monitor the condition of streams, rivers, lakes, reservoirs, estuaries, coastal waters, wetlands, and wells. Volunteers who monitor are people who want to help protect a stream, lake, bay or wetland near where they live, work, or play. Their efforts are of particular value in providing quality data and building stewardship of local waters.

Volunteers make visual observations of habitat, land uses, best management practices used to protect soil and water resources; and the impacts of storms; measure the physical and chemical characteristics of waters; and assess the abundance and diversity of living creatures–aquatic insects, plants, fish, birds, and other wildlife. Volunteers also clean up garbage-strewn waters, count and catalog beach debris, and become involved in restoring degraded habitats. The number, variety, and complexity of these projects are continually on the rise.

Volunteer monitoring programs are organized and supported in many different ways. Projects may be entirely independent or may be associated with state, interstate, local, or federal agencies; with environmental organizations; or with schools and universities. Financial support may come from government grants, partnerships with business, endowments, independent fundraising efforts, corporate donations, membership dues, or a combination of these sources.

Many volunteer groups collect data that supplements the information collected by state and local resource management or planning agencies. These agencies might use the data to

- Evaluate the success of best management practices designed to mitigate problems.
- Screen water for potential problems, for further study or for restoration efforts.
- Establish baseline conditions or trends for waters that would otherwise go unmonitored.

In general, a volunteer monitoring program should work cooperatively with state and local agencies in developing and coordinating its technical components. To ensure that its

data are used, the monitoring program also develops a strong quality assurance project plan that governs how volunteers are trained, how samples are collected and analyzed, and how information is stored and disseminated.

By educating volunteers and the community about the value of local waters, the kinds of pollution threatening them, and how individual and collective actions can help solve specific problems, volunteer monitoring programs can

- Make the connection between watershed health and our individual and collective behaviors (cumulative impacts).
- Build bridges among various agencies, businesses, and organizations.
- Create a constituency for local waters that promotes personal and community stewardship and cooperation.

Information on volunteer monitoring efforts locally and nationwide can be found through USEPA. The *National Directory of Volunteer Environmental Monitoring Programs*, published by USEPA, provides information on existing groups around the country and the kinds of monitoring taking place. In addition, USEPA's *Adopt Your Watershed* site on the World Wide Web (http://www.epa.gov/adopt/) provides information on active volunteer groups on a watershed basis.

Local or state environmental protection, natural resource, parks, or fish and game agencies might also be good sources of information. Even if the agency does not sponsor a volunteer program, it might be aware of other programs or groups that are active. Other potential sponsors or sources of information include

- Local community-based groups such as civic or watershed associations, garden clubs, universities, and activist organizations
- Chapters of national environmental organizations
- Regional offices of federal agencies such as USEPA, the US Department of Agriculture's Extension Service, the U.S. Park Service, and the U.S. Fish and Wildlife Service

Volunteer Monitoring Resources

USEPA supports volunteer monitoring by sponsoring national conferences, publishing methods manuals, producing a nationwide directory of volunteer programs, and funding a national newsletter, *The Volunteer Monitor*. Volunteer coordinators in the 10 EPA Regional offices provide some technical assistance for local programs and help coordinate regionwide conferences. The Regions are also responsible for grants to the states that can be used, in part, to support volunteer monitoring programs that help assess nonpoint sources of pollution or that serve to educate the public about nonpoint source issues.

Some USEPA resources on the World Wide Web

Volunteer Monitoring Homepage	http://www.epa.gov/owow/monitoring/volunteer/
Monitoring Water Quality Homepage	http://www.epa.gov/owow/monitoring/
Surf Your Watershed	http://www.epa.gov/surf/
Adopt Your Watershed	http://www.epa.gov/adopt/
Index of Watershed Indicators	http://www.epa.gov/iwi/

Documents on volunteer monitoring published by USEPA are listed below. Copies can be obtained by contacting the Volunteer Monitoring Coordinator, USEPA (4503F), 401 M Street SW, Washington, DC 20460.

National Directory of Citizen Volunteer Environmental Monitoring Programs, Fifth Edition. EPA 841-B-98-009, November 1998.

Proceedings of the Fifth National Citizen's Volunteer Water Monitoring Conference. EPA 841-R-97-007, October 1997.

Proceedings of the Fourth National Citizen's Volunteer Water Monitoring Conference. EPA 841/R-94-003, February 1995.

Proceedings of the Third National Citizen's Volunteer Water Monitoring Conference. EPA 841/R-92-004, September 1992.

Volunteer Estuary Monitoring: A Methods Manual. EPA 842-B-93-004, December 1993.

Volunteer Lake Monitoring: A Methods Manual. EPA 440/4-91-002, December 1991.

Volunteer Monitor's Guide to Quality Assurance Project Plans. EPA 841-B-96-003, September 1996.

Volunteer Stream Monitoring: A Methods Manual. EPA 841-B-97-003, November 1997.

Volunteer Water Monitoring: A Guide for State Managers. EPA 440/4-90-010, August 1990.

The Volunteer Monitor, published semiannually, is the national newsletter of volunteer water monitoring. The newsletter facilitates the exchange of ideas, monitoring methods, and practical advice among volunteer monitoring groups across the country. Subscriptions are free. Address all correspondence to Eleanor Ely, Editor, 1318 Masonic Avenue, San Francisco, CA 94117; phone 415/255-8049; fax 415/255-0199.

Best Management Practices Evaluation Program: U.S. Forest Service, Pacific Southwest Region

The USDA Forest Service Pacific Southwest Region has published *Investigating Water Quality in the Pacific Southwest Region: Best Management Practices Evaluation Program (BMPEP) User's Guide* (USDA-FS, Pacific Southwest Region, 2002). The guide continues an effort begun in 1992 to monitor and evaluate BMP implementation and effectiveness (USDA-FS, Pacific Southwest Region, 1992). The Best Management Practices Evaluation Program, or BMPEP, was developed to facilitate evaluation of BMPs through the generation and analysis of data to assess the efficacy of the Region's water quality program, and identify program shortcomings and initiate corrective actions (USDA-FS, Pacific Southwest Region, 2002).

There are three types of BMP evaluations, Administrative, In-Channel, and On-Site. Individuals or teams of reviewers conduct the evaluations using Forest Service forms. *Administrative Evaluations* involve assessing all BMPs for a project, including procedural BMPs (such as the Timber Sale Planning Process). *In-Channel Evaluations* assess the effectiveness of a set of BMPs applied to a project area for protecting beneficial uses

of water. All BMPs prescribed for a project for water quality protection are evaluated by establishing study sites to assess effects on beneficial uses over time. *On-Site Evaluations* involve assessing both the implementation and effectiveness of specific practices (individual or groups of similar BMPs). The BMPs are assessed at the site of implementation and evaluated relative to attainment of each BMP's stated objectives.

For in-channel evaluations, sites are selected on the basis of their being representative of management activities common to the forest being evaluated (e.g., timber, mineral extraction, developed recreation, range use) and located in watersheds that are representative of the forests' dominant landforms and geologic types. Streams selected for project evaluation have a suitable control (or comparison stream) nearby or have established desired future condition criteria that can serve as the basis of comparison. A monitoring plan is also developed for each in-channel evaluation. The monitoring plan describes the location, beneficial uses to be protected, evaluation objectives, data collection parameters and methods, timing/frequency and duration of collection, analytical techniques, and the decision criteria to be used to determine whether the beneficial uses were protected. A follow-up investigation is conducted when data from an in-channel evaluation indicates that beneficial use protection objectives were not met and to identify causes of nonpoint source degradation.

On-site evaluations focus on the implementation and effectiveness of individual BMPs applied on project sites. These evaluations are essentially used to answer the implementation question "Did we do what we said we were going to do to protect water quality?" and the effectiveness question "How well did we protect water quality?" There are 29 different evaluation procedures, each designed to assess a specific BMP or set of closely related BMPs. For example, one procedure evaluates SMAs; another evaluates grazing; and another evaluates recreational facilities. Each evaluation procedure has its own form where ratings and comments are recorded, and each form has an electronic counterpart in database software. The evaluations are completed by those persons responsible for the execution of the practices being evaluated. For example, a Range Conservationist or Resource Officer would conduct the on-site evaluation of grazing, a Sale Administrator or Planner would conduct the evaluation of SMAs, and an Engineer would conduct the evaluation of road drainage control.

Sites to be evaluated are either selected randomly or selected. Randomly identified sites allow for drawing statistical conclusions on the implementation and effectiveness of BMPs. Random sites are picked from a pool of projects that meet specified criteria. Selected sites are identified in various ways, such as from a monitoring plan prescribed in an EA, EIS or LMP; as part of a routine site visit; as part of a follow-up evaluation to an in-channel evaluation to discover sources of problems; or selected for a particular reason specific to local needs. Note that for statistical analysis, only randomly identified sites are used to develop statistical inferences. Selected sites are clearly identified and kept separate from the random sites during data storage and analysis.

When problems in implementation are discovered during an audit, the probable cause and recommended corrective actions to prevent recurrence are noted. Reviewer comments are extremely valuable in this regard. Effectiveness evaluations are made using specific indicators of the success of the BMPs observed or measured on-site. When effectiveness problems are noted, observers comment on the extent, duration, and magnitude of effects

on beneficial uses. In addition to describing the effects, observers use the following system to rate the effects:

Extent:

- Pollutant has been mobilized off-site, but <u>does not reach the stream channel</u>; effects are evident <u>near the site</u> of the activity.

- Pollutant has been mobilized off-site and <u>reaches the stream channel</u>; effects are evident at the <u>stream reach scale</u> (<20 channel widths downstream).

- Pollutant has been mobilized off-site and <u>reaches the stream channel</u>; effects are evident at the <u>drainage scale</u> (>20 channel widths downstream), effects typically extending downstream and are expressed in larger order channels.

Duration:

- The pollutant or its effects dissipate within a very <u>short</u> (<5 day) period; they are typically associated with a single activity or precipitation event.

- The pollutant or its effects are observable for an <u>intermediate</u> (<1 season) duration; effects are typically expressed intermittently during high flow or precipitation events, dissipating to near background levels by the next wet season.

- The pollutant or its effects are observable for a <u>long</u> (>1 season) duration; effects are typically chronic and persist beyond the next wet season.

Magnitude:

- Effects to beneficial uses <u>insignificant with no measurable</u> water quality impairment; pollutant may be visible, but not likely detectable by compared measurements above and below the site.

- Effects to beneficial uses are <u>minor with measurable</u> water quality impacts the pollutant or its effects may be measurable up to the reach scale, but with no likely effect on biological or economic values.

- Effects to beneficial uses are <u>significant with measurable</u> water quality impacts resulting in degradation to biological or economic values.

The *User's Guide* (USDA-FS, Pacific Southwest Region, 2002) includes detailed instructions for completing each of the 29 on-site evaluation procedures. Included for each procedure is information on developing the sample pool; selecting evaluation sites; timing the evaluation; filling in the form; and the method used to do the observations, measurements, and recording for all the implementation and effectiveness criteria. Also included are hypothetical examples of a completed form for each procedure.

Important Points to Note About the BMPEP

Effectiveness criteria focus on site-specific indicators, which in most cases represent potential effects to water quality rather than actual effects. For example, rill erosion observed on a road would be listed as poor effectiveness, though any sediment from the erosion site that does reach a stream might have anywhere from a negligible to serious effect.

Observations could indicate that a BMP has been implemented but was not effective. Such results are useful as they indicate shortcomings of BMPs, that a BMP might be

inappropriate for a particular area, or that the BMP was implemented poorly. Some form of improvement to the BMP is definitely needed in such a case.

BMPs with a high number of comments about the effects on water quality (potential or real) and/or high ratings of "implemented–not effective" are often those implemented close to water courses. Because of the greater potential of practices near water courses to affect water quality, it is prudent to prescribe conservative BMPs in these locations to provide adequate water quality protection.

It is important for foresters in a particular area to review the specific results from that area and not to rely solely a the regional summary that is generated from the individual evaluations. A BMP found to be effective in one area is not guaranteed have the same effectiveness whenever and wherever it is applied. Forest-specific results are more indicative of the changes that can be made to improve BMP effectiveness in a particular locality.

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Readers are encouraged to contact their state department of forestry for information pertaining to BMPs for forestry in their state and region. In addition, some of the above guidances that represent a synthesis of current information are recommended for further reading and are marked with an asterisk (*).

GLOSSARY

Access road: A temporary or permanent road over which timber is transported from a loading site to a public road. Also known as a haul road.

Alignment: The horizontal route or direction of an access road.

Allochthonous: Derived from outside a system, such as leaves of terrestrial plants that fall into a stream.

Angle of repose: The maximum slope or angle at which a material, such as soil or loose rock, remains stable (stable angle).

Apron: Erosion protection placed on the streambed in an area of high flow velocity, such as downstream from a culvert.

Autochthonous: Derived from within a system, such as organic matter in a stream resulting from photosynthesis by aquatic plants.

Bedding: A site preparation technique whereby a small ridge of surface soil is formed to provide an elevated planting or seed bed. It is used primarily in wet areas to improve drainage and aeration for seeding.

Berm: A low earth fill constructed in the path of flowing water to divert its direction, or constructed to act as a counterweight beside the road fill to reduce the risk of foundation failure (buttress).

Borrow pit: An excavation site outside the limits of construction that provides necessary material, such as fill material for embankments.

Broad-based dip: A surface drainage structure specifically designed to drain water from an access road while vehicles maintain normal travel speeds.

Brush barrier: A sediment control structure created of slash materials piled at the toe slope of a road or at the outlets of culverts, turnouts, dips, and water bars.

Buck: To saw felled trees into predetermined lengths.

Buffer area: A designated area around a stream or waterbody of sufficient width to minimize entrance of forestry chemicals (fertilizers, pesticides, and fire retardants) into the waterbody.

Cable logging: A system of transporting logs from stump to landing by means of steel cables and winch. This method is usually preferred on steep slopes, wet areas, and erodible soils where tractor logging cannot be carried out effectively.

Check dam: A small dam constructed in a gully to decrease the flow velocity, minimize channel scour, and promote deposition of sediment.

Chopping: A mechanical treatment whereby vegetation is concentrated near the ground and incorporated into the soil to facilitate burning or seedling establishment.

Clearcutting: A silvicultural system in which all merchantable trees are harvested within a specified area in one operation to create an even-aged stand.

Contour: An imaginary line on the surface of the earth connecting points of the same elevation. A line drawn on a map connecting the points of the same elevation.

Crown: A convex road surface that allows runoff to drain to either side of the road prism.

Culvert: A metal, wooden, plastic, or concrete conduit through which surface water can flow under or across roads.

Cumulative effect: The impact on the environment that results from the incremental impact of an action when added to other past, present, and reasonably foreseeable future actions regardless of what agency or person undertakes such action.

Cut-and-fill: Earth-moving process that entails excavating part of an area and using the excavated material for adjacent embankments or fill areas.

DBH: Diameter at breast height; the average diameter (outside the bark) of a tree 4.5 feet above mean ground level.

Disking (harrowing): A mechanical method of scarifying the soil to reduce competing vegetation and to prepare a site to be seeded or planted.

Diversion: A channel with a supporting ridge on the lower side constructed across or at the bottom of a slope for the purpose of intercepting surface runoff.

Drainage structure: Any device or land form constructed to intercept and/or aid surface water drainage.

Duff: The accumulation of needles, leaves, and decaying matter on the forest floor.

Ephemeral drainage: A natural channel that carries water only during and immediately following rainstorms and whose channel bottom is seldom below the local water table. Sometimes referred to as a dry wash.

Felling: The process of cutting down standing trees.

Fill slope: The surface formed where earth is deposited to build a road or trail.

Firebreak: Naturally occurring or man-made barrier to the spread of fire.

Fire line: A barrier used to stop the spread of fire constructed by removing fuel or rendering fuel inflammable by use of fire retardants.

Foam line: A type of fire line that incorporates the use of fire-resistant foam material in lieu of, or in addition to, plowing or harrowing.

Ford: Submerged stream crossing where the traffic surface is reinforced to bear intended traffic.

Forest filter strip: Area between a stream and construction activities that achieves sediment control by using the natural filtering capabilities of the forest floor and litter.

Forwarding: The operation of moving timber products from the stump to a landing for further transport.

Geotextile: A product used as a soil reinforcement agent and as a filter medium. It is made of synthetic fibers manufactured in a woven or loose nonwoven manner to form a blanket-like product.

Grade (gradient): The slope of a road or trail expressed as a percentage of change in elevation per unit of distance traveled.

Harrowing (disking): A mechanical means to scarify the soil to reduce competing vegetation and to prepare a site to be seeded.

Harvesting: The felling, skidding, processing, loading, and transporting of forest products.

Haul road: See access road.

Intermittent stream: A stream that flows only during the wet periods of the year or in response to snow melt and flows in a well-defined channel. The channel bottom may be periodically above or below the local water table.

Landing (log deck): A place in or near the forest where logs are gathered for further processing, sorting, or transport.

Leaching: Downward movement of a soluble material through the soil as a result of water movement.

Logging debris (slash): The unwanted, unutilized, and generally unmerchantable accumulation of woody material, such as large limbs, tops, cull logs, and stumps, that remains as forest residue after timber harvesting.

Merchantable: Forest products suitable for marketing under local economic conditions. With respect to a single tree, it means the parts of the bole or stem suitable for sale.

Mineral soil: Soil that contains less than 20 percent organic matter (by weight) and contains rock less than 2 inches in maximum dimension.

Mulch: A natural or artificial layer of plant residue or other materials covering the land surface that conserves moisture, holds soil in place, aids in establishing plant cover, and minimizes temperature fluctuations.

Mulching: Providing any loose covering for exposed forest soils, such as grass, straw, bark, or wood fibers, to help control erosion and protect exposed soil.

Muskeg: A type of bog that has developed over thousands of years in depressions, on flat areas, and on gentle to steep slopes. These bogs have poorly drained, acidic, organic soils supporting vegetation that can be (1) predominantly sphagnum moss; (2) herbaceous plants, sedges, and rushes; (3) predominantly sedges and rushes; or (4) a combination of sphagnum moss and herbaceous plants. These bogs may have some shrub and stunted conifers, but not enough to classify them as forested lands.

Ordinary high water mark: An elevation that marks the boundary of a lake, marsh, or streambed. It is the highest level at which the water has remained long enough to leave its mark on the landscape. Typically, it is the point where the natural vegetation changes from predominantly aquatic to predominantly terrestrial.

Organic debris: Particles of vegetation or other biological material that can degrade water quality by decreasing dissolved oxygen and by releasing organic solutes during leaching.

Outslope: To shape the road surface to cause runoff to flow toward the outside shoulder.

Patch cutting method: A silvicultural system in which all merchantable trees are harvested over a specified area at one time.

Perennial stream: A watercourse that flows throughout a majority of the year in a well-defined channel and whose bottom (in rainfall dominant regimes) is below the local water table throughout most of the year.

Persistence: The relative ability of a pesticide to remain active over a period of time.

Pioneer roads: Temporary access ways used to facilitate construction equipment access when building permanent roads.

Prescribed burning: Skillful application of fire to natural fuels that allows confinement of the fire to a predetermined area and at the same time produces certain planned benefits.

Raking: A mechanical method of removing stumps, roots, and slash from a future planting site.

Regeneration: The process of replacing older trees removed by harvest or disaster with young trees.

Residual trees: Live trees left standing after the completion of harvesting.

Right-of-way: The cleared area along the road alignment that contains the roadbed, ditches, road slopes, and back slopes.

Riprap: Rock or other large aggregate that is placed to protect streambanks, bridge abutments, or other erodible sites from runoff or wave action.

Rut: A depression in access roads made by continuous passage of logging vehicles.

Salvage harvest: Removal of trees that are dead, damaged, or imminently threatened with death or damage in order to use the wood before it is rendered valueless by natural decay agents.

Sanitation harvest: Removal of trees that are under attack by or highly susceptible to insect and disease agents in order to check the spread of such agents.

Scarification: The process of removing the forest floor or mixing it with the mineral soil by mechanical action preparatory to natural or direct seeding or the planting of tree seedlings.

Scour: Soil erosion when it occurs underwater, as in the case of a streambed.

Seed bed: The soil prepared by natural or artificial means to promote the germination of seeds and the growth of seedlings.

Seed tree method: Removal of the mature timber in one cutting, except for a limited number of seed trees left singly or in small groups.

Selection method: An uneven-aged silvicultural system in which mature trees are removed, individually or in small groups, from a given tract of forestland over regular intervals of time.

Shearing: A site preparation method that involves the cutting of brush, trees, or other vegetation at ground level using tractors equipped with angles or V-shaped cutting blades.

Shelterwood method: Removal of the mature timber in a series of cuttings that extend over a relatively short portion of the rotation in order to encourage the establishment of essentially even-aged reproduction under the partial shelter of seed trees.

Silt fence: A temporary barrier used to intercept sediment-laden runoff from small areas.

Silvicultural system: A process, following accepted silvicultural principles, whereby the tree species constituting forests are tended, harvested, and replaced. Usually defined by, but not limited to, the method of regeneration.

Site preparation: A silvicultural activity to remove unwanted vegetation and other material, and to cultivate or prepare the soil for regeneration.

Skid: Short-distance moving of logs or felled trees from the stump to a point of loading.

Skid trail: A temporary, nonstructural pathway over forest soil used to drag felled trees or logs to the landing. Skid trails may either be constructed or simply develop due to use depending on the terrain.

Slash: See logging debris.

Slope: Degree of deviation of a surface from the horizontal, measured as a numerical ratio, as a percent, or in degrees. Expressed as a ratio, the first number is the horizontal distance (run) and the second number is the vertical distance (rise), as 2:1. A 2:1 slope is a 50 percent slope. Expressed in degrees, the slope is the angle from the horizontal plane, with a 90 degree slope being vertical (maximum) and a 45 degree slope being a 1:1 slope.

Stand: A contiguous group of trees sufficiently uniform in species composition, arrangement of age classes, and condition to be a homogeneous and distinguishable unit.

Streamside management area (SMA): A designated area that consists of the stream itself and an adjacent area of varying width where management practices that might affect water quality, fish, or other aquatic resources are modified. The SMA is not an area of exclusion, but an area of closely managed activity. It is an area that acts as an effective filter and absorptive zone for sediments; maintains shade; protects aquatic and terrestrial riparian habitats; protects channels and streambanks; and promotes floodplain stability.

Tread: Load-bearing surface of a trail or road.

Turnout: A drainage ditch that drains water away from roads and road ditches.

Water bar: A diversion ditch and/or hump installed across a trail or road to divert runoff from the surface before the flow gains enough volume and velocity to cause soil movement and erosion, and deposit the runoff into a dispersion area. Water bars are most frequently used on retired roads, trails, and landings.

Watercourse: A definite channel with bed and banks within which concentrated water flows continuously, frequently or infrequently.

Windrow: Logging debris and unmerchantable woody vegetation that has been piled in rows to decompose or to be burned; or the act of constructing these piles.

Yarding: Method of transport from harvest area to storage landing.

APPENDIX A:
EPA FORESTRY RESOURCES

Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska. EPA910991001.

The above document is available from U.S. EPA Public Information Center - S1043, 1200 Sixth Avenue, Seattle, WA 98101; phone 206-553-1200, fax 206-553-1049.

Summary of current state nonpoint source control practices for forestry. EPA841S93001.

Water quality effects and nonpoint source control for forestry: An annotated bibliography. EPA841B93005.

Nonpoint pointers: Managing nonpoint source pollution from forestry, pointer no. 8. EPA841F96004H.

Techniques for tracking, evaluating, and reporting the implementation of nonpoint source control measures: Forestry. EPA841B97009.

Evaluating the effectiveness of forestry best management practices in meeting water quality goals or standards (bound copy). EPA841B94005B.

The above publications are out of print, but can be viewed on the Web from the following link: http://www.epa.gov/clariton/clhtml/pubtitleOW.html.

Facts about silvicultural activities in wetlands. EPA904F91100.

The above is available from U.S. EPA, Region 4, Library, 345 Courtland Street, N.E., Atlanta, GA 30365; phone 404-347-4216.

Evaluating the effectiveness of forestry best management practices in meeting water quality goals or standards (3-hole punch). EPA841B94005A.

EPA Nonpoint Source News-Notes: published by EPA quarterly and available on the Internet. Occasionally has articles of interest to foresters and forest land owners. Articles from the Nonpoint Source News-Notes series can be obtained from the Internet at: http://www.epa.gov/owow/info/NewsNotes/. Forestry-related articles have included:

- Scientist Links Nutrient Runoff with Forest Defoliation (No. 51, April/May 1998)

- New Management Policies Proposed for National Forest Road System (No. 52, July/August 1998)

- Urban Forests Decline; Runoff Increases in Puget Sound Area (No. 53, September/October 1998)

- Working Buffer Strips Provide Profit and Protection (No. 54, November 1998)

- Report Lists Communities Suffering Flood Losses (No. 54, November 1998)

- Watershed Management Helps Lake Quality (No. 54, November 1998)

- Applying a Watershed Model to Reduce Nonpoint Source Runoff (No. 56, February/March 1999)

- Texas Forest Service Teaches Loggers about BMPs and Water Quality (No. 56, February/March 1999)

- Nine Salmon Listed in Urban Pacific Northwest (No. 57, May 1999)

- Riparian Forest Wildlife Guidelines for Landowners and Loggers (No. 58, July 1999)

- Getting Started With TMDLs (No. 59, November 1999)

Other EPA publications related to forests and forestry can be found at the EPA publications Web site by searching on "forest" or "forestry": http://www.epa.gov/ncepihom/.

Resources for Non-Industrial Private Forest (NIPF) Landowners:

The Sustainable Forestry Partnership has a web page devoted to Nonindustrial Private Forest Landowners: http://sfp.cas.psu.edu/nipf.htm.

USDA Forest Service—List of Publications, Resources

The USDA Forest Service, Washington Office and regional offices have a number of publications and other resources related to forestry. Lists of available publications, some of which are available electronically, and ordering information can be viewed at the Internet sites of the respective offices. Access to the Washington, DC office and the regional office Internet sites can be gained through the Internet site for publications for the USDA Forest Service: http://www.fs.fed.us/publications/.

The documents of the *Water-Road Interaction Technology Series*, published by the U.S. Forest Service, San Dimas Technology and Development Center, San Dimas, California, are available at: http://www.stream.fs.fed.us/water-road.

Other resources that will be of interest to forestland owners and that are available electronically include:

- FishXing (software and learning system for fish passage through culverts): http://www.stream.fs.fed.us/fishxing

- Forest Service Roads Analysis Process: http://www.fs.fed.us/news/roads/DOCSroad-analysis.shtml

- Forest Roads Science Synthesis: http://www.fs.fed.us/news/roads/science.pdf

APPENDIX B:
SOURCES OF TECHNICAL ASSISTANCE

U.S. Department of Agriculture
Natural Resources Conservation Service
P.O. Box 2890
Washington, DC 20013

U.S. Department of Interior
Fish and Wildlife Service
Public Affairs Office
18th and C Streets, NW
Washington, DC 20240

U.S. Department of the Interior
Geological Survey
12201 Sunrise Valley Drive
Reston, Virginia 22092

U.S. Forest Service
Office of Information
Room 3238
P.O. Box 2417
Washington, DC 20013

U.S. Department of Commerce
National Climatic Center
Federal Building
Asheville, North Carolina 28801
(Attn: Publications)

American Forest Institute
1619 Massachusetts Ave., NW
Washington, DC 20036

American Forests
P.O. Box 2000
Washington, DC 20013-2000

Association of Consulting Foresters of America
5400 Grosvenor Lane, Suite 300
Bethesda, Maryland 20814

International Society of Arboriculture
P.O. Box 71
5 Lincoln Square
Urbana, Illinois 61801

International Society of Arboriculture
P.O. Box GG
6 Dunlap Court
Savoy, Illinois 61874

National Arbor Day Foundation
100 Arbor Avenue
Nebraska City, Nebraska 68410

National Arborist Association
P.O. Box 1094
Amherst, New Hampshire 03031-1094

National Association of State Foresters
Hall of the States, #526
444 North Capital Street, NW
Washington, DC 20001

National Urban Forest Council
c/o American Forests
P.O. Box 2000
Washington, DC 20013

Soil and Water Conservation Society
7515 Northeast Ankney Road
Ankney, Iowa 50021-9764

American Sod Producers Association, Inc.
9th and Minnesota Streets
Hastings, Nebraska 68901

The IPM Practitioner
P.O. Box 7414
Berkeley, California 94707
510-524-2567
Directory of Least-Toxic Pest Control Products

Pesticide Hot Line (Autovon 584-3773)
U.S. Army Environmental Hygiene Agency
Pest Management and Pesticide
Monitoring Division
Aberdeen Proving Ground, Maryland 21005

The Internet site of the *National Association of State Foresters,* http://www.stateforesters.org/, has links to many forestry resources, including:

• State Forestry Statistics

• State Forester Directory

• State Forester Home Pages

• State and Private Forestry Programs

• Other Forestry Links

APPENDIX C: FOREST MANAGEMENT CERTIFICATION PROGRAMS

Forest Management and Forest Product Certification

In the past 10 years, forest management monitoring has been extended beyond an evaluation of whether best management practices have been implemented according to state or federal specifications for the protection of habitat values and water quality to encompass ecological, social, and economic values. Independent organizations offer certification of forest management and forest products to forestry operations managed according to an internationally accepted set of criteria for sustainable forest management (Crossley, 1996). The principles and criteria of sustainable forestry are general enough to be applicable to tropical, temperate, and boreal forests, but the standards used to certify individual operations are sufficiently site- and region-specific for critical evaluation of individual forests and forestry operations.

To be certified, forest management must adhere to principles of resource sustainability, ecosystem maintenance, and economic and socioeconomic viability. Resource sustainability means that harvesting is conducted such that the forest remains productive on a yearly basis. Large scale clear-cutting, for instance, such that the forest would have to remain idle and unproductive for many years, would generally not be acceptable. Ecosystem maintenance means that the ecological processes operating in a forest continue to operate without interruption and the forest's biodiversity is maintained. The principle implies that harvesting does not fundamentally alter the nature of the forest. Economic and socioeconomic viability incorporate the two previous principles and imply that forest operations are sufficiently profitable to sustain operations from year to year and that social benefits provided by a forest, such as existence and recreational value, are also maintained over the long term. Economic and socioeconomic viability are incentives for local people to sustain the ecosystem and resources of the forest (Evans, 1996).

Development of guidelines for sustainable forest management began with the International Tropical Timber Organization (ITTO). In 1989 the ITTO Council requested that "best practice" guidelines for sustainable management of natural tropical forests be developed. Soon afterward, global efforts to define and implement "sustainable forest management" began with the United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro, Brazil, in 1992. Non-binding "Forest Principles" were endorsed by more than 170 countries attending that conference, though many attending countries hoped that a binding "Forests Convention," similar to those for biodiversity and ozone layer protection, would be endorsed. Since Rio, dozens of fora, groups, and processes have been developed to define and evaluate sustainable forest management.

The movement to evaluate forest management and forest products based on principles of sustainable management is an expansion of focus as more knowledge is gained about forest ecological processes and the impacts, both local and global, of poorly managed forests on ecological systems and, consequently, on human economic and social systems. The expansion is similar to the natural expansion of EPA's focus in the realm of water pollution control from point sources of pollution to nonpoint sources of pollution to the present focus on watershed processes. Progress gained in overcoming one problem (e.g., point sources of water pollution) highlight the impacts of other problems (e.g., nonpoint sources of water pollution) and the search for overcoming these problems naturally expands to encompass the new problems that are highlighted. As more sources of impact are recognized, the focus must expand to encompass them. Thus, while water pollution control has become focused on watershed processes and activities occurring within watersheds, forest management is naturally expanding to encompass the processes dependent on the forest (i.e., ecological, social, and economic) and which can be severely limited by poor management.

Two steps are involved in certifying wood products. First, forest management is certified as sustainable according to an evaluation based on accepted principles of sustainable forest management. Various organizations refer to this certification process as forest certification, forest management auditing, or timber certification. Evaluations are always conducted by a third, independent party. The second step is wood-product certification, or forest product labeling. Again, a third party follows the harvested wood through the manufacturing and product development processes, a "chain-of-custody" inspection process, to certify and label the products created from wood harvested from a "sustainable" forestry operation. Both types of certification are currently carried out by both for-profit companies and not-for-profit organizations that are predominantly based in the United States and the United Kingdom.

The Forest Stewardship Council (FSC) accredits regional groups to certify forest operations. Well known examples of FSC-accredited groups are Scientific Certification Systems (SCS) and the Rainforest Alliance's Smart Wood Program (Evans, 1996). These groups and others not associated with FSC are active in the United States and their evaluation processes are described below.

Forest Stewardship Council

The Forest Stewardship Council was formed in 1993 and is a nonprofit organization registered in Mexico. FSC strives to serve as a global foundation for the development of region-specific forest-management standards with its *Principles and Criteria for Forest Management*. Independent certification bodies, accredited by the FSC in the application of these standards, conduct impartial, detailed assessments of forest operations at the request of landowners. If the forest operations are found to be in conformance with FSC standards, a certificate is issued, enabling the landowner to bring product to market as "certified wood" and to use FSC trademark logo. In 1996 the FSC accredited the SmartWood Program, Scientific Certification System (SCS), the SGS Forestry QUALIFOR Programme (based in the United Kingdom), and the Soil Association for worldwide forest management and chain-of-custody certification.

The FSC-U.S. Working Group, Inc., is the U.S. arm of the FSC. FSC-U.S. partners are businesses (wood product distributors such as Home Depot, timber producers such as

Seven Islands Land Company, and certification bodies), foundations, and non-governmental organizations (NGO). Currently there are 40 NGO partners, including the Consumer's Choice Council, Defenders of Wildlife, and Friends of The Earth.

Programs accredited under the FSC provide two types of service, forest management certification and chain-of-custody certification. For forest management certification, a third party evaluation of a forest management operation is conducted in conformity with FSC principles–specific environmental, social, and economic standards. Certification enables an organization to guarantee that its product or service conforms to FSC standards, which could affect product marketability.

To certify a forest management operation, the certification body studies the forest management system and policies and visits the operation for an evaluation. A certified operation must be monitored annually to ensure that the standards of forest stewardship are maintained throughout the period of certification.

The FSC *Principles and Criteria for Forest Stewardship* emerged out of a desire to provide market rewards through the labeling of forest products with a distinct logo derived from lands recognized for "exemplary" forest management. The principles and criteria apply to all tropical, temperate, and boreal forests and must be incorporated into the evaluation systems and standards of all certification organizations seeking accreditation by FSC. More detailed standards may be prepared at national and local levels.

Principle No. 6 in the FSC criteria relates to environmental impact. It does not specify BMPs, but requires the certified body to maintain, enhance, or restore ecological functions and values; protect and record representative samples of existing ecosystems within the landscape; and prepare written documentation on controlling erosion, minimizing forest damage, and protecting water resources.

Many regional standards and policies require that certified bodies meet or exceed the specifications listed in state forest practices:

- 6.5 (Appalachian Region): Harvesting, road construction and other mechanical operations shall meet or exceed state Best Management Practices, whether voluntary or mandatory, and other applicable water quality regulations. In advance of these activities, planning shall be done to minimize damage to the soil, water and forest resources from these activities. A written description of the operational plan, demonstrating how damage will be minimized, shall be incorporated into the management plan or harvesting contract as appropriate.

- 6.5.1 (Southeast Region): Harvesting, road construction, and other mechanical operations shall be designed to meet or exceed state best management practices and applicable water quality regulations.

Forest Conservation Program—Scientific Certification Systems (US)

The Forest Conservation Program (FCP) was established by Scientific Certification Systems (SCS) in 1991 as a certification program for sustainable forestry. SCS has certified forests in California (Collins Pine Almanor Forest), Pennsylvania (Collins Pennsylvania Forest), Wisconsin (Menominee Forest), and Mexico.

The FCP uses an evaluation process based on the program elements mentioned above: resource sustainability, ecosystem maintenance, and economic and socioeconomic viability. Each program element is evaluated according to a set of criteria that best represents appropriate benchmarks of sustainable forest management in the region of interest. Timber resource sustainability is evaluated based on criteria relating to how fully-stocked stands are, growing conditions, age and/or size class distribution (even-aged management or uneven-aged management), and whether management allows for sustained yearly harvests and avoids idle years.

The forest ecosystem maintenance element is evaluated based on criteria relating to whether non-timber resource values are a part of management and the extent to which natural ecosystem conditions and processes are altered by harvests. The economic and socioeconomic element is concerned with the overall economic viability of forest operations and the socioeconomic impacts of operations on harvesters and the local community.

The FCP program is designed to provide a quantitative and qualitative approach to certification. Forest evaluations are based on five sources of information. The landowner; investigations of information related to harvesting operations (e.g. timber inventory data, timber management plans, business management plans, and employee records); field sampling (e.g., wildlife surveys); field reviews; and interviews with employees, contractors, and individuals and organizations from the community.

SCS provides two levels of recognition under the FCP program, "Well-managed" and "State-of-the-Art Well-managed." Well-managed forests meet FCP standards for sustainable management as described below. "State-of-the-Art Well-managed" forests rank in the top 10 percent of all forests evaluated under the FCP program.

Evaluations are conducted by an evaluation team that consists of persons with expertise in relevant disciplines, such as forestry, wildlife biology, ecology, and economics. Persons with local or regional expertise are incorporated into evaluation teams and all evaluations are peer reviewed. Periodic monitoring of the forest after initial evaluation, lasting 1 to 3 years, is required as part of certification. Evaluation criteria are selected and weighted to account for regional circumstances.

Each criterion is given a ranking from 1 to 100 based on its perceived importance to sustainable management of the particular forest. Forest management is then scored by the evaluation team according to the chosen criteria. Sixty points on a normalized 100-point scale is the "failure threshold" for each criterion. Forests that receive 60 points or more in all three categories are designated "Well-managed." Forests among the top 10 percent of all SCS-rated forests are given the "State-of-the-Art" designation. The designation given to the forest management operation is also applied to products from wood harvested from the certified forest.

The program is practical and feasible for forest managers to implement because standards of what constitutes good performance and what leads to failure to attain certification for each criterion are clearly described and adaptable for local or regional circumstances. The credibility of the certification process depends largely on the strength of the evaluation team (Evans, 1996).

Smart Wood Program—Rainforest Alliance (US)

The Rainforest Alliance established Smart Wood as the first independent forestry certification program in the world in 1990. The program initially focused on tropical forests but is now used to certify forests of all types. Forests have been certified in Java, Honduras, Mexico, Brazil, and Papua New Guinea. The Smart Wood program is similar to the FCP.

Under the program, long-term management data is used to demonstrate that a forest can be classified as a "sustainable source". Without long-term data but with demonstration that management has a commitment to sustainability, a forest can be classified as "well-managed".

Smart Wood companies are companies that handle Smart Wood-certified products. Category 1 companies sell products made exclusively from Smart Wood forests, and Category 2 companies sell products made from a mix of certified and noncertified sources. Products from Smart Wood companies carry one of these designations.

Smart Wood certification is based on three broad principles:

- All operations maintain ecosystem functions, including watershed stability and conservation of biological resources.
- Planning and implementation incorporate sustained yield production for all forest products.
- Management activities have a positive impact on local communities.

Smart Wood is developing detailed regional standards with the assistance of local specialists (Evans, 1996).

Sustainable Forestry Initiative (SFI) SM Program of the American Forest & Paper Association

The American Forest & Paper Association (AF&PA) is the national trade association of the forest, pulp, and paper, paperboard, and wood products industry. AF&PA represents approximately 138 member companies and licensees controlling 84 percent of paper production, 50 percent of solid wood production, and 90 percent of the industrial timberland in the United States.

AF&PA member companies, as a condition of membership, must commit to conduct their business in accordance with the principles and objectives of the Sustainable Forestry InitiativeSM program, instituted in October 1994.

The SFISM program is a comprehensive system of principles, objectives and performance measures that integrates the perpetual growing and harvesting of trees with the protection of wildlife, plants, soil and water quality. It is based on the premise that responsible environmental practices and sound business practices can be integrated to the benefit of landowners, shareholders, customers and the people they serve.

Professional foresters, conservationists and scientists developed the SFI program. They were inspired by the concept of sustainability that evolved from the 1987 report of the World Commission on Environment and Development and was subsequently adopted by

the 1992 Earth Summit in Rio de Janeiro. The original 1994 SFI Principles and Imple-
mentation Guidelines were modified and implemented to become the industry "Standard"
in 1999. The standards will continue to be updated periodically to reflect new informa-
tion concerning forest management and social changes.

SFI State Implementation Committees have formed in 32 states to bring industry repre-
sentatives together with other stakeholders to support logger-training programs and
provide outreach to nonindustrial private landowners and opportunities for public in-
volvement.

In a response to public pressure to broaden the SFI program to include nonmember
participation in the SFI, a licensee program has been developed. To date, more than 1.5
million acres have been added to the SFI program through licensee agreements, increas-
ing the total forest acres enrolled in the SFI program to 56.5 million acres.

Member companies and licensees are required to submit annual reports to AF&PA
describing progress in implementing the SFI program. Since its inception, member
companies of AF&PA have invested more than $247 million on research related to
wildlife, biodiversity, ecosystem management and the environment. By 1998 more than
30,000 independent loggers and foresters completed training in sustainable forestry with
an additional 20,000 completing partial training. In addition, SFI participants and profes-
sional loggers have distributed information regarding the SFI program to approximately
242,000 landowners across the country since 1994.

Summary of Certification Initiatives in the United States

Independent certification programs provide a framework of broad principles and core
criteria against which forest management can be assessed. Similar to state forestry
programs for best management practice monitoring, forest management under the certifi-
cation programs is evaluated with field sampling, examinations of documents, and
interviews with staff and local stakeholders. Evaluation teams are interdisciplinary and
knowledgeable of local conditions, and certification is based on scores for identifiable
management actions.

Although many certification programs are international in scope and focus, the flexibility
to tailor the evaluation to local circumstances is built into the process, so the programs
have credibility and can be practically implemented on a local level. Furthermore, the
framework of the certification process is a practical forest management tool as the
internationally accepted criteria on which evaluations are based provide guidance to
forest managers for managing operations for sustainability.

The credibility of the process depends on the expertise of the evaluation team. Persons with
local expertise must be used for evaluations in order for the certification process to be
placed within a local context, and a local context is absolutely necessary because of the
complex inclusion of social, economic, and ecological dimensions in the certification
process. This complexity can lead to inconsistencies in evaluations and certifications, but
some certification programs, notably the Smart Wood Program, are providing regional,
national, and international consistency with the development of regional-specific standards.

A separate approach, the Canadian Standards Association Sustainable Forest Management Project (CSA SFM), is based on developing a preferred future condition that meets society's goals, developing an action plan to move toward the future condition, monitoring progress toward achieving that condition, and correcting one's course of action based on monitoring results. An essential element missing from this approach, and an element that makes the FCP and Smart Wood programs so powerful, is a set of clear criteria that define sustainable forest management. In the CSA SFM approach, this definition is left for local stakeholders to define. The result is a lack of consistency from operation to operation and certification to certification (Evans, 1996).

APPENDIX D: NONINDUSTRIAL PRIVATE FOREST (NIPF) MANAGEMENT

The approximately 10 million nonindustrial private forest (NIPF) owners in the United States include individuals, partnerships, estates, trusts, clubs, tribes, corporations, and associations (Pennsylvania State University, 2000). NIPF owners control 261 million acres of timberland and 58 percent of the commercial forests in the United States. More than two-thirds of timberland east of the Mississippi River is in NIPF ownership, whereas the majority of timberland in the West is in public ownership. NIPFs protect watersheds, provide wildlife habitat, offer scenic beauty, and supply 49 percent of the timber harvested in the United States (USDA-FS, 1992).

Many NIPF owners are not fully aware of the potential economic value of properly-managed timberland. Some are unaware of how to properly manage their timber resources (Pennsylvania State University, 2000). Proper management might be secondary to avoiding annual property taxes and capital gains taxes for some owners. Some other owners who do not plan properly for the inheritance their timberland might lose ownership upon their death, and still others, unaware of either management techniques or the economic value of the land, might decide to convert the land to other uses, such as development or agriculture. Owners who view harvesting of the timber on their land as a one-time capital gain may not be aware of the long-term economic and environmental benefits of sustainable timberland management. Andrew Egan of West Virginia University and Stephan Jones of the Alabama Cooperative Extension System studied NIPF owners and timberland management, and found that landowners with knowledge of forests and forestry are more likely to manage their forests in a sustainable manner (Pennsylvania State University, 2000).

Forest*A*Syst, by Rick Hamilton, extension forestry specialist with the Department of Forestry, North Carolina State University, is a self-assessment guide directed at encouraging forest owners to manage their forests for recreation and aesthetics, wildlife, and timber production, while protecting water quality. The guide discusses steps in developing a forest management plan and strongly recommends the assistance of a professional forester in this process. Major topics are site preparation, natural regeneration, artificial seeding, tree planting, weed control, and fertilization in young and middle-age stands; harvesting the mature forest; managing for wildlife habitat; enhancing the visual appearance of the site; improving recreational opportunities; and using management practices to protect water quality. A *Forest*A*Syst* guide for western North Carolina has been developed from the national *Forest*A*Syst* prototype developed by Mr. Hamilton. A similar guide is available for eastern North Carolina. Other states' programs have spun off from the national version, as well, including Tennessee and Alaska, Georgia (in process), New England (developing a *Forest*A*Syst* model for the region), and Kentucky and Hawaii (in process) (Leith, 2002). For additional information on distribution of the publication and support for adapting it to state and local conditions, contact Rick Hamilton at

(919) 515-5574 or by e-mail (hamilton@cfr.crf.ncsu.edu) or contact Larry Biles, USDA-CSREES (Cooperative State Research, Education and Extension Service), Washington, DC, at (202) 401-4926.

Proper implementation of forestry management measures can maintain fish and wildlife habitat, clean water, biological diversity, aesthetics, and a buffer from urban sprawl. To maintain these values, it is recommended that NIPF landowners follow the guidance of the management measures for forestry to protect water quality set forth in this guidance. Because some of the management measures and BMPs mentioned in the guidance, however, are more relevant to state, federal, and industrial timberland owners, this appendix is provided to focus on certain aspects of planning and managing timberlands that are especially intended to assist NIPF owners in addressing BMP implementation and forest management.

Individual landowners are encouraged to use this guidance to manage and protect water quality on their private forestland. If you have turned directly to this appendix, thinking perhaps that the main sections of the guidance are meant for state agencies and industrial landowners, please take the time to review the rest of the document, especially Section 3. The management measures and practices described in the guidance are applicable to all forest landowners, whether 10 acres or 10,000 acres are being managed. Some of the management measures will be more applicable to some forest management goals than others, but the concepts contained in them are equally relevant to water quality protection in all managed forests where trees are harvested.

Preharvest Planning:

Below are listed some of the more important management practices for achieving the Management Measure for Preharvest Planning. Complete discussions of these and other management practices for preharvest planning can be found in Section 3A. Additional management practices that are particularly applicable to the NIPF landowner follow this listing.

Harvest Planning Practices

◆ *Use topographic maps, aerial photographs, soil surveys, geologic maps, and rainfall intensity charts to augment site reconnaissance to lay out and map harvest units. Identify and mark, as needed:*

◆ *Consider potential water quality and habitat impacts when selecting the silvicultural system as even-aged (clear-cut, seed tree, or shelterwood) or uneven-aged (group or individual selection). The yarding system, site preparation method, and any pesticides that will be used should also be addressed in preharvest planning. As part of this practice the potential impacts from and extent of roads needed for each silvicultural system should be considered.*

◆ *In high-erosion-hazard areas, trained specialists (geologist, soil scientist, geotechnical engineer, wild land hydrologist) should identify sites that have high risk of landslides or that might become unstable after harvest. These specialists can recommend specific practices to reduce the likelihood of erosion hazards and protect water quality.*

Road System Planning Practices

◆ *Preplan skid trail and landing locations on stable soils and avoid steep gradients, landslide-prone areas, high-erosion-hazard areas, and poor-drainage areas.*

◆ *Identify areas that will require the least modification for use as log landings and use them to reduce the potential for soil disturbance. Use topographic maps and aerial photographs to locate these areas.*

◆ *Plot feasible routes and locations on an aerial photograph or topographic map to assist in the final determination of road locations.*

◆ *Design roads and skid trails to follow the natural topography and contour, minimizing alteration of natural features.*

◆ *In moderately sloping terrain, plan for road grades of less than 10 percent, with an optimal grade of between 3 percent and 5 percent. In steep terrain, short sections of road at steeper grades can be used if the grade is broken at regular intervals. Vary road grades frequently to reduce culvert and road drainage ditch flows, road surface erosion, and concentrated culvert discharges.*

◆ *Plan to surface most forest roads, and select a road surface material suitable for the intended road use.*

◆ *Lay out roads, skid trails, and harvest units to minimize the number of stream crossings.*

◆ *To minimize soil disturbance and road damage, plan to suspend operations when soils are highly saturated. Damage to forested slopes can also be minimized by not operating logging equipment when soils are saturated, during wet weather, or when the ground is thawing.*

◆ *Select waterway opening sizes to minimize the risk of washout during the expected life of the structure. Opening size will vary depending on the drainage area of the watershed where the stream-crossing structure is to be placed.*

Additional management practice recommendations for the NIPF landowner

◆ *Locate property lines.*

The location of property lines might restrict the use of the best access locations. If significant environmental impact (e.g., erosion, water body sedimentation, numerous stream crossing) could be avoided by crossing adjacent property to provide access, consider negotiating or purchasing a right-of-way from the owner of the property.

The USDA Forest Service has produced a document titled A Landowner's Guide to Building Forest Access Roads (Wiest, 1998). This document, along with the assistance of a consulting forest engineer, provides support in road planning and location. To receive a copy of this document, contact the USDA Forest Service, Northeastern Area State and Private Forestry, in Radnor, Pennsylvania, (610) 975-4017, or order a copy from the web site at <http://www.na.fs.fed.us/spfo/pubs/stewardship/accessroads/accessroads.htm>.

◆ *Inventory the property.*

Managing timberland requires knowledge of what is on the property. Conduct an inventory to identify features of the land such as streams, steep slopes, eroding or erodible soils, roads and trails, and sensitive wildlife habitats. Aerial photos can be useful for an inventory, but if they are not available for the property, U.S. Geological Survey (USGS) quadrangle map(s) of the area can be used to locate these resources and create a permanent record of them on a map. USGS quadrangle maps show contour lines (steepness of the terrain), existing roads, waterbodies, springs, and buildings. They cost approximately $5 per map and are available for all of the United States.

◆ *Develop a forest management plan.*

Before harvesting operations begin, develop a forest management plan that contains goals, objectives, possible alternatives to harvesting, future planning, and the trade-offs that accompany altering the land. Contact the state department of forestry or cooperative extension service for information on forest harvesting BMPs and their implementation. A logging company is often the primary source of information regarding forestry and nonpoint source pollution control for NIPF owners, and only by first becoming familiar with the various BMPs can the NIPF landowner be assured that a contractor is choosing and implementing BMPs properly.

The use of a consulting forester or state forester is extremely helpful when developing a forest management plan. The forester can assist with all aspects of forest management and harvest, including the layout of roads and logging decks, BMP implementation, stream protection, and the proper use of chemical. The forester can also educate the NIPF owner about topics such as watershed protection and sustainable forest management.

Streamside Management Areas:

Below are listed some of the more important management practices for achieving the Management Measure for Streamside Management Areas. Complete discussions of these and other management practices for preharvest planning can be found in Section 3B.

- Minimize disturbances that would expose the mineral soil of the SMA forest floor. Do not operate skidders or other heavy machinery in the SMA.

- Locate all landings, portable sawmills, and roads outside the SMA.

- Restrict mechanical site preparation in the SMA, and encourage natural revegetation, seeding, and hand planting.

- Limit pesticide and fertilizer usage in the SMA. Establish buffers for pesticide application for all flowing streams.

- Directionally fell trees away from streams to prevent logging slash and organic debris from entering the water body. If slash and debris are in the stream as a result of harvesting practices, remove them immediately.

- Apply harvesting restrictions in the SMA to maintain its integrity.

Road Construction/Reconstruction:

Below are listed some of the more important management practices for achieving the Management Measure for Road Construction and Reconstruction. Complete discussions of these and other management practices for preharvest planning can be found in Section 3C.

Road Surface Construction Practices

◆ *Follow the design developed during preharvest planning to minimize erosion by properly timing and limiting ground disturbance operations.*

◆ *Properly dispose of organic debris generated during road construction.*

◆ *Prevent slash from entering streams and promptly remove slash that accidentally enters streams to prevent problems related to slash accumulation.*

Road Surface Drainage Practices

◆ *Install surface drainage controls at intervals that remove storm water from the roadbed before the flow gains enough volume and velocity to erode the surface. Route discharge from drainage structures onto the forest floor so that water will disperse and infiltrate. Methods of road surface drainage include the following:*

◆ *Install turnouts, wing ditches, and dips to disperse runoff and reduce the amount of road surface drainage that flows directly into watercourses.*

◆ *Install appropriate sediment control structures to trap suspended sediment transported by runoff and prevent its discharge into the aquatic environment.*

Road Slope Stabilization Practices

◆ *Use straw bales, straw mulch, grass-seeding, hydromulch, and other erosion control and revegetation techniques to complete the construction project. These methods are used to protect freshly disturbed soils until vegetation is established.*

◆ *Revegetate or stabilize disturbed areas, especially at stream crossings.*

Stream Crossing Practices

◆ *Construct stream crossings to minimize erosion and sedimentation.*

◆ *Install a stream crossing that is appropriate to the situation and conditions.*

Fish Passage Practices

◆ *On streams with important spawning areas, avoid construction during egg incubation periods.*

◆ *Design and construct stream crossings for fish passage according to site-specific information on stream characteristics and the fish populations in the stream where the passage will be installed.*

Road Management:

Below are listed some of the more important management practices for achieving the Management Measure for Road Management. Complete discussions of these and other management practices for preharvest planning can be found in Section 3D.

Road Maintenance Practices

◆ *Blade and reshape the road to conserve existing surface material; to retain the original, crowned, self-draining cross section; and to prevent or remove berms (except those designed for slope protection) and other irregularities that retard normal surface runoff.*

◆ *Maintain road surfaces by mowing, patching, or resurfacing as necessary.*

◆ *Clear road inlet and outlet ditches, catch basins, culverts, and road-crossing structures of obstructions as necessary.*

Wet and Winter Road Practices

◆ *Before winter, all permanent, seasonal, and temporary roads should be inspected and prepared for the winter months.*

Stream Crossing and Drainage Structure Practices

◆ *When temporary stream crossings are no longer needed, and as soon as possible upon completion of operations, remove culverts and log crossings to maintain adequate streamflow.*

◆ *During and after logging activities, ensure that all culverts and ditches are open and functional.*

◆ *Revegetate disturbed surfaces to provide erosion control and stabilize the road surface and banks.*

Section 319 requires states to assess nonpoint source pollution and implement management programs, and it authorizes EPA to provide grants to assist state nonpoint source pollution control programs.

Timber Harvesting:

Below are listed some of the more important management practices for achieving the Management Measure for Timber Harvesting. Complete discussions of these and other management practices for preharvest planning can be found in Section 3E. Additional management practices that are particularly applicable to the NIPF landowner follow this listing.

Harvesting Practices

◆ *Fell trees away from watercourses whenever possible, keeping logging debris from the channel, except where debris placement is specifically prescribed for fish or wildlife habitat.*

◆ *Immediately remove any tree accidentally felled in a waterway.*

◆ *Remove slash from the water body and place it outside the SMA.*

Practices for Landings

◆ *Landings should be no larger than necessary to safely and efficiently store logs and load trucks.*

◆ *Upon completion of a harvest, clean up, regrade, and revegetate the landing.*

Ground Skidding Practices

◆ *Skid uphill to log landings whenever possible. Skid with ends of logs raised to reduce rutting and gouging.*

◆ *Skid perpendicular to the slope (along the contour), and avoid skidding on slopes greater than 40 percent.*

Cable Yarding Practices

◆ *Use cabling systems or other systems when ground skidding would expose excess mineral soil and induce erosion and sedimentation.*

◆ *Avoid cable yarding in or across watercourses.*

Petroleum Management Practices

◆ *Service equipment at a location where any spilled fuel or oil will not reach watercourses, and drain all petroleum products and radiator water into containers.*

◆ *Dispose of wastes and containers in accordance with proper waste disposal procedures.*

◆ *Take precautions to prevent leakage and spills.*

Additional management practice recommendations for the NIPF landowner

◆ *Participate actively in the timber harvest.*

It is important that the NIPF landowner be an active participant in the timber harvest process. Working with the harvesting contractor and state forester, verify that road layout, stream protection, landing locations, skid trail layout, and drainage BMPs all follow the plan developed in the preharvest planning phase. Review the management measures in this guidance prior to developing a plan, note those measures and BMPs particularly relevant to your situation, discuss them with a state forester, and then participate in the harvest to be certain that it is conducted in a manner compatible with the sustainability of your property.

Site Preparation and Forest Regeneration:

Below are listed some of the more important management practices for achieving the Management Measure for Site Preparation and Forest Regeneration. Complete discussions of these and other management practices for preharvest planning can be found in Section 3F.

Site Preparation Practices

◆ *Mechanical site preparation should not be conducted on slopes greater than 30 percent.*

◆ *Do not conduct mechanical site preparation in SMAs.*

Forest Regeneration Practices

◆ *Order seedlings well in advance of planting time to ensure their availability.*

◆ *Hand plant highly erodible sites, steep slopes, and lands adjacent to stream channels (SMAs).*

Fire Management:

Below are listed some of the more important management practices for achieving the Management Measure for Fire Management. Complete discussions of these and other management practices for preharvest planning can be found in Section 3G. Additional management practices that are particularly applicable to the NIPF landowner follow this listing.

Prescribed Fire Practices

◆ *Carefully plan burning to take into account weather, time of year, and fuel conditions so that these help achieve the desired results and minimize impacts on water quality.*

◆ *Intense prescribed fire for site preparation should not be conducted in the SMA.*

◆ *Execute the burn with a trained crew and avoid intense burning.*

Additional management practice recommendations for the NIPF landowner

◆ *Contact a state forester before any prescribed burning.*

Prescribed burning poses many potential hazards, and the NIPF landowner must be aware of these. Before using fire as a management tool, consult with a professional forester to obtain information on permits, burning times and procedures, equipment, current fire conditions, and safety precautions.

◆ *Notify adjacent landowners.*

Before burning, notify adjacent landowners, the local county sheriff, and local fire departments to let them know the date of the burn. A permit might be required for the burn, and it might specify a time period during which the burn must occur. If the burn is not done during the specified period, a new permit must be obtained. Letting all potentially affected parties know that a burn will take place will lessen the likelihood that the fire department will be called to put out the fire. The date of the prescribed burn is always subject to change due to changing weather and fire hazard conditions, and if the date does change, inform the previously notified parties of the new date.

◆ *Hire a professional.*

A landowner who is not proficient in prescribed burning should hire a contractor to perform the burn. Investigate the background and record of any contractor contacted and

ask the contractor to provide testimonies of his or her work. Ask the local forestry department, cooperative extension service, or fire department if they have knowledge of the contractor as well. Remember that having a contractor perform the burn does not release the landowner of obligations to notify potentially affected parties, obtain legal information and permits, and ensure that the burn is conducted within the conditions of the permit or recommendations made by the fire or forestry department with respect to time of day, safety precautions, and so forth.

Revegetation of Disturbed Areas:

Below are listed some of the more important management practices for achieving the Management Measure for Revegetation of Disturbed Areas. Complete discussions of these and other management practices for preharvest planning can be found in Section 3H.

◆ *Use mixtures of seeds adapted to the site, and avoid the use of exotic species. Species should consist primarily of annuals to allow natural revegetation of native under-story plants, and they should have adequate soil-binding properties.*

◆ *Seed during optimum periods for establishment, preferably just before fall rains or whenever the optimum period might be for the region.*

◆ *Fertilize according to site-specific conditions.*

◆ *Inspect all seeded areas for failures, and make necessary repairs and reseed within the planting season.*

◆ *During non-growing seasons, apply interim surface stabilization methods to control surface erosion.*

Forest Chemical Management:

Below are listed some of the more important management practices for achieving the Management Measure for Forest Chemical Management. Complete discussions of these and other management practices for preharvest planning can be found in Section 3I. Additional management practices that are particularly applicable to the NIPF landowner follow this listing.

◆ *Apply pesticides and fertilizers during favorable atmospheric conditions.*

◆ *Apply slow-release fertilizers when possible.*

◆ *Apply fertilizers during maximum plant uptake periods to minimize leaching.*

◆ *Consider the use of pesticides as only one part of an overall program to control pest problems.*

Additional management practice recommendations for the NIPF landowner

◆ *Contact a state forester.*

Forest landowners who intend to apply chemicals to manage their timber stands should first contact a local forester. The forester will be able to provide information on approved

pesticides and fertilizers, application guidelines or requirements, and a list of licensed applicators. It might be possible to hire state foresters to apply chemicals, or they might be willing to act as a foreman on the site to ensure that proper application procedures are followed and hire a licensed contractor to perform the work. Information on such arrangements, for which the landowner pays only part of the total cost, should be available from the state department of forestry or the local cooperative extension service.

Wetlands Forest Management:

Below are listed some of the more important management practices for achieving the Management Measure for Wetlands Forest Management. Complete discussions of these and other management practices for preharvest planning can be found in Section 3J. Additional management practices that are particularly applicable to the NIPF landowner follow this listing.

◆ *Select the harvesting method to minimize soil disturbance and hydrologic impacts on the wetland.*

Additional management practice recommendations for the NIPF landowner

◆ *Contact a state forester or soil scientist to identify forested wetlands.*

Forested wetlands can be difficult to identify. They can occupy very small areas or large areas, can be of any shape, and need not be permanently flooded. Delineation of an area as a wetland requires that three criteria be met:

- Hydrology—a degree of flooding or soil saturation
- Hydrophytic vegetation (vegetation specific to wetlands)
- Hydric soils

These three components can be very site-specific. Differentiating a forested wetland from a non-wetland forest can be difficult. Wetland areas on a property need not be contiguous, and it is possible for a property to have several wetland areas. Some wetlands might be large and easily identified, whereas others might be small and very inconspicuous (Mitsch et al., 1993). Furthermore, different plant species are adapted to the various conditions that wetlands can occupy, so the absence of wetland plants identified in one wetland area from other areas does not mean that other wetlands do not exist on the property. Because of the complexity of wetland identification, a person licensed in wetland delineation should be consulted if there is any doubt as to whether wetlands exist on a property.

An initial assessment of the existence of wetlands on a property can be done by walking the property and asking some simple questions (Maryland DNR, undated):

- Is the ground moist underfoot?
- Are there springs in the area? (Look at a USGS quadrangle map.)
- Are the tree species considered hydrophytic vegetation? (Use a wetlands tree guide.)
- Are there high-water marks or silt deposits on tree trunks?
- Is water ponded anywhere?

- Do your feet sink into the soil when you walk?

- Dig a hole about a foot deep. Is the soil mostly gray?

- Does the soil in the hole smell like sulphur or rotten eggs?

- Does the hole fill up with water? Does water leak into the hole?

- Is there lush vegetation in some areas and not in others?

To help answer some of the questions, it is useful to have field guides to identify wetland species. Field guides provide descriptions of trees and other wetland vegetation and information on their ranges and habitats.

Contact the local office of the Soil Conservation District to determine whether there are hydric soils on the property. The office will be able to provide a map of the soil series of the property.

Water Quality Protection During Invasive Species Control

Invasive species are gaining a foothold in many parts of the United States, and they can cause extensive damage to a forest. Introduced insects, diseases, and plants can all cause problems for the forest landowner, and the means of control include mechanical, chemical, and biological. Mechanical and chemical control methods, in particular, have the potential to affect water quality. Prior to attempting control of an invasive species, consider using the practices below for the protection of water quality during invasive species control activities. The U.S. Department of Agriculture, the U.S. Forest Service, state forestry agencies, cooperative extension agencies, and local or state universities can provide additional assistance with the identification of invasive species, the problems they cause, and appropriate control methods. Even if you do not believe that you have an invasive species problem, or that your problem is not serious enough to do anything about, it is advised to find out what the invasive species in your area are and what their signs are. Knowing what the problems are can help prevent them or help you identify them before the problem becomes insurmountable and your losses significant.

◆ *Consult a state forester before using mechanical control methods.*

The control of invasive species usually requires the implementation of either chemical or mechanical means of control. To ensure that water quality is not compromised when these practices are used, consult with the local county forester before taking any action.

Mechanical control methods used to eradicate an invasive plant, insect, or disease can potentially impair water quality. Some mechanical methods of invasive species removal are cutting, girdling, hand pulling, burning, and grubbing. Some species that can be managed through mechanical control are kudzu (*Pueraria lobata)*, tree of heaven (*Ailanthus altissima*), leafy spurge (*Euphorbia esula*), mistletoe (*Phorandendron serotinum*), purple loosestrife (*Lythrum salicaria*), scotch broom (*Cytisus scoparius*), saltcedar (*Tamarix ramosissima*), spruce bark beetle (*Dendroctonus rufipennis*), Douglas fir beetle (*Dendroctonus pseudotsugae*), fusiform rust (the fungus *Cronartium fusiform*e), and pine pitch canker (the fungus *Fusarium subglutinans*). The cooperative extension service should be able to provide information on invasive species in your area and appropriate

control methods. The following guidelines apply to water quality protection during invasive species control activities:

- Remove invasive species from the SMA only if water quality will not be compromised.

- Do not burn SMAs to eradicate an invasive species.

- Avoid removing infected trees during wet weather periods. This will help reduce erosion potential at the site of removal and on haul roads.

Chemical control of invasive species involves the application of herbicides, pesticides, or fungicides to remove unwanted pests. Review the guidelines for chemical applications in this guidance and provided by your state forestry department before using chemicals for invasive species control.

Additional Resources for the NIPF Landowner:

Landowner's Guide to Building Forest Access Roads, by Richard L. Wiest, is a designed for landowners in the northeastern United States who will use a tractor and ordinary earth moving equipment to build the simplest access roads on their property, or who will contract for these services. Recommendations cover basic planning, construction, drainage, maintenance and closure of such forest roads. Also covers special situations involving water that require individual consideration. Describes geotextiles to be used during temporary road construction. The guide is published by the U.S. Department of Agriculture, Forest Service, Northeastern Area, State and Private Forestry Division. (1998; 47 p.; order online at http://www.na.fs.fed.us/spfo/pubs/stewardship/accessroads/accessroads.htm; first copy free, other copies $8 ea.).

APPENDIX E: STATE AND PRIVATE FORESTRY PROGRAMS

Education and Training

Education and training are vital to effective BMP implementation. Educating and training loggers and landowners about the importance and use of BMPs is an effective way to reduce water quality effects from forest operations because harvesters and landowners are responsible for forest harvesting and decisions concerning the management of much of the forested land in the Nation. A logger education program that has been adopted in various forms and under numerous names in many states is the Logger Education to Advance Professionalism (LEAP) program (APA, 1995). It is modeled after Vermont's very successful Silviculture Education for Loggers Project and began as a national pilot program of the USDA Extension Service to promote responsible forest BMPs and to teach forest ecology and silviculture to loggers. These programs are based on the premise that it is important to teach forest ecology and silviculture to loggers because professional foresters supervise less than a third of all the acres harvested in the United States while loggers are involved in all of the harvests. Before these programs, few people employed in logging had training in forestry and silviculture, and the logger education programs are changing that situation. To accomplish its goal, logger training emphasizes five areas—safety and first aid, business management, harvesting operations, professionalism, and forest ecology and silviculture.

Currently there are nearly 500 million acres of non-federal forests in the United States. More than 50 percent of these acres are privately owned (USDA Forest Service).

A USDA Natural Resources Conservation Service (NRCS) program, *Soil and Water Conservation Assistance* (SWCA), provides cost share and incentive payments to farmers and ranchers to voluntarily address threats to soil, water, and related natural resources, including forest land, grazing land, wetlands, and wildlife habitat. SWCA can help landowners comply with federal and state environmental laws and make beneficial, cost-effective changes their land management practices. Through the nearly 3,000 Soil and Water Conservation Districts nationwide with 2,500 field offices, nearly a million private landowners are assisted annually with land management decisions.

NRCS also administers the Forestry Incentives Program (FIP), which supports good forest management practices on privately owned, nonindustrial forest lands nationwide. FIP is designed to benefit the environment while meeting future demands for wood products. Eligible practices are tree planting, timber stand improvement, site preparation for natural regeneration, and other related activities. FIP is a nationwide program available in counties designated on the basis of a Forest Service survey of total eligible private timber acreage that is potentially suitable for production of timber products. Federal cost-share money is available—with a limit of $10,000 per person per year with the stipulation that no more than 65 percent of the cost may be paid. A local USDA office, state forester, conservation district, or Cooperative Extension office can provide information on whether a particular county participates in FIP.

Numerous non-governmental organizations, such as the Forest Stewards Guild (http://www.foreststewardsguild.org/) and National Network of Forest Practitioners (http://www.nnfp.org/) are also available to be contacted for assistance in sustainable management of forest land.

Cooperative Forestry Programs

Cooperative Forestry is a nationwide program funded through Congress and administered nationally by the USDA Forest Service. Since 1978, the USDA has connected rural, urban, and nonindustrial private forest (NIPF) landowners with resources and ideas to assist with the care of their forests. The Cooperative Forestry program provides technical and financial assistance through partnerships with the state and private forestry organizations (USDA Forest Service, 1999). The Cooperative Forestry program was created under section 2101 of Title 16 of the United States Code, in which it is stated that it is the policy of Congress that the Secretary of Agriculture work through and in cooperation with state foresters, or equivalent state officials, nongovernmental organizations, and the private sector in implementing federal programs affecting non-federal forestlands. The landowner assistance programs covered under Cooperative Forestry are the Forest Legacy Program, the Forest Stewardship Program, and the Forest Land Enhancement Program. The Forest Service's Web site for Forestry Landowner Assistance, http://www.fs.fed.us/spf/coop/, provides further information about the programs discussed below.

- *Forest Legacy Program.* The Forest Legacy Program (FLP), a federal program in partnership with states, supports state efforts to protect environmentally sensitive forest lands. Designed to encourage the protection of privately owned forest lands, FLP is an entirely voluntary program. To maximize the public benefits it achieves, the program focuses on the acquisition of partial interests in privately owned forest lands. FLP helps the states develop and carry out their forest conservation plans. It encourages and supports acquisition of conservation easements, legally binding agreements transferring a negotiated set of property rights from one party to another, without removing the property from private ownership. Most FLP conservation easements restrict development, require sustainable forestry practices, and protect other values.

- *Forest Stewardship Program.* This program helps private forest landowners develop plans for the sustainable management of their forests. This is accomplished through active forest management for present and future landowners, increasing the economic value of the timber along with providing environmental benefits. The Forest Service also provides public outreach programs to assist NIPF landowners with information regarding seedling production and tree stand improvements.

The 2002 Farm Bill incorporates the following cooperative forestry assistance programs:

- Forest Land Enhancement Program: The Forest Land Enhancement Program (FLEP) is established to provide financial, technical, educational and related assistance to state foresters to assist private landowners in actively managing their land. Note that the FLEP replaces the Stewardship Incentives Program (SIP) and the Forestry Incentives Program (FIP). To be eligible for cost-share assistance under the FLEP on up to 1,000 acres, a landowner must agree to develop and implement for not less than 10 years a management plan that has been approved by the state forester.

Cost share payments will be available to landowners for up to 75 percent of the total cost of implementing the plan.

- Enhanced Community Fire Protection: Recognizing the significant federal interest in enhancing community protection from wildfire, the Department of Agriculture will cooperate with state foresters to manage lands to (1) focus the federal role in promoting optimal firefighting efficiency at the federal, state and local levels; (2) expand outreach and education programs to homeowners and communities about fire protection; and (3) establish space around homes and property that is defensible against wildfire.

Congress passed the Healthy Forests Restoration Act of 2003 (P.L. 108-148) on December 3, 2003, based on legislation proposed by the Bush Administration. The law provides critical tools needed to fully implement the Healthy Forests Initiative and the funding necessary to reduce wildfire risks and improve forest and rangeland health (USDOI, USDA, 2004). The Healthy Forests Restoration Act establishes procedures to expedite forest and rangeland restoration projects on Forest Service and BLM lands. It focuses on lands (1) near communities in the wildland urban interface, (2) in high risk municipal watersheds, (3) that provide important habitat for threatened and endangered species where catastrophic wildfire threatens the survival of the species, and (4) where insects or disease are destroying the forest and increasing the threat of catastrophic wildfire. The law:

- Helps communities use wood, brush, and other plant materials removed in forest health projects as a fuel supply for biomass energy.
- Authorizes a program to support community-based watershed forestry partnerships that address critical forest stewardship and watershed protection and restoration needs at the state and local level.
- Directs research focused on the early detection and containment of insect and disease infestations.
- Establishes a private forestland easement program focused on recovering forest ecosystem types and protecting valuable wildlife habitat.

The Watershed Forestry Assistance Program, created by the law, enacts the Watershed Forestry Cost-Share Program. The cost-share program provides up to 75 percent of project funding to communities, nonprofit groups, and NIPF landowners for watershed forestry projects that:

- Use trees as solutions to water quality problems in urban and rural areas.
- Employ community-based planning, involvement, and action through State, local and nonprofit partnerships.
- Apply and disseminate monitoring information on forestry best-management practices relating to watershed forestry.
- Implement watershed-scale forest management activities and conservation planning.
- Restore wetland and stream-side forests and establish riparian vegetative buffers.

Forest Land Ownership

Nonindustrial private forest land (NIPF) owners in the United States own 58 percent of all timberland. Of this, 29 percent is owned by farmers who can benefit from the numerous provisions of the 2002 Farm Bill that involve land management. The rest of the timberland in the United States is owned by the federal government (20 percent), the forest industry (14 percent), state government (6 percent), and counties and municipalities (2 percent). Because of the large percentage of timberland owned by nonindustrial private forest land owners, an important part of protecting forests and water quality during forest harvest is educating those landowners about forest management and proper timber harvesting techniques to protect water quality (Powell et al., 1994). Birch (1996a) reports that private forest land owners (including industrial owners) have diverse reasons for owning their land, including "… it's just part of the land" (40 percent), a private source for forest products (8 percent), recreation and aesthetic enjoyment (23 percent), investment (9 percent), and timber production (3 percent). The last group, those who hold their land for timber production, represents 29 percent of private forest land ownership. It is estimated (Birch, 1996a) that 5 percent of private forest land owners have a written management plan and these owners control 39 percent of private forest land.

With so much land owned and controlled by private forest land owners, and specifically NIPF owners, it is crucial that the importance of protecting water quality be considered as part of NIPF harvesting. Some private landowners may not place an emphasis on water quality protection when planning a harvest because it appears to provide benefits only for downstream users, not for the harvesting landowner. Other management measures–such as site preparation to improve regeneration–provide direct benefits to landowners and are therefore more likely to be part of the landowner's harvest plan (Alden et al., 1996).

Forest Program Administration and BMP Effectiveness

A survey to compare the attitudes of persons involved with forestry program administration and implementation about the effectiveness of various approaches to protecting water quality and forests in general rated methods for protecting water quality from most effective to least effective as follows (Ellefson et al., 1995): technical assistance, fiscal incentives, educational programs, voluntary programs, regulatory programs, and tax incentives (Figure E-1).

In this survey, forestry program administrators were asked to rate specifically the effectiveness of educational programs for protecting water quality: 19 were neutral about their effectiveness, 17 said that they thought they were effective, and 12 thought that they were ineffective. The results for a similar rating of the effectiveness of technical assistance programs for protecting water quality showed that 26 administrators thought they were effective, 17 were neutral about their effectiveness, and 6 thought them to be ineffective.

The importance of education in forest harvesting and forest stewardship can be judged from the fact that many state departments of forestry have BMP guidebooks and education programs geared not only to loggers and industrial owners but also to the landowners who are not trained in forest management and harvesting. A review of some states' educational programs is provided below, and this review represents the variety of
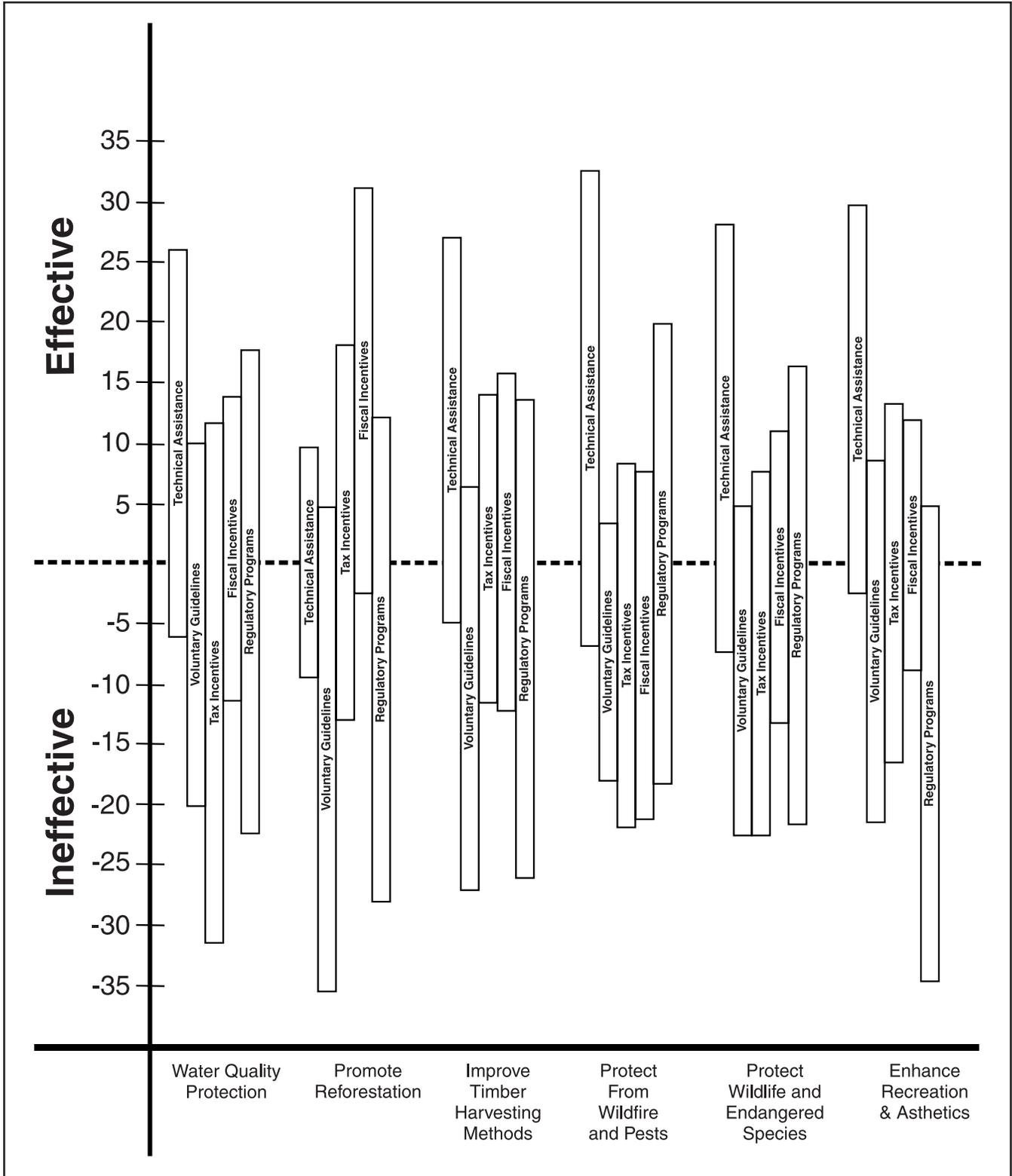
Figure E-1. Ratings of the effectiveness of various types of programs for accomplishing specific forestry objectives. Height of line above or below the center line indicates the number of state program administrators who rated the program type as effective or ineffective, respectively, for accomplishing the specific objective (Ellefson et al., 1995).

educational and technical assistance programs offered by states and the importance states place on education.

Examples of State Forestry Assistance Programs

Provided below are some examples of state programs for forestry assistance and education. Links to information on state forest protection and education programs can be found at the Web site www.usabmp.net.

Washington State

In 1999, Washington State created a Forestry Riparian Easement Program to be managed by a Small Forest Landowner Office within DNR. Responding to the federal Endangered Species Act by listing several salmon species and authorizing the Forest Practices Board to adopt rules for salmon recovery, the size of riparian buffers was increased and further measures were created to protect water quality and restore salmon habitat. Recognizing that these rules would have a disproportionate impact on small forest landowners, the easement program under the Forestry Riparian Easement Program acknowledges the importance of small forest landowners and the contributions they make to protect wildlife habitat. The program is also intended to help small forest landowners keep their land in forestry.

DNR's Forestry Riparian Easement Program partially compensates eligible small forest landowners in exchange for a 50-year easement on "qualifying timber." This is the timber the landowner is required to leave unharvested as a result of new forest practices rules protecting Washington's forests and fish. Landowners cannot cut or remove the qualifying timber during the easement period. The landowner still owns the property and retains full access, but has "leased" the trees and their associated riparian function to the state.

Washington's Backyard Forest Stewardship Program is especially designed for owners of small-forested parcels (from a "forested lot" up to ten acres) and anyone who owns a home in a forested environment. Guidelines for forest protection are provided on a DNR Web site (http://www.wa.gov/dnr/htdocs/rp/stewardship/bfs/) and can be obtained in print as well. Landowners who implement the guidelines relevant to their property can apply for recognition under the program from the state.

The Federal Coastal Nonpoint Pollution Control Program (6217) is designed to enhance state and local efforts to manage land use activities that degrade coastal habitats and waters.

Virginia

The Virginia Department of Forestry (DOF) reports that surveys show most landowners sell timber and make other forest management decisions without professional advice. These same studies have demonstrated that landowners who sell timber with the assistance of a professional forester receive 50 percent more for their timber (Virginia DOF, 1998). Since professional foresters are knowledgeable of water protection BMPs, having a landowner contact a professional benefits both the landowner and the environment (Virginia Department of Forestry, 1998).

The Virginia DOF inspects harvesting sites for compliance with the Seed Tree Law and The Silvicultural Water Quality Law. During an inspection, compliance with other state and federal laws is observed so the landowner and logger can be informed and kept in

compliance with applicable regulations. Other laws that landowners need to be aware of and in compliance with include, depending on their particular location and situation, the Chesapeake Bay Act, the Virginia Marine Resources Law, and the Federal Clean Water Act. The logger, consultant forester, industry forester, and/or the landowner are contacted by Virginia DOF during logging operations concerning BMP installation. The landowner is contacted concerning needs for forest renewal and future management.

Regardless of the origin of the request, if the landowner wishes to reforest an area or implement other recommended management practices, Virginia DOF will provide them with the names of consultants or contractors who can implement the recommended practices, and will inform them of any cost share assistance for which they might be eligible.

The Virginia DOF has the responsibility to administer and give technical approval for cost-share programs. A reforestation cost-share examination must be completed along with application forms and other paperwork for cost-share programs. For cost-share assistance, the area must be inspected for needs determination before the practice is started and after the practice is completed to determine if the practice was completed correctly. Again, required compliance with all applicable state and federal laws and regulations are checked.

Tennessee

Forestry assistance in Tennessee is handled by the Tennessee Department of Agriculture (DOA), Forestry Division. The Forestry Division trains loggers and others involved in land management in the use of logging techniques to prevent erosion and leave streams unharmed. Tennessee DOA has also developed a number of training aids for water quality, including a video, printed material, and a number of forest management demonstration sites. One of the Forestry Division's primary services is offering advice to landowners, often in person on the individual's property. A forest land owner can contact a local Area Forester to discuss management objectives for the property. The Area Forester will work through a sequence of steps to help meet the objectives. A local forestry office can also provide information on what landowner options are for managing their land. The DOA Forestry Division web site provides *A Practical Introduction to Forestry for Landowners* that gives information on a variety of forest management options and has references and links to other sources of information.

The Tennessee Reforestation Incentive Program (TRIP) was created in mid-1997 to provide financial assistance to landowners for planting trees on marginal and highly erodible crop and pasture lands. Money provided by the State Agricultural Nonpoint Water Pollution Control Fund administered by the Department of Agriculture is used to share the cost of planting trees to stabilize eroding lands and improve water quality.

Another training program available to loggers is the Master Logger Program. The mission of the Master Logger Program is "to enhance the professionalism of the Tennessee logger" through a complete educational program designed to improve the health and well-being of the logging industry and the forest resource. The Master Logger curriculum consists of five 1-day courses, one of which is on forest ecology and BMPs. Loggers attend individual sessions of the program 1 day every 2 weeks, and it takes 10 weeks to complete the workshop. Master Loggers must continue their education to retain Master Logger status. Many other states provide programs similar to the Master Logging

Program under various names, and all of the programs stem from the original pilot program of the USDA Extension Service, the LEAP program.

the number 10 years ago. The largest number of operations occur on small private forests where the landowners are typically not as familiar with the state's forest practice rules as are large industrial landowners. The state therefore puts a great deal of energy into providing information, training, and resources to landowners and operators (Oregon DOF, 1997).

The Oregon Department of Forestry's Forest Practices Program involves more than 150 people in the department's main offices and in field offices who provide face-to-face information and guidance to landowners. Program staff work with industry and environmental representatives to develop programs and incentives for encouraging sound stewardship of forest resources.

Small woodland owners in Oregon can request on-site assistance from their local service forester, who can provide information and guidance on insect and disease issues, reforestation and young growth management, financial incentives, and other forest related topics and resources. Private forest consultants are available throughout the state to provide comprehensive assistance to landowners. Consultants provide services that are beyond the scope of public agency assistance programs, such as the development of Forest Stewardship Plans.

The Oregon Forest Resource Trust provides monies for the direct cost payments of site preparation, tree planting, seedling protection, and competitive release activities. The program encourages landowners to establish and maintain healthy forests on underproducing forestlands—lands capable of growing forests but that are in brush, cropland, pasture, or that are very poorly stocked. The landowner commits to establishing a healthy "free-to-grow" forest stand and takes responsibility for seeing that the work gets done. The service forester provides technical assistance on how to complete the reforestation project and is available to provide direction with respect to the landowner's project management responsibility. If timber is harvested from the forests created with trust monies, participating landowners repay the trust (up to set amounts) with a portion of the profits. Eligible underproducing land must be at least 10 contiguous acres, zoned for forest or farm use, located in Oregon, and part of a private forestland ownership of no more than 5,000 acres. The trust can fund 100 percent of the reforestation cost up to $100,000 every two years.

The Oregon 50% Tax Credit, the "Underproductive Forest Land Conversion Tax Credit," encourages landowners to establish and maintain healthy and productive forests. Fifty percent of the cost of establishing a stand of trees on underproductive forestland may be applied as a credit against Oregon state taxes. The 50 percent tax credit applies on brushland, grassland, or on very poorly stocked forestland.

South Carolina

The South Carolina Forestry Commission provides timber management assistance to forest landowners in the state. Forestry Commission foresters will examine forestland and potential forestland at the request of a landowner. A written plan and map are prepared for the landowner, giving forest management recommendations that best meet the owner's needs and objectives, provided that they are compatible with good forest BMPs (South Carolina Forestry Commission, 1998). When conditions warrant, such as a request

for a detailed plan on a large tract, the Forestry Commission forester can recommend consultants or industry foresters who can be of assistance.

Two-thirds of the state's forestlands are under private ownership, and the South Carolina Forestry Commission provides assistance to these landowners geared toward educating them so that they can take an active role in managing their forests. A South Carolina Forestry Commission staff member will help the landowner put together a multiple-resource Stewardship Management Plan (SMP) that provides detailed recommendations for timber management activities designed to help prevent soil erosion and protect water quality and might also provide details on wildlife habitat improvement. Anyone who owns at least 10 acres of forestland can qualify for assistance under the SMP program.

Ohio

The Ohio Department of Natural Resources Division of Forestry participates in the Service Forestry Program, the mission of which is to develop better stewardship of the forest resources on private lands in Ohio through on-site technical assistance and the dissemination of information to landowners. There are twenty-five Service Foresters statewide that work one on one with the woodland owners. The Service Foresters are available to provide landowners with current information for the long term management of their woodlands. The Service Foresters can provide management plans and advice on how to accomplish the plan's objectives. The Service Foresters also provide landowners with technical assistance and information on tree planting projects, woodland improvement activities and timber marketing assistance. The Service Foresters also direct landowners to other education participation programs in the state.

The Ohio Forestry Association maintains a Safety Training and Certification Program for logging contractors and their employees. It is the Ohio equivalent of a LEAP program. One of the requirements for certification as a Certified Logging Company is to have employees trained to use BMPs to reduce soil erosion and improve the appearance of timber harvesting activities (Ohio Forestry Association, 1999).

California

The California Department of Forestry & Fire Protection (CDF) administers several state and federal forestry assistance programs with the goal of reducing wildland fuel loads and improving the health and productivity of private forest lands. California's Forest Improvement Program (CFIP) and other federal programs that CDF administers, offer cost-share opportunities to assist individual landowners with land management planning, conservation practices to enhance wildlife habitat, and practices to enhance the productivity of the land.

The CFIP provides technical assistance to private forest landowners, forest operators, wood processors, and public agencies. Cost share assistance is provided to private forest landowners, Resource Conservation Districts, and nonprofit watershed groups. Cost-shared activities include management planning, site preparation, tree purchase and planting, timber stand improvement, fish and wildlife habitat improvement, and land conservation practices for ownerships containing up to 5,000 acres of forest land.

A Forest Legacy Program (FLP) protects environmentally important forestland threatened with conversion to non-forest uses, such as subdivision for residential or commercial development by promoting the use of permanent conservation easements.

Maine

The Forest Policy and Management Division of the Maine Department of Conservation, Forest Service provides technical assistance, information, and educational services to forest landowners. Part of the Division's implementation of the Forest Practices Act is providing educational workshops, field demonstrations, and media presentations, and contacting landowners personally to discuss forest management issues (Maine DOC, 1998).

North Dakota

The majority of North Dakota's rural forests are privately owned. Forest resource management in the state focuses on education and assisting nonindustrial private landowners to better manage, protect, and use their natural resources. This is accomplished through the development of a forest stewardship plan and direct financial assistance for forest improvement practices. Rural forestry services are delivered through an agreement with North Dakota's local Soil Conservation Districts (NDSU, 1998).

The Environmental Quality Incentives Program (EQIP) and the Wildlife Habitat Incentives Program (WHIP) offer up to 75 percent cost-share assistance to landowners for accomplishing forest stewardship projects such as tree planting, forest stand improvement, soil and water protection, riparian protection, windbreak renovation and wildlife habitat enhancement. Eligible landowners may sign up at their local FSA office for WHIP or EQIP practices.

Technical forestry assistance is provided to more than 600 rural landowners each year in North Dakota. Since 1991, 1,405 forest stewardship plans have been requested and completed for 71,777 acres of privately-owned native and planted woodlands and 456 forest improvement practices were awarded $548,887 in Stewardship Incentive Program cost-share funds. A total of 587 landowners enrolled 39,384 acres in the Forest Stewardship Tax Law.

Missouri

The vast majority of land in Missouri is under direct ownership and influence of private landowners. Private individuals own more than 93 percent of all land and 85 percent of forest land. The Department offers two levels of assistance based upon the landowner's need and interest in long term forest management. The two levels are Advisory Service and Management Service. Advisory Service is available to all landowners, including urban residents. This service includes group training sessions, publications, film and video loan, office consultation, insect and disease identification and analysis, referrals to consultants, on-site visits under certain conditions, and help with evaluating and choosing land management options.

Management Service is available to landowners interested in the long term management of their forest land. Those who receive management services agree to develop and carry out a management program for the immediate and long term stewardship of their property. Management plan implementation activities include guidance in soil and watershed protection, erosion control, wildlife habitat improvement, and forest road location and construction. A visit to the landowner's property is part of MDC's assistance in management plan development (Missouri DOC, 2000).

The Society of American Foresters' Certified Forester Program

The Society of American Foresters (SAF), a nonprofit, scientific, and educational organization, established the Certified Forester (CF) program in 1994. The term *Certified Forester* is registered with the U.S. Patent and Trademark Office and may only be used by individuals who meet SAF's certification requirements. The CF program is voluntary, nongovernmental, and open to qualified SAF members and nonmembers. A Certified Forester agrees to abide by current CF program requirements and procedures for certification and recertification; to maintain continuing professional development; and to conduct all forestry practices in a responsible, professional manner consistent with state and federal regulations governing environmental quality and forest BMPs.

Through the CF program and other activities, SAF advocates wise stewardship in forest resources management. The CF program provides a consistent, national credential. Certification constitutes recognition by SAF that, to the best of SAF's knowledge, a Certified Forester meets and adheres to certain minimum standards of academic preparation, professional experience, continuing education, and professionalism. No individual is eligible to receive or to maintain Certified Forester status or recertification unless the individual meets and continues to adhere to all requirements for eligibility. Some of the requirements that must be met by all CF applicants can be found in Appendix C.

Effectiveness of Education and Technical Assistance

Researchers with the U.S. Forest Service reviewed state BMP implementation and monitoring programs and the results from those programs in 1994. At the time, 21 states were assessing BMP effectiveness. The U.S. Forest Service found that the states had generally concluded that carefully developed and applied BMPs can prevent serious deterioration of water quality and that the availability of well-qualified personnel at the field level is probably the most cost-effective approach to meeting water quality standards. Most water quality problems, they found, were associated with poor BMP implementation, and trained field personnel could help correct problems with implementation (Greene and Siegel, 1994).

The researchers also concluded that an iterative self-education process at the state level was important for BMP improvement. Water quality monitoring is essential to understanding the relationship between land disturbance and water quality, they found, and it leads to improved understanding of the interaction of soils and topography with BMP implementation. This understanding was considered essential to continually reassessing BMP guidelines to make them more cost-effective. BMPs need to be specified, used, monitored, and fine tuned to provide cost-effective water quality protection.

Ellefson and others (1995) reviewed forest practice programs in many states, and one aspect of their review involved asking program managers what they thought were the most effective means to protect water quality. State program managers rated the following in program effectiveness, from most effective to least effective: technical assistance, fiscal incentives, educational programs, voluntary programs, regulatory programs, and tax incentives. For promoting reforestation and improving timber harvesting methods,

technical assistance and fiscal incentives were rated as the most effective means and regulatory programs and voluntary guidelines were rated as the two least effective.

When the Vermont Agency of Natural Resources (ANR) studied BMP implementation and effectiveness, ANR personnel accompanied harvesters in the field during harvests. During the harvests monitored, logging personnel appeared to become much more aware of the water quality issues related to their activities and the intent of the BMPs. By the end of the project, the loggers were extremely conscientious in their efforts to protect water quality. Vermont ANR personnel felt that without the oversight of the forestry agency, it was likely that water quality problems would have been more severe, particularly in the early phase of the project. After the assistance provided by the personnel, managers for the logging companies were fully capable of implementing appropriate BMPs with little or no oversight.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

September 30, 2019

DP Barcodes: 451809
PC Codes: 116000 116001, 116002, 116004

MEMORANDUM

SUBJECT: **Triclopyr (Acid, Choline salt, TEA salt, BEE):** Draft Ecological Risk Assessment for Registration Review

FROM: Brian Montague, Fishery Biologist
Keith Sappington, Senior Science Advisor
Mohammed Ruhman, PhD, Senior Scientist
Environmental Risk Branch 5
Environmental Fate and Effects Division (7507P)

MOHAMMED RUHMAN Digitally signed by MOHAMMED RUHMAN Date: 2019.09.30 15:04:18 -04'00'

Digitally signed by Keith Sappington Date: 2019.09.30 14:51:23 -04'00'

THRU: Ryan Mroz, Risk Assessment Process Leader
Justin Housenger, Branch Chief
Environmental Risk Branch 5
Environmental Fate and Effects Division (7507P)

RYAN MROZ 2019.09.30 15:46:01 -04'00'

2019.09.30 for 15:46:40 -04'00'

TO: Andrew Muench, Chemical Review Manager
Khue Nguyen, Team Leader
Cathryn Britton, Branch Chief
Risk Management and Implementation Branch 5
Pesticide Re-evaluation Division (7508P)

The Environmental Fate and Effects Division (EFED) has completed the draft environmental fate and ecological risk assessment in support of the Registration Review of the four active ingredients contained in formulated products of triclopyr: triclopyr acid, triclopyr choline; triclopyr triethylamine salt (TEA); and, triclopyr butoxyethyl ester (BEE).

Draft Ecological Risk Assessment for the Registration Review of Triclopyr Acid, Triclopyr Choline, Triclopyr TEA, and Triclopyr BEE
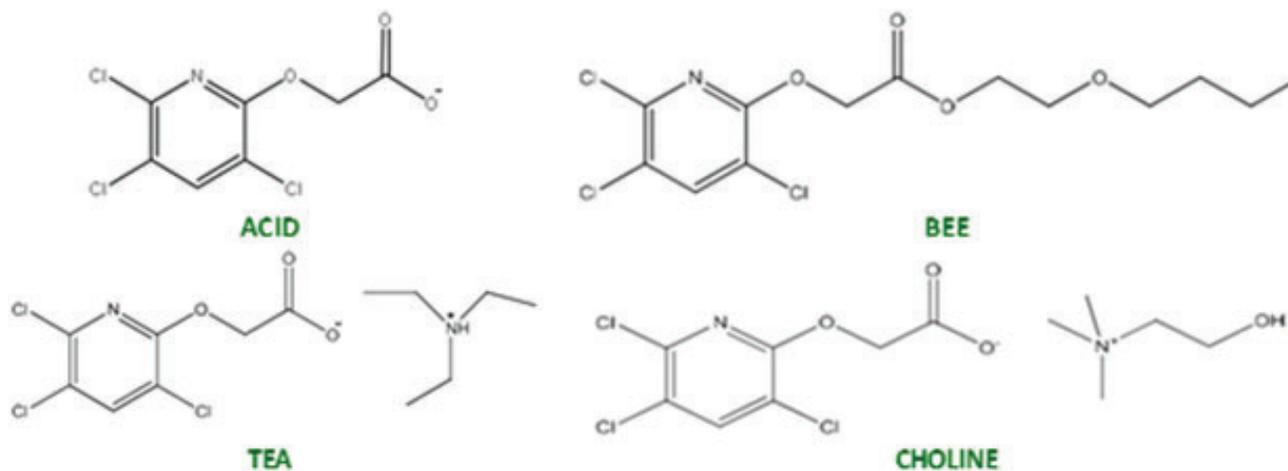
Chemicals (USEPA PC Code/CAS No.):
Triclopyr acid (ACID; 55335-06-3/116001), Triclopyr Butoxyethyl Ester (BEE; 64700-56-7/116004),
Triclopyr Triethylamine Salt (TEA; 57213-69-1/116002) and Triclopyr Choline (CHOLINE; 104837-85-8/116000)

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Environmental Fate and Effects Division
Office of Pesticide Programs
United States Environmental Protection Agency

Table of Contents

1 Executive Summary

1.1 Overview

This risk assessment evaluates four registered active ingredients within the pyridine carboxylic acid family of systemic herbicides: triclopyr acid (ACID), triclopyr choline salt (COLN), triclopyr triethylamine salt (TEA) and triclopyr butoxyethyl ester (BEE). These herbicides are used in various formulated products on rice, orchards, range and pasture lands, forests, rights of way, commercial turf such as golf courses, residential turf and aquatic sites (lakes, ponds rivers, marshes and wetlands) to control herbaceous weeds and some woody plants. According to the Weed Science Society of America (WSSA) triclopyr herbicides mimic natural plant hormones (auxins) responsible for cell elongation and growth. At low concentrations, triclopyr causes uncontrolled cell division and growth resulting in vascular tissue destruction. At higher concentrations, they can inhibit cell division and growth, usually in the meristematic regions of the plant.[1]

Each of the triclopyr TEA and choline salts active ingredients rapidly dissociates in water (< 1 minute) to the triclopyr acid/anion (negatively charged ion) which can further degrade to the following major transformation products: 3,5,6-trichloro-2-pyridinol (TCP); 3,6-dichloro-2-pyridinol (DCP); 5-chloro-2hydroxypyridine (5-CLP); 6-chloro-2hydroxypyridine (6-CLP);and various minor transformation products. Triclopyr BEE metabolizes rapidly (half-life <1 d) to triclopyr acid in soil and water under aerobic and anaerobic conditions. As described in Section 5, this Draft Risk Assessment (DRA) examines the potential aquatic ecological risks associated with labeled uses of the ACID, TEA and COLN active ingredients of triclopyr (collectively assessed due to their similar fate and effects profiles) and the BEE active ingredient (assessed separately due to its different fate and effects profile). The ACID, TEA and COLN forms of triclopyr are highly water soluble (EFED solubility classes), highly mobile (FAO classification) and exhibit a low potential to bioaccumulate in aquatic food webs (KAPAM manual)[2]. The BEE form of triclopyr is much less soluble in water, is much more toxic to aquatic animals than the other active ingredients and has a potential to bioaccumulate given its higher octanol-water partition coefficient (log K_{ow}= 4.01). This bioaccumulation potential of BEE, however, is expected to be mitigated substantially by its aforementioned short persistence of the triclopyr BEE in the aquatic environment. The taxonomic focus of this assessment includes aquatic and terrestrial plants, bees, birds, terrestrial-phase amphibians, reptiles, mammals, and aquatic invertebrates.

1.2 Risk Conclusions Summary

Aquatic ecological risks were assessed for the ACID, TEA, COLN active ingredients based on two approaches: (1) Total Residue (TR) method to estimate exposure via all residues of concern

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[1] http://wssa.net/wp-content/uploads/WSSA-Mechanism-of-Action.pdf
[2] https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/kabam-version-10-users-guide-and-technical

(ROC) which assumes equal toxicity among the parent (triclopyr ACID) and degradates (TCP + 3,6-DCP + 5-CLP + 6-CLP degradates); and (2) the Formation/Decline method which considers the TCP-specific chemical properties and toxicity. For the triclopyr BEE active ingredient, the Formation/Decline method was used to estimate exposure as represented by triclopyr BEE, ACID and the TCP degradate. Registered uses that were assessed include rice, aquatic weed control, citrus, forestry, range/pasture land, meadows, rights-of-way, turf and Christmas trees.

This analysis indicates that acute and chronic risk levels of concern (LOCs) are exceeded for terrestrial and aquatic taxa as summarized in **Table 1-1** below. For the ACID/TEA/COLN active ingredients, the highest rates of application were generally responsible for acute risk LOC exceedances that did occur. The exception was for triclopyr BEE which is classified as highly toxic to aquatic organisms on an acute exposure basis.

1.2.1   Triclopyr ACID, TEA, COLN

For the triclopyr ACID, TEA and COLN, no acute or chronic risks are identified for aquatic animals for any of the proposed uses based on the ROC using the TR method. However, chronic risks to freshwater fish and invertebrates are indicated with the 2,500 ppb and 5,000 ppb aquatic weed control use based on the formation of TCP (determined by the F/D method). The TCP degradate is several orders of magnitude more chronically toxic compared to triclopyr ACID or TEA. For aquatic plants, no risk is identified for vascular plants based on the ROC or TCP degradate. However, risk to non-vascular plants is indicated for the maximum (5000 ppb) aquatic weed control use. Monitoring data indicate maximum detected levels of triclopyr ACID are several orders of magnitude below toxicity endpoints for the most sensitive tested species.

There are no acute risks of concern for birds and mammals from registered uses of triclopyr ACID/TEA/COLN for the rice and turf uses which have application rates of 0.375 and 1 lb a.e./A, respectively). For the forest/campground and range/pasture land/rights-of-way uses, acute risks of concern occur due to their higher application rates (6 and 9 lb a.e./A, respectively) compared to the rice and turf uses. There are chronic risks of concern for birds via foraging on at least one dietary item for all four use patterns assessed. For the turf, forestry/campground and pasture/rangeland uses, the dietary-based EECs exceed the avian lowest observed adverse effect concentration (LOAEC) of 200 mg a.e./kg-diet at which there was a 14% reduction in the number of 14-day old survivors. Similarly, chronic risks of concern for mammals are identified among all four use patterns. Chronic risks associated with the rice use are sensitive to the use of upper bound vs. mean Kenega exposure values. Furthermore, the large gap between the mammalian no observed adverse effect level (NOAEL) of 25 mg/kg-bw/d and the LOAEL (250 mg/kg-bw/d based on 28%-39% reductions in litter size) introduces additional uncertainty in the interpretation of chronic risks; except for forestry/campground and range/pasture land uses, whereby the EECs exceed the LOAEC.

For bees, the acute contact-based risk estimates are below the acute risk LOC of 0.4 for all of the registered uses of triclopyr ACID/TEA/COLN active ingredients. However, acute oral exposure to adult forager bees estimated with the forestry/campground and pasture/rangeland

uses exceeds the highest concentration tested in the acute oral toxicity test which failed to produce an LD_{50} due to lack of mortality. Therefore, acute oral risk to adult honey bees is considered uncertain for these uses due to the non-definitive toxicity values. Notably, chronic risks of concern to adult and larval bees are indicated for all triclopyr ACID/TEA/COLN use patterns; notably however, these are based on default estimates of residues in pollen and nectar and could not be refined due to lack of measured residue data and/or colony-level toxicity studies.

Risks to terrestrial plants are identified from aerial spray applications of triclopyr ACID, TEA, or COLN across all of the use patterns assessed. Due to the lack of a definitive toxicity endpoint from the seedling emergence study with TEA, risks associated with applications to dry and semi-aquatic areas could not be assessed. Numerous ecological incidents associated with terrestrial plants have been reported in association with the use of triclopyr active ingredients.

1.2.2 Triclopyr BEE

On an acute exposure basis, triclopyr BEE is consistently 2 to 3 orders of magnitude more toxic to aquatic animals compared to triclopyr ACID or TEA, with LC_{50} values ranging from 0.35 to 0.46 mg a.i./L. The chronic toxicity of triclopyr BEE is also several orders of magnitude greater than triclopyr ACID or TEA. However, triclopyr BEE is much less persistent than triclopyr ACID due to its rapid transformation to triclopyr ACID and results in lower aquatic EECs.

For aquatic animals, there acute risk concerns are indicated for freshwater and estuarine/marine fish with the assessed uses of triclopyr BEE when considering the parent (BEE) active ingredient but no chronic risk concerns are evident. For aquatic invertebrates, there are acute and chronic risks of concern for the range/pasture land and meadow uses which have the highest application rates of 6 and 9 lb a.i./A, respectively. Chronic risk concerns to estuarine/marine invertebrates are indicted for uses on citrus, range/pasture land, and meadows. There are no risks of concern for sediment-dwelling invertebrates exposed to triclopyr BEE via pore water. Risks to vascular aquatic plants is not indicated for triclopyr BEE, but risks to non-vascular plants are identified for citrus, range/pasture land, and meadows. Formation of triclopyr ACID or TCP from triclopyr BEE did not result in any acute or chronic risk concerns to aquatic organisms.

There are acute risks of concern for birds among all modeled use patterns due to the greater acute toxicity of triclopyr BEE to birds compared to ACID/TEA. Chronic risks to birds could not be assessed due to lack of data for triclopyr BEE. Chronic risks to mammals are indicated for all assessed uses for multiple size classes and dietary items. In most cases, these risks estimates are not sensitive to the use of mean vs. upper-bound Kenega residue values.

There are no acute risks of concern for bees since triclopyr BEE is practically non-toxic to bees on an acute contact basis. No other bee toxicity data were submitted for triclopyr BEE. However, the triclopyr BEE is expected to degrade relatively quickly to the ACID form based on submitted environmental fate data. Therefore, since there are chronic risks of concern for both

adult and larval bees from the ACID, these risks would presumably extend to BEE which is serving as a source of the ACID.

The assessed uses of BEE present risks to terrestrial monocotyledonous (monocot) and dicotyledonous (dicot) plants involving multiple use areas from both ground and aerial applications. Reported ecological incidents for triclopyr BEE involving terrestrial plants represent a line of evidence supporting the risk findings for terrestrial plants.

Table 1-1. Summary of Risk Quotients (RQ for Taxonomic Groups from Current Uses of Triclopyr acid equivalents and Triclopyr BEE

Taxa	Exposure Duration	Risk Quotient (RQ) Range[2]	RQ Exceeding the LOC for Non-listed Species	Additional Information/ Lines of Evidence
Triclopyr Acid, TEA and Choline Salt (Including TCP degradate)				
Freshwater Fish	Acute	<0.01 - 0.05	No	–
	Chronic	< 0.01 – 1.8	**Yes** (TCP)	Exceeded only for the maximum aquatic use rate with the TCP degradate
Freshwater Invertebrates	Acute	<0.01 - 0.04	No	--
	Chronic	<0.01 – 6.0	**Yes** (TCP)	Exceeded for only maximum and middle rate aquatic use with the TCP degradate
Estuarine/ marine fish	Acute	< 0.01 - 0.04	No	--
	Chronic	Not calculated (no data)		
Estuarine/ Marine invertebrates	Acute	<0.01 - 0.12	No	--
	Chronic	<0.01 - 0.75	No	Acute to chronic ratio used
Aquatic Plants	Vascular	<0.01 - 0.79	No	--
	Non-vascular	<0.01 – 1.2	**Yes** (ROC)	Exceeded only for maximum aquatic use rate only with ROC
Birds	Acute	<0.01 - 2.8	**Yes**	Exceeded for forestry, campground, recreational area, range and pasture land, and rights of way uses (dose-based RQs; application rates 6.0 - 9.0 lbs a.i/A)
	Chronic	0.09 - 22	**Yes**	LOC exceeded for all use patterns; based on 14% reduction in number 14-day old survivors.
Mammals	Acute	<0.01 - 1.5	**Yes**	Exceeded for forestry, campground, recreational area, range and pasture land, and rights of way uses (application rates 6.0 - 9.0 lbs a.i/A)
	Chronic	0.2 - 37	**Yes**	Exceeded for all use patterns; based on 28%-39%reduction in litter size (dose and dietary based RQs)
Terrestrial Invertebrates[3]	Adult Acute Contact	<0.1 - <0.24	No	Non-definitive LD$_{50}$ (> 100 µg a.e./bee)

Taxa	Exposure Duration	Risk Quotient (RQ) Range[2]	RQ Exceeding the LOC for Non-listed Species	Additional Information/ Lines of Evidence
(Honey bee)	Adult Acute Oral	<0.32 - <2.9	**Uncertain**	Non-definitive LD$_{50}$ (> 99 µg a.e./bee). EECs for forestry and rangeland uses exceed highest dose tested
	Adult Chronic Oral	2.3 - 20	**Yes**	Exceeded for all registered uses (rice not attractive); based on 35% reduction in adult survival.
	Acute Larval	Not calculated (no data)		
	Chronic Larval	22 - 211	**Yes**	Exceeded for all uses (rice not attractive), based on 10% reduction in emergence and 13% reduction in mortality.
Terrestrial Plants	Monocots	Not calculated	N/A	Non-definitive endpoints for monocots. For dicots, exceedances for all uses except rice; majority of incidents with Triclopyr products have been non-target plant damage incidents from spray drift
	Dicots	<0.01 - 83	**Yes**	
Triclopyr BEE (Including TCP Degradate)				
Freshwater Fish	Acute	<0.01 - 0.74	**Yes** (BEE)	Exceedances for range/pasture land and meadow uses only with triclopyr BEE (9.0 lbs a.i/A).
	Chronic	<0.01 - 0.38	No	--
Freshwater Invertebrates	Acute	<0.01 - 0.76	**Yes** (BEE)	Exceedances for range/pasture land and meadow uses only with triclopyr BEE (9.0 lbs a.i/A)
	Chronic	<0.01 - 0.16	No	--
Estuarine/Marine Fish	Acute	<0.01 - 0.59	**Yes** (BEE)	Exceedances for range and pasture land uses only for triclopyr BEE (9.0 lbs a.i/A)
	Chronic	<0.01 - 0.54	No	--
Estuarine/Marine Invertebrates (Water Column)	Acute	<0.01 - 0.58	**Yes** (BEE)	Exceedances for range/pasture land and meadow uses only with triclopyr BEE (9.0 lbs a.i/A).
	Chronic	<0.01 - 2.6	**Yes** (BEE)	Exceedances for citrus, range/pasture land, and meadow uses with BEE (LOAEC = 16% reduction in weight).
Freshwater Invertebrates (Sediment)	Acute	<0.01 - <0.01	No	Pore water EECs compared to water column endpoints
	Chronic	<0.01 - <0.29	No	
Estuarine/Marine Invertebrates (Sediment)	Acute	<0.01 - <0.01	No	Pore water EECs compared to water column endpoints
	Chronic	<0.01 - 0.04	No	
Aquatic Plants	Vascular	0.01 - 0.30	No	--

Taxa	Exposure Duration	Risk Quotient (RQ) Range[2]	RQ Exceeding the LOC for Non-listed Species	Additional Information/ Lines of Evidence
	Non-vascular	0.1 - 2.7	**Yes** (BEE)	Exceedances for citrus, range/pasture land and meadow uses for BEE; based on reduction in cell counts.
Birds	Acute	<0.01 - 4.6	**Yes**	Exceedances for turf, forestry, campground, recreational area, range/pasture lands, and rights-of way uses (application rates of 1 - 9 lbs a.i/A)
	Chronic	Not calculated (no data)		
Mammals	Acute	<0.01 - 1.2	**Yes**	Exceedances for forestry, campground, recreational area, range/pasture lands, and rights-of way uses (application rates of 6 - 9 lbs a.i/A)
	Chronic	0.3 - 18	**Yes**	Exceeded for all registered uses; endpoint based on reduction in body weight
Terrestrial Plants	Monocot	0.14 - 18	**Yes**	Exceedances for all use patterns
	Dicots	0.32 - 51	**Yes**	Exceedances for all use patterns

Level of Concern (LOC) Definitions: Terrestrial Animals: Acute risk LOC=0.5; Chronic risk LOC=1.0; Terrestrial Invertebrates: Acute risk LOC=0.4; Chronic risk LOC=1.0; Aquatic Animals: Acute=0.5; Chronic=1.0; Terrestrial and Aquatic Plants: LOC=1.0

[1] Based on water-column toxicity data compared to pore-water concentration.

[2] For Triclopyr ACID, TEA, COLN active ingredients, RQ ranges reflect Triclopyr acid residues of concern (ROC) and the TCP degradate. For Triclopyr BEE, RQ ranges reflect parent BEE and the TCP degradate. Estimated exposure concentrations are based on the maximum application rates allowed on labels.

[3] RQs for terrestrial invertebrates are applicable to honey bees, which are also a surrogate for other species of bees. Risks to other terrestrial invertebrates (*e.g.,* earthworms, beneficial arthropods) are only characterized when toxicity data are available.

1.3   Environmental Fate and Exposure Summary

The environmental fate and transport data needed for this ecological risk assessment of the four forms of triclopyr (the ACID, TEA, COLN and BEE) and their major degradates are complete except for water[3] and sediment/soil environmental chemistry methods (ECMs) and associated independent laboratory validation ((ILVs).

In comparing the four forms of triclopyr active ingredients, the most persistent form is the ACID which is applied as ACID or result from rapid dissociation of TEA, COLN and BEE forms of triclopyr. The primary routes of surface water exposure to the triclopyr acid are run-off and

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[3] Submitted Environmental chemistry method (ECM) for triclopyr and its major degradate 3,5,6-Trichloro and 2-Pyridinol (TCP) in water by gas chromatography (MRID No. 417143-08) was independently evaluated by EPA BEAD/ACB/Environmental Chemistry Section. The method provided satisfactory measurement for the residues of triclopyr with a limit of detection/limit of quantification (LOD/LOQ) of 10/50 for triclopyr and 50/150 ppb for 3,5,6-Trichloro-2-pyridinol. The respective LOQ is currently near/higher the lowest toxicological level of concern determined for TCP/BEE respectively. Therefore, the method is reclassified at this time as un-acceptable and a new method is requested.

spray drift while that for ground water is leaching to vulnerable shallow ground water (the chemical is classified as mobile). All forms of triclopyr are semi to non-volatile; although BEE has a log K_{ow} of 4.01, none of the actives are expected to bioconcentrate in aquatic animals such as fish. Triclopyr acid is highly vulnerable to abiotic photolysis ($t_{1/2}$ <1 d) and non-persistent in the aerobic soil/aquatic systems. In contrast, the chemical is moderately persistent in anaerobic soil/aquatic conditions and is stable to hydrolysis and soil photolysis (refer to Section 5).

The major degradates of triclopyr acid are TCP and 3,6 DCP and both are exposure concerns. Additionally, the degradates 5-CLP and 6-CLP could also be of exposure concerns as they are expected to form in major amounts in some aerobic aquatic systems (refer to **Section 5**). Exposure modeling was conservatively executed considering the maximum label rates and minimum application intervals.

1.4   Ecological Effects Summary

1.4.1   Aquatic Toxicity

Acute toxicity data for aquatic animals generally indicate that triclopyr ACID and TEA are practically non-toxic to fish and invertebrates, while triclopyr BEE is moderately to highly toxic to these same taxa on an acute exposure basis (**Table 6-1**). Specifically, triclopyr BEE median lethal concentrations for 50% of the organisms tested (LC_{50} values) are consistently 2 to 3 orders of magnitude lower (*i.e.*, more sensitive) for aquatic animals compared to triclopyr ACID or TEA. The TCP degradate is classified as slightly toxic on an acute exposure basis to fish and aquatic invertebrates, except for the Eastern oyster (*Crassostrea virginica*), where it is classified as moderately toxic.

The chronic toxicity of triclopyr ACID and TEA to freshwater fish and invertebrates is relatively similar to acute toxicity values and range from 24 to 74 mg a.i./L. In contrast, the chronic toxicity of triclopyr BEE to freshwater fish and invertebrates tends is much greater than the ACID or TEA active ingredients. Chronic NOAECs for triclopyr BEE range from 0.011 mg ai/L for the estuarine/marine mysid shrimp (*Americamysis bahia*) to 0.17 mg ai/L for the freshwater invertebrate waterflea (*Daphnia magna*). The chronic toxicity of TCP, a major degradate of the four triclopyr active ingredients is similar to that of triclopyr BEE, with the lowest NOAEC occurring at 0.058 mg a.i./L for *D. magna*.

With respect to aquatic plants, triclopyr both ACID and TEA are toxic between 4.2 and 6.3 mg a.e./L whereas, triclopyr BEE is toxic about an order of magnitude lower (0.1 to 0.88 mg ai/L). The toxicity of the TCP degradate falls within the range to aquatic plant toxicity values for the ACID and BEE (2 – 8 mg ai/L).

No acute or chronic toxicity data are available for triclopyr COLN, but it is expected to exhibit similar toxicity as triclopyr ACID and TEA due to its rapid dissociation to the acid form. Similarly,

no aquatic toxicity data are available for the other major degradates of triclopyr active ingredients (3,6 DCP; 5-CLP; 6-CLP). Further characterization of the potential toxicity of these degradates is provided later in the document using the Ecological Structure Activity Relationships (ECOSAR) model.

1.4.2   Terrestrial Toxicity

Similar to that observed with aquatic animals, the ACID and COLN are slightly to practically non-toxic to birds and mammals on an acute exposure basis (**Table 6-2**). This acute toxicity pertains to both dose and dietary-based exposures. Triclopyr BEE showed the lowest acute oral LD_{50} for birds (735 mg/kg-bw) which renders it as slightly toxic to avian species on an acute exposure basis. With mammals, triclopyr BEE, TEA and ACID are all classified as slightly toxic on an acute oral exposure basis. Triclopyr BEE and the TCP degradate were of similar acute toxicity as the ACID and TEA and are also classified as slightly toxic on an acute exposure basis.

Chronic avian toxicity data are only available for triclopyr ACID based on a single species, i.e., mallard duck (*Anas platyrhynchus*). This study indicates a NOAEC of 100 mg a.e./kg-diet based on 14-day old survivors. Although chronic toxicity data are not available for BEE, the compound degrades quickly to the ACID ($t_{½}$< 1 day). For mammals, a 2-generation reproduction study with ACID produced a NOAEL of 25 mg/kg-bw/d (LOAEL = 250 mg/kg-bw/d) based on reproductive and body weight effects, including a 28%-39% reduction in litter size. The 10-fold difference between the NOAEL and LOAEL introduces uncertainty in the interpretation of potential effects from exposures above the NOAEC.

With the honey bee (*Apis mellifera*), triclopyr ACID and BEE are both practically non-toxic on an acute contact basis (**Table 6-2**). Acute oral toxicity information is only available for triclopyr ACID, where it also is classified as practically non-toxic. On a chronic exposure basis, adult bees were less sensitive (NOAEL = 22 μg ai/bee/d) compared to larvae (0.58 μg ai/bee/d). No toxicity data were submitted on the acute toxicity to honey bee larvae.

As expected, the triclopyr herbicides are toxic to terrestrial plants. The 25% effect concentration (IC_{25}) value of triclopyr ACID (0.0054 lb a.e./A) is 3 orders of magnitude lower than the maximum single application rate of 9 lb a.e./A. The most sensitive dicot species is about 10 times more sensitive compared to monocots based on the vegetative vigor study with BEE. However, the most sensitive dicot and monocots are of similar sensitivity based on seedling emergence with triclopyr BEE.

1.5   Identification of Data Needs

Currently, nearly all ecological effects data requested in the 2014 Problem Formulation have been submitted, evaluated and found acceptable, with the exception of the following three studies:
- avian acute oral toxicity study with a passerine bird (OCSPP 850.2100);

- acute study with larval honey bees with triclopyr ACID (OECD test guideline No 237); and,
- chronic avian reproduction study with triclopyr BEE (OCSPP 850.2300).

2 Introduction

This Draft Risk Assessment (DRA) examines the potential ecological risks associated with labeled uses of triclopyr acid (ACID), triclopyr choline salt (COLN), triclopyr triethylamine salt (TEA) and triclopyr butoxyethyl ester (BEE) active ingredients on non-target organisms not listed under the Endangered Species Act. Federally listed threatened/endangered species ("listed") are not evaluated in this document. For additional information on listed species see **Appendix G**.

The Food Quality Protection Act (FQPA) requires EPA to screen pesticide chemicals for their potential to produce effects similar to those produced by estrogen in humans and gives EPA the authority to screen certain other chemicals and to include other endocrine effects. In response, EPA developed the Endocrine Disruptor Screening Program (EDSP). Additional information on the EDSP is available in **Appendix F.**

The DRA uses the best available scientific information on the use, environmental fate and transport, and ecological effects of all triclopyr active ingredients. The general risk assessment methodology is described in the *Overview of the Ecological Risk Assessment Process in the Office of Pesticide Programs* ("Overview Document," USEPA, 2004a). Additionally, the process is consistent with other guidance produced by the Environmental Fate and Effects Division (EFED) as appropriate. When necessary, risks identified through standard risk assessment methods are further refined using available models and data. This risk assessment incorporates the available exposure and effects data and most current modeling and methodologies.

3 Problem Formulation Update

The purpose of problem formulation is to provide the foundation for the environmental fate and ecological risk assessment being conducted for the labeled uses of triclopyr ACID, TEA, COLN and BEE active ingredients. The problem formulation identifies the objectives for the risk assessment and provides a plan for analyzing the data and characterizing the risk. As part of the Registration Review (RR) process, a detailed preliminary Problem Formulation for this DRA was published to the docket in November 13, 2014 (DP Barcode 417819)[4]. As summarized in the 2014 preliminary Problem Formulation document, prior ecological risk assessments identified potential risks to birds, mammals, terrestrial plants and aquatic plants from the triclopyr ACID, TEA, COLN and BEE active ingredients. In addition, potential risks to fish and aquatic invertebrates were indicated with the BEE active ingredient.

As a result of the preliminary Problem Formulation, several data gaps were identified, and additional data were requested of the registrant. The following ecological effects and

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[4] Registration Review; Preliminary Problem Formulation for Environmental Fate, Ecological Risk, Endangered Species, and Human Health Drinking Water Exposure Assessments for Triclopyr [Triclopyr Acid (PC Code 116001), Triclopyr Triethylamine Salt (PC Code 116002), and Triclopyr Butoxyethyl Ester (PC Code 116004). DP Barcode 417819 dated November 13, 2014.

environmental fate studies were submitted in support of the RR process for the triclopyr active ingredients since the time of the preliminary Problem Formulation.

Ecotoxicity Data:

(1) Daphnid Chronic Toxicity Test of triclopyr BEE (MRID 49992406);
(2) Fish Early Lifestage Toxicity Test of triclopyr degradate TCP using Rainbow Trout (MRID 49992407);
(3) Chronic lifecycle toxicity of triclopyr BEE using mysid shrimp (MRID 50673901);
(4) Honey Bee Adult Acute Oral Toxicity Test of triclopyr ACID (MRID 49992409);
(5) Honey Bee Larvae Chronic (repeat dose) Toxicity Test of triclopyr ACID (MRID 50673902); and,
(6) Honey Bee Adult Chronic (repeat dose) Toxicity Test of triclopyr ACID (MRID 50673903).

These new ecological effects data are described in more detail in the aquatic and terrestrial effects characterization sections of this document (**Sections 8.2 and 10.2,** respectively**)**.

Fate and Chemistry Data:

(1) Photodegradation in Water using triclopyr ACID (MRID 49992401);
(2) Aerobic Soil Metabolism using triclopyr degradate TCP in four soils (MRID 499924-02);
(3) Anaerobic Soil Metabolism using triclopyr ACID in four soils (MRID 49992403);
(4) Aerobic Soil Metabolism using triclopyr BEE in two soils (MRID 47293801);
(5) Aerobic Aquatic Metabolism using triclopyr BEE in two systems (MRID 49992404);
(6) Anaerobic Aquatic Metabolism using triclopyr BEE in two systems (MRID 00151967);
(7) Uptake, metabolism, and depuration of triclopyr BEE in Coho Salmon (*Oncorhynchus kisutch*; MRID 49992408); and
(8) Environmental chemistry methods (ECMs) and associated independent laboratory validation (ILVs) for water and sediment (MRIDs: 44456105, 44456106, 44456109, 44456110 and 44456111).

These new fate and transport data are described in more detail in the environmental fate **Section 5**.

3.1   Mode of Action for Target Pests

According to the Weed Science Society of America (WSSA) triclopyr herbicides are part of Group 4 (synthetic auxins) Auxins, a natural plant hormone, is responsible for cell elongation and growth. At low concentrations, triclopyr herbicides cause uncontrolled cell division and growth resulting in vascular tissue destruction. At higher concentrations, the herbicides can inhibit cell division and growth, usually in the meristematic regions of the plant.[5] Triclopyr is a selective/systemic broadleaf herbicide that enters plants through their leaves, woody stems, cut surfaces in addition to hydrosol roots of aquatic plants.

3.2   Label and Use Characterization

3.2.1   Label Summary

The Biological and Economic Assessment Division (BEAD) prepared a Pesticide Label Use Summary (PLUS) Report summarizing registered uses of Triclopyr active ingredients based on a selection of actively registered labels in March 29, 2018[6]. The PLUS report was used as the source to summarize representative uses for this DRA. Additionally, most labels were consulted to complement the PLUS report.

The triclopyr active ingredients are found in one of the following forms:

- **ACID:** 3,5,6-trichloro-2-pyridinyloxyacetic acid;
- **BEE:** 3,5,6-trichloro-2-pyridinyloxyacetic acid, butoxyethyl ester;
- **TEA:** 3,5,6-trichloro-2-pyridinyloxyacetic acid, triethylamine salt; or,
- **COLN:** 2-[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid, choline salt.

However, many formulations contain one or more herbicide actives mixed with either, **BEE**, or **TEA** forms of triclopyr:

- Three formulations with BEE: 2,4-dichlorophenoxyacetic acid; fertilizer; and fluroxypyr; and

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[5] http://wssa.net/wp-content/uploads/WSSA-Mechanism-of-Action.pdf
[6] Triclopyr (116001) Pesticide Label Use Summary (PLUS) Reports in Support of Registration Review Draft Risk Assessment (DRA) dated March 29, 2018; Triclopyr Choline Salt (116000) Pesticide Label Use Summary (PLUS) Reports in Support of Registration Review Draft Risk Assessment (DRA) date April 5, 2018; Triclopyr butoxyethyl ester (116004) Pesticide Label Use Summary (PLUS) Reports in Support of Registration Review Draft Risk Assessment (DRA) dated April 10, 2018; and Triclopyr triethylamine salt (116002) Pesticide Label Use Summary (PLUS) Reports in Support of Registration Review Draft Risk Assessment (DRA) dated April 11, 2018

Six formulation with TEA: clopyralid; 2,4-D, diethanolamine salt; (2,4-D, diethanolamine salt + dicamba, dimethylamine salt); (penoxsulam + sulfentrazone + quinclorac); (penoxsulam + quinclorac); and (clopyralid + fertilizer).

General Use Patterns

Nearly 80 active labels for representative triclopyr products were analyzed by BEAD for use in this analysis: 36 Section 3 (New Use); and, 43 Section 24c (Special Local Needs; SLN) labels. Most of the products are formulated as liquid concentrates (pressurized, soluble concentrate "SC", emulsifiable concentrate "EC", or flowable "Flowable") followed by dry products (granular "G" and water dispersible granules "WDG"), and ready to use solutions "RTU". Except for the granular products, all other formulations are applied as liquid spray using ground and/or aerial equipment. Two of the granular products contain fertilizers + **TEA** and fertilizers + **BEE** and are used as ground applications to turf for selective control of annual and perennial weeds and fertilization. The rest of the granular formulations are **TEA** products formulated for ground or aerial applications to aquatic areas.

The pesticide is used for the following purposes:

(1) To control annual and perennial broadleaf weeds, woody & herbaceous plant species, brushes, and vines in forestry, grassland, premises, range/pastureland, rice, turf and Christmas trees; and, for control of similar plant species in and around standing water sites (such as marshes, wetlands, and the banks of ponds and lakes);
(2) To control re-sprouts from cut stumps in Florida citrus groves; and, for controlling re-sprouts from cut stumps in forestry and in California orchards (after tree removal to hasten death of root system); and,
(3) To control floating/immersed/submersed aquatic plants in surface water bodies such as ponds, lakes, reservoirs, marshes, wetlands, and non-irrigation canals and ditches which have little or no continuous outflow.

Triclopyr **ACID/BEE/TEA/COLN** are labelled for use in many sites targeting unwanted terrestrial and aquatic weeds, woody plants and shrubs. A qualitative description of these use patterns, application sites and target plants are included in **Table 3-1**.

Table 3-1. Summary of Triclopyr Herbicide[1] Use Patterns, Application Sites Types/target(s) & Equipment.

Use Patterns	Application Sites	Application Type/Target
Aquatic sites	Lentic/Lotic water bodies in the terrestrial landscape	Broadcast/Aquatic plants & water
Citrus (Florida)	Citrus groves	Directed Spray/Cut stem

Use Patterns	Application Sites	Application Type/Target
Forestry	Coniferous/Evergreen/Softwood tree plantations; Woodland/Nature Areas (open space such as campgrounds, parks, prairie management, trails and trailheads, recreation areas; Animal habitat/ establishment and maintenance Wildlife openings	- Broadcast/foliage for control of weeds and susceptible (easy to control) woody plants and shrubs; and - Directed basal bark treatment, brush or injection/weeds, foliage, stump, bark, cut stem for woody plants
Non-crop areas	Non-crop land; Industrial areas; Non-irrigation ditch banks; Storage sites; Airports, Barrow/road side ditches; s; Fence/hedge rows; Gravel pits; Military lands; Mining and drilling areas; Oil and gas pads; Parking lots; Petroleum tank farms; Storm water retention areas; Farmstead; Substations, Unimproved rough turf grasses; vacant lots; Standing water sites such as marshes, wetlands, and the banks of ponds and lakes; Ditch banks; Seasonally dry wetlands, flood plains, deltas, marshes, swamps, bogs, and transitional areas between upland and lowland sites	- Broadcast/Foliage for weed control; and - Like forestry in case of the presence of unwanted woody plant and shrubs
Orchards (California)	Orchards	Directed Spray/Cut stem
Premises	Around farm/residential buildings; Cabins; Walkways	- Broadcast/Foliage for weed control; and - Like forestry in case of the presence of unwanted woody plant and shrubs
Range/Grass/Pastureland	Range/Permanent/ Perennial grass pastures; grasses grown for hay; Conservation Reserve Program (CRP) sites	
Rice	Pre/post-flood Rice fields	Broadcast/Foliage
Right-of-Way	Electrical power and utility; Communication/transmission lines or structures; oil and gas pipelines; Roadsides; Railroad	- Broadcast/Foliage for weed control; and - Like forestry in case of the presence of unwanted woody plant and shrubs
Turf	Residential, Commercial, and Recreational Turf; Golf course, excluding greens; Sod farms	
Christmas Trees	Christmas tree plantations	

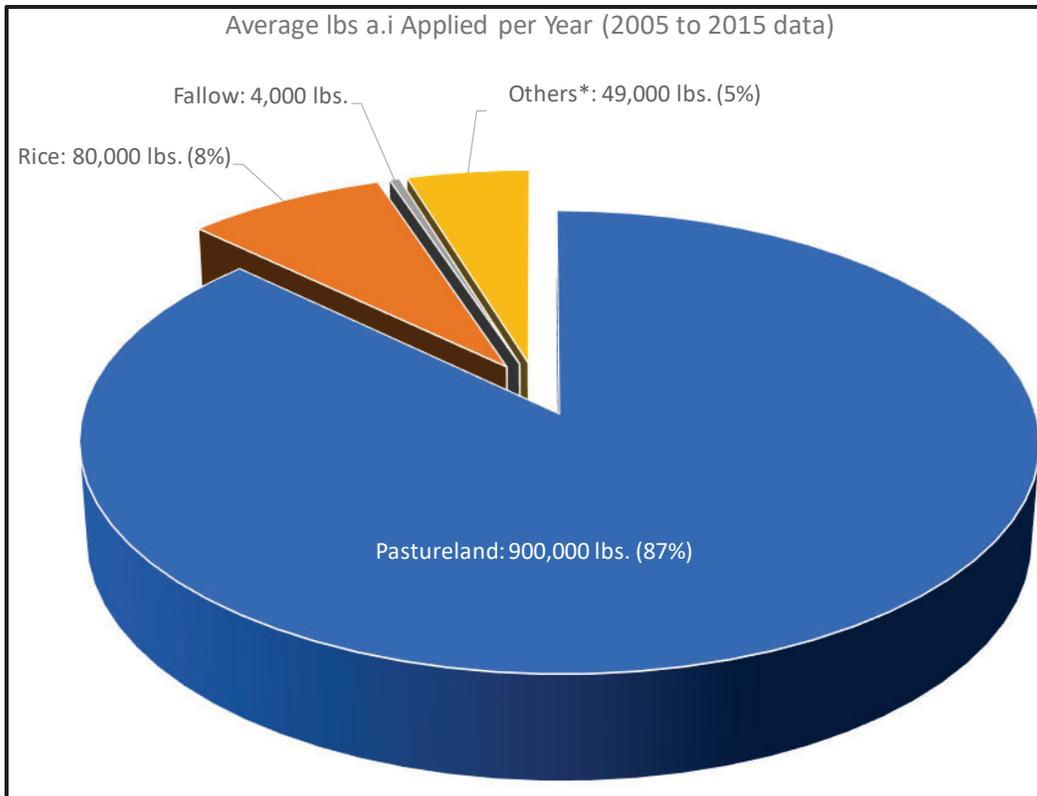[1]Triclopyr herbicide active ingredients include: 3,5,6-trichloro-2-pyridinyloxyacetic acid; 3,5,6-trichloro-2-pyridinyloxyacetic acid, butoxyethyl ester; 3,5,6-trichloro-2-pyridinyloxyacetic acid, triethylamine salt; and, 2-[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid, choline salt.

Several application methods are specified for applying triclopyr active ingredients depending on the formulation, target, and type of equipment. For liquid formulations and WDGs, a tank mix is prepared with an agriculturally labeled non-ionic surfactant and/or other herbicide, and the liquid is sprayed onto the plants to be controlled or onto aquatic weeds present on/in water (**Figure 3-1**). For granular formulations, granules are broadcasted onto wet conditions (following rainfall or pre-treatment irrigation) turf in case of two formulations and onto aquatic weeds present on the water surface and those present in the subsurface.

Figure 3-1. Broadcast Spray Treatment for Aquatic Weeds (source: label)

Other types of applications include:

(1) **Broadcast application:** This method may be made using ground (backpack or truck-mounted pressure sprayers) or aerial equipment (helicopter). Broadcast applications are used for control of weeds and specified woody plants in most labelled use areas by uniform spray targeting plant foliage. Ground equipment is used for spraying individual brushy plants, woody plants and vines or spot treatment of weeds (**Figure 3-2**).

Brush, Woody Plants and Vine Control   **Spot Treatment for Weed Control**

Figure 3-2. Broadcast Application for Control of Woody Plants and Spot Treatment of Weeds (source: label)

(2) **Basal Bark treatment:** The method is used to control susceptible woody plants with stems <6" inches in basal diameter. This treatment uses low pressure knapsack or power sprayers to spray the basal parts of brush and tree trunks to a height of 12 to 15 inches from the ground. Thorough wetting of the indicated area is necessary for good control (**Figure 3-3a**).

(3) **Stump treatment:** The method is used in forestry, citrus and orchards for freshly cut tree stumps with undiluted liquid formulation by spraying/painting the cut surface especially the cambium area next to the bark. The purpose is to prevent regrowth of the tree (**Figure 3-3b**).

(a) Basal Bark Treatment	**(b) Stump Treatment**

Figure 3-3. Basal Bark and Stump Treatments of Woody Plants (source: label)

(4) **Tree injection treatment:** The method is used to control unwanted trees by injecting the tree trunk through the bark with undiluted liquid formulation; injections (3 to 4" apart) are to surround the tree at any convenient height.

(5) **Hack and squirt treatment:** The method is used to control unwanted trees by making slightly overlapped cuts around the tree trunk with a hatchet. Cuts are to form a circle around the trunk to fill (using a squirt bottle) with undiluted or 1:1 diluted liquid formulation.

(6) **Frill or girdle treatment:** The method is used to control unwanted trees by making a single gridle through the bark completely around the tree. Diluted or undiluted liquid formulation is applied to frill which hold it to be absorbed into the plant.

Other application parameters were extracted from the BEAD PLUS report along with examination of the labels to clarify the data, identify missing use information, and suggest needed clarifications. It is noted that most of the labels specify the required information including the maximum annual rates for each type of application. These data are summarized in **Table 3-2**.

Label Restrictions

Common use restrictions were identified from various triclopyr labels including:

(1)   Specific restrictions for application near drinking water intakes;
(2)   Requirement that permits be obtained for direct application to water;
(3)   Restrictions specific to application via surface irrigation waters, including:
   a.   Waiting for a period of 4 months (or a season) before use;
   b.   Levels of triclopyr are determined to be ≤1 ppb;
(4)   A 20-day holding period for water in rice paddies; and,
(5)   Lower than maximum application rates (*e.g.*, 2 lbs. acid equivalents (a.e)/A/year) in sites where grazing and haying is allowed.

Application Rates

Other application parameters were extracted from the BEAD PLUS report along with examination of the labels to clarify the data, identify missing information and suggest possible improvements in label language. It is noted that most of the labels specify the required information including the maximum annual rates for each type of application. These data are summarized in **Table 3-2.**

Table 3-2. Summary of Application Parameters for Triclopyr Active Ingredient Use (All Rates Are Maximum Use Rates in Acid Equivalent "a.e")

Use Pattern (Active Ingredient(s))	Application Equipment and Timing		Application Parameters[1]			
	Equip.	Timing	MSR (lb a.e./A)	No.	MYR (lb a.e./A)	MI
Aquatic Sites [2] (ACID, TEA, COLN): • Applied near drinking water intakes @ 400 ppb • Applied @ 2,500 ppb • Applied @ 5,000 ppb	A/G	Determined solely by pest pressure	Calculated by equation present in the label	1	Same as MSR	N/A
Citrus-FL (BEE)	G	When required for stump treatment of removed trees	6	1	6	N/A
Forestry (ALL)	A/G	Specified for certain woody plants and shrubs. Generally, timing of active growth (Not to be used in AZ)	6	1	6	N/A
Non-crop areas (ALL)	A/G	Dependent on weed pressure	9	1	9	N/A
Orchards-CA (TEA)	G	When required for stump treatment of removed trees	6	1	6	N/A
Premises (ALL)	A/G	Determined solely by pest pressure	9	1	9	N/A
Range/Grass/Pastureland (ALL)	A/G	PHI for Hay 14-d	9	1	9	N/A
Rice (ACID; TEA)	A/G	Pre- plant/flood; Post- flood; Before booting	0.375	2	0.75	20
Right-of-Way (ALL)		Determined solely by pest pressure	9	1	9	N/A
Turf (ACID, BEE, TEA)	A/G	Early spring through fall	1	4	4	28
X-mas Trees (ACID, BEE, TEA)	G	late summer or early autumn after terminal growth has hardened of, before leaf drop	6	1	6	N/A

[1]**Application Parameters: MSR=** Maximum single rate (lbs. a.e/A); **NO.=** Number of applications**; MYR=** Maximum yearly rate (lbs. a.e/A/Y); **MI=** Minimum intervals in days; **a.e=** Acid equivalent; N/A= Not applicable; **Equipment**: A= aerial, G= Ground.

[2]*Application to Aquatic Sites:* One of the labels permits dividing the rate into three applications 8 hours apart

Use Pattern (Active Ingredient(s))	Application Equipment and Timing		Application Parameters[1]			
	Equip.	Timing	MSR (lb a.e./A)	No.	MYR (lb a.e./A)	MI

[3]Triclopyr herbicide active ingredients include: 3,5,6-trichloro-2-pyridinyloxyacetic acid (**ACID**); 3,5,6-trichloro-2-pyridinyloxyacetic acid, butoxyethyl ester (**BEE**); 3,5,6-trichloro-2-pyridinyloxyacetic acid, triethylamine salt (**TEA**); and, 2-[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid, choline salt (**COLN**); all actives combined (**ALL**).

Maximum rates presented in **Table 3-2** are based on statements specifying the maximum annual application rate for each use. For comparative purposes, application rates were adjusted to acid equivalents (*i.e.,* lb a.e. of triclopyr acid). Triclopyr labels allows for spot and/or individual tree treatment with rates within the maximum rates specified for the use patterns in **Table 3-2**. Most of these rates are expected to be much lower in case of small size, high susceptibility, younger actively growing, and low frequency of target plants present in areas to be treated within an acre. For this purpose, labels specify that the total rate for these types of treatments in an acre may not exceed the maximum rates. Additionally, it is noted that some labels give lower rates than the maximums presented in **Table** 3-2 (*e.g.*, 8 lbs. a.e/A/Y instead of 9 lbs. a.e/Y). Lower rates of triclopyr were also identified for formulations containing other herbicide(s).

3.2.2   Usage Summary

Agricultural Uses

BEAD provided a Screening Level Usage Analysis (SLUA; available in docket: EPA-HQ-OPP-2014-0576; https://www.regulations.gov/document?D=EPA-HQ-OPP-2014-0576-0006), summarizing usage data for triclopyr products including the ACID, BEE, TEA and COLN. The data indicate that the highest usage is in pasture land and rice and that the percent of crop treated is 25% for rice. **Figure 3-4** depicts 2005 – 2015 triclopyr usage data reported by BEAD.

Average lbs a.i Applied per Year (2005 to 2015 data)

Fallow: 4,000 lbs.

Others*: 49,000 lbs. (5%)

Rice: 80,000 lbs. (8%)

Pastureland: 900,000 lbs. (87%)

* Others: include crops that are not currently registered noting that data do not include a major use: forestry

Figure 3-4. Average lbs. of Triclopyr Products applied (2005 to 2015 data)

Non-Agricultural Uses

Since usage data for non-agricultural use patterns are typically scarce, there is uncertainty regarding the scale and magnitude of non-crop uses for triclopyr active ingredients. This usage could be substantial as illustrated by nationwide estimates for rights-of-way and commercial turf operations as discussed below.

Use for vegetation control along transportation rights-of-way could potentially expose thousands of miles of roadways. Currently over 46,000 miles of interstate, 112,000 miles of national highway systems and 3,760,000 miles of other smaller roadways currently exist in the United States (U.S. Department of Transportation estimate).

The U.S. electrical grid contains 200,000 miles of high-voltage transmission lines and 5.5 million miles of local distribution lines, linking thousands of generating plants to factories, homes and businesses. These utility rights-of-way sites are all possible use areas for triclopyr products used to control vegetation which might interfere with transmission lines or access to the support structures. https://www.scientificamerican.com/article/what-is-the-smart-grid/

Uses in forest areas are generally made to control unwanted invasive (noxious weeds or woody shrubs and trees) plants, for site preparation, conifer and hardwood release and for right-of-

way management. The United States Forest Service use of triclopyr active ingredients is concentrated in the Southeastern U.S. (over 80%) and involved application of approximately 12,500 pounds of triclopyr in 2004. In 2007, California reported 10,186 lbs of triclopyr BEE applied to timberland areas and 21,029 lbs applied to rights-of-way. Similarly, over 8900 lbs of triclopyr TEA was used for forestry-related applications. These are examples of forestry uses, but do not include plant management in millions of acres of other state, commercially owned, or privately-owned forest lands where these products are also registered for use.

In its 2017 report the Golf Course Superintendents Association of America (GCSAA) estimated the total 2015 acreage for golf courses in the United States at 2,301,808 acres on 14,289 facilities. Of this acreage, 1,408,412 acres were considered maintained turf and are considered potential turf use areas for triclopyr products used in weed control. Use in residential and other turf would add significant additional acreage to this total.

Label Uncertainties

A review of the labels indicates the following uncertainties:

(1) Except of application to rice, turf, and aquatic sites, the labels appear to indicate that yearly application is applied one time. Additionally, Labels do not specify multiple applications or re-application intervals.
(2) Some of the labels needed revisions to include the following:
    a. The maximum yearly rate for EACH *use pattern* in lbs. a.e/A/Y;
    b. The maximum single rate for *each type of application* lbs. a.e/A;
    c. When applicable, specify that the maximum yearly rate is applied *one time* and if not, indicate the *number of applications per year and the minimum re-application intervals* between applications in days.
(3) For aquatic use, some of the labels indicate that the maximum yearly rate is 6 lbs. a.e/A/Y without specifying the average depth/area of the water body or lbs. a.e./acre-foot of water to be treated to arrive at the effective acid concentration necessary to kill the weeds. This information would add clarity to the label.

4   Residues of Concern

In this risk assessment, the stressors are those chemicals that may exert adverse effects on non-target organisms at environmentally relevant concentrations. Collectively, these stressors are known as the Residues of Concern (ROC). The ROC usually include the active ingredient, or parent chemical, and may include one or more degradates that are observed in laboratory or field environmental fate studies. Inclusion of one or more degradates in the ROC is based on two factors: exposure (considering their percent formation relative to the application rate of the parent compound and modeled exposure) and toxicity (considering submitted toxicity data and/or predicted toxicity using structure-activity relationships (SARs). Structure-activity analysis

may be qualitative, based on retention of functional groups in the degradate, or they may be quantitative, using programs such as ECOSAR, the Organization for Economic Cooperation and Development (OECD) Toolbox[7], the Assessment Tool for the Evaluation of Risk (ASTER[8]), or others.

For acute and chronic aquatic exposure, triclopyr ACID is considered representative of the acid form and the TEA and COLN active ingredients. This is based on the observed rapid or instantaneous dissociation of TEA and COLN into the ACID form and similar aquatic toxicity profile observed for the ACID and TEA active ingredients. Although triclopyr BEE shows relatively short persistence in water, it exhibits much greater acute and chronic toxicity to aquatic organisms compared to triclopyr ACID and is therefore modeled separately. Detailed information supporting the decision on acute and chronic exposures for the parent active ingredients is presented in **Section 5**.

Regarding the inclusion of degradates into the ROC, the degradation profile of the ACID (and by extension the TEA and COLN active ingredients) indicates that TCP and 3,6-DCP are major degradates (>10% formation) common to multiple degradation pathways (**Section 5**). Additionally, the degradates 5-CLP and 6-CLP are also expected to form in major amounts in certain aerobic aquatic systems. ECOSAR analysis indicates 3,6-DCP, 5-CLP and 6-CLP are similar in toxicity to aquatic plants and animals as the ACID active ingredient (representing ACID, TEA and COLN). In contrast, submitted aquatic toxicity data for the TCP degradate indicates it is at least 10X more toxic than the parent ACID active ingredient and forms at a maximum rate of 33% relative to parent ACID under aerobic aquatic conditions. Given this substantially greater toxicity of the TCP degradate with aquatic organisms, assuming equivalent toxicity of TCP to the parent and other degradates was not considered appropriate. Therefore, a separate analysis was conducted to quantify potential risks associated with TCP at this maximum observed formation rate.

With the BEE active ingredient, the major degradates include the ACID, TCP, 3,6 DCP, 5-CLP and 6-CLP. However, the BEE active ingredient and TCP degradate are much more toxic to aquatic animals and plants compared to ACID, 3,6 DCP, 5-CLP and 6-CLP degradates (*e.g.,* by 2-3 orders of magnitude). Therefore, a separate analysis was conducted to evaluate the risk associated with BEE and TCP in aquatic ecosystems.

In summary, the stressors of concern for aquatic organisms include:

(1) **The ROC: ACID + TCP + 3,6 DCP + 5-CLP + 6-CLP** for the ACID, TEA and COLN active ingredients (ROC and TCP were modeled separately: ROC using TTR approach and TCP using the F/D approach); and,

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[7] https://www.oecd.org/chemicalsafety/risk-assessment/oecd-qsar-toolbox.htm
[8] https://cfpub.epa.gov/si/si_public_record_Report.cfm?Lab=&dirEntryID=2804

(2) **BEE + ACID + TCP + 3,6 DCP + 5-CLP + 6-CLP** for the BEE active ingredient (Modeled separately).

For terrestrial organisms, the BEE active ingredient is modeled separately from the ACID/TEA/COLN due to its different use pattern and some indication that BEE is more acutely toxic to birds compared to the ACID or TEA. For terrestrial plants, similar toxicity is seen with TEA and BEE based on vegetative vigor, but BEE appears more toxic on the basis of seedling emergence. Acute toxicity data to terrestrial animals are available for only one degradate (TCP) which indicates lower to similar acute toxicity to birds and mammals compared to ACID, BEE, and TEA. No toxicity data are available for the other potential degradates of triclopyr nor are SAR estimates of toxicity available for terrestrial organisms.

Therefore, given the similarities in toxicity among active ingredients to terrestrial organisms, the terrestrial ROC for the ACID, TEA and COLN active ingredients include ACID + TCP + 3,6 DCP + 5-CLP + 6-CLP while that for BEE include BEE+ ACID + TCP + 3,6 DCP + 5-CLP + 6-CLP [9].

5   Environmental Fate Summary

Triclopyr herbicides consist of four separately formulated active ingredients: ACID, BEE, TEA and COLN. **Table 5-1** contains a summary of the chemical, physical properties of these compounds. Detailed information of the environmental fate of the parent and degradate chemicals is provided in **Appendix A.**

Table 5-1. Physical-Chemical Properties of Triclopyr ACID, BEE, TEA and COLN forms; Soil Water Distribution Coefficient for the ACID and Bioconcentration Properties for BEE[1]

Properties	Triclopyr ACID	Triclopyr BEE	Triclopyr TEA	Triclopyr COLN
Chemical Name	3,5,6-trichloro-2-pyridinyloxyacetic acid	3,5,6-trichloro-2-pyridinyloxyacetic acid, butoxyethyl ester	3,5,6-trichloro-2-pyridinyloxyacetic acid, triethylamine salt	2-[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid, choline salt
Formula	$C_7H_4Cl_3NO_3$	$C_{13}H_{16}Cl_3NO_4$	$C_{13}H_{20}Cl_3N_2O_3$	$C_{12}H_{17}Cl_3N_2O_4$
CAS No.	55335-06-3	64700-56-7	57213-69-1	104837-85-8
Molecular Weight	256.5 g mol-1	356.6 g mol^{-1}	358.67 g mol^{-1}	345.6 g mol^{-1}
Structures	ACID	BEE		
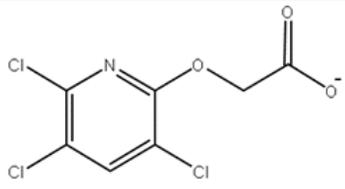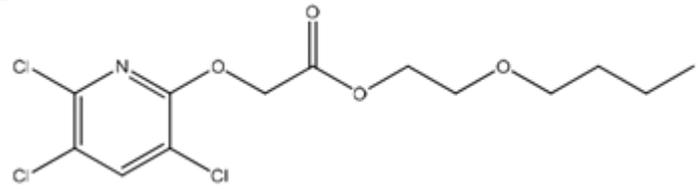
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[9] Currently used terrestrial exposure model do not enable combined exposure of parent and degradates to be modeled. If data had indicated a degradate was substantially more toxic than parent chemical, separate modeling would have been done for that degradate.

Properties	Triclopyr ACID	Triclopyr BEE	Triclopyr TEA	Triclopyr COLN
	TEA		COLN	

Properties	Triclopyr ACID	Triclopyr BEE	Triclopyr TEA	Triclopyr COLN
Water Solubility	440 ppm @ 25° C	7.4 ppm @ 25° C	412,000 ppm @ 25° C	Dissolve in seconds (MRID 493785-02; A)
Vapor Pressure (VP)[2]	1.3×10^{-6} torr @ 25° C	3.6×10^{-6} torr @ 25° C	3.6×10^{-7} torr @ 25° C	No Data
HLC @ 25° C	10.0×10^{-10} atm m^3 mol^{-1} (Calculated; non-volatile)	2.3×10^{-7} atm m^3 mol^{-1} (Calculated; non-volatile)	4.1×10^{-13} atm m^3 mol^{-1} (Calculated; non-volatile)	No Data
Log Kow (K_{ow})[3]	-0.65 (0.2) (MRID 412191-06; A) Low potential for bioaccumulation	4.01 (10,233) High potential for bioaccumulation	-0.51 (0.3) (MRID 412191-06; A) Low potential for bioaccumulation	No Data
pK$_a$	2.93 Rapid dissociation at environmentally relevant pHs (5 to 7)(MRID 412191-06; A)	No value	No value Dissociates/ in ≤1 minute (MRID 430114-01; A)	No value, Dissociates in seconds over various concentrations (pH not reported (MRID 493785-02; A)
Air-water Partition Coefficient (K_{AW}; Unitless)[4]	3.3×10^{-11} (log K_{AW} = -11)	3.3×10^{-11} (log K_{AW} = -11)	3.3×10^{-11} (log K_{AW} = -11)	Estimated from VP and H$_2$O solubility at 25°C; Nonvolatile from H$_2$O

Soil-Water Distribution Coefficients (K_d in L/kg-soil or sediment) Organic Carbon-Normalized Distribution Coefficients (K_{oc} in L/kg-organic carbon) for the ACID[5]	Soil/Sediment	K_d	K_{OC}	Reference
	Sand pH 5.0 and O.C 0.73%	0.975	134	407498-01 (A): Mobile (FAO classification system) [10]
	Silt loam, pH 7.7 and O.C 0.67%	0.165	25	
	Clay loam, pH 6.6 and O.C 1.38%	0.733	53	
	SL, pH 7.5 and O.C 2.25%	0.571	25	
	Mean	0.611	59.2	K_d better predictor of sorption based on lower CV
	Coefficient of Variation (CV)	56%	87%	

Bioconcentration in Fish for BEE[6]	Triclopyr BEE bioconcentrate in fish tissue relative to water for a brief period (a few hours or less), after which it is expected to be metabolized to the acid form. Furthermore, the acid is not expected to bioconcentrate in tissue relative to water; although indirectly, the acid ends up being higher in fish tissue vs. water because of its metabolism, in fish, from BEE to acid (MRID 499924-08[N])

[10] Food and Agriculture Organization of the United Nations. FAO PESTICIDE DISPOSAL SERIES 8. Assessing Soil Contamination: A Reference Manual. Appendix 2. Parameters of pesticides that influence processes in the soil. Editorial Group, FAO Information Division: Rome, 2000.
URL: http://www.fao.org/DOCREP/003/X2570E/X2570E00.htm

Properties	Triclopyr ACID	Triclopyr BEE	Triclopyr TEA	Triclopyr COLN

Data in **Table 5-1** indicate that the ACID/TEA/COLN forms of triclopyr are moderatley to highly soluble in water while BEE form is practically insoluble (solubility of 7.4 mg/L; 7.4 parts per million [ppm]). All forms of triclopyr are classified as non-volatile from water and dry non-adsorbing surfaces (USEPA, 2010a). Furthermore, the ACID form of triclopyr is classified as mobile based on measured K_{oc} values and the FAO classification system (FAO, 2000). The ACID form of triclopyr and its degradate may be transported to surface water via spray drift and runoff or to groundwater via leaching.

The ACID form of triclopyr may be found in both water and sediment, the octanol-water partition coefficient (K_{OW}) and organic-carbon normalized soil-water distribution coefficient (K_{OC}) values are much lower than the values that would trigger the need to conduct a separate sediment exposure assessment (40 CFR Part 158.630).[11] Compounds with a log K_{OW} of 3.0 and above are generally considered to have the potential to bioconcentrate in aquatic organisms. Based on log K_{OW}'s of -0.65 and -0.51 for the ACID and TEA, bioconcentration of the ACID and TEA forms of triclopyr are not of primary concern.; however, with an estimated log K_{ow} of 4.01 for BEE, bioconcentration of BEE is of potential concern (based on log K_{OW} alone). An analysis of bioaccumulation of triclopyr BEE using the KABAM model indicates accumulation of BEE in aquatic food webs is not a risk concern to piscivorous birds and mammals, based on its Kow, available toxicity data, and 21-d aquatic EECs of 0.022 and 0.014 mg a.i./L obtained from the range/pasture land use with the highest EECs (**Table 8-5**).

In preparing the tank mix, the TEA and COLN forms of triclopyr dissolve and dissociate instantaneously into the ACID plus triethanol amine and choline moieties, respectively. Similarly (as will be shown later), BEE form of triclopyr is expected to ultimately convert into the ACID form plus the butoxy ethanol moiety within a relatively short period of time (hydrolysis $t_{1/2}$= 9 days; aerobic/anaerobic metabolism soil and aquatic systems $t_{1/2}$= <1 day in) (**Figure 5-1**). Triclopyr acid itself (the ACID) and that forming from BEE, TEA and COLN is a weak acid which will dissociate completely to the triclopyr anion at environmentally-relevant pH values

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[11] Sediment data may be required if the soil-water distribution coefficient (K_d) is ≥ 50 L/kg, K_{OC}s are ≥1000 L/kg-organic carbon, or the log K_{OW} is ≥ 3 (40 CFR Part 158.630). Sediment data may also be requested if there may be a toxicity concern.

(dissociation constant pKa 2.93). Therefore, triclopyr anion will be the predominant moiety present in the environment when products containing the four forms of triclopyr are used (**Figure 5-1**).
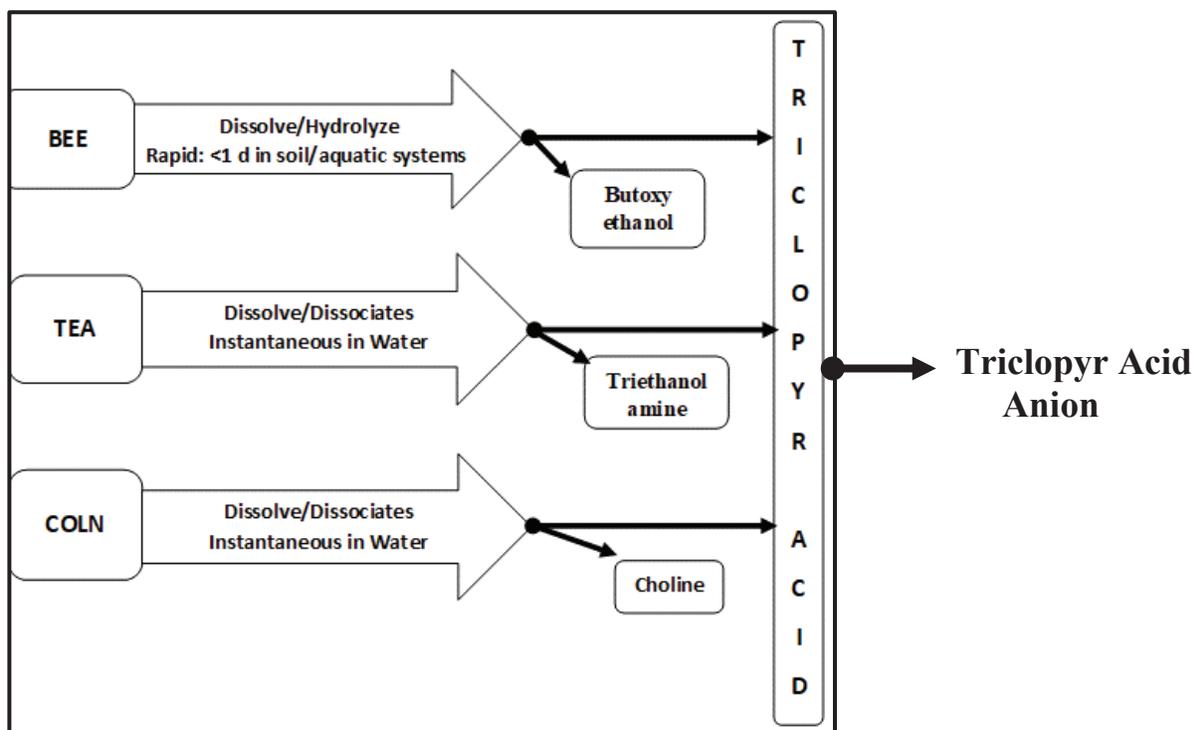
Figure 5-1. Expected Initial Dissolution/ Dissociation/Hydrolysis of Various Triclopyr Forms in the Environment. Triclopyr herbicides consist of the **ACID**: 3,5,6-trichloro-2-pyridinyloxyacetic acid (**ACID**); **BEE:** 3,5,6-trichloro-2-pyridinyloxyacetic acid, butoxyethyl ester; **TEA**: 3,5,6-trichloro-2-pyridinyloxyacetic acid, triethylamine salt; and, **COLN**: 2-[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid, and, choline salt.

As shown in **Figure 5-1**, dissociation of TEA and COLN and hydrolysis of the BEE are expected to produce, in addition to the ACID moiety, triethanolamine, choline and butoxyethanol moieties, respectively. These products were claimed, by the registrant, to dissipate rapidly by microbial degradation and/or of no toxicological concern. Other lines of evidence for rapid dissociation are presented in **Appendix A** support the registrant's claim and therefore triethanolamine, choline and butoxyethanol moieties were not considered as residues of concern in this assessment. In this assessment, two forms of triclopyr are considered: the ACID (representing itself, TEA and COLN forms) and BEE. Therefore, it is only necessary to present and discuss fate and transport data for these two forms of triclopyr (the ACID and BEE).

Hereunder, a complete review of new and previously submitted studies available for the ACID and BEE forms of triclopyr with the first representing the ACID, TEA and COLN forms.

Triclopyr ACID

Table 5-2 below summarizes representative half-life values derived using laboratory degradation data for triclopyr acid and its residue of concern.

Table 5-2. Summary of Environmental Degradation Data for Triclopyr Acid (ACID) plus Triclopyr Residue of Concern (ROCs).[1]

Study	System Details	Representative Half-life (days)[2]		Source/ Study Classification
		Parent	ROCs	
Abiotic Hydrolysis	pH 5, 7, 9	Stable	Stable	418796-01 (A)
Atmospheric Degradation	Hydroxyl Radical	1.1 (SFO)	N/A	EPI Suite V 4.1
Aqueous Photolysis	pH 7, 25°C, 40°N sunlight	0.4 (SFO)	0.4[3]	499924-01 [N] (A)
Soil Photolysis	IL Loam, 25°C, PH 7, 40°N sunlight	Stable	Stable	MRID 12345-67 (A)
Aerobic Soil Metabolism	MO Silt loam, 25°C	6 (SFO)	14.9 (SFO)	499924-02 [N] (A)
	TX Sandy clay loam, 25°C	21 (SFO)	29.0 (SFO)	
	ND Sandy loam, 25°C	18 (SFO)	33.4 (SFO)	
	CA Clay, 25°C	13 (SFO)	17 (SFO)	
Anaerobic Soil Metabolism	WY Clay, 25°C	115 (SFO)	N/A	499924-03 [N] (A)
	UK Silt Loam, 25°C	94 (SFO)	N/A	
	UK Sandy Loam, 25°C	170 (Slow DFOP)	N/A	
	UK Clay, 25°C	69 (SFO)	N/A	
Aerobic Aquatic Metabolism[3]	Italy loam sediment: Water, 25°C	23 (SFO)	183.1 (SFO)	499924-04 [N] (S)
	French Sand Sediment: Water, 25°C	26 (SFO)	127.3 (SFO)	
Anaerobic Aquatic Metabolism[4]	GA Sandy Loam, 25°C	1,433 (SFO)	Stable	001519-67 [N] (S)
	VA Sandy loam, 25°C	1,339 (SFO)	Stable	

[1] **General Notes:** Studies submitted since the Problem Formulation was completed are designated with an [N] in association with the MRID number; **Studies classification:** A= Acceptable, S= Supplemental; N/A= Not applicable

[2] **Half-lives:** SFO=single first order; DFOP=double first order in parallel; DFOP slow DT_{50}=slow rate half-life of the DFOP fit

[3] The test substance is the 3,5,6-trichloro-2-pyridinyloxyacetic acid, butoxyethyl ester (BEE) form of triclopyr. BEE was a transient species transforming relatively quickly into the 3,5,6-trichloro-2-pyridinyloxyacetic acid (ACID) form of triclopyr. ACID maximums reached 98 & 90% in seven days. Therefore, starting from the 7-day time interval, the study can be considered to represent the fate of the ACID form of triclopyr in an aerobic aquatic system

[4] The test substance is the BEE form of triclopyr. BEE transformed completely into the ACID form of triclopyr. ACID maximums reached 101 & 98% in one-day. Therefore, the study can be considered to represent the fate of the ACID form of triclopyr in an aerobic aquatic system.

As shown in **Table 5-2**, triclopyr acid is highly vulnerable to abiotic photolysis ($t_{1/2}$ <1 d) and non-persistent in the aerobic soil/aquatic systems ($t_{1/2}$ range: 6 to 21 days at 25°C in six soils; and, from 23 to 26 days in two aquatic systems; Goring *et al*., 1975)[12]. In contrast, anaerobic

metabolism is expected to be slower (t½ range: 69 to 170 days) than aerobic metabolism as the chemical is moderately persistent in such systems according to Goring scale. Finally, the ACID is stable to abiotic hydrolysis at pH 5, 7, and 9/photolysis on soil and essentially stable to anaerobic aquatic metabolism (t½ >1,000 days).

A summary of major/minor degradation products observed in laboratory fate studies with triclopyr is shown in **Table 5-3**.

Table 5-3. Summary of Major/Minor Degradation Products of Triclopyr Herbicides[1] Observed in Laboratory-based Environmental Fate Studies (refer to Appendix A, Table III-1 for acronyms, structures and other information on the degradates).

Study	Half-life (days)/Other Data
Aqueous photolysis (End of study= EOS= 30 d)	**Major:** 29% [(3-Chloro,5,6-dihydroxy-2-pyrindinyl)oxy]acetic acid @ 1 d declining to non-detect @ EOS; 27 to 28% mixture of chloromaleamic acid, fumaric acid, and chlorofumaric amide @ 6 d to EOS; 10% maleamic acid @ 0.5 d declining to 6% @EOS; and 60% CO_2 @ EOS. **Minor:** 8% fumaric amide; <1% TMP and mixture of succinamic succinic acids.
Aerobic soil (6 soils: EOS for the 1st two= 56 d @25°C while it is 120 d for the others) @20 °C	**Major: TCP:** Max range from 19-35% @ 14-59 d declining to 2-19% @ EOS (Estimated t½ for TCP 20-70 days**)**; and CO_2= 51-58% @ EOS. **Minor: TMP:** Max range from <1-5% @ 14 d-EOS then <1-5% @EOS; MTCP: <1-6% @ 59-90 d then <1-5 @ EOS; 3,5-DCMP**:** <1-1% @ 59 d-EOS then 0-1 @ EOS; and 5,6-DCMP**:** Max <1 @ EOS
Anaerobic soil (EOS= 120-122 days) @20 °C	**Major: TCP:** Max range 33-54% @ 19 d-EOS then to 13-54% @ EOS (Estimated t½ for TCP 29-70 days**)**; and 3,6-DCP**:** Max 11-32% @ EOS; and CO_2= 4-20% @ EOS. **Minor: TMP:** 4-5% @ 7 d ranging from 2-4% @ 7-60 d with slight or no decline @ EOS; [(5,6-dichloropyridin-2-yl)oxy]acetic acid: Detected in one soil at a Max of 2.5% @ 60 d with no apparent decline; and X79402**:** Detected in one soil at a Max of 0.7% @ 60 d declining to no detection @ EOS.
Aerobic Aquatic[2] (EOS= 106 d @20 °C)	**Major: TCP:** Max 33 & 24% @ 59 d & EOS declining to 19% @ EOS in one system and remaining at 24% @ EOS in the other; 3,6-DCP**:** Max 34 & 52% @ 59-EOS declining to 30% @ EOS in one system and remaining at 52% @ EOS in the other; and the total of 5-CLP and 6-CLP: Max 26% @ 59 d declining to 21% @ EOS in one system while it was a minor degradate in the other (Max 1.2%) **Minor: 5-CLP** and **6-CLP**: Max 1% @EOS in one system only; TMP: Max 2% @ 29 Minutes declining to 0.04% @ EOS; and CO_2**:** 0.5-2% @ EOS.
Anaerobic Aquatic[3] (EOS= 365 d @25 °C)	**Major: TCP:** Max. 43% @ 201 d declining to 22% @ EOS in one system while the maximum was 26% @ EOS **Minor: CO_2:** 0.01%

Study	Half-life (days)/Other Data

[1] Triclopyr herbicide active ingredients include: 3,5,6-trichloro-2-pyridinyloxyacetic acid (**ACID**); 3,5,6-trichloro-2-pyridinyloxyacetic acid, butoxyethyl ester (**BEE**); 3,5,6-trichloro-2-pyridinyloxyacetic acid, triethylamine salt (**TEA**); and, 2-[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid, choline salt (**COLN**); degradates include: 3,5,6-Trichloro-2-pyridinol (**TCP**); ,6-Dichloro-2-pyridinol (**3, 6 DCP**)

[2] The test substance is the BEE form of triclopyr. BEE was a transient species transforming relatively quickly into the ACID form of triclopyr. ACID maximums reached 98 & 90% in seven days then decreased to 11 & 5% at the end of the 106-day studies (t ½= 0.6-0.7 days). Therefore, major and minor degradates observed in the study, are considered to be that of the ACID

[3] The test substance is the BEE form of triclopyr. BEE transformed completely into the ACID form of triclopyr. The ACID maximums reached 101 & 98% in one-day. The ACID form of triclopyr was highly persistent. Again, observed degradation products in the study, are considered to be that of the ACID.

Data in **Table 5-3** indicate that the major transformation products resulting from environmental degradation of triclopyr acid are:

- 3,5,6-trichloro-2-pyridinol (**TCP**): A slightly to moderately persistent degradate (estimated half-life of 20 to 70 days) that forms in aerobic/anaerobic soil and aquatic systems. The maximum formation levels range from 33 to 54%; and,
- 3,6-dichloro-2-pyridinol (**3,6-DCP**): A degradate that forms to a maximum of 21% in some anaerobic soil systems and up to a maximum of 52% in aerobic aquatic systems. This degradate show only a slight decline.

It is important to note the following:
- The total amount of the degradates **5-CLP** and **6-CLP** combined was observed as a major degradate in only one aerobic aquatic study (Max 26%) with only slight decline to 21% at the end of a 106-day study;
- Carbon dioxide forms as a major degradate in aerobic soil systems only; and,
- Many major/minor degradates were observed in the aqueous photolysis study (refer to **Table 5-3**, above). These degradates are expected to form in significant amounts in shallow clear water systems. However, aqueous photolysis is not expected to play a major role in dissipation of this chemical in other water bodies due to the limited penetration of light in these systems.

A table summarizing the maximum amounts of degradates formed in different studies and the structures (the Residue of Concern Knowledgebase Subcommittee "ROCKS" table) is available in **Appendix A**

Based on the degradation profile described, above and summarized in **Figure 5-2,** the major degradates of triclopyr acid are **TCP** and **3,6 DCP** and both are of exposure concern. Additionally, the degradates **5-CLP** and **6-CLP** could also be of exposure concern as they expected to form in major amounts in some aerobic aquatic systems. Except for the photolysis degradates, all other degradates are not included in the **ROC** because they form in minor amounts and most of them declined following maximum formation. Exposure to the major photolysis degradates, listed in **Table 5-3**, is limited to shallow clear water bodies.
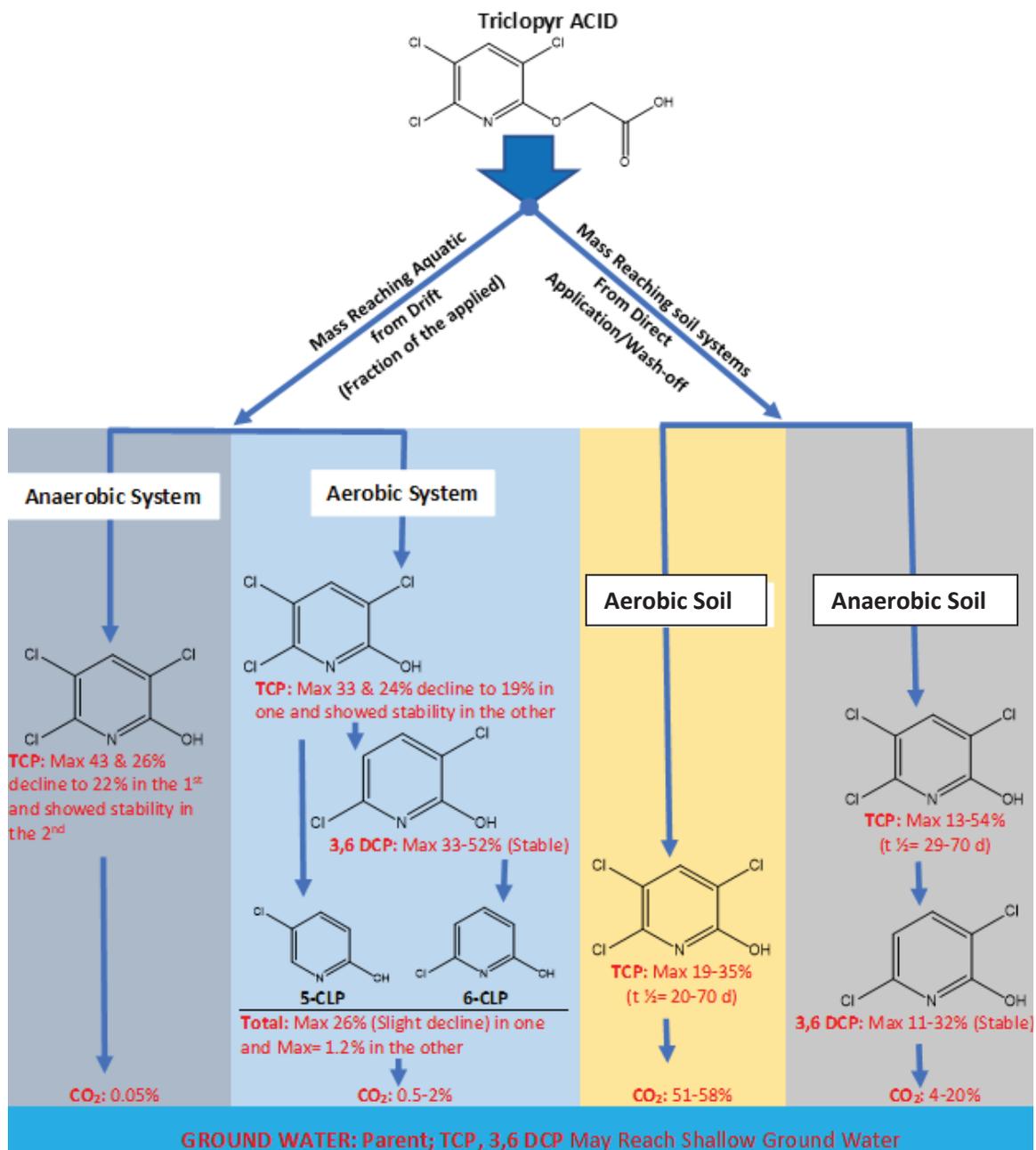
Figure 5-2. The Degradation Profile of Triclopyr Acid in Various Compartments of the Environment (Only major degradates are included)

Triclopyr BEE

As stated previously, acute and chronic risk resulting from the ACID form of triclopyr and its residue can be used to represent the ACID itself, and the acid equivalent of its TEA and COLN forms. Instantaneous dissociation of TEA and COLN forms of triclopyr to the ACID supports this equivalency. For BEE, despite the relatively short time lag (days) observed in the process of transformation of BEE to the ACID, its much greater toxicity to aquatic organisms combined with aquatic exposure modeling indicates that both acute and chronic (in terms of the uncertainty as to when the chronic effects would initiate) exposure to BEE are of toxicological concern. Fate data on BEE are necessary to characterize acute and chronic risk resulting from expected exposure and toxicity to this form triclopyr before its transformation to the ACID form. **Table 5-4** summarizes representative degradation half-life values from laboratory degradation data for BEE.

Table 5-4. Summary of Environmental Degradation Data for Triclopyr 3,5,6-trichloro-2-pyridinyloxyacetic acid, butoxyethyl ester (BEE).[1]

Study	System Details	Half-life (days)[2]/Other Data	Source (MRID)/ Study Classification
Hydrolysis	Sterile buffered solutions (End of study= EOS= 40 d @25 $^{\circ}$C)	**84.0** days **@ pH 5**; **9.0** days **@ pH 7**; and **0.3** days **@ pH 9** Triclopyr **ACID** is the only degradate	001341-74 (A)
Aqueous photolysis	Sterile buffered aqueous solution @ pH 5; Natural sunlight (End of study= EOS= 30 d @25 $^{\circ}$C)	**6.6** days **Major:** CO_2= 29.4% @ EOS **Minor:** dichloropyridinyloxy acetic acid; 2-hydroxy ethyl ester; and (5/6)-chloro-3-hydroxy-s-pyridinone	430076-01 (A)
Aerobic soil	**Soil 1:** MS Loamy soil (pH 8; O.C= 0.5%) **Soil 2:** GA Sandy loam soil (pH 5.1; O.C= Organic carbon= 1.0%) (EOS= 9 d @25 $^{\circ}$C)	**0.2** day (SFO-LN) in **soil 1**; and **0.6** day (SFO-LN) in **soil 2**. **Major:** Triclopyr ACID increasing continuously to 83% @EOS **Minor:** CO2= <1% @EOS.	472938-01 [N] (S)
Aerobic aquatic	**System 1:** L sediment from Italy (pH 7.3; O.C= 4.89%): water (pH 7.9) **System 2:** S sediment from France (pH 5.3; O.C= 2.43%) : water (pH 6.2) (EOS= 106 d @20 $^{\circ}$C)	**0.7** day (SFO) in **system 1**; **0.6** day (SFO) in **system 2** **Major & Minor Degradates in System1 & System 2:** Refer to the summary of fate studies for the ACID (**Table 5-3**)	499924-04 [N] (A)
Anaerobic aquatic	**System 1:** GA Sandy loam soil (pH 5.7; O.C= 0.95%): water **System 2:** VA Sandy loam soil (pH 6.3; O.C= 0.65%): water (EOS= 365 d @25 $^{\circ}$C)	**<1 d**[3] in both systems **Major & Minor Degradates in System1 & System 2:** Refer to the summary of fate studies for the ACID (**Table 5-3**)	001519-67 [N] (S)

[1] **General Notes:** Studies submitted since the Problem Formulation was completed are designated with an [N] associated with the Master Record Identification (MRID) number **Studies classification:** A= Acceptable, S= Supplemental; Photolysis on soil and mobility studies were waived assuming that BEE will hydrolyze very quickly to the ACID

[2] *Half-lives:* SFO=single first order; **SFO-LN**=SFO calculated using natural log transformed data

[3] This is the *observed* half-lives, fitted half-lives could not be calculated due to the extremely rapid dissipation of BEE

Field Studies

Several aquatic, forestry and terrestrial field studies were submitted for TEA and BEE forms of triclopyr. Table 5-5 contains a summary of the results obtained from these studies

Table 5-5 Summary data for Aquatic, forestry and terrestrial field studies

Site	Application Type(s)/ Parameters	Tracked Degradate(s)	Reference and Results
Triclopyr TEA: Aquatic field studies			
Lake Seminole, Georgi (21 d study)	Surface and Aerial Applications/ 2500 ppm	ACID and TCP	MRID 417143-04 (S) **Water: ACID** DT_{50}= 0.5 for surface application DT_{50}= 3.5 for aerial application **Sediment: ACID** Sediment: ACID (up to 10 cm deep) <LOQ of 50 ppb **TCP** ND in surface and bottom sediment after one day (LOQ= 100 ppb)
Pond, TX	Ground Application 2,500 ppb		MRID 44561-04 ACID: DT_{50}= 6 d in water and 4 d in sediment Low formation of TCP and TMP. TMP not detected in the sediment
Lake Minnetonka at Phelps Bay, sub-surface applied and Carsons Bay sites, surface applied (42 d study)	Ground Broadcast subsurface and sub-surface Applications/ 2500 ppb mixed with a dye	ACID, TCP, and TMP	MRID 444561-02 **Water: ACID** DT_{50}= 3 d; Phelps Bay; DT_{50}= 5 d; Carsons Bay; **Sediment: ACID** DT_{50}= 3 d; Phelps Bay; DT_{50}= 7 d; Carsons Bay; **Water: Degradate** Not significant formation: **TCP** Max. 24/20 ppb @ 3 hrs. (DT_{50}= 1 d observed); **TMP** Max 4.0/4.0 ppb @ 3 d (DT_{50}= ND, no enough data) **Sediment: Degradate** Not significant formation (<1%/<0.1%): **TCP** Max. 27/65 ppb @ 3 wks **TMP** Not detected
Static man-made ponds located in CA, MO and TX (28 d study) Problems: no freezer Stabilty	Ground Application 2500 ppb	ACID, TCP, and TMP	MRID 444561-03 **Water: ACID** DT_{50}= 7-9 d; CA pond; DT_{50}= 6 d; MO & TX ponds; **Sediment: ACID** DT_{50}= 4 d; CA pond; DT_{50}= Not determined; MO pond; DT_{50}= 5 d; TX pond; **Water: Degradate** Not significant formation: **TCP** Max. ≤21.7 ppb @ 2 d **TMP** Max 4.0-7.4 ppb @ 2-5 d **Sediment: Degradate**

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			Not significant formation: **TCP** Max. ≤0.16 ppb @ 7 d; **TMP** Not detected
Rice fields in AR (silty clay loam soil) and LA (silty clay loam soil) Before flood After flood (100 d study)	Ground application of 0.375 lbs a.e/A each	ACID, TCP, and TMP	MRID 439559-01 **Before flood (soil):** DT_{50} = 8 d; AR DT_{50} = 3 d; LA **After flood (Rice Paddy)** DT_{50} = 2 d; AR; DT_{50} = 3 d; LA **After flood (flooded soil)** DT_{50} = 12 d; AR and LA TCP Max found in Paddy water and flooded soil after the second application and was 10 times TMP Max (TCP Max 1%) TCP leached down to 12" in AR and to 9" in LA (concentration near LOQ of 10 ppb)
		Triclopyr BEE: TFD Studies	
ROW: loam soil, CA, bare and vegetative with Native short grass plots (65 Wks study)	Ground application of 6.4 lbs. a.e/A each	BEE, ACID, TCP and TMP	MRID 427306-01 **ACID** DT_{50} = 39 d (top 6", un-vegetative); DT_{50} = 33 d (top 6", vegetative) **TCP Max** 21-25% (Weeks 12-16) reaching 4-ND @ EOS **TMP Max** 2-3% (Weeks 12-16) reaching ND @ EOS Neither triclopyr nor its degradates were detected below the 6-inch soil depth (sampled to 36")
ROW: loam soil, NC, bare ground sandy loam soil (52 Wks study)	Ground application of 8.1 lbs. a.e/A each	BEE, ACID, TCP and TMP	MRID 430334-01 **BEE and ACID** DT_{50} Of BEE= 1 d (top 7.5 cm) DT_{50} Of ACID+BEE= 11 d (top 7.5 cm) **TCP and TMP** TCP Max 23% (7 d) reaching 1% @ EOS TMP Max 5% (1 d) reaching 1% @ EOS (% of Max ACID observed) Neither triclopyr nor its degradates were detected below the 30-cm soil depth
Forest Site (364 days for soil and 29 days for foliage)	Aerial application of 3.1 to 3.4 lbs. a.e./A	BEE, ACID, TCP and TMP	**BEE** transformed to ACID in the stream within hours **ACID** DT_{50} = 26 d in soil; DT_{50} = 4-11 d in aquatic plants **TCP** detected up to 90 cm, TMP up to 30 cm **ACID** detected in foliage, soil, water, sediment, leaf litter and aquatic plants. **TCP** detected in foliage (<0.2% of the ACID), soil (DT_{50} = 85 d), **TMP** detected in soil only. Level of TCP in exposed soil 5-6% of the ACID and 10-20% in soils under litter. Level of TMP one order of magnitude less than TCP sporadically detected
Clear cut timberland, WA	Aerial application 6 lbs. a.e/A	ACID, TCP TMP	430116-01 **ACID** DT_{50} = 15 d in foliage; DT_{50} = 20 d in leaf litter; DT_{50} = 5 d in pond water; DT_{50} = 24 d in pond sediment; DT_{50} = 96 d in soil (loam soil)

In submitted aquatic field dissipation studies ACID and degradates TCP and TMP were tracked following application of TEA to non-static lakes in GA, TX and MN and static ponds in CA, MO, and TX. The ACID form of triclopyr is a result of quick dissociation of TEA and degradation of the ACID produce TCP and TMP. Dissipation half-life of the ACID in lake waters of non-static lakes ranged from 0.5 to 5 days while it was 7-9 days in static lakes (**Table 5-5**). Only small amounts of the ACID partitioned into the sediment and degraded with half-lives ranging from 3-7 days in non-static lakes and 4-5 days in static lakes. Although concentrations of the ACID following application were very near to the target concentrations of 2,500 ppb, the ACID dissipated very quickly (half-lives in the range of 0.5 to 9 days) indicating that movement rather than degradation played a role in its dissipation. In comparison, the ACID 90th percentile laboratory aerobic aquatic half-live is 29 days confirming the importance of transport over degradation in determining the half-life of the ACID in the field. Levels of TCP indicates no significant formation with no discrete formation and decline profile. The same is indicated for the degradate TMP with even lower levels of formation compared to TCP. In the laboratory, TCP forms at a maximum level of 24-33% which is much higher than observed in the field reflecting the importance of transport rather than degradation.

Two field studies were submitted for rice fields in AR and LA. Half-lives of the ACID in the soil before floods ranged from 3-8 days and after flood 2-3 days supporting non-persistence of the ACID observed in laboratory aerobic soil (t ½ = 11 to 20 days). Half-life of the ACID after flood was 12 days in both AR and LA compared to 90th percentile laboratory aerobic aquatic half-live of 29 days. Again, half-lives in the field are shorter because dissipation in the field involves transport in addition to degradation.

BEE form of triclopyr was used in submitted terrestrial field studies for CA, NC. In these studies, the laboratory predicted rapid transformation of BEE to the ACID was confirmed (BEE t ½ = 1 day compared to the same value in aerobic soil). Half-lives of the ACD ranged from 11 to 39 days compared to aerobic soil half-lives range of 8-29 days. Levels of TCP formation was close to those observed in the aerobic soil in the laboratory (21 to 25% compared to 11-25%). The maximum observed TMP formation range from 2-5% compared to 5 to 8% in laboratory.

BEE form of triclopyr was also used in forestry field dissipation studies in a forested site in WA. In ontario site it was observed that BEE reaching the stream transformed to the ACID within hours. Following aerial application, the herbicide distributed throughout the forest floor reaching soil (exposed and under leaf litter), foliage, stream water and sediment, leaf litter. Half-lives were determined for soil and aquatic plants in the Ontario forest site (half-lives 26 to 4-11 days, receptively). Half-lives were calculated for the ACID reaching foliage (15 days), Leaf litter (20 days), pond water (5 days), Pond sediment (24 days) and soil (96 days). The level of TCP varies from 5-6% in exposed soil to 10-20% in soils under leaf litter. The level of TMP was one order of magnitude less than TC

6   Ecotoxicity Summary

Ecological effects data are used to estimate the toxicity of the four triclopyr active ingredients to surrogate species. The ecotoxicity data for the active ingredients and their associated products have been reviewed previously in multiple ecological risk assessments, including the Registration Eligibility Decision document in 1998 (USEPA 1998), the California Red-Legged Frog (*Rana draytonii*) ecological risk assessment in 2009 (USEPA 2009) and the preliminary Problem Formulation for Registration Review (USEPA 2014, D417819). These data are summarized in **Section 6.1** for aquatic organisms and **Section 6.2** for terrestrial organisms. Various studies have been submitted with aquatic animals and honey bees exposed triclopyr active ingredients since the preliminary Problem Formulation was issued in 2014. These studies include:

Aquatic Toxicity Studies:
> MRID 49992406: Lifecycle Chronic Toxicity for *Daphnia magna* exposed to triclopyr BEE;
> MRID 49992407: Early Lifestage Testing with the triclopyr degradate TCP on Rainbow Trout; and,
> MRID 50673901: Lifecycle Chronic Toxicity for Mysid shrimp exposed to triclopyr BEE.

Bee Toxicity Studies:
> MRID 49992409: Acute (single dose) oral toxicity test with adult honey bees exposed to triclopyr ACID;
> MRID 50673902: Chronic (repeat dose) toxicity test to honey bee larvae exposed to triclopyr ACID; and,
> MRID 50673903: Chronic (repeat dose) oral toxicity test with adult honey bees exposed to triclopyr ACID.

The results of these studies are described briefly in this section and in more detail in **Appendix D**.

6.1   Aquatic Toxicity

As described previously, triclopyr TEA and COLN undergo near instantaneous dissociation to triclopyr ACID in water. Therefore, toxicity data for the ACID, TEA, COLN are all considered representative of the ACID active ingredient and are expressed as acid equivalents (a.e.) using the molar ratio relative to triclopyr ACID. Triclopyr BEE is being assessed separately due to its different physical/chemical and toxicological characteristics. A summary of the submitted aquatic toxicity data for the ACID, TEA and COLN are described separately from that of the BEE active ingredient below.

6.1.1   Triclopyr ACID, TEA, COLN

The submitted acute toxicity data for triclopyr ACID and TEA indicate that it is practically non-toxic to freshwater fish (which serve as surrogates for aquatic-phase amphibians) and slightly

toxic to estuarine/marine fish indicate (LC_{50} values range from 93 to 172 mg a.e./L; **Table 6-1**). Similarly, the ACID and TEA are slightly to practically non-toxic to aquatic invertebrates on an acute exposure (LC/EC_{50} values range from 42 to 554 mg a.e./L).

The chronic toxicity of triclopyr ACID or TEA to freshwater fish and invertebrates is relatively similar to their acute toxicity values (*i.e.,* the chronic NOAECs are within a factor of 2 of the acute LC_{50}), with NOAECs ranging from 24.4 mg a.e./L (estimated for Grass Shrimp, *Palaemonetes pugio,* using an acute-to-chronic ratio of 9.6;) to 74.4 mg a.e./L (for fathead minnow). A chronic NOAEC could not be estimated for triclopyr ACID since acute and chronic toxicity values for freshwater fish were determined on different species, *i.e.,* Bluegill Sunfish (*Lepomis macrochirus*) and Fathead Minnow (*Pimephales promelas*). No acute or chronic toxicity data are available for triclopyr COLN, but the active is expected to exhibit similar toxicity as triclopyr ACID and TEA due to its rapid dissociation to the ACID form.

With respect to aquatic plants, the most sensitive IC_{50} for tested vascular aquatic plants (duckweed; *Lemna gibba*) is 6.3 mg a.e./L while that for non-vascular plants is 4.2 mg a.e./L (cyanobacteria; *Anabaena flos-aquae*). Toxicity data for sediment-dwelling organisms would not be triggered for triclopyr ACID, TEA or COLN given their low hydrophobicity (*i.e.,* log K_{ow} < 3).

6.1.2   Triclopyr BEE

In contrast to the slightly to practically non-toxic ACID and TEA forms of triclopyr to fish and aquatic invertebrates, BEE is moderately to highly toxic to these taxa (**Table 6-1**) on an acute exposure basis. Toxicity data are expressed on an a.i. basis (rather than a.e.) since BEE is being assessed separately from the ACID, TEA and COLN active ingredients. Specifically, triclopyr BEE is consistently 2 to 3 orders of magnitude more acutely toxic to aquatic animals compared to triclopyr ACID or TEA, with a LC_{50} values ranging from 0.35 to 0.46 mg a.i./L. The chronic toxicity of BEE is approximately 1 order of magnitude lower than acute toxicity to these same taxa (NOAECs range between 0.011 to 0.17 mg a.i./L). Due to lack of chronic toxicity data for BEE with estuarine/marine fish, a NOAEC of 0.018 mg a.i./L was estimated using ACR of 25 from Rainbow Trout.

The BEE active ingredient also appears to be more toxic to aquatic plants compared to the ACID and TEA active ingredients. Specifically, the most sensitive EC_{50} values for BEE with vascular and nonvascular plants (0.88 and 0.1 mg a.i./L, respectively) are roughly an order of magnitude lower than those for the TEA and ACID (8.8 and 5.9 mg a.i./L respectively).

Given its log K_{ow} of 4.01, sediment toxicity data would be triggered for triclopyr BEE in accordance with 40 CFR Part 158. However, the short persistence of BEE in water (half-life 1 day) would introduce significant challenges in ensuring adequate exposure of benthic invertebrates to BEE given that sediment studies are only spiked once with test material at the test initiation. Therefore, sediment toxicity data were not recommended based on the 2014 preliminary Problem Formulation. In absence of sediment toxicity data, the chronic NOAECs for

water column-dwelling invertebrates are used to estimate risk associated with BEE in sediment pore water.

6.1.3 Degradates

TCP is the only major degradate of triclopyr for which toxicity data have been submitted (**Table 6-1)**. The aquatic toxicity of the TCP degradate generally falls in between that of the ACID/TEA and BEE active ingredients. Specifically, TCP is classified as slightly toxic on an acute exposure basis to fish and aquatic invertebrates (LC/EC$_{50}$ values between 10.4 and 58.4 mg a.i./L), with the exception of the Eastern oyster, where BEE is classified as moderately toxic (EC$_{50}$ = 9.3 mg a.i./L).   The chronic toxicity of TCP to fish and invertebrates is in some cases up to 2 orders of magnitude below its acute toxicity to the same species. For example, the acute EC$_{50}$ for *D. magna* is 10.4 mg a.i./L while its chronic NOAEC is 0.058 mg a.i./L. The NOAEC value of 0.825 mg a.i./L for estuarine/marine fish was estimated using an ACR of 71 derived from tests of TCP with Rainbow Trout and applied to the LC$_{50}$ of 58.4 mg a.i./L for the Atlantic Silverside (*Menidia menidia*). A NOAEC of 0.463 mg a.i./L for estuarine/marine invertebrates was estimated using an ACR of 179 derived from tests with *D. magna* and applied to the acute LC$_{50}$ of 83 mg a.i./L for Grass shrimp. The toxicity of TCP to aquatic vascular and non-vascular plants with EC$_{50}$ values of 8.2 and 2.0 mg a.i./L, respectively, is similar to that of the ACID/TEA active ingredients.

No aquatic toxicity data are available for the other major degradates of triclopyr active ingredients (3,6 DCP, 5-CLP, and 6-CLP). Further characterization of the potential toxicity of these degradates is provided below using ECOSAR (**Section 6.3**).

6.1.4 Open Literature – ECOTOX database

A search of the public ECOTOXicology (ECOTOX) Knowledgebase in 2009 and updated in 2019, yielded no new data from studies with more sensitive (lower) toxicity endpoints than those previously used in risk assessments and which were considered reliable for use in regulatory risk assessment.

Table 6-1. Aquatic Toxicity Endpoints for Triclopyr ACID, TEA, COLN, BEE and the TCP degradate.

Study Type	Test Substance (% a.i.)	Test Species	Toxicity Value in mg a.e./L (unless otherwise specified)	MRID or ECOTOX No./ Classification	Comments (Effects at LOAEC)
Freshwater Fish (surrogates for vertebrates)					
Acute	Triclopyr ACID technical	Rainbow Trout *Oncorhynchus mykiss*	96-h LC$_{50}$ = **117**	00049637 Acceptable	Practically non-toxic
	Triclopyr TEA Salt (47.8)	Bluegill Sunfish, *Lepomis macrochirus*	96-h LC$_{50}$ = 172	00062622 Acceptable	Practically non-toxic
	Triclopyr BEE (97)	Bluegill Sunfish, *Lepomis macrochirus*	96-h LC$_{50}$ = **0.36 mg a.i./L**	42917901 Acceptable	Highly toxic

Study Type	Test Substance (% a.i.)	Test Species	Toxicity Value in mg a.e./L (unless otherwise specified)	MRID or ECOTOX No./ Classification	Comments (Effects at LOAEC)
	TCP Degradate (99.9)	Rainbow Trout *Oncorhynchus mykiss*	96-h LC_{50} = **12.6 mg a.i./L**	41829004 Acceptable	Slightly toxic
Chronic	Triclopyr acid	No data			Reliable acute-to-chronic ratio (ACR) for estimating NOAEC could not be determined
	Triclopyr TEA Salt (44.9)	Fathead Minnow, *Pimephales promelas*	28-d Early Life Stage LOAEC= 116; NOAEC= **74.4**	00151958 Acceptable	Larval length and survival reduced 8% & 20% at 162 ppm
	Triclopyr BEE (97)	Rainbow Trout *Oncorhynchus mykiss*	60-d Early Life Stage LOAEC = 0.048; NOAEC = **0.026 mg a.i./L**	43230201 Acceptable	Larval weight ($\downarrow$92%), hatch success ($\downarrow$2.3%) and survival (percent effect not available)
	TCP Degradate	Rainbow Trout *Oncorhynchus mykiss*	60-d Early Life Stage LOAEC = 0.278; NOAEC = **0.178 mg a.i./L**	49992407[N] Acceptable	Mean length ($\downarrow$2.8%) and wet weight ($\downarrow$5.6%)
Estuarine/marine Fish					
Acute	Triclopyr TEA Salt (44.7)	Inland silverside *Menidia beryllina*	96-h LC_{50} = **93**	41633703 Acceptable	Slightly toxic
	Triclopyr BEE (96.1)	Inland silverside *Menidia beryllina*	96-h LC_{50} = **0.45 mg a.i./L L**	42053901 Acceptable	Highly toxic
	TCP (99.9)	Atlantic silverside *Menidia menidia*	96-h LC_{50} = **58.4 mg a.i./L**	42245901 Acceptable	Slightly toxic
Chronic	Triclopyr ACID	No Data			Reliable ACR for estimating NOAEC could not be determined
	Triclopyr BEE	**No Data** (Inland Silverside)	NOAEC = **0.018 mg a.i./L** (estimated)	NA	Estimated using ACR of 25 for Rainbow Trout tested with BEE
	TCP degradate	**No Data** (Atlantic Silverside)	NOAEC = **0.825 mg a.i./L** (estimated)	NA	Estimated using ACR of 71 for Rainbow Trout tested with TCP
Freshwater Invertebrates (water-column)					
Acute	Triclopyr ACID (technical)	Water flea, *Daphnia magna*	48-h EC_{50}= **133**	40346504 Acceptable	Practically non-toxic
	Triclopyr TEA Salt (64.7)	Water flea, *Daphnia magna*	48-h EC_{50} = 554	00151956 Acceptable	Practically non-toxic
	Triclopyr BEE (62.4)	Water flea, *Daphnia magna*	48-h EC_{50} = **0.35 mg a.i./L**	43442603 Acceptable	Highly toxic

Study Type	Test Substance (% a.i.)	Test Species	Toxicity Value in mg a.e./L (unless otherwise specified)	MRID or ECOTOX No./ Classification	Comments (Effects at LOAEC)
	TCP Degradate (99.9)	Water flea, *Daphnia magna*	48-h EC_{50} = **10.4 mg a.i./L**	41829005 Acceptable	Slightly toxic
Chronic	Triclopyr TEA Salt (44.9)	Water flea, *Daphnia magna*	21-d LOAEC= 107; NOAEC= 57.7	00151959 Acceptable	Total young and mean brood size effected -25% reduction
	Triclopyr BEE (96.5)	Water flea, *Daphnia magna*	21-d LOAEC= 0.52; NOAEC= **0.17 mg a.i./L**	49992406[N] Supplemental	Survival ($\downarrow$13%), growth endpoints not measured
	TCP Degradate	Water flea, *Daphnia magna*	21-d LOAEC= 0.130; NOAEC= **0.058 mg a.i./L**	45861301 In Review	15% $\downarrow$ offspring/female at 0.13 mg/L; 58% $\downarrow$ @ 1.5 mg/L
Estuarine/ marine invertebrates (water-column) Crustacea and Mollusca					
Acute	Triclopyr TEA Salt (46.2)	Grass shrimp *Palaemonetes pugio*	96- h LC_{50} = 234	42646102 Acceptable	Practically non-toxic
	Triclopyr BEE (96.1)	Grass shrimp *Palaemonetes pugio*	96-h LC_{50} = 2.48 µg a.i./L	41971601 acceptable	Moderately toxic
	TCP Degradate	Grass shrimp *Palaemonetes pugio*	96- h LC_{50} = 83 µg a.i./L	42245902 Acceptable	Slightly toxic
	Triclopyr TEA Salt (46)	Eastern Oyster *Crassostrea virginica*	96-h EC_{50} = **41.5**	42646101 Acceptable	Slightly toxic (shell growth)
	Triclopyr BEE (96.1)	Eastern Oyster *Crassostrea virginica*	96-h EC_{50} = **0.46 mg a.i./L**	41971602 Acceptable	Highly toxic (shell growth)
	TCP degradate (99.9)	Eastern Oyster *Crassostrea virginica*	96-h EC_{50} = **9.3 mg a.i./L**	42245903 Acceptable	Moderately toxic
Chronic	Triclopyr TEA	**No Data** (Grass Shrimp)	NOAEC = 24.4 (estimated)	NA	Estimated using ACR of 9.6 from *D. magna* tested with TEA
	Triclopyr BEE	Mysid *Americamysis bahia*	28-day NOAEC = **0.0109**; LOAEC = 0.0204 **mg a.i./L**	50673901[N] Acceptable	Weight ($\downarrow$16%)
	TCP degradate	**No Data** (Grass Shrimp)	NOAEC = **0.463 mg a.i./L** (estimated)	NA	Estimated using ACR of 179 from *D. magna* tested with TCP
Freshwater invertebrate (sediment)					
Chronic	Triclopyr BEE	**No Data**			Risk estimation based on water column invert toxicity and pore water exposure
Estuarine/ marine invertebrates (sediment)					

Study Type	Test Substance (% a.i.)	Test Species	Toxicity Value in mg a.e./L (unless otherwise specified)	MRID or ECOTOX No./ Classification	Comments (Effects at LOAEC)
Chronic	Triclopyr BEE	**No Data**			Risk estimation based on water column invert toxicity and pore water exposure
Aquatic plants and algae					
Vascular	Triclopyr TEA Salt (45)	Duckweed, *Lemna gibba*	EC_{50} = **6.3**; NOAEC = < 5.9	41633709 Supplemental	NOAEC could not be determined due to significant effects at all treatment levels.
	Triclopyr BEE technical	Duckweed, *Lemna gibba*	EC_{50} = **0.88 mg a.i./L**; NOAEC < 0.16	42719101 Acceptable	Significant effects on frond number at all treatment levels
	TCP degradate (99.9)	Duckweed, *Lemna gibba*	EC_{50} = **8.2 mg a.i/L** ; NOAEC = 1.02	45312002 Acceptable	↓ Frond number (20% reduction at 2.3 mg ai/L)
Non-vascular	Triclopyr ACID (technical)	FW green algae *Pseudokirchneriella subcapitata*	EC_{50} = 32.5; NOAEC = 7.0	41736303 Supplemental	50% Reduced cell count 12% reduction at 13 mg/L (LOAEC)
	Triclopyr TEA Salt (45)	Bluegreen algae *Anabaena flos-aquae*	EC_{50} = **4.2**; NOAEC = 1.4	41633706 Acceptable	↓Cell count (percent reduction from control not available from DER)
	Triclopyr BEE (97)	Freshwater diatom, *Navicula pelliculosa*	24-h EC_{50} = **0.10 mg a.i./L**; NOAEC = 0.002	42721102 Supplemental	↓Cell count (percent reduction from control not available from DER)
	TCP Degradate (99)	Bluegreen algae, *Anabaena flos-aquae*	EC_{50} = **2.0 mg a.i./L**; NOAEC = 0.353	45312003 Acceptable	↓Cell density (56%)

ACID: 3,5,6-trichloro-2-pyridinyloxyacetic acid; **BEE:** 3,5,6-trichloro-2-pyridinyloxyacetic acid, butoxyethyl ester; **TEA**: 3,5,6-trichloro-2-pyridinyloxyacetic acid, triethylamine salt; **COLN**: 2-[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid, and, choline salt; **TCP**: 3,5,6-trichloro-2-pyridinol.

TGAI=Technical Grade Active Ingredient; TEP= Typical end-use product; a.i.=active ingredient

[N] Studies submitted since the problem formulation was completed are designated with an N associated with the Master Record Identification (MRID) number.

Bolded value represents most sensitive endpoint used for assessing risk for taxon/test material.

>Greater than values designate non-definitive endpoints where no effects were observed at the highest level tested, or effects did not reach 50% at the highest concentration tested (USEPA, 2011).

< Less than values designate non-definitive endpoints where growth, reproductive, and/or mortality effects are observed at the lowest tested concentration.

6.2 Terrestrial Toxicity

6.2.1 Triclopyr ACID, TEA, COLN

Similar to that observed with aquatic animals, the ACID and TEA active ingredients of triclopyr are slightly toxic to practically non-toxic to birds (which serve as surrogates for reptiles and terrestrial-phase amphibians), mammals and bees on an acute exposure basis (acute oral LD_{50} values range from 1,698 to 2,271 mg a.e./kg bw for birds, from 630 to 1,321 mg a.e./kg bw for mammals, and >100 µg a.e.i/bee for the honey bee; **Table 6-2**). For birds, triclopyr ACID is also

slightly to practically non-toxic on a subacute dietary exposure basis (LC_{50} = 2,934 to >7,151 mg a.e./kg-diet).

Chronic exposure of birds (Mallard duck) to triclopyr ACID at 200 mg a.e./kg-diet resulted in a significant (14%) reduction in 14-d old survivors (NOAEC = 100 mg a.e./kg-diet). Mallard duck was the only species of bird tested. For mammals, results from a 2-generation reproduction study with rat indicate significant (28%) reductions in first (F_1) generation litter size and a 39% reduction in second (F_2) generation litter size at the LOAEL of 250 mg a.e./kg bw/d with a corresponding NOAEL of 25 mg a.e./kg bw/d. The large difference (10X) between the NOAEL and LOAEL introduces uncertainty in the interpretation of potential effects from exposures above the NOAEC.

Food consumption of adult honey bees was significantly reduced by 26% following 10 days oral exposure to triclopyr ACID at 22.3 µg a.e./bee/d. At the next highest dose level (33.4 µg a.e./bee/d), adult bee mortality increased 35% relative to controls. The overall NOAEL for adult honey bees is 14.3 µg a.e./bee/d. Larval honey bees appear to be much more sensitive to chronic (repeat doses during 4-day larval development period) exposures of triclopyr ACID compared to adult honey bees. Specifically, adult emergence of larval honey bees was reduced by 17% relative to controls at 1.5 µg a.e./bee/d during the 22-d study, resulting in a NOAEL of 0.58 µg a.e./bee/d.

Terrestrial plants appear to be much more sensitive to triclopyr TEA based on the vegetative vigor study (direct foliar exposure) compared to the seedling emergence study (exposure via soil). A vegetative vigor EC_{25} of 0.0054 lb a.e./A was determined based on reductions in plant shoot length for the most sensitive dicot (sunflower; *Helianthus annuus*) while that for the most sensitive monocot (onion; *Allium cepa*) was determined as 0.119 lb a.e./A based on reductions in plant shoot weight. These endpoints are 1-3 orders of magnitude lower than the maximum registered application rate 9 lb a.e./A for triclopyr products. In contrast, EC_{25} values for seedling emergence exceeded the highest application rates tested for dicots and monocots (i.e., EC_{25}> 0.238 and > 0.715 lb a.e./A, respectively).

6.2.2   Triclopyr BEE

Triclopyr BEE exhibits similar acute and chronic toxicity to birds and mammals as triclopyr ACID/TEA in contrast to that observed for aquatic animals, where BEE was much more toxic to aquatic animals (**Table 6-2**). Triclopyr BEE is slightly to practically non-toxic to birds and mammals on an acute exposure basis (LD_{50} = 735 – 5,401 mg ai/kg-bw). No chronic toxicity study of birds was submitted for BEE active ingredient. For mammals, a 2-generation reproduction study was also not available; therefore, results from a subchronic 91-d study with rat were used for risk assessment purposes. Results from this study indicate that body weight was reduced by 25%-27% at the highest treatment level (LOAEL=350 mg a.i./kg-bw/d) depending on gender, thereby resulting in a NOAEL of 70 mg a.i./kg-bw/d. Food consumption was also reduced at 350 mg a.i./kg-bw/d but results were not statistically significant. Reduction

in food consumption may be an indication of palatability issues at the highest test dose. No toxicity data are available for the effects of triclopyr BEE on honey bees.

Based on vegetative vigor studies, triclopyr BEE appears to affect dicots and monocots at similar levels as triclopyr TEA, with EC_{25} values of 0.0089 and 0.088 lb a.i./A based on reductions in plant shoot weight in sunflowers and onions. Unlike triclopyr TEA where definitive EC_{25} values could not be determined using the seedling emergence test, EC_{25} values of 0.062 and 0.073 lb a.i./A were calculated for triclopyr BEE for the most sensitive dicot and monocot tested, respectively.

6.2.3   Degradates

The TCP degrade of triclopyr is classified as practically non-toxic to birds on an acute oral and dietary exposure basis (**Table 6-2**). For mammals, the most sensitive acute oral LD_{50} values range 380 mg a.i./kg-bw for mouse to 794 mg a.i./kg-bw for rat, placing them into the "moderately toxic" and "slightly toxic" acute toxicity categories, respectively. On an acute exposure basis, TCP appears to be of similar toxicity as the ACID and TEA to birds and mammals. Notably, however, aquatic toxicity data indicate more sensitive chronic toxicity values for TCP relative to the acute toxicity values; it is not known if this same pattern in chronic toxicity would hold for terrestrial vertebrates due the lack of additional toxicity data on TCP or any other degrade for terrestrial animals or plants. The extent to which TCP forms in terrestrial plants that serve as food sources for terrestrial animals is unknown.

6.2.4   Open Literature – ECOTOX database

A search of the public ECOTOX in 2009 yielded some studies with more sensitive (lower) toxicity endpoints than those previously used in risk assessments as well as species not previously tested. One test in particular involved testing of the Zebra finch (*Taeniopygia guttata*) (Holmes, *et al*. 1994) with triclopyr BEE. This study yielded a dietary LC_{50} of 1,923 mg ai/kg diet which is somewhat lower (more sensitive) than the Bobwhite quail LC_{50} used in this assessment (5,401 mg a.i./kg-diet). However, inadequate raw data in the article precluded statistical verification of the results. Therefore, this study is considered qualitatively in risk characterization. Additional information can be found in **Appendix D**.

Table 6-2. Terrestrial Toxicity Endpoints for Triclopyr Acid, TEA, COLN, BEE and the TCP degradate

Study Type	Test Substance (% a.i.)	Test Species	Toxicity Value[1]	MRID or ECOTOX No./ Classification	Comments (Effect at LOAEC/ LOAEL)
Birds (surrogates for terrestrial amphibians and reptiles)					
Acute Oral	Triclopyr Acid (Technical)	Mallard duck, *Anas platyrhynchos*	LD_{50} = **1,698** mg a.e./kg-bw	40346601 Acceptable	Slightly toxic

Study Type	Test Substance (% a.i.)	Test Species	Toxicity Value[1]	MRID or ECOTOX No./ Classification	Comments (Effect at LOAEC/ LOAEL)
	Triclopyr TEA (64.7)	Mallard duck, *Anas platyrhynchos*	LD_{50} = 2271 mg a.e./kg-bw	00134178 Supplemental	Practically non-toxic
	Triclopyr BEE (96.1)	Bobwhite quail, *Colinus virginianus*	LD_{50} = **735** mg a.i./kg-bw	41902002 Acceptable	Slightly toxic
	TCP Degradate	Bobwhite quail, *Colinus virginianus*	LD_{50} > 2,000 mg a.i./kg-bw	41829001 Acceptable	Practically non-toxic
Sub-acute dietary	Triclopyr acid (99)	Bobwhite quail, *Colinus virginianus*	LC_{50} = **2,934** mg a.e./kg-diet	40346403 Acceptable	Slightly toxic
	Triclopyr TEA (64.7)	Bobwhite quail, *Colinus virginianus*	LC_{50} > 7,151 mg a.e/kg-diet	40346503 Acceptable	Practically non-toxic
	Triclopyr BEE (96.1)	Bobwhite quail, *Colinus virginianus*	LC_{50} = **5,401** mg a.i./kg-diet	41905501 Acceptable	Practically non-toxic
	TCP degradate	Mallard duck, *Anas platyrhynchos*	LC_{50} > 5,620 mg a.i./kg-diet	41829002 Supplemental	Practically non-toxic
Chronic	Triclopyr acid (99)	Mallard duck, *Anas platyrhynchos*	LOAEC = 200 mg a.i./kg-diet NOAEC = **100** mg a.i/kg-diet	00031250 Acceptable	14-day old survivors (↓ 14%)
Mammals					
	Triclopyr acid	Laboratory rat, *Rattus norvegicus*	LD_{50} = **630** mg a.e./kg-bw (females)	00031940 (Acceptable)	Slightly toxic
	Triclopyr TEA salt	Laboratory rat, *Rattus norvegicus*	LD_{50} = 1,321 mg a.e./kg-bw (males and females)	41443301	Slightly toxic
Acute Oral	Triclopyr BEE	Laboratory rat, *Rattus norvegicus*	LD_{50} = **803** mg a.i./kg/bw (males and females)	40557004	Slightly toxic
	TCP Degradate	Laboratory rat, *Rattus norvegicus*	LD_{50} = 794 mg a.i./kg/bw (males)	00064938	Slightly toxic
	TCP Degradate	Laboratory mouse	LD_{50} = 380 mg a.i./kg/bw (males)	00043243	Moderately toxic
Chronic	Triclopyr acid	Laboratory rat *Rattus norvegicus*	2 gen reproductive LOAEL =250 mg a.e./kg/day NOAEL= **25** mg a.e./kg/day	43545701 (Acceptable)	28%-39%↓litter size, 29-32% ↓ body wt, and 17% ↓ litter survival
	Triclopyr BEE	Laboratory rat *Rattus norvegicus*	90-day LOAEL=350 mg a.i./kg/day NOAEL=**70** mg a.i./kg/day	42274901 (supplemental)	25-27% ↓in mean body weight
Terrestrial Invertebrates					
	Triclopyr acid (99)	Honey bee *Apis mellifera L.*	LD_{50} > **100** µg a.e./bee	40356602 Acceptable	Practically non-toxic

Study Type	Test Substance (% a.i.)	Test Species	Toxicity Value[1]	MRID or ECOTOX No./ Classification	Comments (Effect at LOAEC/ LOAEL)
Acute contact (adult)	Triclopyr BEE (97.7)	Honey bee *Apis mellifera L.*	$LD_{50} > \mathbf{100}$ µg a.i./bee	41219109 Acceptable	Practically non-toxic
	TCP Degradate	**No data**			
Acute oral (adult)	Triclopyr acid (99)	Honey bee *Apis mellifera L.*	LD_{50} =>99 µg a.e./bee	49992409 Acceptable	Practically non-toxic
Chronic oral (adult)	Triclopyr Acid	Honey bee *Apis mellifera L.*	LOAEC = 973 NOAEC = 490 mg a.e./kg diet LOAEL=22.3 NOAEL=**14.3** ug ai/bee/day	50673903 Acceptable	26% ↓ in food consumption; mortality 35% ↓ @ 33.4
Acute oral (larval)	**No Data**				
22 Day Chronic repeat dose oral (larval)	Triclopyr Acid	Honey bee *Apis mellifera L.*	LOAEL = 1.5 NOAEL = **0.58** ug a.e./larvae/day NOAEC=14.6 LOAEC = 38.4 mg a.e./kg diet	50673902 Acceptable	Adult emergence ↓ 15%
Foliage on Residue	**No Data, but data requirement not triggered by 40 CFR Part 158**				
Semi-field study or full field study	**No Data**				
Terrestrial and wetland plants					
Vegetative Vigor	Triclopyr acid	**No data, but triclopyr TEA is considered representative of the acid**			
	Triclopyr TEA (46.5)	Dicot- Sunflower, *Helianthus annuus*	EC_{25} = **0.0054** lb a.e./A	43129801 Acceptable	Shoot length
		Monocot Onion *Allium cepa*	EC_{25} = **0.119** lb a.e./A	43129801 Acceptable	Shoot weight
	Triclopyr BEE (62.2)	Dicot- Sunflower, *Helianthus annuus*	EC_{25} = **0.0089** lb a.i./A	43650001 Acceptable	Shoot weight
		Monocot –Onion *Allium cepa*	EC_{25} = **0.088** lb a.i./A	43650001 Acceptable	Shoot weight
Seedling Emergence	Triclopyr acid	**No data**			
	Triclopyr TEA salt (46.5)	Corn, *Zea mays*	EC_{25} >**0.238** lb a.e./A	43129801 Acceptable	Non-definitive endpoint
		Dicot (all species)	EC_{25} >**0.715** lb a.e./A	43129801 Acceptable	Non-definitive endpoint
	Triclopyr BEE (62.2)	Dicot – Alfalfa, *Medicago sativa*	EC_{25} = **0.062** lbs a.i./A	43650001 Acceptable	% emergence
	Triclopyr BEE (62.2)	Monocot – Onion, *Allium cepa*	EC_{25} = **0.073** lb a.i./A	43650001 Acceptable	Shoot weight

ACID: 3,5,6-trichloro-2-pyridinyloxyacetic acid; **BEE:** 3,5,6-trichloro-2-pyridinyloxyacetic acid, butoxyethyl ester; **TEA**: 3,5,6-trichloro-2-pyridinyloxyacetic acid, triethylamine salt; **COLN**: 2-[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid, and, choline salt; **TCP**: 3,5,6-trichloro-2-pyridinol.
TGAI=Technical Grade Active Ingredient; TEP= Typical end-use product; a.i.=active ingredient
[N] Studies submitted since the problem formulation was completed are designated with an N associated with the MRID number.
[1] NOAEC and LOAEC are reported in the same units.
>Greater than values designate non-definitive endpoints where no effects were observed at the highest level tested, or effects did not reach 50% at the highest concentration tested (USEPA, 2011).
< Less than values designate non-definitive endpoints where growth, reproductive, and/or mortality effects are observed at the lowest tested concentration.

6.3 ECOSAR Analysis

An analysis of triclopyr parent and degradate acute and chronic aquatic toxicity was conducted using ECOSAR (v.2.0 2017) and is presented in **Table 6-3** and **Table 6-4**, respectively. The purpose of this analysis is to help in the identification of which degradates should be included as residues of concern. The first step in this analysis is to evaluate the reliability of ECOSAR predictions using available toxicity data (shown in bold in the tables below). If ECOSAR predicted toxicity is within a reasonable range of actual toxicity data (*e.g.*, within 10X), then the level of confidence in ECOSAR predictions for substances with no toxicity data is increased. The ECOSAR chemical class used for this analysis are:

- Triclopyr ACID and 3-Chloro,5,6-dihydroxy-2-pyrindinyl)oxy]acetic acid: (Halopyridines – acid);
- Triclopyr BEE: (Esters); and
- TCP, 3,6-DCP, 5-CLP, 6-CLP degradates: (Phenols)

With respect to acute toxicity, ECOSAR predictions with the ACID, BEE, and TCP degradate are within an order of magnitude of measured toxicity data (**Table 6-3**). For the ACID and TCP, ECOSAR predictions are lower (more sensitive) than measured values, while for the BEE active ingredient they are higher (less sensitive) than measured values. Therefore, it is concluded with confidence that ECOSAR predictions within an order of magnitude of actual values if measured. There were no predicted values from ECOSAR for aquatic algae for the ACID.

The remaining predictions of toxicity for degradates that have no measured toxicity data are generally an order of magnitude more toxic than the ACID (2 orders for 3,6-DCP daphnid toxicity), for aquatic animals. For aquatic plants the degradates are predicted to be about one order of magnitude less toxic than BEE along with 3,6-DCP toxicity for daphnids. All other endpoints are predicted to be about two orders of magnitude less sensitive for the degradates relative to BEE. Therefore, the acute toxicity ECOSAR analysis supports the inclusion of these major degradates in the ROC for the ACID/TEA/COLN active ingredients, but not for triclopyr BEE, since they are at least 1 order of magnitude less toxic than BEE.

Table 6-3. Comparison of acute ecological toxicity endpoints with estimated endpoints using ECOSAR predictions (in parentheses).

Test Material	FW Fish 96 Hr	Daphnid 48 hr	Aquatic Algae 96 hr
ECOSAR predictions for substances with toxicity data			
Triclopyr Acid	**117 ppm** (18.34 ppm)	**132.9 ppm** (13 ppm)	**32.5 ppm** (None)
Triclopyr BEE	**0.36 ppm** (3.18 ppm)	**0.35 ppm** (5.3 ppm)	**0.1 ppm** (1.6 ppm)
TCP Degradate	**12.5 ppm** (5.5 ppm)	**10.4 ppm** (2.7 ppm)	**2.0 ppm** (0.502 ppm)
ECOSAR predictions for major degradates without toxicity data			
3,6-DCP*	12.6	6.42	1.12
3-Chloro,5,6-dihydroxy-2-pyrindinyl)oxy]acetic acid**	34.4	20.1	None
5-CLP, 6-CLP***	27.6	10.5	2.4

ppm=parts per million (mg/L)
* Highest % formation is 52%
** Highest % formation is 29%
***Highest % formation is 26%

With respect to chronic toxicity, ECOSAR predictions are again within an order of magnitude of measured chronic toxicity values for triclopyr BEE (ester SAR) and the TCP degradate (phenol SAR), suggesting reasonable reliability using these ECOSAR classes (**Table 6-4**). However, the ECOSAR predictions of chronic toxicity are 100X more toxic than measured values for the ACID active ingredient. This suggests that the ECOSAR predictions of chronic toxicity are not reliable for chemicals that have a similar structure/MOA as the ACID active ingredients (*e.g.,* those modeled with the halopyridine acid SAR, which include the ACID and 3-Chloro,5,6-dihydroxy-2-pyrindinyl)oxy]acetic acid). For aquatic animals, the remaining degradates are predicted to be 2-3 orders or magnitude more sensitive than the ACID but 1-2 orders of magnitude less sensitive than the BEE. Therefore, the chronic toxicity ECOSAR predictions also support the inclusion of these major degradates into the ROC for the ACID but not for the BEE.

Table 6-4. Comparison of chronic ecological toxicity endpoints with estimated endpoints using ECOSAR predictions (in parentheses).

Test Material	Fish Chronic	Daphnia Chronic
ECOSAR predictions for substances with toxicity data		
Triclopyr ACID/TEA	**117 ppm** (3.34 ppm)	**104 ppm** (0.408 ppm)
Triclopyr BEE	**0.026 ppm** (0.157 pm)	**0.17 ppm** (2.0 ppm)
TCP Degradate	**0.178 ppm** (0.602 ppm)	**2.7 ppm** (0.489 ppm)
ECOSAR predictions for major degradates without toxicity data		
3,6-DCP*	1.29	0.748
3-Chloro,5,6-dihydroxy-2-pyrindinyl)oxy]acetic acid**	23.1	1.25
5-CLP, 6-CLP***	2.65	1.1

ppm=parts per million (mg/L); **ACID**: 3,5,6-trichloro-2-pyridinyloxyacetic acid; **BEE:** 3,5,6-trichloro-2-pyridinyloxyacetic acid, butoxyethyl ester; **TEA**: 3,5,6-trichloro-2-pyridinyloxyacetic acid, triethylamine salt.
* Highest % formation is 52%
** Highest % formation is 29%
***Highest % formation is 26%

6.4   Incident Data

The Incident Data System (IDS) provides information on the available ecological pesticide incidents, including those that have been aggregately reported to the EPA since registration to when the database was searched in May 2019. **Appendix C** provides a listing of the available incident data by active ingredient along with summaries and details on year and location and type of plants or animals observed to have been adversely affected.

The IDS has recorded over 100 individual incidents from 1990 to 2019 in which triclopyr ACID, TEA, or BEE products were applied and implicated in adverse effects. Most involved damage to non-target terrestrial and aquatic plants and were considered "probable" (direct application to affected crop or drift verified) or "possible" in their causality classification (drift suspected- no residue analysis performed). Nine incidents involved losses of honey bee hives and although triclopyr products were confirmed as having been used in nearby areas, exposures were not verified by residue analysis. In no cases were bees killed immediately, but eventually (*i.e.*, over time) hives failed. In some cases, bees displayed sublethal effects such as disorientation, failure to produce larvae or starvation. Two incidents involved fish kills near a rice field and a railroad crossing adjacent to a river. As triclopyr use was verified and drift or runoff confirmed these incidents are considered probable, but mortality was potentially from secondary effects (oxygen depletion from algae die off). In this respect, labels suggest avoidance of one-time treatment of water bodies to prevent oxygen depletion. In many of these incidents, other herbicides were also used on site or as product mixtures with triclopyr active ingredients and thus may have been contributory.

Triclopyr Active and Product Unspecified:

Seventeen incidents specify only triclopyr and do not indicate the products used.   These were placed under separate category for triclopyr product and active not specified.

Triclopyr Acid:

Four plant damage incidents involved triclopyr ACID (products identified) with three involving 1 or two other herbicides (*e.g.*, 2,4-D or glyphosate) used with the triclopyr ACID.

Triclopyr TEA:

Sixty incidents with TEA product applications were reported in IDS. Many involve plant damage to trees, shrubs, *etc.* in conjunction with lawn care products and residential uses, while others involved uses on or near rice. Many of the 25 rice incidents are crop injury complaints from weed control efforts within the crop itself which resulted in reduced yield, twisting or knotting of plants, rice tip burn and discoloration. Twenty-eight of the plant incidents were with the TEA product itself while 28 involved use as mixtures or multi-active application with dicamba, MCPA, metsulfuron, aminopyralid and 2,4-D herbicide products. Four of the TEA incidents involved bee hives near application sites, but no definitive determination has been made as to the causative agents. Additionally, a total of 1,383 incidents were reported in the aggregate as part of the IDS.

Triclopyr BEE:

Twenty-two incidents were recorded for products containing triclopyr BEE and most involved accidental non-target plant damage to ornamental bushes, trees, food crops or vineyards from spray drift when used along fence lines, utility rights-of-way, roads or aerially applied to pastureland. Eleven of the incidents resulted from usage with other herbicides such as 2,4-D, picloram, imazapyr, glyphosate, and tebuthiuron, which could also have contributed to the adverse effects observed.

An aggregation of all incidents involving triclopyr products is shown in **Table 6-5.**

Table 6-5. Triclopyr Products Aggregate Incidents from the Incident Data System (IDS)

Taxa	Number of Incidents 1995-2018
Triclopyr ACID- 2	
Vertebrate Wildlife (W-B)	0
Plant (P-B)	2
Non-vertebrate (ONT)	0
Triclopyr TEA- total 1397	
Vertebrate Wildlife (W-B)	13
Plant (P-B)	1383
Non-vertebrate (ONT)	1
Triclopyr BEE- total 67	
Vertebrate Wildlife (W-B)	8
Plant (P-B)	57
Non-vertebrate (ONT)	2

Aggregate incidents are only reported as a count-based measure. **ACID**: 3,5,6-trichloro-2-pyridinyloxyacetic acid; **BEE:** 3,5,6-trichloro-2-pyridinyloxyacetic acid, butoxyethyl ester; **TEA**: 3,5,6-trichloro-2-pyridinyloxyacetic acid, triethylamine salt.

7   Analysis Plan

7.1   Overall Process

This assessment uses a weight of evidence approach that relies heavily, but not exclusively, on a risk quotient (RQ) method. The RQs are calculated by dividing an estimate environmental concentration (EEC) by a toxicity endpoint (*i*.e., EEC/toxicity endpoint). This is a way to determine if an estimated concentration is expected to be above or below the concentration associated with the adverse effect. The RQs are compared to regulatory levels of concern (LOCs). The LOCs for non-listed species are meant to be protective of community-level effects. For acute and chronic risks to vertebrates, the LOCs are 0.5 and 1.0, respectively, and for plants, the LOC is 1.0. The acute and chronic risk LOCs for bees are 0.4 and 1.0, respectively. In addition to RQs, other available data (*e.g.*, incident data) can be used to help understand the potential risks associated with the use of the pesticide.

7.2   Modeling

Model inputs are based on a range of labeled use patterns, application scenarios, rates and other label information that best reflects typical uses of the actives assessed in this document. Various models are used to calculate aquatic and terrestrial EECs and risk quotients for these uses. The specific models used in this assessment are discussed further below (see **Table 7-1**).

Table 7-1. List of the Models Used to Assess Risk

Environment	Taxa of Concern	Exposure Media	Exposure Pathway	Model(s) or Pathway
Aquatic	Vertebrates/ Invertebrates (including sediment dwelling)	Surface and Porewater	Runoff and Spray drift	PWC version 1.52[1] PFAM version 2.0[2]
	Aquatic Plants (vascular and nonvascular)			
	Piscivorous birds and mammals	Aquatic food web	Runoff and Spray drift	KABAM version 1.0
Terrestrial	Vertebrate	Dietary items		T-REX version 1.5.2[3]
	Plants	Spray drift/runoff	Runoff and spray drift to plants	TERRPLANT version 1.2.2
	Bees and other terrestrial invertebrates	Contact Dietary items	Spray contact and ingestion of residues in/on dietary items as a result of direct application	BeeREX version 1.0
All Environments	All	Movement through air to aquatic	Spray drift	AgDRIFT version 2.1.1 (Spray drift)

Environment	Taxa of Concern	Exposure Media	Exposure Pathway	Model(s) or Pathway
		and terrestrial media		

[1] The Pesticide in Water Calculator (PWC) is a Graphic User Interface (GUI) that estimates pesticide concentration in water using the Pesticide Root Zone Model (PRZM) and the Variable Volume Water Model (VVWM). PRZM-VVWM.

[2] Pesticides in Flooded Applications Model (PFAM) is used to simulate EECs when pesticides are applied to flooded or intermittently flooded areas.

[3] The Terrestrial Residue Exposure (T-REX) Model is used to estimate pesticide concentration on avian and mammalian food items.

8 Aquatic Organisms Risk Assessment

8.1 Aquatic Exposure Assessment

8.1.1 Modeling

Surface water aquatic modeling was simulated using the Pesticide in Water Calculator (PWC version 1.52) for use patterns to terrestrial areas and the Pesticides in Flooded Applications Model (PFAM; version 2.0 dated September 27, 2016) for use on rice grown in flooded fields. Modeling was executed for the ACID ROC, and BEE and the degradate TCP. The ACID ROC modeling represents use patterns for the ACID formulation as well as TEA and COLN formulations. The degradates TCP + 3,6 DCP + 5-CLP + 6-CLP were included in the aquatic exposure modeling of the ACID using a Total Toxic Residue (TTR) approach, which assumes equivalent toxicity to ACID. As noted in Section 6, the chronic toxicity of TCP to freshwater invertebrates (*D. magna*) is much greater than the ACID or other degradates. Therefore, a separate risk analysis was conducted for TCP, the major degradate of all forms of triclopyr: the ACID, TEA, COLN and BEE. Exposure EECs for this degradate required using the formation and decline (F/D) approach in which separate EECs are calculated for TCP. Details for this exercise are included in **Appendix B**.

For BEE, the parent BEE and TCP are more toxic to aquatic animals by several 1-3 orders of magnitude compared to ACID and its other degradates (3,6 DCP + 5-CLP + 6-CLP). Therefore, modeling focused on the BEE and TCP degradate using the F/D approach, since the EECs for ACID and other degradates were confirmed to be 1-3 orders of magnitude below acute and chronic risk LOCs. Notably, the BEE does not include direct application to water as per ACID, TEA and COLN; therefore, EECs for the ACID component of BEE are well below Agency LOCs.

Table 8-1. Aquatic Modeling Input Parameters for Chemical Tab for BEE, the ACID and Triclopyr Residue of Concern (Designated with ROC)

Parameter (units)	Value (s)		Referenced MRID[1]	Comments
	BEE	ACID ROC (ACID only)		
K_d- K_{0c} (mL/g) [1]	0.611[2]	0.611- 611[3] (Same)	407498-01	Average of 4 values for the **ACID= ROC**
Water Column Metabolism t ½ (days) @ 25°C	0.8	241 (29.1)	499924-04*	Represents the 90 percent upper confidence bound on the mean (n=2)
Benthic Metabolism t ½ (days) @ 25°C	0.5	Stable (1,531)	001519-67*	For BEE: Assumed= 0.5 days[4]; For the **ACID/ROC:** Represents the 90 percent upper confidence bound on the mean (n=2)
Aqueous Photolysis t ½ (days)@ pH 5 and 40°N	6.6	0.4 (Same)	430076-01* 499924-01	One measured value for either **BEE** or the **ACID**; **ROC** value= **ACID** (Only species present)
Hydrolysis Half-life @ pH 7 (days)	9[5]	Stable (Same)	001341-74* 418796-01	One measured value for **BEE** or the **ACID**
Soil Half-life (days) at 25°C	1.0	31 (20)	472938-01* 499924-02	For BEE: Represents the 90 percent upper confidence bound on the mean (n= 4) For the **ACID/ROC:** Same
Molecular Weight (g/mol)	356.6	256.5	Chemical profile	
VP (Torr) at 25°C	3.6×10^{-6}	1.3×10^{-6} (Same)	Triclopyr ACID value/Chemical profile	
Solubility in Water (mg/L)	7.4	440 (Same)	Triclopyr ACID value/Chemical profile	
Heat of Henry (J/mol) @ 25°C	N/A[6]	54,041 (Same)	Calculated for triclopyr ACI from EPIWEB 4.1	

[1] **BEE studies** are marked with * all other studies are for the **ACID**
[2] K_d **for BEE** is assumed to be the same as the ACID based on the observed rapid conversion to the ACID
[3] 0.611-611: K_d=0.611 converted to Koc of 611 ml/g for use in PFAM modeling on the assumption that the organic carbon % equals 0.01.
[4] This is because the observed half-lives were <1 d and data could not be fitted due to the extremely rapid dissipation of BEE
[5] **Note:** The chemical is persistent to hydrolysis in acidic conditions (t ½ = 84 days); [5] No need to use PFAM (no use on rice)
[6] BEE formulation of triclopyr are not modeled with PFAM as the formulation is not used on rice

Except for the rice and aquatic use patterns, input parameters specific to the application scenario for *all other use patterns* are specified in **Table 8-2.** Based on the use information described in **Section 3.2.** It is noted that the PWC Scenarios are used to specify soil, climatic, and agronomic inputs in PRZM, and are intended to result in high-end water concentrations associated with a crop and pesticide within a geographic region. Each PWC scenario is specific to a vulnerable area where the crop is commonly grown. Soil and agronomic data specific to the location are built into the scenario, and a specific climatic weather station providing 30 years of daily weather values is associated with the location. **Table 8-2** identifies the use sites associated with each PRZM scenario.

Table 8-2. PWC Input Parameters Specific to Use Patterns for Triclopyr Residues of Concern (ROC) (Applications Tab and Crop/land Tab).

Run Name	Use Site	PWC Scenario	Application Parameters[1]		Other Parameters[2]
			Window	MSR X No.= MYR @ Days	
FL-CTRS	**Citrus (FL)**	FLcitrusSTD	1	6.73 X 1= 6.73 kg/ha @ N/A	**G=** See below
FORST-CA	**Forestry**	CAForestryRLF	1	6.73 X 1= 6.73 kg/ha @ N/A	**A=** Air/above crop: Application Efficiency (AE)= 0.95; Drift= 0.0125
Medw-TX	**Grass/Range/ Pasture land**	MeadowBSS	1	10.09 X 1= 10.09 kg/ha @ N/A	
		MeadowBSS			
Rang-CA		CArangelandhayRLF	1	10.09 X 1= 10.09 kg/ha @ N/A	
TX-ROW					
CA-ALMND	**Orchards (CA)**	CAalmond_WirrigSTD	1	6.73 X 1= 6.73 kg/ha @ N/A	**G=** Ground/ below crop: Application Efficiency= 0.99; Drift= 0.062
CA-CTRS		CAcitrus_WirrigSTD_			
CA-FRTS		CAfruit_WirrigSTD			
Res-CA	**Premises**	CAresidentialRLF/CAImpervious RLF	1	10.09 X 1= 10.09 kg/ha @ N/A	
Res-BSS		ResidentialBSS/ImperviousBSS			
Rice	**Rice**	Refer to the rice modeling parameters, below			
ROW-CA	**Right-of-Way**	CArightofwayRLF_V2/CAImpervi ousRLF	1	10.09 X 1= 10.09 kg/ha @ N/A	**G=** See above
ROW-TX		RightOfWayBSS/ImperviousBSS			
Turf-CA	**Turf**	CATurfRLF	2	1.12 X 4= 4.48 @ N/A	
Turf-FL		FLturfSTD			
Turf-PA		PAturfSTD			
Turf-TX		TurfBSS			
Christmas	**X-mass Trees**	ORXmasTreeSTD	1	6.73 X 1= 6.73 kg/ha @ N/A	**G=** See above

[1] *Application Parameters: Window*= Simulated application window using batch feature in PWC: Three windows were chosen to represent possible application timing: **Window 1**: April to September in 5-day steps for all scenarios except **Window 2** for turf scenarios from February to June in 14-day steps; These windows were chosen based on BEAD recommended timing for similar herbicides. **MSR X No.= MYR @ Days=** Maximum single application X No. of applications per year= Maximum yearly application @ Minimum application intervals (days). **Example:** The application parameters for the first use pattern: Citrus= 6.73 X 1= 6.73 @ N/A= Maximum single rate= 6.73 kg a.e./ha applied One time @ N/A minimum application interval (only one application). Note: single label application rate for citrus is given in lbs. a.e./A= 6 x 1.121= 6.73 kg a.e./ha

[2] **Other Parameters Include:** Application equipment: **A=** Aircraft; **G=** Ground equipment and associated parameters including application efficiency and drift fraction.

The input parameters, inError! Reference source not found., were selected in accordance with EFED's guidance documents (USEPA, 2009b; USEPA, 2010b; USEPA, 2012b; USEPA, 2013a; USEPA, 2013b; USEPA, 2014a; USEPA, 2014b; USEPA and Health Canada, 2013).

Since the previous ecological risk assessment was completed, new aerobic soil metabolism, aerobic aquatic metabolism, and anaerobic aquatic metabolism data are available. These new data were incorporated into the risk assessment and resulted in some changes in the aquatic modeling inputs. Additionally, it is now recommended that the daily average value be used to

calculate acute risk quotients for aquatic organisms rather than the peak value used in previous risk assessments (USEPA, 2017).

For the residential and rights-of-way uses, were executed for pervious and impervious areas. For the residential scenario simulation, 2% of the application rate was assumed to reach impervious services and the daily concentrations obtained from residential and impervious services were combined to arrive at required averages using a post-processing spreadsheet. Daily concentrations were combined using the following equation: [{daily EECs for pervious area X 0.5 "assume 50% pervious area" X 0.5 "assume 50% of the area is treated"}] + [{daily EECs for impervious area X 0.5 "assume 50% impervious area"}]. Required averages, maximum averages, and the 1-in-10-year averages were calculated (latter value is the 90th percentile values). The same process was used for the rights-of-way except that 5% of the application rate was assumed to reach impervious services.

For the rice use, aquatic modeling was conducted using PFAM. In modeling, the same PWC chemical parameters were used in addition to the following:

(1) Application rate: two application of 0.42 kg/ha each; and

(2) Application timing: Timing was chosen to abide by label directions/restrictions including: type of rice culture (pre-flood, post-flood, mixed or ratoon); post-harvest interval (PHI)= 60 days (no application 60-days pre-harvest); paddy is not drained within 20-day following application; stage of rice growth and agronomic practices related to modeled crop area. Information were obtained from labels, scenarios and the literature[13].

Based on the above, three application scenarios were established/modeled using applicable rice scenarios (**Table 8-3**).

Table 8-3. Triclopyr Modeled Rice Scenarios for Different Rice Areas, Applications, and Agronomic Practices.

Agronomic Practice	*AR[1]*	*CA[2]*	*LA[3]*	*MO[4]*	*MS[5]*	*TX[6]*
First scenario						
1st App Date (Dry field)	**17-Apr**	**29-Apr**	**31-Mar**	**21-Apr**	**18-Apr**	**26-Mar**
Flood	4-May	3-May	11-Apr	6-May	10-May	10-Apr
2nd App Date (Flooded field)	**24-Jun**	**7-Jul**	**31-May**	**29-Jun**	**20-Jun**	**27-May**
Drain	3-Sep	25-Sep	11-Aug	10-Sep	12-Sep	7-Aug
Second scenario						

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[13] URLs for information obtained from the literature for rice modeling:
https://www.lsuagcenter.com/profiles/vdartez/articles/page1489673261615
https://www.lsuagcenter.com/portals/communications/publications/agmag/archive/2009/winter/evaluation-of-stubble-height-on-ratoon-growth-in-rice
https://www.uaex.edu/publications/pdf/mp192/chapter-2.pdf
https://www.uaex.edu/publications/pdf/mp192/chapter-2.pdf

Agronomic Practice	AR[1]	CA[2]	LA[3]	MO[4]	MS[5]	TX[6]
Flood	4-May	3-May	11-Apr	6-May	10-May	10-Apr
1st App Date (Flooded field)	**17-Jun**	**30-Jun**	**24-May**	**22-Jun**	**13-Jun**	**20-May**
2nd App Date (Flooded field)	**7-Jul**	**20-Jul**	**13-Jun**	**12-Jul**	**3-Jul**	**9-Jun**
Drain	3-Sep	25-Sdryep	11-Aug	10-Sep	12-Sep	7-Aug
Third scenario [7]						
Only in Gulf Coast rice growing areas represented by TX with the following agronomic practices and flood schedule: **Shallow flood**: 25-Aug; **1st App Date (Shallow flooded field): 10-Sep; Full flood:** 15-Sep; **2nd App Date (Flooded field): 30-Sep; and Drain:** 18-Nov						

Scenarios: [1] ECO AR noWinter; [2] ECO CA Winter; [3] ECO LA noWinter; [4] ECO MO noWinter; [5] ECO MS noWinter; [6] ECO TX noWinter; and [7] Ratoon Rice, TX

For the aquatic use, modeling was executed using PWC by applying mass that would result in a peak value of 400 (Labels call for application of mass up until the concentration reaches 400 µg /L (parts per billion; ppb). This requires application of 7.803 kg/ha of direct application to the standard pond. In this run both efficiency and drift were set to equal 100% so that all mass applied reaches the standard pond (one hectare; 20,000 cubic meter volume; 2.0-meter deep water-body).

Maximum surface water EECs representing use of triclopyr ACID, TEA and COLN are presented in **Table 8-4** based on the residue of concern (ROC) and the degradate, TCP. For each use pattern, the maximum of the range of ROC EECs obtained for April to late September window was taken to represent exposure for the use patterns. Ranges of representative exposure EECs ranges represented different crop scenarios or differences in the 1st application dates. For TCP, the F/D method was used to calculate the EEC using maximum and minimum molecular formation and decline ratio obtained from varied soil and aquatic systems. Only the maximum values are shown in **Table 8-4,** while both minimum and maximum EECs are provided in **Appendix B.**

Table 8-4. Maximum Surface Water and Pore Water Estimated Environmental Concentrations (EECs) for triclopyr ACID ROC and TCP Degradate Representing the ACID, TEA and COLN Active Ingredients (Estimated Using PWC version 1.52 and PFAM).

Use Site	PWC Scenario (1st Appl. Date; Yearly Rate; Application Type)1	Chemical Species[2]	1-in-10-year Mean EECs				
			Water Column (µg/L)			Pore-Water (µg/L)	
			1-day	21-day	60-day	1-day	21-day
Aquatic Weed Control	Applied @ 400 ppb	ROC (acid equivalent= a.e.)	396	343	255	152	151
		TCP (High MFDR)	27.6	27.7	25.5	18.1	16.6
	Applied @ 2,500 ppb	ROC (a.e.)	2,480	2,140	1,590	949	943
		TCP (High MFDR)	173	173	159	113	104
	Applied @ 5,000 ppb	ROC (a.e.)	4,950	4,290	3,180	1,900	1,890
		TCP (High MFDR)	346	347	319	226	208
Citrus (FL)	FLcitrusSTD (6; 26-May; G)	ROC (a.e.)	297	242	164	99	98.2
		TCP (High MFDR)	28.6	28.2	25.3	17.7	17.6
Forestry		ROC (a.e.)	86	71.6	53.5	38	37.6

Use Site	PWC Scenario (1st Appl. Date; Yearly Rate; Application Type)[1]	Chemical Species[2]	1-in-10-year Mean EECs				
			Water Column (µg/L)			Pore-Water (µg/L)	
			1-day	21-day	60-day	1-day	21-day
	CAForestryRLF (6; 11-Apr; A)	TCP (High MFDR)	4.45	4.32	4.12	3.17	3.16
Grass: Ranger/ Pasture	RangeBSS (9; 15-May; A)	ROC (a.e.)	403	336	232	138	137
		TCP (High MFDR)	36.6	36.2	33.1	23.5	23.4
Grass: Meadow	MeadowBSS (9; 15-May; A)	ROC (a.e.)	346	289	200	118	117
		TCP (Highest MFDR)	30.9	30.5	27.9	19.9	19.7
Orchards (CA)	CAalmond_WirrigSTD (6; 11-May; G)	ROC (a.e.)	29	25.4	18.5	11	11
		TCP (Highest MFDR)	2.59	2.57	2.4	1.76	1.75
Premises	ResidentialBSS /ImperviousBSS (9; 21-May; G)	ROC (a.e.)[3]	32	26.1	18.5	12	11.9
Rice		ECO MO noWinter: ROC (a.e.)[3]	369	84	54.9	39	36.7
Rights-of-Way	RightOfWayBSS/ ImperviousBSS (9; 1-May; A)	ROC (a.e.)	259	214	147.5	89	88.7
		TCP (Highest MFDR)	23.9	23.6	21.9	15.2	15.1
Turf	TurfBSS (4; 11-Apr; A)	ROC (a.e.)	23	18.2	15	11	10.9
		TCP (Highest MFDR)	2.87	2.82	2.57	2.06	2.05
Christmas Trees	ORXmasTreeSTD (6; 24-Aug; G)	ROC (a.e.)	24	20.8	16.2	10	10.7
		TCP (Highest MFDR)	2.27	2.24	2.06	1.76	1.83

[1] **PWC Scenario** *(1st Application Date; Yearly Rate; Application Type):* Scenario (Yearly application rate in lbs. a.e/A/Year; 1st application date in the window; Ground (if A= Aerial). Example: FLcitrusSTD (6; 3-Sep; G) = FL citrus scenario with an application rate of 6 lbs. a.e/A/Year (entered 6.73 Kg a.e./ha in PWC) applied on September 3 using ground equipment

[2] **ROC (acid equivalent= a.e.)** = Residue of Concern (total concentrations in µg/L of **ACID + TCP + 3,6 DCP + 5-CLP + 6-CLP** in acid equivalent); ACID= Triclopyr acid concentrations in µg/L; TCP (Highest MFDR)= TCP degradate concentrations in µg/L based on the highest molecular formation and decline ratio obtained from varied soil and aquatic systems[14]

[3] **For rice,** concentrations of the residue of concern in µg/L of **ACID + TCP + 3,6 DCP + 5-CLP + 6-CLP** in acid equivalent were only estimated and due to the low ROC concentrations, no values were estimated for the ACID or TCP because F/D method cannot be used in PFAM

Finally, maximum surface water EECs representing use of triclopyr BEE and its degradate, TCP are presented **Table 8-5.** Additional details including minimum and ACID EECs resulting from BEE application are provided in **Appendix B.**

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[14] Estimated according to the formation and decline method guiding principles presented in Attachment 2 for Methods for Assessing Aquatic Exposure to Residue(s) of Concern, EFED division Director Memo dated June 20, 2019

Table 8-5. Maximum Surface and Pore Waters Estimated Environmental Concentrations (EECs) for the BEE and TCP Representing the Use of BEE Form of Triclopyr (Estimated Using PWC version 1.52)

Use Site	PWC Scenario (1st Application Date; Yearly Rate; Application Type)[1]	Chemical Species [2]	1-in-10-year Mean EECs				
			Water Column (µg/L)			Pore-Water (µg/L)	
			1-day	21-day	60-day	1-day	21-day
Citrus (FL)	FLcitrusSTD (8.342; 26-May; G)	BEE	140	11.30	3.94	5.4	0.33
		TCP (Highest MFDR)	20.5	20.2	18.2	12.7	12.6
Forestry	CAForestryRLF (8.342; 4-Aug; A)	BEE	47	6.33	2.46	2.4	0.25
		TCP (High MFDR)	2.61	2.57	2.44	2.00	2.02
Grass: Range/ Pasture/Non-Crop Lands	RangeBSS (12.512; 15-May; A)	BEE	267	28.00	9.79	3.2	0.48
		TCP (High MFDR)	26.2	25.9	23.7	16.8	16.7
Grass: Meadow	MeadowBSS (12.512; 15-May; A)	BEE	264	27.50	9.64	2.8	0.43
		TCP (High MFDR)	22.3	22.0	20.1	14.3	14.2
Premises	ResidentialBSS/ImperviousBSS (12.512; 21-May; G)	BEE[3]	10	0.90	0.30	0.1	0.13
Rights-of-Way	RightOfWayBSS/ImperviousBSS (12.512; 21-May; A)	BEE[3]	57	6.64	2.41	0.8	0.12
Turf	TurfBSS (5.561; 11-Apr; A)	BEE	9.3	1.50	0.97	0.12	0.03
		TCP (High MFDR)	2.06	2.03	1.86	1.49	1.48
Christmas Trees	ORXmasTreeSTD (8.342; 24-Aug; G)	BEE	22	2.32	0.81	0.24	0.05
		TCP (High MFDR)	1.88	1.82	1.57	1.31	1.38

[1] *PWC Scenario (1st Application Date; Yearly Rate; Application Type):* Scenario (Yearly application rate in lbs. a.i./A/Year (a.i is BEE active ingredient noting that a.i values used in modeling were in Kg a.i./ha) ; 1st application date in the window; Ground (if A= Aerial). **Example**: FLcitrusSTD (6; 3-Sep; G) = FL citrus scenario with an application rate of 8.34 lbs. a.i./A/Year (entered 9.35 kg a.i./ha) applied on September 3 using ground equipment: Note: BEE Label gave application rate= 6 lbs. a.e = 6 lbs. x (M. Wt. of BEE divided by M. Wt. of ACID)= 6 lbs. of BEE or a.i x (356.6 divided by 256.5) = 8.34 lbs. of BEE or a.i/A entered 9.35 kg a.i/ha in PWC (8.34 x 1.121= 9.35)

[2] **BEE** = Concentrations in µg/L of BEE; **ACID=** Triclopyr acid concentrations in µg/L; **TCP** (Highest MFDR)= TCP degradate concentrations in µg/L based on the highest Molecular formation and decline ratio obtained from varied soil and aquatic systems per the aforementioned 2019 guidance.

[3] **BEE** = Concentrations in µg/L of BEE were only estimated and due to the **low BEE** concentrations, no values were estimated for the **ACID or TCP**

8.1.2 Monitoring

The following databases and sources were searched for monitoring information on triclopyr in June 2019:

- Water Quality Portal[15]

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[15] https://www.waterqualitydata.us/

- California Environmental Data Exchange Network (CEDEN) (State Water Resources Control Board, 2015)[16]
- California Department of Pesticide Regulation Surface Water Database (CAdpr)[17]
- Litrature[18]

Surface Water

Though not targeted, monitoring data are available for triclopyr with specified limits of detection/quantification (LOD/LOQ). Nearly 100% of the data obtained from the State of California and at the national level were associated with LOQs of <1 ppb. Data were for surface water, ground water, potable water intakes, and finished/treated water. Collected data may not be considered as targeted data as none were obtained from a field study in which sampling occurring after a known triclopyr application at a known location, with a well-described relationship to the sampling event. Sampling were collected without consideration of triclopyr use patterns, *i.e.*, the data represent non-targeted monitoring. Furthermore, most of the sampling frequencies were in 1-6 months followed by 1 week to a month with only few occurring one-week apart. As a result, the likelihood of capturing peak exposure is expected to be low. **Table 8-6** contains a summary of California data.

Table 8-6. California Surface Water Monitoring Data for Triclopyr

Sites: Counties & Water Body Type (Reference No.)	Monitoring Period (Month-Y)	No. of Sites (Samples)	Sampling Frequency	Maximum/Range Concentrations (ppb)	Detection Frequency
Aquatic Sites (Reference No. 2)					
Aquatic: Aquatic monitoring program	Jul-03-Aug-03	8 (1)	Irregular	250	13%
Urban Sites: Creeks and Streams (Reference No's. 3 & 4)					
Sacramento	2008- 2011	12 (NR)	24 hrs. after rainfall (Oct-Apr) & during dry season (May-Sep)	6.8 (wet season) and 1.5 (dry season)	40%
San Francisco Bay	2008- 2011	7 (NR)			65%
Orange County (4)	2008- 2011	11 (NR)			82%
Sacramento	Apr -16- Jun-17	1 (3)	6-8 Months	0.09- 1.4	100%
San Diego	Apr-08- Jun-17	2 (15)	1-10 Months	0.05- 0.27	33%
Los Angeles (3)	Aug-15- Jun-17	1 (4)	2-10 Months	0.13	25%
Other Areas: Drains, Creeks, Rivers & Lakes (Reference No's. 2 & 3)					
Alameda: Drainage	Apr-08- May-10	3 (30)		0.2- 0.3	40-70%
Alameda: Creek/Streams	Apr-08- Jun-17	2 (16)		0.11- 1.00	56%
Alpine: River	Jun-94- Jun-17	1 (3)		0.0- 0.79	0%
Amador: Drainage	Sep-04- Aug-12	1 (23)		1.10	4%

[16] http://www.ceden.org/
[17] http://www.cdpr.ca.gov/docs/emon/surfwtr/surfdata.htm
[18] M. P. Ensminger, R. Budd, K. C. Kelley and K. S. Goh 2013. *Pesticide occurrence and aquatic benchmark exceedances in urban surface waters and sediments in three urban areas of California, USA, 2008–2011;* Environ Monit. Assess (2013) 185: 3697–3710

Sites: Counties & Water Body Type (Reference No.)	Monitoring Period (Month-Y)	No. of Sites (Samples)	Sampling Frequency	Maximum/Range Concentrations (ppb)	Detection Frequency
Calaveras: Creek	Jul-03- Aug-03	2 (8)		7.50- 15.00	38%
Colusa: Drainage	Mar-98- Jun-13	2 (55)		5.64- 14.5	81-100%
Contra Costa: Drainage	Apr-08- Aug-09	2 (16)		0.2- 0.3	63-88%
Contra Costa: Creek/Streams	Apr-08- Jun-17	4 (17)		0.09- 12.70	76%
Contra Costa: River	Apr-11- May-12	1 (20)		0	0%
Contra Costa: Others such as canals	Apr-11- May-12	7 (96)		0	0%
Del Norte, CA: Creek	May-99- Jul-16	9 (70)		0.12- 1.06	27%
Imperial: River	Mar-13	1 (1)		0.16	100%
Inyo: River	Mar-04- Mar-04	2 (2)		0.07	50%
Kern: Others	Jun-13- Jun-14	2 (6)		0	0%
Kings: Others	Mar-14- Jun-14	1(2)		0	0%
Los Angeles: Creek/Streams	May-04- Jun-17	3 (24)		0.06- 0.35	71%
Los Angeles: River	Jun-15- Jun-17	2 (9)		0.14- 0.20	33%
Los Angeles: Others	Jul-99	1 (1)		0	0%
Orange: Drainage	Apr-08- Jun-17	9 (243)	**For Drains:** Irregular: <1 Wk. (13%); 1 Wk-1 Month (9%); 1-6 Months (71%); 6 Months-Year (6%); and >Year (2%)	0.5- 6.4	62-100%
Orange: Drainage: Creek/Streams	Apr-08- Jun-17	2 (35)		0.05- 1.50	97%
Orange: Drainage: River	Oct-96- Apr-00	2 (37)		0	0%
Placer: Drainage	Apr-08- Jun-17	6 (97)		0.0- 3.5	0-73%
Placer: Drainage	Oct-98- Jun-17	5 (37)		0.06- 0.42	46%
Placer: Drainage	Aug-11- Jun-12	2 (8)		0.08- 2.98	88%
Placer: Drainage	Aug-98- Aug-98	2 (2)		0	0%
Riverside: River	Oct-96- Mar-18	1 (136)		0.09- 0.34	13%
Sacramento: Drainage	Aug-09- Apr-17	6 (71)		0.1- 2.5	31-60%
Sacramento: Creek	Nov-96- Apr-16	3 (89)		0.09- 0.46	21%
Sacramento: River	Dec-96- Feb-18	5 (153)		0.12- 0.62	7%
Sacramento: Others	May-14	1 (1)		0	0%
San Bernardino: Creek	Nov-97- May-04	3 (11)	**For creeks, Rivers & Lakes:** Irregular: <1 Wk. (35%); 1 Wk-1 Month (38%); 1-6 Months (21%); 6 Months-Year (2%) and >Year (4%)	0	0%
San Bernardino: River	Mar-04- Mar-04	1 (1)		0.06	100%
San Bernardino: Others	May-04- Jun-14	2 (4)		0	0%
San Diego: Drainage	Apr-08- Aug-09	5 (18)		0.0- 0.1	0-25%
San Diego: Creek	Feb-01- Jun-17	1 (4)		0	0%
San Diego: River	Feb-01- Jun-17	2 (17)		0	0%
San Diego: Lake	Apr-08- Aug-09	2 (7)		0	0%
San Diego: Others	Jun-02- Jun-06	4 (33)		0	0%
San Joaquin: Drainage	Sep-04- Sep-08	2 (39)		0.0- 1.7	0-19%
San Joaquin: River	Mar-93- Feb-18	1 (158)		0.09	1%
Stanislaus: Drainage	Jun-94- Aug-12	4 (18)		0.00	0%
Stanislaus: creek	Mar-93- Mar-17	4 (99)		0.03- 0.04	4%
Stanislaus: River	Dec-93- Jul-94	4 (24)		0	0%
Stanislaus: Others	Jun-94- Oct-08	3 (27)		0	0%
Stanislaus: Irrigation Water	Jul-04- Jul-08	1 (14)		1.10	1.10
Sutter: Drainage	Nov-96- Aug-12	3 (39)		0-6.4	0-74%
Monterey: Drainage	Mar-14- Mar-14	1 (1)		0.14	100%
Yolo: Drainage	Nov-96- Aug-12	1 (48)		5.20	15%

Sites: Counties & Water Body Type (Reference No.)	Monitoring Period (Month-Y)	No. of Sites (Samples)	Sampling Frequency	Maximum/Range Concentrations (ppb)	Detection Frequency
Merced; Modoc; Siskiyou; Solano, Yolo & Yuba, CA: Drainage	Mar-93- Jul-16	17 (107)		No Detects	
Tuolumne, El Dorado, Humboldt, Merced, Santa Barbara/Clara & Tulare: Creeks	Jun-94- Jun-17	13(22)		No Detects	
El Dorado, Mariposa, Merced, Nevada, Santa Clara, Sutter & Tulare: Mixed	Mar-93- Aug-14	17(110)		No Detects	
El Dorado, Mariposa & Tulare: Mixed (3)	Aug-98- Nov-13	7 (10)		No Detects	
California Central Valley: Irrigated Land Program	Jul-03- May-12	21 (258)	Irregular	0.14-11	62%
San Francisco Bay: Suisun Bay monitoring project (2)	Apr-11- May-12	6 (130)	Irregular	0.1	1%

ppb=parts per billion; µg/L, NR= Not reported

Data in **Table 8-6** show an observed concentration of 250 ppb reported for one out of 8 aquatic samples possibly reflecting direct applications for aquatic weed control some time before sampling. High treatment concentrations are expected as it is required for effective aquatic weed control. Observed concentrations in urban areas[4] are related to run-off and range from 1.5 ppb during the dry season and 6.8 ppb 24 hours after rainfall. These values are not far from modeled EECs for California turf (15 and 11 ppb for 1-d and 60-d averages) if exposure in these urban areas are related only to use on turf. Although watersheds for these study areas were selected so as to exclude agriculture, exposure contributions from applications to rights-of-way and forested sites may not be excluded. No related triclopyr usage data were reported in this study.

The bulk of triclopyr monitoring data are for drains, creeks, streams, rivers and lakes (**Table 8-6**). **Figure 8-1** depicts the distribution of the data (no. of sites/samples) between various types of water bodies as well as the observed overall triclopyr detection frequencies. This figure indicates that triclopyr was most frequently detected in samples from drainage (49% detection frequency) and urban sites (41% detection frequency). It should be noted however, that detection frequency is one measure and should be viewed along with the extent to which those detections exceeded the limit of quantification. For this, the maximum and range of detected concentrations in **Table 8-6** should be considered.
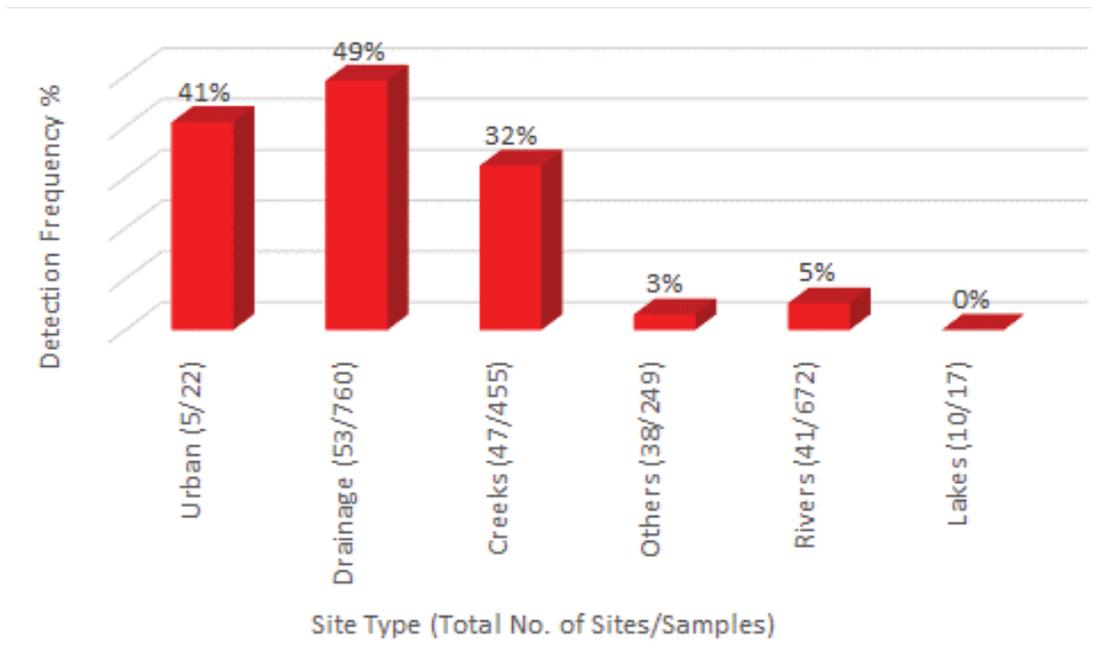
Figure 8-1. Observed Triclopyr Detection Frequencies in Various California Water Bodies

Finally, **Figure 8-2** contains detected concentrations of triclopyr in California surface waters with time from 1977 to end of 2016.

Figure 8-2. Monitored Concentrations of Triclopyr in California Surface Waters (1997-2016)

Data in **Figure 8-2** suggest the following:

(1) The frequency of low concentration detections appears to be higher in more recent years. This may be related to the increase in sensitivity of instrumentation to detect lower concentrations (low LOQ values).

(2) Although no apparent trend in observed concentrations with time there is an indication of detecting of lower concentration in recent years. This may be related to reported decline in triclopyr usage from 1.3 to 0.9 million lbs./year on its main uses (pasture and hay) from the year 2005 to 2016[19].

(3) Most of the observed concentrations were in the range of 0.01 (near the LOQ) to 1 ppb;

(4) Concentrations ranging from 1 to 15 ppb were sporadic and generally between 1 and 5 ppb;

(5) Relatively higher concentrations and frequency of detections were in urban areas, drains, creeks and streams as opposed to rivers;

(6) Low concentrations and frequencies of detections were observed in rivers and lakes possibly due to dilution;

(7) There was a relatively high frequency of detections in drains associated with rice production areas (*e.g.*, Colusa basin drain with detected concentrations of 5.6 to 14.5 ppb).

With the exception of rice, modeled concentrations for California scenarios were in the range of 12 to 99 ppb for the 1-day averages and 5 to 38 ppb for the 60-day averages. These modeled values are not far from concentrations detected at monitoring sites as they are within one order of magnitude for the 1-day average and the 60-day averages. However, it is important to note that modeled concentrations are for triclopyr residues of concern (ROC= ACID + TCP + 3,6 DCP + 5-CLP and 6-CLP degradates) while monitored concentrations were for triclopyr ACID alone. Fate data indicate that TCP + 3,6 DCP + 5-CLP and 6-CLP degradates are significant constituent of the triclopyr ROC (*i.e.,* the observed TCP maximum concentration alone represent 33% in aquatic systems and 54% of applied residues in aerobic soil systems). Modeled concentrations for rice are high because it represents concentrations in the rice paddy which are expected to decrease in surface waters outside the rice paddy due to dilution and possible degradation during the 20-day holding period and following release.

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[19] URL for USGS Estimated annual agriculture use of triclopyr:
https://water.usgs.gov/nawqa/pnsp/usage/maps/show_map.php?year=2016&map=TRICLOPYR&hilo=L&disp=Triclopyr

Monitoring data at the national level were also extensive in time (1993 to late 2018) and coverage; of the 38,172 samples there were 738 sites with detects. Data are characterized by low LOQs: 59% in the range of 0.01-0.10 ppb and 33% in the range of 0.1-0.5 ppb. While most of the data are not considered as targeted to triclopyr use sites/times, the data appear to reflect triclopyr use on rice in California. Frequency of sampling is distributed between few at 7-days, most at monthly intervals and some at intervals as high as several years. A summary of available data is included in **Table 8-7.**

Table 8-7. Nationwide Surface Water Monitoring Data for Triclopyr.

Water Body	Monitoring Dates (M-Year)	Monitored Sample Distribution			Detection Frequency	No. of Site with Detects	Max Observed Concentration (ppb)
		Non-detects	Detects	Total			
Drains	Mar-93- Oct-18	1,197	57	1,254	5%	19	14.1
Creeks & Streams	Aug-83- Nov-18	14,609	1,779	16,388	11%	389	16.0
Sewage Treatment Plants (STP)	Jul-10- Nov-10	188	9	197	5%	8	3.9
Rivers	Apr-92- Nov-18	17,146	1,440	18,586	8%	264	12.4
Canals	May-12- Oct-18	401	29	430	7%	16	13.0
Others	Mar-94- Sep-18	1,089	25	1,114	2%	14	11.0
Lakes	Aug-01- Jul-18	1,778	125	1,903	7%	17	0.7
Estuaries	Jun-94- Oct-18	268	5	273	2%	5	0.2
Springs	Jun-93- Aug-18	1,291	4	1,295	0%	4	0.1
Wetlands	Mar-93- Aug-17	205	2	207	1%	2	0.1
Overall	Aug-83- Nov-18	38,172	3,475	41,647	8%	738	0.1- 16.0

Data in **Table 8-7** indicate that the range of maximum observed concentration is as low as 0.1 ppb and as high as 16 ppb. Higher concentrations were observed in drains, creeks/streams, canals and rivers with lower concentrations in sewage treatment plant (STP) discharged waters, springs, wetlands and estuaries. Detections were observed in 738 sites with an overall detection frequency of 8%.

Figure 8-3 provides a summary of detected concentrations of triclopyr in surface waters with time from 1993 to end of 2018. Conclusions stated previously for California monitoring data are similar to those that may be obtained from data at the national scale. However, the number of detections in larger bodies of water (rivers) appears to be frequent and at higher concentrations.
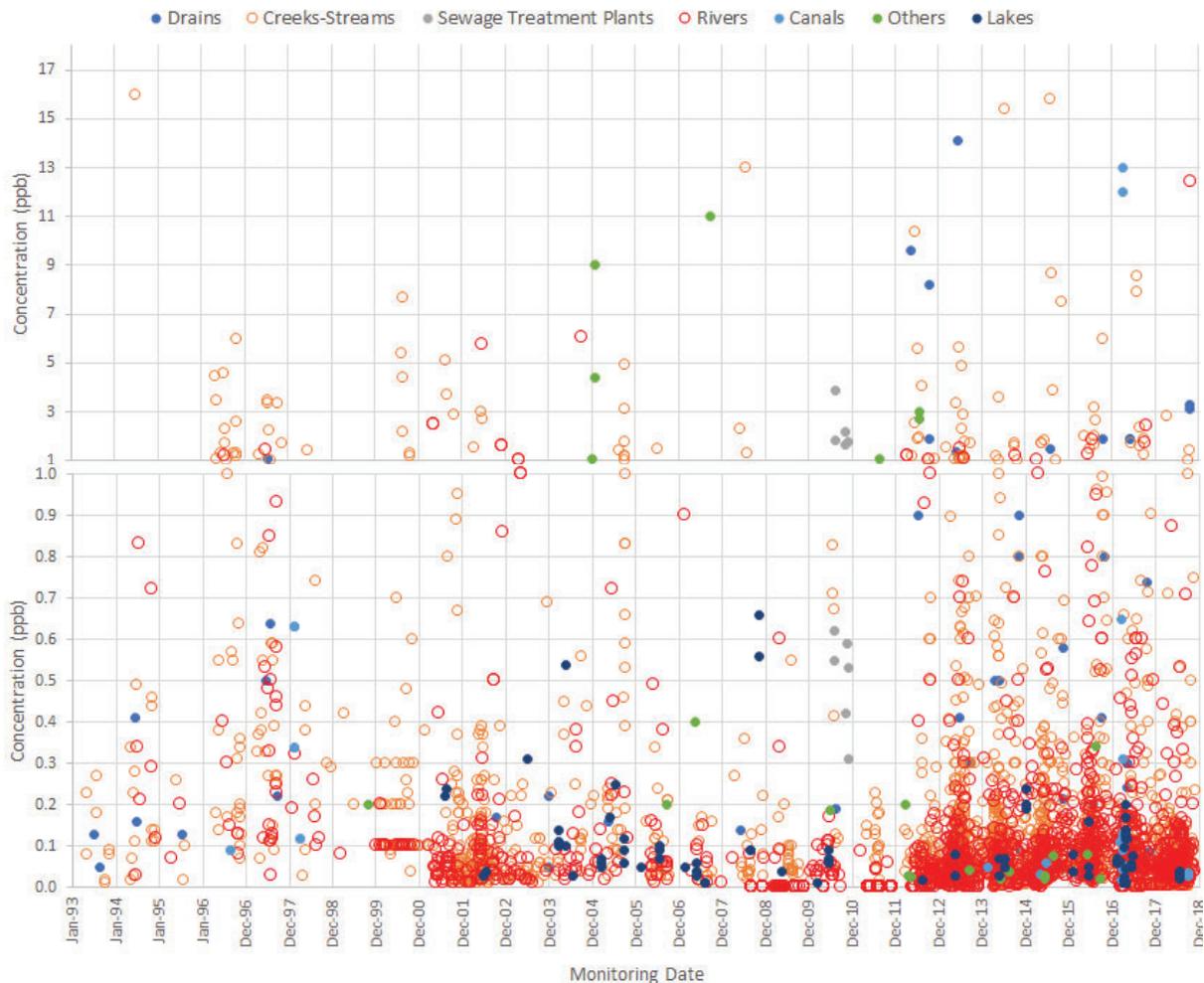
Figure 8-3. Monitored Concentrations of Triclopyr in California Surface Waters (1993-2018)

8.2 Aquatic Organism Risk Characterization

Aquatic RQs for triclopyr acid residues of concern (ROC) representing ACID, TEA and COLN active ingredients) and triclopyr BEE are based on the maximum EECs within each use scenario divided by the most sensitive toxicity value for each of the two groups of triclopyr active ingredients. In addition, since the TCP degradate is several orders of magnitude more toxic than other chemical components of the ROC, separate EECs are calculated for TCP and compared to the most sensitive TCP toxicity values in **Table 6-1**. For triclopyr BEE, aquatic risks are estimated BEE and TCP after confirming that the EECs for the ACID component are 1-3 orders of magnitude below Agency LOC values. The EECs for the ACID component of triclopyr BEE are shown in **Appendix B**.

8.2.1 Aquatic Vertebrates

The potential for acute and chronic risks to freshwater fish (used as a surrogate for aquatic-phase amphibians) or estuarine/marine fish is considered low for the ACID, TEA and COLN active ingredients of triclopyr based on the ROC EECs (ACID+TCP; 3,6-DCP; 5-CLP and 6-CLP) modeled using the Total Residue method (**Table 8-8**). This determination is based on the maximum exposure scenario (direct application to water at 5,000 ppb) with the resultant acute and chronic RQs all being below their LOCs of 0.5 and 1.0, respectively. Therefore, all other exposure scenarios which presented reduced ROC EECs from this highest exposure scenario would also result in acute and chronic RQs below their respective LOCs.

In contrast to the ROC, which assumes equal toxicity among the ACID and degradates (including TCP), a potential for chronic risk to freshwater fish is indicated for the highest aquatic use rate (5,000 ppb) based the more toxic TCP degradate which was separately modeled using the formation/decline (F/D; **Table 8-8**). This 60-d EEC for TCP (319 µg a.i./L) slightly exceeds the LOAEC of 278 µg a.i./L from rainbow trout chronic study, which reflects a 3% and 6% reduction in mean length and weight of fish. No other modeled uses of triclopyr ACID, TEA, of COLN result in exceedances of the acute or chronic risk LOCs.

Table 8-8. Triclopyr Acid Acute and Chronic Risk Quotients (RQs) for Non-Listed Fish Species Applicable to the ACID, TEA and COLN Triclopyr Active Ingredients

Use Sites/ Use scenario	1-in-10 Yr EEC Max (µg/L)		Risk Quotient			
			Freshwater Fish		Estuarine/Marine Fish	
	Daily Mean	60-day Mean	Acute	Chronic	Acute	Chronic
			LC_{50} = 117,000 µg a.e./L	NOAEC = 74,400 µg a.e./L	LC_{50} = 93,000 µg a.i./L	No Data
Residue of Concern[1]						
Aquatic: Weed Control-Applied at 5,000 ppb	4950	3180	0.04	0.04	0.05	
TCP Degradate[2]						
	Daily Mean	60-day Mean	Acute	Chronic	Acute	Chronic
			LC_{50} = 12,600 µg a.i./L	NOAEC = 178 µg a.i./L	LC_{50} = 58,400 µg a.i./L	NOAEC = 825 µg a.i./L[3]
Aquatic: Weed Control-Applied at 5,000 ppb	346	319	0.03	**1.8**	<0.01	0.39

ppb=parts per billion; µg/L. **Bold RQ** = exceeds acute or chronic risk LOC of 0.5 or 1.0, respectively.
The toxicity endpoints listed in the table are those used to calculate the RQ.
[1] Aquatic estimated environmental concentrations (EECs) for the ROC are from **Table 8-4** based on residues of concern via Total Residue method (ACID; TCP; 3,6-DCP; 5-CLP and 6-CLP) expressed as acid equivalents (ug a.e./L).
[2] Aquatic estimated environmental concentrations (EECs) for TCP are from **Table 8-4** based on TCP (ug a.i./L) via the F/D method.
[3] NOAEC estimated using acute-to-chronic ratio (see **Table 6-1**)

Risk concerns associated with modeled uses of triclopyr BEE are limited to the two uses with the highest EECs; **Table 8-9)**. Specifically, acute RQ values exceed of the acute risk LOC for fish

are Range/Pasture Land and Meadow uses (RQs range from **0.59-0.74**). No exceedances of the chronic risk LOC of 1.0 for fish are indicated with the modeled uses of triclopyr BEE nor are acute risks indicated or any other modeled uses. Model results for the TCP degradate also indicate no exceedance of acute or chronic risk LOCs (0.5 and 1.0, respectively).

Table 8-9. Triclopyr BEE And TCP Acute and Chronic Risk Quotients (RQs) for Non-Listed Fish Species Applicable to the BEE Active Ingredient.

Use Sites or Use scenario	1-in-10 Yr EEC (µg/L)		Risk Quotient			
			Freshwater Fish		Estuarine/Marine Fish	
	Daily Mean	60-day Mean	Acute	Chronic	Acute	Chronic estimated
			LC_{50} = 360 µg a.i./L	NOAEC =26 µg a.i./L	LC_{50} = 450 µg a.i./L	NOAEC = 18 µg a.i./L (ACR)
BEE[1]						
Grass: Range/ Pasture land	267	9.8	**0.74**	0.38	**0.59**	0.54
Grass: Meadow	264	9.6	**0.73**	0.37	**0.59**	0.54
TCP Degradate[2]						
	Daily Mean	60-day Mean	Acute	Chronic	Acute	Chronic estimated
			LC_{50} = 12,600 µg a.i./L	NOAEC = 178 µg a.i./L	LC_{50} = 58,400 µg a.i./L	NOAEC = 825 µg a.i./L[3]
Grass: Range/ Pasture land	26	24	<0.01	0.13	<0.01	0.03
Grass: Meadow	22	20	<0.01	0.11	<0.01	0.02

Bolded RQ values exceed the acute risk to non-listed species level of concern (LOC) of 0.5 or the chronic risk LOC of 1.0. The toxicity endpoints listed in the table are those used to calculate the RQ.

[1] Aquatic estimated environmental concentrations (EECs) are from **Table 8-5** and are based on BEE residues modeled via the F/D method.

[2] Aquatic estimated environmental concentrations (EECs) for TCP are from **Table 8-5** based on TCP (ug a.i./L) modeled via the F/D method.

[3] NOAEC estimated using acute-to-chronic ratio (see **Table 6-1**)

8.2.2   Aquatic Invertebrates

The potential for acute and chronic risks to freshwater and estuarine/marine invertebrates is considered low for the ACID, TEA and COLN active ingredients of triclopyr based on the ROC EECs (ACID+TCP; 3,6-DCP; 5-CLP and 6-CLP) modeled using the Total Residue method (**Table 8-10**).). This determination is based on the maximum exposure scenario (direct application to water at 5,000 ppb) with the resultant acute and chronic RQs all being below their LOCs of 0.5 and 1.0, respectively. Therefore, all other exposure scenarios which presented reduced ROC EECs from this highest exposure scenario would also result in acute and chronic RQs below their respective LOCs.

When exposure to the TCP degradate was modeled for the registered uses of triclopyr ACID, TEA and COLN, chronic risk concerns are identified for freshwater invertebrates only with the aquatic weed control uses with the two highest application rates (2,500 and 5,000 ppb; **Table 8-10**). Specifically, chronic RQ values of **3.0** and **6.0** are determined for the 2,500 and 5,000 ppb

aquatic uses based on a NOAEC of 58 µg a.i./L. In this study, a LOAEC of 130 µg a.i./L reproductive effects on the water flea, *D. magna* based on a 15% reduction in the number of young/female. The chronic EECs for TCP for the 2,500 and 5,000 ppb aquatic uses (173 and 346 µg a.i./L both exceed this LOAEC. At 1,500 µg a.i./L TCP, a 58% reduction in was observed the number of young/female. Therefore, the expected percent reduction in reproduction associated with the aquatic use EECs is expected to be between 15% and 58%. Acute or chronic risks concerns to freshwater or estuarine/marine invertebrates were not identified with any other modeled uses of triclopyr ACID, TEA, or COLN.

Table 8-10. Triclopyr acid acute and chronic risk quotients for aquatic invertebrates applicable to the ACID, TEA and COLN triclopyr active ingredients

Use Sites	1-in-10 Yr EEC Max (µg/L) [1]		Risk Quotient			
			Freshwater Invertebrate		Estuarine/Marine Invert.	
	Daily Mean	21-day Mean	Acute	Chronic	Acute	Chronic
			LC_{50} = 133,000 µg a.e./L	NOAEC= 57,700 µg a.e./L	EC_{50}= 41,500 µg a.e./L	NOAEC=24,400 µg a.e./L (ACR)
Residue of Concern[1]						
Aquatic: Weed Control-Applied at 5,000 ppb	4,950	4,290	0.04	0.07	0.12	0.18
TCP Degradate[2]						
	Daily Mean	21-day Mean	Acute	Chronic	Acute	Chronic estimated
			LC_{50} = 10,400 µg a.i./L	NOAEC = 58 µg a.i./L	LC_{50} = 9,300 µg a.i./L	NOAEC = 463 µg a.i./L[3]
Aquatic: Weed Control-Applied at 2,500 ppb	173	173	0.02	**3.0**	0.02	0.37
Aquatic: Weed Control-Applied at 5,000 ppb	346	346	0.03	**6.0**	0.04	0.75

ppb=parts per billion; µg/L. **Bold RQ** = exceeds the non-listed acute or chronic risk LOC of 0.5 or 1.0, respectively.
The toxicity endpoints listed in the table are those used to calculate the RQ.
[1] Aquatic estimated environmental concentrations (EECs) for the ROC are from **Table 8-4** based on residues of concern via Total Residue method (ACID; TCP; 3,6-DCP; 5-CLP and 6-CLP) expressed as acid equivalents (ug a.e./L).
[2] Aquatic estimated environmental concentrations (EECs) for TCP are from **Table 8-4** based on TCP (ug a.i./L) via the F/D method.
[3] NOAEC estimated using acute-to-chronic ratio (see **Table 6-1**)

Acute RQ values for triclopyr BEE only exceed the acute risk LOC of 0.5 for aquatic invertebrates with the Range/Pasture and Meadow uses (**Table 8-11**). In addition, chronic risk concerns to estuarine/marine invertebrates are identified for these uses in addition to Citrus. Chronic risk of BEE is driven by the sensitivity of mysid shrimp (NOAEC = 11 µg a.i./L) where a 16% reduction in mysid mean weight occurred at the LOAEC of 20 µg a.i./L. The chronic EECs from the Range/Pasture and Meadow uses (27.5 and 28 µg a.i./L) exceed the mysid LOAEC.

Table 8-11. Triclopyr BEE acute and chronic risk quotients (RQs) for non-listed aquatic invertebrates applicable to application of triclopyr BEE active ingredient.

Use Sites	1-in-10 Yr EEC (µg a.i./L) [1]		Risk Quotient			
			Freshwater		Estuarine/Marine	
	Daily Mean	21-day Mean	Acute $LC_{50} = 350$ µg a.i./L	Chronic NOAEC = 170 µg a.i./L	Acute $EC_{50} = 460$ µg ai/L	Chronic NOAEC = 11 µg a.i./L
Citrus (FL)	140	11.3	0.40	0.07	0.30	**1.0**
Forestry	47	6.3	0.13	0.04	0.10	0.6
Grass: Range/ Pasture land	267	28	**0.76**	0.16	**0.58**	**2.6**
Grass: Meadow	264	27.5	**0.75**	0.16	**0.57**	**2.5**
Residential	10	0.9	0.03	<0.01	0.02	0.08
Right-of-Way	57	6.6	0.16	0.04	0.12	0.6
Turf	9	1.5	0.03	<0.01	0.02	0.14
X-mas Trees	22	2.3	0.06	0.01	0.05	0.21

Bolded RQ values exceed the acute risk to non-listed species level of concern (LOC) of 0.5 or the chronic risk LOC of 1.0. The toxicity endpoints listed in the table are those used to calculate the RQ.
[1] Aquatic estimated environmental concentrations (EECs) are from **Table 8-5** and are based on BEE residues modeled via the F/D method.

Acute and chronic risks to aquatic invertebrates were also evaluated for the TCP degradate of triclopyr BEE using the F/D method. Acute and chronic RQ values were all below their respective LOCs of 0.5 and 1.0, indicating a low potential for risk via the formation of this degradate from the modeled uses of BEE.

Table 8-12. TCP degradate acute and chronic risk quotients for non-listed aquatic invertebrates applicable to the triclopyr BEE active ingredient

Use Sites/ Use scenario [1]	1-in-10 Yr EEC Max (µg/L) [2]		Risk Quotient			
			Freshwater Invertebrate		Estuarine/Marine Invertebrate	
	Daily Mean	21-day Mean	Acute $LC_{50} = 10,400$ µg a.i./L	Chronic NOAEC = 58 µg a.i./L	Acute $LC_{50} = 9,300$ µg a.i./L	Chronic NOAEC = 463 µg a.i./L (ACR)[3]
Citrus (FL)	20.5	20.2	<0.01	0.35	<0.01	0.04
Forestry	2.61	2.57	<0.01	0.04	<0.01	0.01
Grass: Range/ Pasture land	26.2	25.9	<0.01	0.45	<0.01	0.06
Grass: Meadow	22.3	22	<0.01	0.38	<0.01	<0.01
Turf	2.06	2.03	<0.01	0.04	<0.01	<0.01
Christmas Trees	1.88	1.82	<0.01	0.03	<0.01	<0.01

None of the RQ values exceed the acute risk to non-listed species level of concern (LOC) of 0.5 or the chronic risk LOC of 1.0. The toxicity endpoints listed in the table are those used to calculate the RQ.
[1] TCP EECs were not estimated for the residential and rights of way uses. These uses have low BEE EECs and risk concerns are not expected.
[2] Aquatic estimated environmental concentrations (EECs) for TCP are from **Table 8-5** based on TCP (ug a.i./L) modeled via the F/D method.
[3] NOAEC estimated using acute-to-chronic ratio (see **Table 6-1**)

8.2.3   Benthic Invertebrate Risk Assessment

Of the four triclopyr active ingredients, only triclopyr BEE has chemical properties (*e.g.*, log K_{ow} >3.0) that would trigger submission of sediment toxicity data. However, triclopyr BEE is expected to degrade rapidly to the acid form (metabolism half-lives $\leq$1 day), rendering the conduct of spiked sediment assays as impractical. Therefore, sediment toxicity studies were not required for triclopyr products. In lieu of sediment toxicity data, toxicity endpoints for triclopyr BEE for water column invertebrates are compared with EECs in sediment pore water, in accordance with EFED risk assessment guidance (USEPA 2014). In addition, pore water EECs for TCP formed through degradation of triclopyr BEE were also calculated and compared to invertebrate toxicity endpoints for TCP.

Although triclopyr BEE is more toxic on an acute and chronic exposure basis than the ACID and TEA active ingredients, the corresponding EECs in sediment porewater are much lower due to the greater partitioning of BEE onto sediment particles. As a result, maximum RQs for triclopyr BEE and its TCP degradate are all well below either acute or chronic risk LOCs for benthic invertebrates (**Table 8-13**).

Table 8-13. Maximum Acute and Chronic Risk Quotients (RQs) for Benthic Invertebrates Representative of the Triclopyr BEE Active Ingredient

Use Sites	21-day Pore Water EEC µg a.i./L	Risk Quotient			
		Freshwater Invertebrates		Estuarine/Marine Inverts.	
		Acute	Chronic	Acute	Chronic
		LC_{50} =350 µg a.i./L	NOAEC = 170 µg a.i./L	EC_{50}= 460 µg ai/L	NOAEC =11 µg a.i./L
BEE[1]					
Range grass/ Pasture	0.48	<0.01	<0.01	<0.01	0.04
TCP Degradate[2]					
	21-day Pore Water EEC µg a.i./L	Acute	Chronic	Acute	Chronic estimated
		LC_{50} = 10,400 µg a.i./L	NOAEC = 58 µg a.i./L	LC_{50} = 9,300 µg a.i./L	NOAEC = 463 µg a.i./L (ACR)[3]
Range grass/ Pasture	16.7	< 0.01	0.29	< 0.01	0.04

No RQ values exceed the acute risk to non-listed species level of concern (LOC) of 0.5 or the chronic risk LOC of 1.0. The toxicity endpoints listed in the table are those used to calculate the RQ.
[1] Aquatic estimated environmental concentrations (EECs) are from **Table 8-5** and are based on BEE residues modeled via the F/D method.
[2] Aquatic estimated environmental concentrations (EECs) for TCP are from **Table 8-5** based on TCP (ug a.i./L) modeled via the F/D method.
[3] NOAEC estimated using acute-to-chronic ratio (see **Table 6-1**)

8.2.4   Aquatic Plants

With aquatic plants, only the aquatic weed control scenarios at 2500 and 5000 ppb are presented (**Table 8-14**) as they represent the highest EECs. The RQs based on aquatic EECs for triclopyr ACID ROC (applicable to ACID, TEA, COLN) are below the LOC for vascular plants with all modeled uses. However, a chronic risk concern for non-vascular plants is identified for the maximum rate (5,00 ppb) based on an RQ value of **1.2**.

TCP is noted to be more toxic to aquatic plants relative to other triclopyr active ingredients. Therefore, aquatic EECs calculated for TCP using the F/D method as described Section 8.1 and compared to TCP toxicity endpoints for aquatic plants. The resulting TCP RQ values are below the LOC of 1.0 for risk to both vascular and non-vascular aquatic plants from TCP (**Table 8-15**). Therefore, despite increased toxicity of degradate TCP to aquatic plants relative to triclopyr ACID, TEA and COLN, risk estimates are still below the LOC for risk to aquatic vascular and non-vascular plants due to the lower EECs for TCP relative to triclopyr ACID ROC.

Table 8-14. Maximum Triclopyr Acid and TCP Risk Quotients (RQs) for Non-Listed Aquatic Plants Representative of the Triclopyr ACID, TEA and COLN Active Ingredients

Use Sites	1-in-10 Year Daily Mean EEC (µg/L) Triclopyr ROC (TCP)[1, 2]	Risk Quotients	
		Vascular	Non-vascular
		IC_{50} = 6,300 µg a.e./L IC_{50} =8,200 µg a.i./L (TCP)	IC_{50} =4,200 µg a.e./L IC_{50} =2,000 µg a.i./L (TCP)
Aquatic Weed Control- Applied at 2500 ppb	2480 (173)	0.39 (0.02)	0.59 (0.09)
Aquatic Weed Control- Applied at 5000 ppb	4950 (346)	0.79 (0.04)	**1.2** (0.17)

ppb=parts per billion; µg/L. **Bold RQ** = exceeds acute or chronic risk LOC of 0.5 or 1.0, respectively.
The toxicity endpoints listed in the table are those used to calculate the RQ.
[1] Aquatic estimated environmental concentrations (EECs) for the ROC are from **Table 8-4** based on residues of concern via Total Residue method (ACID; TCP; 3,6-DCP; 5-CLP and 6-CLP) expressed as acid equivalents (ug a.e./L).
[2] Aquatic estimated environmental concentrations (EECs) for TCP are from **Table 8-4** based on TCP (ug a.i./L) via the F/D method.

With triclopyr BEE, RQ values exceed the LOC for risk to non-vascular aquatic plants for selected use scenarios only (Citrus, Range/pasture land, Meadows) but not for vascular aquatic plants (**Table 8-15**). No risk concerns for the TCP degradate of triclopyr BEE are indicated for any modeled use (**Table 8-16**).

Table 8-15. Triclopyr BEE Risk Quotients (RQs) for Aquatic Vascular and Non-vascular Plant Species Representative of the Triclopyr BEE Active Ingredient

Use Sites	1-in-10 Year Daily Mean EEC (µg/L) [1]	Risk Quotients	
		Vascular	Non-vascular
		IC_{50} = 880 µg a.i./L	24 hr IC_{50} = 102 µg a.i./L
Citrus (FL)	140	0.16	**1.4**
Forestry	47	0.05	0.5
Grass: Range/ Pasture land	267	0.30	**2.7**
Grass: Meadow	264	0.30	**2.6**
Premises	10	0.01	0.1

Use Sites	1-in-10 Year Daily Mean EEC (µg/L) [1]	Risk Quotients	
		Vascular	Non-vascular
		IC_{50} = 880 µg a.i./L	24 hr IC_{50} = 102 µg a.i./L
Right-of-Way	59	0.06	0.6
Turf	9	0.01	0.1
X-mas Trees	22	0.03	0.2

Bolded values exceed the risk to non-listed aquatic plant species level of concern (LOC) is 1. The toxicity endpoints listed in the table are those used to calculate the RQ.

[1] Aquatic estimate environmental concentrations (EECs) are from **Table 8-5.**

Table 8-16. TCP Degradate Acute and Chronic Risk Quotients for Aquatic Vascular and Non-Vascular Plant Species Representative of the Triclopyr BEE Active Ingredient

Use Sites/ Use scenario [1]	1-in-10 Yr EEC Max (µg/L) [2] Daily Mean	Risk Quotients	
		Vascular IC_{50} =8,200 µg a.i./L	Vascular IC_{50} =2,000 µg a.i./L
Citrus (FL)	20.5	< 0.01	0.01
Forestry	2.61	< 0.01	< 0.01
Grass: Range/ Pasture land	26.2	< 0.01	0.01
Grass: Meadow	22.3	< 0.01	0.01
Turf	2.06	< 0.01	< 0.01
Christmas Trees	1.88	< 0.01	< 0.01

No RQ values exceed the risk to non-listed aquatic plant species level of concern (LOC) is 1. The toxicity endpoints listed in the table are those used to calculate the RQ.

[1] TCP EECs were not estimated for the residential and rights of way uses. These uses have low BEE EECs and risk concerns are not expected

[2] Aquatic estimated environmental concentrations (EECs) for TCP are from **Table 8-5** based on TCP (ug a.i./L) via the F/D method.

8.2.5   Aquatic Risk Summary

Based on the available toxicity data and ROC EECs determined for representative uses triclopyr ACID, TEA and COLN, risks of concern to aquatic organisms are indicated only with one use for non-vascular aquatic plants (aquatic weed control at 5,000 ppb). However, both the moderate (2,500 ppb) and maximum (5,000 ppb) aquatic weed control use have potential chronic risk concerns to freshwater invertebrates resulting from the formation of TCP (RQ values = **3.0** and **6.0**, respectively). The maximum aquatic use rate also poses a chronic risk to freshwater fish via degradation to TCP (RQ = **1.8**). With respect to aquatic vascular plants, it is noted that the tested species (*i.e.*, duckweed) may differ in its sensitivity compared to rooted vascular plants, particularly targeted aquatic weeds, in part due to its different physiology. Therefore, the lack of risk to vascular aquatic plants identified in this assessment should be considered with caution, particularly since triclopyr ACID, TEA and COLN are registered for control of aquatic weeds. Additional testing with other aquatic vascular plants (e.g., OECD guideline 239: *Myriophyllum spicatum*) could help address this uncertainty. Notably, only two ecological incidents were reported for triclopyr ACID/TEA/COLN products; however, these involved applications of more than one active ingredient which makes establishing causality to triclopyr ACID/TEA/COLN uncertain. Furthermore, available monitoring data for triclopyr ACID indicates

that maximum measured concentrations (~ 16 ppb) among the more than 40,000 reported values are 2 orders of magnitude below toxicity endpoints for aquatic plants (*e.g.,* 4,200 µg a.e./L for non-vascular plants) and 3 to 4 orders of magnitude below those for aquatic animals. It is likely, however, that the aquatic monitoring data do not targeted high end uses such as direct application to aquatic ecosystems for weed control.

For TCP (a major degradate of triclopyr ACID), chronic risk to aquatic invertebrates is indicated only for the 5,000 ppb and 2,500 ppb aquatic weed control use scenarios. In addition, chronic risk to fish is identified with the 5,000 ppb aquatic weed control use.

Modeled usage of triclopyr BEE on range/pasture land and meadows resulted in acute risk concerns for freshwater and estuarine marine fish and for aquatic invertebrates. In addition, chronic risks to marine/estuarine invertebrates and risks to non-vascular aquatic plants were also indicated with these uses. Modeled usage of triclopyr BEE on citrus also resulted in chronic risk concerns to estuarine/marine invertebrates and non-vascular aquatic plants. No risk concerns to aquatic organisms were identified based on the formation of TCP degradate of triclopyr BEE.

9 Terrestrial Vertebrates Risk Assessment

9.1 Terrestrial Vertebrate Exposure Assessment

9.1.1 Dietary Items on the Treated Field

For triclopyr ACID, TEA, and COLN active ingredients, potential dietary exposure for terrestrial wildlife in this assessment is based on consumption of triclopyr acid residues on food items following spray (foliar or soil) applications. Estimates from possible dietary ingestion of chemical granules were not presented because they are all below the acute risk LOC of 0.5. Dietary EECs for birds[20] and mammals from consumption of dietary items on the treated field were calculated using T-REX v.1.5.2. For the foliar uses, EECs are based on application rates, number of applications, and re-application intervals presented in 2018 BEAD PLUS reports. A default foliar dissipation half-life of 35 days was used which assumes the ROC degrades to non-toxic degradates according to a first order rate constant of 0.02^{-d}.

Four major use scenarios for triclopyr ACID (representative of ACID, TEA and COLN) were modeled which give a wide range of single maximum application rates ranging from 0.375 on rice (2 apps/year) to a single foliar application to pastures and rangeland at 9.0 lbs ai/A. Triclopyr BEE is not registered for use on rice, so this scenario is not applicable. Since the avian LD_{50} of triclopyr BEE (735 mg/Kg/bw) is over 50% lower than the LD_{50} acid (1,698 mg/Kg/bw) there is a separate run of T-REX for triclopyr BEE included for avian RQs.

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[20] Birds are also used as a surrogate for reptiles and terrestrial-phase amphibians.

Upper-bound Kenaga nomogram values were used to derive EECs for triclopyr ACID exposures to terrestrial mammals and birds on the field of application based on a 1-year time period. Triclopyr TEA and COLN degrade quickly to the acid form, thus the assumption is that the estimates based on acute and chronic values for the acid are reflective of the TEA and COLN actives. Consideration is given to different types of feeding strategies for mammals, including herbivores, insectivores and granivores. Dose-based exposures are estimated for three weight classes of birds (20 g, 100 g, and 1,000 g) and three weight classes of mammals (15 g, 35 g, and 1,000 g). EECs on terrestrial food items range from 59 to 2,160 mg ai/kg-diet based on upper-bound Kenaga values. Dose-based EECs, adjusted for body weight, range from 2.0 to 2,640 mg ai/Kg/bw for birds and 2.0 to 2,950 mg/Kg/body weight for mammals. A summary of these EECs for several application scenarios is found in **Table 9-1**.

For Triclopyr BEE, the dietary- and dose-based EECs are the same as the ACID presented in **Table 9-1** except there is no use on rice.

Table 9-1. Summary of dietary- (mg a.i./kg-diet) and dose-based estimated environmental concentrations (EECs; mg a.i./kg-bw) of triclopyr acid as food residues for birds, reptiles, terrestrial-phase amphibians and mammals from labeled uses of triclopyr ACID, TEA and COLN products (T-REX v. 1.5.2, Upper-Bound Kenaga)

Food Type	Dietary-Based EEC (mg/kg-diet)	Dose-Based EEC (mg/kg-body weight)					
		Birds			Mammals		
		Small (20 g)	Medium (100 g)	Large (1000 g)	Small (15 g)	Medium (35 g)	Large (1000 g)
Rice at 0.375 lb a.i./acre, 2 apps, with 20 day interval[1]							
Short grass	150	171	98	44	144	99	23
Tall grass	69	79	45	20	66	45	11
Broadleaf plants/small insects	85	96	55	24	81	56	13
Fruits/pods/seeds (dietary only)	9.4	11	6	3	9.0	6.2	1.4
Arthropods	59	67	38	17	56	39	9.0
Seeds (granivore)[2]	▨	2.4	1.4	0.6	2.0	1.4	0.3
Turf 1.0 lb a.i./acre, 4 applications/28-day intervals							
Short grass	502	572	326	146	479	331	77
Tall grass	230	262	150	67	220	152	35
Broadleaf plants/small insects	283	322	184	82	269	186	43
Fruits/pods/seeds (dietary only)	31	36	20	9.1	30	21	4.8
Arthropods	197	224	128	57	188	130	30
Seeds (granivore)[1]	▨	7.9	4.5	2.0	6.7	4.6	1.1
Forestry and Open Campground and Recreation areas at 6.0 lb ai/acre. 1 application							
Short grass	1440	1640	935	419	1372	949	220
Tall grass	660	752	429	192	629	435	101

Food Type	Dietary-Based EEC (mg/kg-diet)	Dose-Based EEC (mg/kg-body weight)					
		Birds			Mammals		
		Small (20 g)	Medium (100 g)	Large (1000 g)	Small (15 g)	Medium (35 g)	Large (1000 g)
Broadleaf plants/small insects	810	922	526	236	772	534	124
Fruits/pods/seeds (dietary only)	90	102	58	26	86	59	14
Arthropods	564	642	366	164	538	372	86
Seeds (granivore)[1]		23	13	6.0	19	13	3.0
Range and Pastureland and Utility or Road Rights-of-Way at 9.0 lb ai/acre. 1 application							
Short grass	2160	2460	1403	628	2059	1423	330
Tall grass	990	1127	643	287	944	652	151
Broadleaf plants/small insects	1215	1383	789	353	1158	801	186
Fruits/pods/seeds (dietary only)	135	154	88	39	129	89	21
Arthropods	846	964	549	246	807	557	129
Seeds (granivore)[1]		34	19	8.7	29	20	4.6

[1]Triclopyr BEE is not registered for Rice use

[2] Seeds presented separately for dose – based estimated environmental concentrations (EECs) due to difference in food intake of granivores compared with herbivores and insectivores. This difference reflects the difference in the assumed mass fraction of water in their diets.

9.2 Terrestrial Vertebrate Risk Characterization

Terrestrial wildlife exposure estimates are typically calculated for birds and mammals by emphasizing the dietary exposure pathway. Triclopyr products are applied through aerial and ground application methods, which includes sprayers or direct injection into trees. Therefore, potential dietary exposure for terrestrial wildlife in this assessment is based on consumption of triclopyr acid residues on or in food items following spray (foliar or soil) applications. The EECs for birds[21] and mammals from consumption of dietary items on the treated field were calculated using T-REX v.1.5.2.

9.2.1 Birds/Mammals: Triclopyr ACID, TEA, COLN

Table 9-2 summarizes the acute and chronic RQs for birds resulting from the registered uses of triclopyr ACID/TEA/COLN active ingredients. There were no acute and chronic risk LOC exceedances for the rice use with the exception of an exceedance of the chronic risk LOC for one food item (RQ = **1.5**). Chronic risk LOC exceedances were of a higher magnitude and were determined for a greater number of food items for the turf use, although dose- and dietary-based RQs were still below the acute risk LOC. For the forest, campground, recreation, range, pasture land, and rights-of-way uses, acute dose-based RQs for birds exceed the LOC with RQs up to **1.9** for the forestry, campground, and recreational field uses, and up to **2.8** for the range,

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[21] Birds are also used as a surrogate for reptiles and terrestrial-phase amphibians.

pasture land, and rights-of-way uses. Acute dietary-based RQs for the range, pasture land, and rights-of-way uses are marginally above the LOC (max RQ of **0.74**). Chronic RQs for birds exceed the chronic risk LOC for these uses and range from **0.9 - 22**. The differential risk picture for the forestry, campground, recreational area, range/pasture land, and rights-of-way uses relative to rice is driven by their high application rates 6.0 - 9.0 lbs a.e./A. Lower application rates associated with rice largely do not result in LOC exceedances. The maximum single application rate at which all avian RQs are below the LOC is 0.4 lb a.e./A.

Table 9-2. Acute and Chronic RQ values for Birds, Reptiles, and Terrestrial-Phase Amphibians from Labeled Uses of Triclopyr ACID, TEA and COLN products (T-REX v. 1.5.2, Upper Bound Kenaga)

Food Type	Acute Dose-Based RQ LD_{50} = 1,698 mg a.i./kg-bw			Acute Dietary-Based RQ LC_{50} =2,934 mg a.i./kg-diet	Chronic Dietary RQ NOAEC = 100 mg a.i./kg-diet
	Small (20 g)	Medium (100 g)	Large (1000 g)		
Rice at 0.375 lb a.i./acre, 2 apps, with 20-day interval					
Herbivores/Insectivores					
Short grass	0.19	0.09	0.03	0.05	**1.5**
Tall grass	0.09	0.04	0.01	0.02	0.69
Broadleaf plants	0.11	0.05	0.02	0.03	0.85
Fruits/pods/seeds	0.01	0.01	<0.01	<0.01	0.09
Arthropods	0.08	0.03	0.01	0.02	0.59
Granivores					
Seeds[1]	<0.01	<0.01	<0.01		
Turf at 1.0 lb ai/acre. 4 apps, with 28-day intervals					
Herbivores/Insectivores					
Short grass	0.65	0.29	0.09	0.17	**5.0**
Tall grass	0.30	0.13	0.04	0.08	**2.3**
Broadleaf plants	0.37	0.16	0.05	0.10	**2.8**
Fruits/pods/seeds	0.04	0.02	0.01	0.01	0.31
Arthropods	0.25	0.11	0.04	0.07	**2.0**
Granivores					
Seeds[1]	0.01	0.01	<0.01		
Forestry and Open Campground and Recreation areas at 6.0 lb ai/acre. 1 application					
Herbivores/Insectivores					
Short grass	**1.9**	**0.83**	0.26	0.49	**14**
Tall grass	**0.85**	0.38	0.12	0.22	**6.6**
Broadleaf plants	**1.0**	**0.47**	0.15	0.28	**8.1**
Fruits/pods/seeds	0.12	0.05	0.02	0.03	0.90
Arthropods	0.73	0.33	0.10	0.19	**5.6**
Granivores					
Seeds[1]	0.03	0.01	<0.01		
Range and Pastureland and Utility or Road Rights-of-Way at 9.0 lb ai/acre. 1 application					
Herbivores/Insectivores					
Short grass	**2.8**	**1.2**	0.40	**0.74**	**22**
Tall grass	**1.3**	**0.57**	0.18	0.34	**9.9**
Broadleaf plants	**1.6**	**0.70**	0.22	0.41	**12**
Fruits/pods/seeds	0.17	0.08	0.02	0.05	**1.4**
Arthropods	**1.1**	**0.49**	0.16	0.29	**8.5**

Food Type	Acute Dose-Based RQ LD$_{50}$ = 1,698 mg a.i./kg-bw			Acute Dietary-Based RQ LC$_{50}$ =2,934 mg a.i./kg-diet	Chronic Dietary RQ NOAEC = 100 mg a.i./kg-diet
	Small (20 g)	Medium (100 g)	Large (1000 g)		
Granivores					
Seeds[1]	0.04	0.02	0.01		

Bolded values exceed the acute risk to non-listed species level of concern (LOC) of 0.5 or the chronic risk LOC of 1.0. The toxicity endpoints listed in the table are those used to calculate the RQ.

[1] Seeds presented separately for dose – based RQs due to difference in food intake of granivores compared with herbivores and insectivores. This difference reflects the difference in the assumed mass fraction of water in their diets.

Acute RQs for mammals with the ACID/TEA/COLN active ingredients are below LOC for the rice and turf uses but exceed the acute risk LOC by up to 3X (RQs up to **1.5**) for the forestry, campground, recreation areas, range, pasture land, and rights-of-way uses (**Table 9-3**). These exceedances of the acute risk LOC are limited to small- and medium-sized mammals only and pertain primarily to mammals foraging on short grasses and broadleaf plants.

Table 9-3. Acute RQ values for Mammals from Labeled Uses of ACID, TEA and COLN products (T-REX v. 1.5.2, Upper-Bound Kenaga)

Food Type	Acute Dose-Based RQ LD$_{50}$ =630 mg a.e./kg-bw		
	Small (15 g)	Medium (35 g)	Large (1000 g)
Rice at 0.375 lb a.e./acre, 2 apps, with 20 day interval			
Herbivores/Insectivores			
Short grass	0.10	0.09	0.05
Tall grass	0.05	0.04	0.02
Broadleaf plants	0.06	0.05	0.03
Fruits/pods/seeds	0.01	0.01	<0.01
Arthropods	0.04	0.03	0.02
Granivores			
Seeds[1]	<0.01	<0.01	<0.01
Turf at 1.0 lb a.e./acre. 4 apps, 2with 28-day intervals			
Herbivores/Insectivores			
Short grass	0.35	0.30	0.16
Tall grass	0.16	0.14	0.07
Broadleaf plants	0.19	0.17	0.09
Fruits/pods/seeds	0.02	0.02	0.01
Arthropods	0.14	0.12	0.06
Granivores			
Seeds[1]	0.01	<0.01	<0.01
Forestry and Open Campground and Recreation areas at 6.0 lb a.e./acre. 1 application			
Herbivores/Insectivores			
Short grass	**0.99**	**0.85**	0.45
Tall grass	0.45	0.39	0.21
Broadleaf plants	**0.56**	**0.48**	0.26
Fruits/pods/seeds	0.06	0.05	0.03
Arthropods	0.39	0.33	0.18
Granivores			
Seeds[1]	0.01	0.01	0.01
Range and Pastureland and Utility or Road Rights-of-Way at 9.0 lb a.e./acre. 1 application			

Food Type	Acute Dose-Based RQ LD$_{50}$ =630 mg a.e./kg-bw		
	Small (15 g)	Medium (35 g)	Large (1000 g)
Herbivores/Insectivores			
Short grass	**1.5**	**1.3**	0.68
Tall grass	**0.68**	**0.58**	0.31
Broadleaf plants	**0.84**	**0.71**	0.38
Fruits/pods/seeds	0.09	0.08	0.04
Arthropods	0.58	0.50	0.27
Granivores			
Seeds[1]	0.02	0.02	0.01

Bolded values exceed the acute risk to non-listed species level of concern (LOC) of 0.5. The toxicity endpoints listed in the table are those used to calculate the RQ.

[1] Seeds presented separately for dose – based RQs due to difference in food intake of granivores compared with herbivores and insectivores. This difference reflects the difference in the assumed mass fraction of water in their diets.

Available data for the ACID/TEA/COLN active ingredients also show risk to mammals on a chronic basis (**Table 9-4**). Dose-based RQs exceed the chronic risk LOC for multiple size classes and multiple food items for every use pattern (RQs **0.07 - 2.6** for rice; **0.25 – 8.7** for turf; **0.7 - 25** for forestry, campground, and recreational sites; and **0.24 - 37** for range, pasture land, and rights-of-way). Dietary-based RQs are markedly lower than dose-based values, with all RQs below chronic risk LOC for rice; however, for the use on turf, one of the mammalian forage items (short grass) has a chronic risk concern (RQ = **1.0**). For the forestry, campground, recreational area, range, pasture lands, and rights-of-way uses, chronic RQs exceed the LOC for most food items (RQs up to **4.3**).

It is important to note that the LOAEL for the mammalian chronic toxicity study (250 mg a.i./kg-bw/d based on a 28%-39% reduction in F$_1$ and F$_2$ litter size, a 29%-31% reduction in pup body weight and a 17% reduction in pup survival) is 10X above the NOAEL. This wide range between the NOAEL and LOAEL introduces uncertainty in the interpretation of these chronic LOC exceedances because the threshold for chronic effects could be anywhere between 25 and 250 mg/kg-bw/d. However, even when based on the LOAEL of 250 mg/kg bw/d, RQs for forestry, campground, recreational area, range, pasture lands, and rights-of-way uses for multiple size classes and dietary items exceed the chronic risk LOC. Thus, there is greater certainty of the potential for chronic effects on mammals with these uses compared to uses on turf and rice.

Table 9-4. Chronic Risk Quotient (RQ) values for Mammals from Labeled Uses of Triclopyr ACID, TEA and COLN products (T-REX v. 1.5.2, Upper-Bound Kenaga)

Food Type	Chronic Dose-Based RQ NOAEL =25 mg a.e./kg-bw			Chronic Dietary RQ NOAEC = 500 mg a.e./kg-diet
	Small (15 g)	Medium (35 g)	Large (1000 g)	
Rice at 0.375 lb a.e./acre, 2 apps, with 20 day interval				
Herbivores/Insectivores				
Short grass	**2.6**	**2.2**	**1.2**	0.30
Tall grass	**1.2**	**1.0**	0.55	0.14
Broadleaf plants	**1.5**	**1.3**	0.67	0.17
Fruits/pods/seeds	0.16	0.14	0.07	0.02
Arthropods	**1.0**	0.87	0.47	0.12

Food Type	Chronic Dose-Based RQ NOAEL =25 mg a.e./kg-bw			Chronic Dietary RQ NOAEC = 500 mg a.e./kg-diet
	Small (15 g)	Medium (35 g)	Large (1000 g)	
Granivores				
Seeds[1]	0.04	0.03	0.02	
Turf at 1.0 lb a.e./acre. 4 apps, 2with 28-day intervals				
Herbivores/Insectivores				
Short grass	**8.7**	**7.4**	**4.0**	**1.0**
Tall grass	**4.0**	**3.4**	**1.8**	0.46
Broadleaf plants	**4.9**	**4.2**	**2.2**	0.57
Fruits/pods/seeds	0.54	0.47	0.25	0.06
Arthropods	**3.4**	**2.9**	**1.6**	0.39
Granivores				
Seeds[1]	0.12	0.10	0.06	
Forestry and Open Campground and Recreation areas at 6.0 lb a.e./acre. 1 application				
Herbivores/Insectivores				
Short grass	**25**	**21**	**11**	**2.9**
Tall grass	**12**	**9.8**	**5.2**	**1.3**
Broadleaf plants	**14**	**12**	**6.4**	**1.6**
Fruits/pods/seeds	**1.6**	**1.3**	0.72	0.18
Arthropods	**9.8**	**8.4**	**4.5**	**1.1**
Granivores				
Seeds[1]	0.35	0.30	0.16	
Range and Pastureland – Utility or Road Rights-of-Way at 9.0 lb a.e./acre. 1 application				
Herbivores/Insectivores				
Short grass	**37**	**32**	**17**	**4.3**
Tall grass	**17**	**15**	**8**	**2.0**
Broadleaf plants	**21**	**18**	**10**	**2.4**
Fruits/pods/seeds	**2.3**	**2.0**	**1.1**	0.27
Arthropods	**15**	**13**	**6.7**	**1.7**
Granivores				
Seeds[1]	0.52	0.44	0.24	

Bolded values exceed the chronic risk level of concern (LOC) of 1.0. The toxicity endpoints listed in the table are those used to calculate the RQ.

[1] Seeds presented separately for dose – based RQs due to difference in food intake of granivores compared with herbivores and insectivores. This difference reflects the difference in the assumed mass fraction of water in their diets.

9.2.2   Birds/Mammals: Triclopyr BEE

Acute dose-based RQs for birds with the BEE uses are generally higher than those of the ACID and TEA active ingredients and were driven by the 2-fold greater sensitivity of BEE relative to the either the ACID or TEA (**Table 9-5**). There are acute risk LOC exceedances for at least 2 avian sizes classes and one food item for every registered use (RQs range from 0.01 - **4.6**). Dietary-based RQs for birds are markedly lower, with RQs for all uses below the acute risk LOC. No chronic toxicity data are available for birds with BEE and therefore, chronic RQs were not calculated. There is uncertainty as to how rapid BEE would degrade on foliage into triclopyr ACID, for which chronic LOC exceedances for birds are generally indicated with the use patterns that are associated with application rates of 0.5 lb a.i/A or more.

Table 9-5. Acute Risk Quotient (RQ) values for Birds, Reptiles, and Terrestrial-Phase Amphibians from Labeled Uses of Triclopyr BEE products (T-REX v. 1.5.2, Upper Bound Kenaga)

Food Type	Acute Dose-Based RQ LD$_{50}$ = 735 mg a.i./kg-bw			Acute Dietary-Based RQ LC$_{50}$ =5,401 mg a.i./kg-diet	Chronic Dietary RQ NOAEC = No Data
	Small (20 g)	Medium (100 g)	Large (1000 g)		
Turf at 1.0 lb ai/acre. 4 apps, with 28-day intervals					
Herbivores/Insectivores					
Short grass	**1.1**	**0.48**	0.15	0.09	
Tall grass	**0.5**	0.22	0.07	0.04	
Broadleaf plants	**0.6**	0.27	0.09	0.05	
Fruits/pods/seeds	0.07	0.03	0.01	0.01	
Arthropods	0.42	0.20	0.06	0.04	
Granivores					
Seeds[1]	0.02	0.01	<0.01		
Forestry and Open Campground and Recreation areas at 6.0 lb ai/acre. 1 application					
Herbivores/Insectivores					
Short grass	**3.1**	**1.4**	0.44	0.27	
Tall grass	**1.4**	**0.6**	0.20	0.12	
Broadleaf plants	**1.7**	**0.8**	0.25	0.15	
Fruits/pods/seeds	0.2	0.09	0.03	0.02	
Arthropods	**1.2**	**0.5**	0.17	0.10	
Granivores					
Seeds[1]	0.04	0.02	0.01		
Range and Pastureland and Utility or Road Rights-of-Way at 9.0 lb ai/acre. 1 application					
Herbivores/Insectivores					
Short grass	**4.6**	**2.1**	0.66	0.40	
Tall grass	**2.1**	**0.95**	0.30	0.18	
Broadleaf plants	**2.6**	**1.2**	0.37	0.22	
Fruits/pods/seeds	0.29	0.13	0.04	0.02	
Arthropods	**1.8**	**0.82**	0.26	0.16	
Granivores					
Seeds[1]	0.06	0.03	0.01		

Bolded values exceed the LOC for acute risk to non-listed species of 0.5 or the chronic risk LOC of 1.0. The endpoints listed in the table are the endpoint used to calculate the RQ.

[1] Seeds presented separately for dose – based RQs due to difference in food intake of granivores compared with herbivores and insectivores. This difference reflects the difference in the assumed mass fraction of water in their diets.

For mammals, there are no acute risks of concern associated with triclopyr BEE use rates on turf (1 lb a.i./A x 4) but RQs exceed the acute risk LOC (0.5) for use rates for forestry/camp grounds (6 lb a.i./A) and range land/rights-of-way (9 lb a.i./A; **Table 9-6**). These acute risks are driven by the relatively high application rates associated with these uses, since triclopyr BEE is classified as being moderately toxic to mammals on an acute exposure basis.

Table 9-6. Acute Risk Quotient (RQ) values for Mammals from Labeled Uses of Triclopyr BEE products (T-REX v. 1.5.2, Upper Bound Kenaga)

Food Type	Acute Dose-Based RQ LD$_{50}$ =630 mg a.i./kg-bw		
	Small (15 g)	Medium (35 g)	Large (1000 g)
Turf at 1.0 lb ai/acre. 4 apps, 2with 28-day intervals			

Food Type	Acute Dose-Based RQ LD$_{50}$ =630 mg a.i./kg-bw		
	Small (15 g)	Medium (35 g)	Large (1000 g)
Herbivores/Insectivores			
Short grass	0.27	0.23	0.12
Tall grass	0.12	0.11	0.06
Broadleaf plants	0.15	0.13	0.07
Fruits/pods/seeds	0.02	0.01	0.01
Arthropods	0.11	0.09	0.05
Granivores			
Seeds[1]	<0.01	<0.01	<0.01
Forestry and Open Campground and Recreation areas at 6.0 lb ai/acre. 1 application			
Herbivores/Insectivores			
Short grass	**0.78**	**0.66**	0.36
Tall grass	0.36	0.30	0.16
Broadleaf plants	0.44	**0.37**	0.20
Fruits/pods/seeds	0.05	0.04	0.02
Arthropods	0.3	0.26	0.14
Granivores			
Seeds[1]	0.01	0.01	<0.01
Range and Pastureland and Utility or Road Right of Way at 9.0 lb ai/acre. 1 application			
Herbivores/Insectivores			
Short grass	**1.2**	**1.0**	**0.53**
Tall grass	**0.53**	**0.46**	0.24
Broadleaf plants	**0.66**	**0.56**	0.30
Fruits/pods/seeds	0.07	0.06	0.03
Arthropods	0.46	0.4	0.21
Granivores			
Seeds[1]	0.02	0.01	0.01

Bolded values exceed the acute risk to non-listed species level of concern (LOC) of 0.5. The toxicity endpoints listed in the table are those used to calculate the RQ.

[1] Seeds presented separately for dose – based RQs due to difference in food intake of granivores compared with herbivores and insectivores. This difference reflects the difference in the assumed mass fraction of water in their diets.

Dose-based RQs for BEE were above the chronic risk LOC for all size classes of mammals and most feeding strategies and for all registered uses (turf RQs range from 0.03 - **4.1**; forestry/ campground/recreational areas RQs ranges from 0.07 - **12**; and range, pasture land, and rights-of-way RQs ranges from 0.11 – **18; Table 9-7)**. It is noted that all modeled uses of triclopyr BEE except rice result in chronic dose-based EECs that exceed the LOAEC of 350 mg a.i./kg/d (*i.e.,* RQ values that exceed 5). Dietary based RQs were markedly lower than dose-based RQs, with LOC exceedances only for the range, pasture land, and rights-of-way uses (max RQ of **1.5**).

Table 9-7. Chronic Risk Quotient (RQ) values for Mammals from Labeled Uses of Triclopyr BEE products (T-REX v. 1.5.2, Upper-Bound Kenaga)

Food Type	Chronic Dose-Based RQ NOAEL =70 mg a.i./kg-bw			Chronic Dietary RQ NOAEC =1400 mg a.i./kg-diet
	Small (15 g)	Medium (35 g)	Large (1000 g)	
Turf at 1.0 lb ai/acre. 4 apps, 2with 28 day intervals				
Herbivores/Insectivores				

Food Type	Chronic Dose-Based RQ NOAEL =70 mg a.i./kg-bw			Chronic Dietary RQ NOAEC =1400 mg a.i./kg-diet
	Small (15 g)	Medium (35 g)	Large (1000 g)	
Short grass	**4.1**	**3.5**	**1.9**	0.36
Tall grass	**1.9**	**1.6**	**0.86**	0.16
Broadleaf plants	**2.3**	**2.0**	**1.1**	0.20
Fruits/pods/seeds	0.26	0.22	0.12	0.02
Arthropods	**1.6**	**1.4**	0.74	0.14
Granivores				
Seeds[1]	0.06	0.05	0.03	
Forestry and Open Campground and Recreation areas at 6.0 lb ai/acre. 1 application				
Herbivores/Insectivores				
Short grass	**12**	**10**	**5.4**	**1.0**
Tall grass	**5.4**	**4.6**	**2.5**	0.47
Broadleaf plants	**6.6**	**5.7**	**3.0**	0.58
Fruits/pods/seeds	0.74	0.63	0.34	0.06
Arthropods	**4.6**	**3.9**	**2.1**	0.40
Granivores				
Seeds[1]	0.16	0.14	0.07	
Range and Pastureland – Utility or Road Right of Way at 9.0 lb ai/acre. 1 application				
Herbivores/Insectivores				
Short grass	**18**	**15**	**8.1**	**1.5**
Tall grass	**8.1**	**6.9**	**3.7**	0.71
Broadleaf plants	**10**	**8.5**	**4.6**	0.87
Fruits/pods/seeds	**1.1**	0.94	0.51	0.10
Arthropods	**6.9**	**5.9**	**3.2**	0.60
Granivores				
Seeds[1]	0.25	0.21	0.11	

Bolded values exceed the chronic risk level of concern (LOC) of 1.0. The toxicity endpoints listed in the table are those used to calculate the RQ.

[1] Seeds presented separately for dose – based RQs due to difference in food intake of granivores compared with herbivores and insectivores. This difference reflects the difference in the assumed mass fraction of water in their diets.

9.2.3 Terrestrial Vertebrate Risk Summary

Triclopyr is adsorbed into plant tissues which are expected to be ingested by terrestrial herbivores and spray applications are expected to coat other food sources. Based on the available toxicity data and upper-bound EECs for terrestrial food items, the acute risk level of concern for birds is met or exceeded with a single application of 1.5 lb a.e./A or greater in at least one dietary item for the ACID/TEA/COLN active ingredients. With mammals, the acute risk LOC is exceeded in at least one dietary item at approximately 3 lb a.e./A and greater.

Chronic risk levels of concern for birds are exceeded with one application of the ACID/TEA/COLN active ingredients at 0.4 lb a.i./A or greater and risks were identified with at least 1 food item and 1 size class for all registered used modeled. Notably, the one chronic risk LOC exceedance for rice (chronic RQ= 1.5 for short grass) is sensitive to the use of the default 35-d foliar dissipation half-life and the use of upper-bound Kenega residue values. The chronic risk LOC for rice would not be exceeded for birds if the foliar dissipation half-life was <10 days

or if exposure was based on mean Kenega residue values. Chronic risk for mammals is indicated for all use patterns with at least one food group/size class. Chronic dose-based risk concerns are indicated with a single application rate of 0.25 lb a.i./A or greater. As discussed previously, there is greater uncertainty with interpretation of chronic risks to mammals due to the wide (10X) dose spacing used in the chronic test. With the forestry and range/pasture land uses (6 and 9 lb ai/A, respectively), the chronic risk LOC is exceeded for all weight classes of mammals among multiple food groups. It should be noted though that applications at these high rates would likely result in lethality to the target plants. Therefore, chronic risk from consumption of contaminated dietary items might be mitigated somewhat when plants die after treatment, assuming such forage would be unattractive to birds and mammals.

For triclopyr BEE, acute risk to birds is indicated for small- and medium-sized birds only. The acute risk identified for birds with the turf use is sensitive to the use of upper-bound vs. mean Kenega residue values (*i.e.,* risk would not be indicated with mean residue values which are approximately 3X lower than upper-bound residue values). Acute risk to mammals with triclopyr BEE are not indicated for the turf use, but are indicated for the forestry and rangeland uses. Notably, acute risk LOC exceedances for mammals are not indicated for any use based on mean Kenega residue values.

Chronic risk to mammals from triclopyr BEE is identified for all modeled uses for dose-based RQs and for all but the turf use for diet-based RQs. The chronic, diet-based RQs for mammals are sensitive to use of upper-bound Kenega values whereas, the dose-based chronic RQs are not sensitive to the choice of mean vs. upper bound values.

10 Terrestrial Invertebrate Risk Assessment

10.1 Bee Exposure Assessment

For agricultural uses, the primary source of information used to determine the potential exposure of bees to contaminated nectar and pollen is USDA's *Attractiveness of Agricultural Crops to Pollinating Bees for the Collection of Nectar and/or Pollen*[22]. Rice is primarily wind pollinated and not attractive to pollinators. However, most uses of triclopyr active ingredients involve non-crop areas which are not represented in USDA's crop attractiveness document. Potential exposure of bees via the turf uses depends on the use area, where residential turf is presumed to contain blooming weeds; whereas, commercial turf (sod farms) is generally presumed to be devoid of blooming weeds. For forestry, campground areas, recreational sites,

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[22]

https://www.usda.gov/oce/opmp/Attractiveness%20of%20Agriculture%20Crops%20to%20Pollinating%20Bees%20Report-FINAL_Web%20Version_Jan%203_2018.pdf

range and pasture lands, and rights-of-way, it is presumed that these areas could contain flowering plants that are attractive to *Apis* and non-*Apis* bees (which is supported by further discussion below). Flowering ornamentals near turf or lawn use sites and wild flowers in pastures, rangeland and rights of way could provide potential locations for direct contact from spray drift if pollinators are visiting during the period of application[23,24]. Certain triclopyr labels specify that drift to flowers should be avoided while others do not mention such precautions.

A summary of the potential exposure of bees to triclopyr active ingredients via their registered uses is provide in **Table 10-1.**

Table 10-1. Summary of Information on the Attractiveness of Registered Non-Crop Use Patterns for Triclopyr Active Ingredients to Honey Bees (*Apis mellifera*), Bumble Bees (*Bombus spp*) and Non-*Apis* solitary bees. (source: USDA Crop Attractiveness to Pollinators; USDA 2018)

Use Area	Honey Bee Attractive?[1,2]	Bumble Bee Attractive?[1,2]	Solitary Bee Attractive?[1,2]	Notes
Rice	N (nectar and pollen)			Wind pollinated
Citrus, Apple, orchards (tree injection)	Yes (pollen and nectar)	Y	Y	May use managed pollinator services. Honey specifically from citrus trees (orange blossom) requires use of pollination services.
Rangeland/Pastures	Attractiveness not specified but assumed to be attractive based on potential presence of flowering plants and weeds in these use areas			
Utility Right of Way, fence line, railroad and roadside uses				
Forestry, Park and Campsite use				
Ornamental Flowering Plants				
Aquatic Shorelines				
Residential and Commercial Turf Golf course uses	Commercial turf (sod) not assumed to be pollinator attractive due to presumed control of flowering weeds; residential turf assumed not be attractive if weeds are similarly controlled, but may be potentially attractive if not.			

[1]Attractiveness rating is a single "+", denoting a use pattern is opportunistically attractive to bees.
[2] Attractiveness rating is a double "++" denoting a use pattern is attractive in all cases

10.2 Bee Tier I Exposure Estimates

Contact and dietary exposure are estimated separately using different approaches specific for different application methods. The Bee-REX model (Version 1.0) calculates default (*i.e.*, high end, yet reasonably conservative) EECs for contact and dietary routes of exposure for foliar, soil, and seed treatment applications. See **Appendix E** for a sample output from Bee-REX for

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[23] https://rangelands.org/pollinators-on-the-rangeland/
[24] https://royalsocietypublishing.org/doi/full/10.1098/rspb.2017.2140

triclopyr acid. Additional information on bee-related exposure estimates, and the calculation of risk estimates in Bee-REX can be found in the USEPA et al. 2014 document: *Guidance for Assessing Pesticide Risks to Bees*[25] Based on this risk assessment guidance, the Tier 1 acute and chronic risk LOCs for pollinator insects are 0.4 and 1.0, respectively. Furthermore, the European honey bee, *A. mellifera*, is considered a surrogate test species for representation of other non-*Apis* bee species if no other species data are available. In cases where the Tier I RQs exceed levels of concern, estimates of exposure may be refined using measured pesticide concentrations in pollen and nectar of treated crops (provided measured residue data are available), and further calculated for other castes of bees using their food consumption rates as summarized in the White Paper to support the FIFRA Scientific Advisory Panel (SAP) on the pollinator risk assessment process (USEPA, 2012c). If the refined Tier 1 RQ values exceed levels of concern, then risks may be evaluated at the colony level using Tier II (semi-field) and/or Tier 3 (full-field) studies. However, with triclopyr, higher-tier effects (colony-level) and exposure (residue) data are have not been submitted.

10.3 Bee Risk Characterization (Tier I)

10.3.1 Tier I Risk Estimation (Contact Exposure)

On-Field Risk

Since an exposure potential to bees is identified for many non-crop uses of triclopyr active ingredient products, the next step in the risk assessment process is to conduct a Tier I risk assessment. By design, the Tier I assessment begins with (high-end) model-generated (foliar and soil treatments) or default (seed treatments-not applicable for triclopyr). Estimates of exposure via contact and oral routes are assessed.   For contact exposure, only the adult (forager and drones) life stage is considered since this is the relevant life stage for honey bees (*i.e.*, since other bees remain primarily in the hive, the presumption is that they would not be subject to contact exposure). Furthermore, acute toxicity testing protocols have been developed only for contact exposures. Effects are defined by laboratory exposures to groups of individual honey bees (which serve as surrogates for solitary non-*Apis* bees and individual social non-*Apis* bees).

With triclopyr ACID and BEE, acute contact LD_{50} values are both "non-definitive" >100 μg ai/bee (practically non-toxic) due to lack of effects at the highest test dose. Therefore, definitive acute RQ values cannot be calculated. As a proxy, the highest test dose is used in the RQ calculation and a "<" sign is assigned to the resulting RQ to indicate that the actual RQ would be lower than this value. This approach provides an the upper bound of the potential RQ value which is useful

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[25] USEPA, Health Canada PMRA, & California Department of Pesticide Regulation. 2014. Guidance for Assessing Pesticide Risks to Bees. June 23, 2014. U.S. Environmental Protection Agency. Health Canada Pest Management Regulatory Agency. California Department of Pesticide Regulation. Available at http://www2.epa.gov/pollinator-protection/pollinator-risk-assessment-guidance.

when this "non-definitive" RQ is less than the LOC. When the non-definitive RQ exceeds the LOC, then the potential for risk is not known.

Based on acute contact data and expected exposure to adult honey bees, RQs range from < 0.1 to < 0.24 for triclopyr ACID and BEE products (**Table 10-2**). Although the exact value of the acute contact RQs are not known due to the non-definitive LD_{50} endpoints, acute contact risks of concern are not evident for any registered use of triclopyr since the non-definitive RQ values are all below the acute risk LOC of 0.4.

Table 10-2. Tier I Adult, Acute Contact Risk Quotients (RQs) for Triclopyr ACID and BEE Honey Bees (*Apis mellifera*) Foraging on Flowering Plants in Treatment Areas from Bee-REX (ver. 1.0)

Use Pattern	Bee Attractiveness	Max. Single Application Rate in lb ae/A	Total Dose (μg a.i./bee per 1 lb a.e./A)	Triclopyr acid Contact Dose (μg a.i./bee) Worker/Drone	Acute Contact RQ[1] Worker/Drone
Turf areas	Potential	4.0	2.7	10.8	<0.11
Forestry, Parks, Campgrounds	Yes	6.0	2.7	16.2	<0.16
Pasture/rangeland	Yes	9.0	2.7	24.3	<0.24

[1] Based on 48-h acute contact LD_{50} values of >100 μg a.i./bee for triclopyr ACID and BEE (MRID 40356602; 41219109). An LD_{50} value of 100 μg/bee was used as a proxy to calculate upper-bound (<) RQ values.

10.3.2 Tier I Risk Estimation (Oral Exposure)

The acute oral LD_{50} value for triclopyr ACID is >100 μg ai/bee (practically non-toxic) due to lack of effects at the highest test dose. Based on estimated acute oral exposure levels from single application rates of 4.0 to 9.0 lbs ai/A, RQs range from <0.32 to <2.9 for adult nectar foragers (**Table 10-3**). Therefore, it can be concluded that triclopyr ACID uses on residential turf do not exceed the acute risk LOC of 0.4. However, for uses on forestry/parks/campground and pastures/ rangelands, it is not known if the acute risk LOC of 0.4 is exceeded due to non-definitive endpoint. Also, no toxicity data were available to assess the acute oral toxicity of triclopyr products to larval honey bees. On a chronic oral exposure basis, RQs range from 2.3 to 20 for adult nectar-foragers and from 23 to 211 for larval worker honey bees.   Based on these analyses, acute oral RQs generated for triclopyr uses of 6.0 to 9.0 lbs ai/A have a potential to exceed the acute risk LOC for adult foragers, but the actual acute risk is considered uncertain. There are chronic risks of concern   for triclopyr uses for rates from 4.0-9.0 lb ai/A are indicated for both adult foragers and larval bees.

Table 10-3. Tier I (Default) Oral Risk Quotients (RQs) for Triclopyr ACID with Adult Nectar Forager and Larval Worker Honey Bees from Bee-REX (ver. 1.0)

Use Pattern	Max. Single Appl. Rate	Bee Caste/Task	5 Day Oral Dose (μg a.i./bee)	Acute Oral RQ[1,2]	Chronic Oral RQ[3]
Residential Turf areas	4.0	Adult nectar forager	128.5	<0.32	**2.3**
		Larval worker	54.4		**23**

Use Pattern	Max. Single Appl. Rate	Bee Caste/Task	5 Day Oral Dose (μg a.i./bee)	Acute Oral RQ[1,2]	Chronic Oral RQ[3]
Forestry, Parks, campground areas	6.0	Adult nectar forager	192.7	<2.0	13
		Larval worker	81.6		141
Pastures and rangeland, Utility and Road Right of Ways	9.0	Adult nectar forager	289.1	<2.9	20
		Larval worker	122.4		211

[1] Based on a 48-h acute oral LD_{50} of >99 μg a.i./bee for adults (MRID 49992409). No data for 7-d LD_{50} for larvae have been submitted.
[2] **Bolded** RQ value exceeds (or potentially exceeds) the acute risk LOC of 0.4 or chronic LOC of 1.0.
[3] Based on a 10-d chronic NOAEL of 14.3 μg a.i./bee/d for adult bees (MRID 50673903) and a 22-d chronic NOAEL of 0.58 μg a.i./bee/d for larvae (MRID 50673902).

It is further noted that the risks identified above for adult nectar forager and larval worker bees also extend to the nurse bee caste, with acute RQs ranging from 0.66 to 1.5 and chronic RQs ranging from 2.9 to 6.6 based on results from this caste from Bee-REX.

Off-Field Risk

In addition to bees foraging on the treated areas, bees may also be foraging areas adjacent to the treated application area in turf, rights-of-way or pasture/grassland areas. Aerial application of triclopyr to rice, forest lands and open range or pastureland is expected to provide potential for drift to non-target areas where pollinator insects may be foraging.

10.3.3 Bee Risk Characterization (Tier II) Bee Risk Characterization (Tier III)

No higher-tier, colony-level data at the semi-field (Tier II) and full field (Tier III) levels have been submitted to further characterize the risk concerns identified for triclopyr and honey bees at the Tier I level.

10.3.4 Bee Risk Characterization

The full battery of Tier I honey bee studies is available for triclopyr acid, with the exception of the acute study with larval honey bees. Based on the Tier I assessment, none of the registered uses of triclopyr active ingredients result in acute contact risks to honey bees. Similarly, acute oral risks to adult honey bees are not indicated with residential turf use. However, acute oral risks via the forestry and rangeland uses are considered uncertain because the resulting EECs exceed the non-definitive toxicity endpoint (LD_{50} >99 μg ai/bee.

Unlike acute risks, chronic oral risks to honey bees are indicated for all registered uses of triclopyr active ingredients at the Tier 1 (individual bee) level. Chronic effects observed in these studies at the LOAEL include decreased food consumption (adults) and decreased emergence (larvae). Notably, estimated exposures to adult and larval bees exceed the LOAELs from these studies which increases the potential for risk. Since the honey bee is used as a surrogate for non-*Apis* bees, these chronic risks extend to non-*Apis* bees as well. It is important to note that

these Tier 1 oral risks are based on default (high-end) estimates of triclopyr in pollen and nectar. Field residue studies involving blooming weeds (*e.g.*, clover/turf) would be useful to refine these estimates of acute and chronic oral risk to bees.

Chronic risk above the LOC was indicated for adult and larval honey bees. Using the AgDrift model, distances of that risk extending off the field were estimated based on the default drift fraction assumptions, application rate, and toxicity endpoints (**Table 10-4**). For the adult chronic oral honey bee analysis, distances the risk would extend off field ranged form 7 - 184 feet, depending on the use pattern and its associated application rate. For larvae, the distance was 220 from residential turf areas, and greater than 1000 feet (upper limit of the model) for forestry, parks, campgrounds, pastures, rangelands, and rights-of-way areas.

Table 10-4. AgDrift analysis of off-field distances to adult and larval honey bees.

Aerial Applications[1]			
Chemical	**Application Rate**	**Adult Chronic Oral Distance in feet (fraction applied)**	**Larvae Chronic Oral Distance in feet (fraction applied)[2]**
Residental Turf	4	7 (0.435)	220 (0.043)
Forestry, Parks, Campground Areas	6	122 (0.077)	>1000 (0.007)
Pastures and rangeland, Utility and Road Right of Ways	9	184 (0.05)	>1000 (0.005)

[1] ASAE Droplet size fine to medium (default assumption)

[2] Fraction Applied = LOC/RQ to determine what fraction of the application rate would not result in an LOC exceedance.

Regarding other lines of evidence, one ecological incident involving bees (I028969) was reported for Garlon™ 4 Ultra (Triclopyr BEE) in which a spoil island (Travatine Island) was treated with Garlon™ 4 and Impel™ Red (a surfactant) on Jan. 20 to Feb. 1, 2016. A beekeeper in Pinellas County, Florida, reported that bees started walking away from the hives in a disoriented manner, unable to fly although no wing or other observed deformities were noted. The beekeeper noted the loss of six of the eleven hives. Following an investigation, the most likely cause was determined to be the use Garlon™ 4 and Impel™ Red on over 12 acres of land that was half a mile from the apiary. It was noted in the report that the bees did not produce young; however, no residue analysis in hive matrices (pollen, nectar, bee bread) was performed to confirm presence of triclopyr or its degradate, TCP. It is unknown whether triclopyr residues were systemically transported within the plant to the pollen and nectar within the plants or whether effects were associated with triclopyr or the Impel™ Red surfactant.

10.4 Other Terrestrial Invertebrates

No data on non-*Apis* pollinator species have been submitted for triclopyr acid, TEA or BEE. However, as noted above, the honey bee serves as a surrogate for other *Apis* and non-*Apis* species of bees. Therefore, the Tier I analysis indicating adult and larval chronic RQ values above the chronic risk LOC for all registered use patterns of triclopyr that are considered to be potentially attractive, applies to individual bees of all other species.

11 Terrestrial Plant Risk Assessment

Triclopyr is registered as an herbicide for broadleaf weed and woody plants control, and as such, toxicity to terrestrial plants is anticipated. Current label precautions include warnings about off-target drift to non-target vegetation or adjacent crops.

11.1 Terrestrial Plant Exposure Assessment

The EECs for terrestrial plants are calculated using TERRPLANT v.1.2.2. Exposure is estimated for a single application that evaluates exposure via spray drift and runoff. In the RQ table, the runoff RQs for dryland and semi-aquatic areas are based on the summation of the exposure from drift and runoff. Additionally, the spray drift RQs are based residues from spray drift alone. It is important to note that for spray drift, the TERRPLANT exposure estimate corresponds to an equivalent AgDrift™ estimated deposition for fine-medium droplets at approximately 200 feet from the edge of the treated field. For runoff, there are a few assumptions regarding the ratio of treated area to receiving non-target area that have an impact on the exposure estimation. In a dry area adjacent to the treatment area, exposure is estimated as sheet runoff. Sheet runoff is the amount of pesticide in water that runs off of the soil surface of a target area of land that is equal in size to the non-target area (1:1 ratio of areas). This differs for semi-aquatic areas, where runoff exposure is estimated as channel runoff. Channel runoff is the amount of pesticide that runs off of a target area 10 times the size of the non-target area (10:1 ratio of areas).

The EECs used to assess risks to terrestrial plants are based on the maximum single application rate for terrestrial uses, solubility, and spray drift fraction. The EECs represent residues from off-site exposure via spray drift and/or run-off to non-target plants found near application sites.

Currently, only triclopyr TEA and triclopyr BEE have available terrestrial plant toxicity data. Although the uses of TEA and BEE are similar in terms of application rate and use site (except for rice), the EECs were modeled separately due to differences in solubility for TEA (440 ppm) and BEE (7.4 ppm) and this effect on the resulting terrestrial plant EECs. As was the case with aquatic taxa and other terrestrial taxa, TEA is assumed to convert rapidly (less than one minute) to ACID, and therefore the EECs summarized in **Table 11-1**, refer to ACID, regardless of whether triclopyr is applied as the ACID or TEA while those in **Table 11-2** pertain to BEE.

Table 11-1. TerrPlant Calculated Estimated Environmental Concentrations (EECs) for Terrestrial and Semi-Aquatic Plants near Triclopyr ACID, TEA, and COLN Use Areas

Use Site	Single Max. Application Rate (lb a.i./A)	EECs (lb a.e./A)[1]					
		Ground[2]			Aerial[3]		
		Dry Areas (Total)	Semi-Aquatic Areas (Total)	Spray Drift	Dry Areas (Total)	Semi-Aquatic Areas (Total)	Spray Drift
Rice	0.375	0.02	0.19	0.004	0.04	0.21	0.02
Residential and Commercial Turf; Golf course uses	1.0	0.05	0.5	0.01	0.1	0.55	0.05
Forestry, Park and Campsite use; aquatic shoreline vegetation control; and X-mass Trees (ground only)	6.0	0.3	3.1	0.06	0.6	3.3	0.3
Utility Rights-of-Way, fence line, railroad and roadside uses; Rangeland/Pasture	9.0	0.54	4.6	0.09	0.9	5.0	0.45

[1] Based on solubility in water of 440 ppm for the acid
[2] Based on a drift fraction of 1% (*i.e.*, 0.01). for ground applications flowable solutions of triclopyr ACID and TEA
[3] Based on a drift fraction of 5% (*i.e.*, 0.05). for aerial applications of flowable solutions of triclopyr ACID and TEA

Table 11-2. TerrPlant Calculated Estimated Environmental Concentrations (EECs) for Terrestrial and Semi-Aquatic Plants near Triclopyr BEE Terrestrial Use Areas

Use Site	Single Max. Application Rate (lb a.i./A)	EECs (lb a.i./A)[1]					
		Ground[2]			Aerial[3]		
		Dry Areas (Total)	Semi-Aquatic Areas (Total)	Spray Drift	Dry Areas (Total)	Semi-Aquatic Areas (Total)	Spray Drift
Residential and Commercial Turf; Golf course uses	1.0	0.02	0.11	0.01	0.06	0.15	0.05
Forestry, Park and Campsite use; aquatic shoreline vegetation control; and X-mass Trees (ground only)	6.0	0.12	0.66	0.06	0.36	0.9	0.3
Utility Rights-of-Way, fence line, railroad and roadside uses; Rangeland/Pasture	9.0	0.18	0.99	0.09	0.54	1.4	0.45

[1] Based on solubility in water of 7.4 ppm for BEE
[2] Based on a drift fraction of 1% (*i.e.*, 0.01). for ground applications flowable solutions of BEE
[3] Based on a drift fraction of 5% (*i.e.*, 0.05). for aerial applications of flowable solutions of BEE

11.2　Terrestrial Plant Risk Characterization

Exposures from runoff and spray drift are compared to measures of survival and growth (*e.g.*, effects to seedling emergence and vegetative vigor) to estimate RQ values. The resulting upper-bound exposure estimates to terrestrial and semi-aquatic (wetland) plants adjacent to the treated field are expressed in lbs ai/A.

The available toxicity data for TEA and BEE products on terrestrial plants indicate greater sensitivity for dicots relative to monocots by at least one order of magnitude, as well as increased sensitivity of plants through the vegetative vigor design relative to the seedling emergence. Triclopyr BEE demonstrated increased toxicity by at least one order of magnitude relative to TEA in the seedling emergence design. This was finding was less pronounced when comparing the two active ingredients in the vegetative vigor design. Across all active ingredients, designs, and types of species (*i.e.* monocot or dicot), the most common significant effects observed were related to growth (*i.e.* inhibited plant shoot length and weight).

A summary of the RQs associated with the registered uses for ACID and TEA for terrestrial plants is provided in **Table 11-3**. Non-definitive endpoints for both monocots and dicots in the seedling emergence study precluded the estimation of RQs for Dry and Semi-Aquatic areas. The EC_{25} values in the TEA seedling emergence study were >0.33 and >1 lbs a.e/A for monocots and dicots, respectively. Although RQs were not estimated, single application rates for the registered use patterns of ACID and TEA range from 0.375 - 9 lbs a.e/A. Therefore, it is uncertain as to the potential for adverse impacts to non-target plants at these rates. The TEA vegetative vigor study determined EC_{25} values of 0.119 and 0.0054 lbs a.e/A, respectively based on effects to shoot length for monocots and dicots, respectively. The RQs associated with spray drift exposure only, range from 0.16 - 83. Dicots were more sensitive relative to monocot and were associated with RQs that exceeded the LOC for all registered uses. For monocots, RQ range from 1.8 to 2.7 with the uses of 6 lbs a.i/A and higher.

Species and toxicity values used for monocot was corn with an EC_{25} of >0.238 lb a.e/A and >0.715 lb a.e/A for all species of dicots tested in the seedling emergence study. The monocot and dicot NOAELs from this study are 0.238 and 0.715 lb a.e/A, respectively. For vegetative vigor the most sensitive monocot was onion with EC_{25} of 0.119 lbs a.e/A, and the most sensitive dicot was sunflower with an EC_{25} of 0.0054 lb a.e/A. Values for vegetative vigor were much lower than endpoints for seedling emergence using the same test material. This could be due to the way in which the product is applied and adsorbed systemically into plant tissues.

Table 11-3. Terrestrial Plant Risk Quotients (RQs) for Triclopyr ACID, TEA, and COLN Use Areas

Type of Plant	Ground Spray RQs			Aerial Spray RQs		
	Dry Areas	Semi-Aquatic Areas	Spray Drift Only	Dry Areas	Semi-Aquatic Areas	Spray Drift Only
Rice uses at 0.375 lb a.e/A - Ground or aerial application						
Monocot	NC	NC	<0.1	NC	NC	0.16
Dicot	NC	NC	0.69	NC	NC	**3.5**

Type of Plant	Ground Spray RQs			Aerial Spray RQs		
	Dry Areas	Semi-Aquatic Areas	Spray Drift Only	Dry Areas	Semi-Aquatic Areas	Spray Drift Only
Residential and Commercial Turf Golf course uses – 1 ground or aerial application at 1.0 lb a.e./A						
Monocot	NC	NC	<0.1	NC	NC	0.42
Dicot	NC	NC	**1.85**	NC	NC	**9.3**
Forestry, Park and Campsite use - 1 ground or aerial application at 6.0 lbs a.e./A						
Monocot	NC	NC	0.50	NC	NC	**2.5**
Dicot	NC	NC	**11**	NC	NC	**55**
Rangeland/Pastures/Utility Right of Way/fence line/ railway/roadside uses - 1 ground or aerial application at 9 lbs a.e/A						
Monocot	NC	NC	0.76	NC	NC	**3.8**
Dicot	NC	NC	**17**	NC	NC	**83**

NC = Not calculated
Bolded RQ values exceed the risk to plant level of concern (LOC) of 1.0.

An AgDrift analysis was conducted to evaluate the potential risk off the treated field to triclopyr ACID, TEA, and COLN use areas (**Table 11-4**). For monocot species, distances ranged for aerial applications from 463 to 801 feet off the treated field, depending on the use pattern. For dicot species, distances ranged from 191 to greater than 100 feet (upper limit of the model), depending on the application rate that is associated with the use area for ground applications. These distances ranged from 699 to greater than 1000 feet for aerial applications. It is noted that for the forestry uses, higher tiers of the model with varying assumptions could be explored to investigate the level of impact these parameters would have on a spray drift distance.

Table 11-4. Spray drift distances off the field for Triclopyr ACID, TEA, and COLN uses areas

Use Area	Application Rate	Distance off the treated field in feet			
		Monocot		Dicot	
		Ground	Aerial	Ground	Aerial
Rice	0.375	NC	NC	NC	699
Residential Turf/Golf Course	1	NC	NC	191	>1000
Forestry, Parks, Campground Areas	6	NC	463	>1000	>1000
Pastures and rangeland, Utility and Road Right of Ways	9	NC	801		

NC: Not calculated
A: ASAE fine to medium droplet size
G: Low boom, ASAE very fine to fine; EC25 Monocots: 0.119 lb a.e./A; Dicots 0.0054 lb a.e./A
Acid rates/endpoints in terms of a.e.

Terrestrial plant data for BEE generally demonstrated greater toxicity to monocot and dicots species relative to the TEA. Definitive EC_{25} values were achieved in both the seedling emergence and vegetative vigor that allowed for the risk estimation of all areas evaluated within TerrPlant. As previously noted, the BEE products do not have registrations on rice, as well as being associated with a lower solubility relative to TEA.

Table 11-5 summarizes the RQs associated with the BEE use areas. The RQs for all areas and use sites were generally higher for dicot species relative to monocot, and for ground sprays, were highest for semi-aquatic areas (RQs range from **1.5** to **22**) relative to sprays drift only RQs, which were highest for aerial sprays (RQs range from **0.14** to **51**). There were RQs that exceeded the LOC for one or more types of RQs for monocots and dicots for all registered uses of BEE.

Table 11-5. Terrestrial Plant RQs for Triclopyr BEE use areas

Type of Plant	Ground Spray RQs			Aerial Spray RQs		
	Dry Areas	Semi-Aquatic Areas	Spray Drift Only	Dry Areas	Semi-Aquatic Areas	Spray Drift Only
Residential and Commercial Turf Golf course uses – 1 ground or aerial application at 1.0 lb ai/A						
Monocot	0.27	**1.5**	0.14	0.82	**2.1**	0.68
Dicot	0.32	**1.8**	**1.1**	0.97	**2.4**	**5.6**
Forestry, Park and Campsite use - 1 ground or aerial application at 6.0 lbs ai/A						
Monocot	**1.6**	**9.0**	**0.82**	4.9	**12**	**4.1**
Dicot	**1.9**	**11**	**6.7**	5.8	**15**	**34**
Rangeland/Pastures/Utility Right of Way/fence line/ railway/roadside uses - 1 ground or aerial application at 9 lbs a.i/A						
Monocot	**2.5**	**14**	**1.2**	**7.4**	**18**	**6.2**
Dicot	**2.9**	**16**	**10**	**8.7**	**22**	**51**

NC = Not calculated
Bolded RQ values exceed the risk to terrestrial plant level of concern (LOC) of 1.0.

An AgDrift analysis was conducted to evaluate the potential risk off the treated field to triclopyr BEE use areas (**Table 11-6**). For monocot species, distances ranged for ground applications from 14 - 63 feet off the treated field, depending on the use pattern. For aerial applications these distances ranged from 112 to greater than 1000 feet. For dicots, that were notably more sensitive, the ranges from ground applications ranged from 109 to 978 feet of the treated field and were greater than 1000 feet for all registered use patterns. It is noted that for the forestry uses, higher tiers of the model with varying assumptions could be explored to investigate the level of impact these parameters would have on a spray drift distance.

Table 11-6. Spray drift distances off the field for Triclopyr BEE uses areas

Use Area	Application Rate	Distance off the treated field in feet			
		Monocot		Dicot	
		Ground	Aerial	Ground	Aerial
Residential Turf/Golf Course	1	14	112	109	>1000
Forestry, Parks, Campground Areas	6	63	680	689	
Pastures and rangeland, Utility and Road Right of Ways	9	99	>1000	978	

A: ASAE fine to medium droplet size
G: Low boom, ASAE very fine to fine; EC25 Monocots: 0.088 lb a.i./A; Dicots 0.0089 lb a.i./A
BEE rates/endpoints are in terms of a.i.

Based on the risk estimation of triclopyr TEA and BEE, RQs for both monocots and dicots exceeded the LOC for all use areas of both active ingredients (for TEA and monocot risk, this finding was only for spray drift RQs). This finding is consistent with triclopyr's use as an herbicide for broadleaf weed control. Additionally, several dozen terrestrial plant and crop damage incidents have been reported to the Agency that originate from legal uses of these products.

12 Final Conclusions

Triclopyr ACID, TEA, COLN and BEE were analyzed under current risk assessment methodology utilizing a range of registered use patterns and application rate scenarios for rice and the many non-crop uses. Ecological risks were assessed separately for the ACID, TEA, COLN active ingredients and the BEE active ingredient. This analysis has concluded that acute and chronic risk levels of concern are exceeded for terrestrial and aquatic taxa as summarized previously in **Table 1-1**. Monitoring data for triclopyr ACID in aquatic systems, however, indicate detected concentrations are 2 to 4 orders of magnitude below acute and chronic risk levels of concern. High application rates were generally responsible for acute risk LOC exceedances that did occur, even though acute toxicity endpoints indicated that triclopyr was practically non-toxic to moderately toxic for most species. The exception was for triclopyr BEE which was highly toxic to aquatic organisms on an acute exposure basis.

12.1.1 Triclopyr ACID, TEA, COLN

Aquatic ecological risks were assessed for the ACID, TEA, COLN active ingredients based on two approaches: (1) Total Residue (TR) method to estimate exposure via all residues of concern (ROC) which assumes equal toxicity among the parent (triclopyr ACID) and degradates (TCP + 3,6-DCP + 5-CLP + 6-CLP degradates); and (2) the Formation/Decline method which considers the TCP-specific chemical properties and toxicity. For the triclopyr BEE active ingredient, the Formation/Decline method was used to estimate exposure as represented by triclopyr BEE, ACID and the TCP degradate. Registered uses that were assessed include rice, aquatic weed control, citrus, forestry, range/pasture land, meadows, rights-of-way, turf and Christmas trees.

This analysis indicates that acute and chronic risk levels of concern (LOCs) are exceeded for terrestrial and aquatic taxa as summarized in **Table 1-1** below. For the ACID/TEA/COLN active ingredients, the highest rates of application were generally responsible for acute risk LOC exceedances that did occur. The exception was for triclopyr BEE which is classified as highly toxic to aquatic organisms on an acute exposure basis.

12.1.2 Triclopyr ACID, TEA, COLN

For the triclopyr ACID, TEA and COLN, no acute or chronic risks are identified for aquatic animals for any of the proposed uses based on the ROC using the TR method. However, chronic risks to freshwater fish and invertebrates are indicated with the 2,500 ppb and 5,000 ppb aquatic weed control use based on the formation of TCP (determined by the F/D method). The

TCP degradate is several orders of magnitude more chronically toxic compared to triclopyr ACID or TEA. For aquatic plants, no risk is identified for vascular plants based on the ROC or TCP degradate. However, risk to non-vascular plants is indicated for the maximum (5000 ppb) aquatic weed control use. Monitoring data indicate maximum detected levels of triclopyr ACID are several orders of magnitude below toxicity endpoints for the most sensitive tested species.

There are no acute risks of concern for birds and mammals from registered uses of triclopyr ACID/TEA/COLN for the rice and turf uses which have application rates of 0.375 and 1 lb a.e./A, respectively). For the forest/campground and range/pasture land/rights-of-way uses, acute risks of concern occur due to their higher application rates (6 and 9 lb a.e./A, respectively) compared to the rice and turf uses. There are chronic risks of concern for birds via foraging on at least one dietary item for all four use patterns assessed. For the turf, forestry/campground and pasture/rangeland uses, the dietary-based EECs exceed the avian lowest observed adverse effect concentration (LOAEC) of 200 mg a.e./kg-diet at which there was a 14% reduction in the number of 14-day old survivors. Similarly, chronic risks of concern for mammals are identified among all four use patterns. Chronic risks associated with the rice use are sensitive to the use of upper bound vs. mean Kenega exposure values. Furthermore, the large gap between the mammalian no observed adverse effect level (NOAEL) of 25 mg/kg-bw/d and the LOAEL (250 mg/kg-bw/d based on 28%-39% reductions in litter size) introduces additional uncertainty in the interpretation of chronic risks; except for forestry/campground and range/pasture land uses, whereby the EECs exceed the LOAEC.

For bees, the acute contact-based risk estimates are below the acute risk LOC of 0.4 for all of the registered uses of triclopyr ACID/TEA/COLN active ingredients. However, acute oral exposure to adult forager bees estimated with the forestry/campground and pasture/rangeland uses exceeds the highest concentration tested in the acute oral toxicity test which failed to produce an LD_{50} due to lack of mortality. Therefore, acute oral risk to adult honey bees is considered uncertain for these uses due to the non-definitive toxicity values. Notably, chronic risks of concern to adult and larval bees are indicated for all triclopyr ACID/TEA/COLN use patterns; notably however, these are based on default estimates of residues in pollen and nectar and could not be refined due to lack of measured residue data and/or colony-level toxicity studies.

Risks to terrestrial plants are identified from aerial spray applications of triclopyr ACID, TEA, or COLN across all of the use patterns assessed. Due to the lack of a definitive toxicity endpoint from the seedling emergence study with TEA, risks associated with applications to dry and semi-aquatic areas could not be assessed. Numerous ecological incidents associated with terrestrial plants have been reported in association with the use of triclopyr active ingredients.

12.1.3 Triclopyr BEE

On an acute exposure basis, triclopyr BEE is consistently 2 to 3 orders of magnitude more toxic to aquatic animals compared to triclopyr ACID or TEA, with LC_{50} values ranging from 0.35 to 0.46 mg a.i./L. The chronic toxicity of triclopyr BEE is also several orders of magnitude greater

than triclopyr ACID or TEA. However, triclopyr BEE is much less persistent than triclopyr ACID due to its rapid transformation to triclopyr ACID and results in lower aquatic EECs.

For aquatic animals, there acute risk concerns are indicated for freshwater and estuarine/marine fish with the assessed uses of triclopyr BEE when considering the parent (BEE) active ingredient but no chronic risk concerns are evident. For aquatic invertebrates, there are acute and chronic risks of concern for the range/pasture land and meadow uses which have the highest application rates of 6 and 9 lb a.i./A, respectively. Chronic risk concerns to estuarine/marine invertebrates are indicted for uses on citrus, range/pasture land, and meadows. There are no risks of concern for sediment-dwelling invertebrates exposed to triclopyr BEE via pore water. Risks to vascular aquatic plants is not indicated for triclopyr BEE, but risks to non-vascular plants are identified for citrus, range/pasture land, and meadows. Formation of triclopyr ACID or TCP from triclopyr BEE did not result in any acute or chronic risk concerns to aquatic organisms.

There are acute risks of concern for birds among all modeled use patterns due to the greater acute toxicity of triclopyr BEE to birds compared to ACID/TEA. Chronic risks to birds could not be assessed due to lack of data for triclopyr BEE. Chronic risks to mammals are indicated for all assessed uses for multiple size classes and dietary items. In most cases, these risks estimates are not sensitive to the use of mean vs. upper-bound Kenega residue values.

There are no acute risks of concern for bees since triclopyr BEE is practically non-toxic to bees on an acute contact basis. No other bee toxicity data were submitted for triclopyr BEE. However, the triclopyr BEE is expected to degrade relatively quickly to the ACID form based on submitted environmental fate data. Therefore, since there are chronic risks of concern for both adult and larval bees from the ACID, these risks would presumably extend to BEE which is serving as a source of the ACID.

The assessed uses of BEE present risks to terrestrial monocotyledonous (monocot) and dicotyledonous (dicot) plants involving multiple use areas from both ground and aerial applications. Reported ecological incidents for triclopyr BEE involving terrestrial plants represent a line of evidence supporting the risk findings for terrestrial plants.

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71-1   850.2100 Avian Single Dose Oral Toxicity

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71-2   850.2200   Avian Dietary Toxicity

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71-4   850.2300 Avian Reproduction

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72-2   850.1010   Acute Toxicity to Freshwater Invertebrates

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Acute Toxicity to Estuarine/Marine Organisms

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42646101   Ward, T.; Kowalski, P.; Boeri, R. (1993) Acute Flow-Through Mollusc Shell Deposition Test with Triclopyr TEA Salt: Lab Project Number: 51-DO: ES-2498. Unpublished study prepared by T. R. Wilbury Labs., Inc. 24 p. PDF 2045584

42646102   Ward, T.; Kowalski, P.; Boeri, R. (1992) Acute Toxicity of Triclopyr TEA Salt to the Grass Shrimp, Palaemonetes pugio: Lab Project Number: 50-DO: ES-2497. Unpublished study prepared by T. R. Wilbury Labs., Inc. 25 p. PDF 2045585

Triclopyr BEE Studies

41971601   Ward, T.; Boeri, R. (1991) Triclopyr Bee: Acute Flow-Through Toxic- ity to the Grass Shrimp, palaemonetes pugio: Lab Project Number: ES-DR-0133-7242-12. Unpublished study prepared by Resource Ana- lysts, Inc. 27 p. PDF 2022109

41971602   Ward, T.; Boeri, R. (1991) Triclopyr Bee: Acute Flow-Through Shell Deposition Test with the Eastern Oyster, Crassostrea virginica: Lab Project Number: ES-DR-0133-7242-14. Unpublished study prep- ared by Resource Analysts, Inc. 25 p.   PDF 2022110

41969901   Ward, T.; Boeri, R. (1991) Garlon 4 Herbicide: Acute Flow-through Toxicity to the Tidewater Silverside, Menidia beryllina: Lab Project Number: ES-DR-0224-6186-6. Unpublished study prepared by Resource Analysts, Inc. 26 p. PDF 2022105

41969902 Ward, T.; Boeri, R. (1991) Garlon 4 Herbicide: Acute Flow-through Toxicity to Grass Shrimp, pugio: Lab Project No: ES-DR-0224- 6186. Unpublished study prepared by Resource Analysts, Inc. 27 p. PDF 2022108

42948001 Alexander, H. (1993) **Supplemental to MRID No. 41969902**--Garlon 4 Herbicide: Acute Flow-through Toxicity to Grass Shrimp Palaemonetes pugio: Lab Project Number: MWM093093. Unpublished study prepared by Dow Chemical Co., Environmental Tox. & Chem. Research Lab and DowElanco. 14 p. Supplement

41969903 Ward, T.; Boeri, R. (1991) Garlon 4 Herbicide: Acute Flow-through Shell Deposition Test with the Eastern Oyster, Crassostrea virginica: Lab Project Number: ES-DR-0224-6186-7. Unpublished study prepared by Resource Analysts, Inc. 26 p. PDF 2022111

41971601 Ward, T.; Boeri, R. (1991) Triclopyr Bee: Acute Flow-Through Toxic- ity to the Grass Shrimp, palaemonetes pugio: Lab Project Number: ES-DR-0133-7242-12. Unpublished study prepared by Resource Ana- lysts, Inc. 27 p. PDF 2022109

41971602 Ward, T.; Boeri, R. (1991) Triclopyr Bee: Acute Flow-Through Shell Deposition Test with the Eastern Oyster, Crassostrea virginica: Lab Project Number: ES-DR-0133-7242-14. Unpublished study prep- ared by Resource Analysts, Inc. 25 p. PDF 2022110

42053901 Ward, T.; Boeri, R. (1991) Triclopyr BEE: Acute Flow-Through Toxic- ity to the Tidewater Silverside, Menidia beryllina: Lab Project Number: ES-DR-0133-7242-13. Unpublished study prepared by EnviroSystems Division & Resource Analysts, Inc. 26 p. PDF 2022121

TCP Degradate

42245901 Graves, W.; Smith, G. (1991) 3,5,6-Trichloro-2-Pyridinol: A 96-Hour Flow-through Acute Toxicity Test with the Atlantic Silverside (Menidia menidia): Amended Report: Lab Project Number: 103A-101A: ES-DR-0037-0423-9. Unpublished study prepared by Wildlife International Ltd. 48 p Amended report 2066446 in PC 059101

72-4   850.1400   850.1300

Fish Early Life Stage/Aquatic Invertebrate Life Cycle Study

MRID	Citation Reference

Triclopyr Acid

No Data

Triclopyr TEA Salt Studies

46269 Swabey, Y.H.; Schenk, C.F. (1963) Report on Algicides and Aquatic Herbicides. (Ontario, Water Resources Commission, Laboratory Division, Biology Branch, unpublished study; CDL:107773-B)

49637 ACC 259511 and 259512 Batchelder, T.L. (1973) Acute Fish Toxicity of Dowco 233 (3,5,6- Trichloro-2-pyridyloxyacetic acid) and Two Derivatives ?sic|: Report WCL--73014. (Unpublished study received Feb 26, 1974 under unknown admin. no.; submitted by Dow Chemical U.S.A.; Midland, Mich.; CDL:222240-E) PDF 2045521 pg 11

116

151958   Mayes, M.; Dill, D.; Mandoza, C.; et al. (1983) The Acute and Chronic Toxicity of Triclopyr (...) Triethylamine Salt Solution to Fathead Minnows (...): ES-582. Unpublished study prepared by Environmental Sciences Research, Dow Chemical U.S.A. 18 p. **ACC 259511** PDF 2045561

151959   Gersich, F.; Mandoza, C.; Hopkins, D.; et al. (1982) The Acute and Chronic Toxicity of Triclopyr (...) Triethylamine Salt Solution to Daphnia magna Straus: ES-583. Unpublished study prepared by Environmental Sciences Research, Dow Chemical U.S.A. 19 p. **ACC 259511** PDF 2045562

151960   Gersich, F.; Hopkins, D.; Milazzo, D. (1985) The Development of Flow-through Acute and Chronic
ACC 259511 Test Methods for Daphnia magna Straus: ES-756. Unpublished study prepared by Dow Chemical U.S.A. 20 p.   Methods development

42090410   Mayes, M. (1991) **Response** to Phase 3 Submssion on Triethylammonium Triclopyr...?Fish Early Life-Stage Test--Fathead Minnow|: Lab Project Number: ES-582. Unpublished study prepared by Dow Chemical Co., Environmental Tox and Chem Res. Lab. 45 p.

42090411   Mayes, M. (1991) **Response** to Phase 3 Submission on Triethylammonium Trichlopyr...?Invertebrate Life-Cycle Test (Daphnia)|: Lab Project Number: ES-583. Unpublished study prepared by Dow Chemical Co., Environmental Tox & Chem Research Lab. 18 p.

43230201   Weinberg, J.; Hugo, J.; Martin, M.; et al. (1994) Evaluation of the Toxicity of Triclopyr Butoxyethyl Ester to the Early Life Stages of the Rainbow Trout, Oncorhynchus mykiss Walbaum: Lab Project Number: DR/0133/7242: DECO/ES/2699. Unpublished study prepared by The Environmental Toxicology & Chemistry Research Lab. 47 p.   PDF 2022128

41736304   Barron, M.; Mayes, M.; Murphy, P.; et al. (1989) Pharmacokinetics And Metabolism of Triclopyr Butoxyethyl Ester In Coho Salmon: Lab Project Number: ES-DR-0133-7242-5: ES-1082. Unpublished Study prepared by The Dow Chemical Co. 31 p.

Triclopyr BEE Studies

49992406   Douglas M., Bell G., and Macdonald I. 1993. Triclopyr BEE Prolonged Toxicity to *Daphnia Magna*. Unpublished study performed by Huntingdon Research Center Ltd., Huntingdon, Cambridgeshire, England. Laboratory Study No. DWC 651(a)/931342. Study sponsored by Dow AgroSciences LLC, Indianapolis, Indiana. Study initiated November 27, 1992 and completed November 9, 1993.

50673901   Gallagher, S.; Milligan, A.; Lockard, L. (2017) Triclopyr BEE: A Flow-Through Life-Cycle Toxicity Test with the Saltwater Mysid (Americamysis bahia). Project Number: 379A/213, 161020, 1191/03A. Unpublished study prepared by EAG Laboratories. 155p

TCP Degradate Studies

44997301   Marino, T.; Gilles, M.; Rick, D. et al. (1999) Evaluation of the Toxicity of 3,5,6-Trichloro-2-Pyridinol
(found in   **(TCP)** to the Early Life Stages of the Rainbow Trout, Oncorhynchus mykiss Walbaum: Lab Project
116002)   Number: 991173. Unpublished study prepared by The Dow Chemical Co. 56 p. PDF 2045587 invalidated

46033201   Marino, T.; McClymont, E.; Hales, C.; et. al. (2003) **Revised Report** for 3,5,6-Trichloro-2-Pyridinol **(TCP):** Evaluation of the Toxicity to the Early Life Stages of the Rainbow Trout, Oncorhynchus mykiss Walbaum. Project Number: 011150, 011150R. Unpublished study prepared by The Dow Chemical Co. 69 p. See 44997301

45861301 Machado, M. (2003) Triclopyr Metabolite 3,5,6-TCP--Full Life-Cycle Toxicity Test with Water Fleas, Daphnia magna, under Static-Renewal Conditions: Lab Project Number: 12550.6286: 021300. Unpublished study prepared by Springborn Smithers Laboratories. 66 p.

49992407 Marino, T. *et al*. 2003. Revised Report for 3,5,6-trichloro-2-pyridinol (TCP): Evaluation of the Toxicity to the Early Life Stages of the Rainbow Trout, *Oncorhynchus mykiss* WALBAUM. Unpublished study performed by Toxicology & Environmental Research and Consulting, The Dow Chemical Company, Midland, Michigan. Laboratory Study No. 011150. Study sponsored by Dow AgroSciences LLC, Indianapolis, Indiana. Study initiated August 29, 2001, completed December 9, 2002, and revised July 2, 2003

72-7 Simulated or Actual Field Testing

MRID	Citation Reference

Triclopyr BEE Study

151961 Washburn & Gillis Associates Ltd. (1983) Assessment of the Effects of the Herbicide Garlon 4 on Aquatic Fauna [Including Methods for Analysis of Soils and Water]. Unpublished study. 88 p. **ACC 259512**

122-1 850.4400 and 850.4150

Seedling Emergence and Vegetative Vigor Tier 1

MRID	Citation Reference

Triclopyr Acid – No data

Triclopyr TEA Salt Studies

41784401 Weseloh, J.; Stockdale, G. (**1990**) A Study to Determine the Effects of Triclopyr on Vegetative Vigor: Lab Project Number: GH-P 1474. Unpublished study prepared by DowElanco/Midland Field Research Station. 47 p. **TEA Salt at 9.0 Lbs ae per Acre** PDF 2022103

42908301 Weseloh, J. (1993) **Supplemental Information for MRID 41734301**: A Study to Determine the Effects of Triclopyr on Seed Germination and Seedling Emergence: Lab Project Number: MLJ083093. Unpublished study prepared by DowElanco. 11 p.

41734301 Weseloh, J.; Stockdale, G. (1990) A Study to Determine the Effects of Triclopyr on Seed Germination and Seedling Emergence: Lab Project Number: GH-P 1475: 90032. Unpublished study prepared by DowElanco. 55 p. **TEA Salt at 9.0 Lbs ae per Acre** PDF 2022101

Triclopyr BEE Studies

41734301 Weseloh, J.; Stockdale, G. (1990) A Study to Determine the Effects of Triclopyr on Seed Germination and Seedling Emergence: Lab Project Number: GH-P 1475: 90032. Unpublished study prepared by DowElanco. 55 p. . **Triclopyr BEE at 8.0 Lbs ae per Acre** PDF 2022101

41784401   Weseloh, J.; Stockdale, G. (1990) A Study to Determine the Effects of Triclopyr on Vegetative Vigor: Lab Project Number: GH-P 1474. Unpublished study prepared by DowElanco/Midland Field Research Station. 47 p. **Applied Triclopyr BEE at 8.0 Lbs ae per Acre** PDF 2022103

123-1   850.4400 and 850.4150
Seed germination/seedling emergence and vegetative vigor

MRID	Citation Reference

Triclopyr TEA Salt Studies

43129801   Schwab, D. (1993) Evaluating the Effects of Triclopyr TEA on the Germination, Emergence, and Vegetative Vigor of Non-Target Terrestrial Plants: Final Report: Lab Project Number: 40874. Unpublished study prepared by ABC Lab., Inc. 168 p. PDF 2045586

40346508   Smith, L.; Geronimo, J. (1977) Response of Seven Crops to Six Auxin-like Herbicides. Unpublished study prepared by Dow Chemi- cal. 29 p. PDF 2045591

49256001   Eley, R. (2008) Evaluation of the Phytotoxicity of GF-1883 190.44 g ai I SL GLP Vegetative Vigour Test Terrestrial Non Target Plants Based on OECD Guideline 227 Europe 2007: Final Report. Project Number: 71132, ACE/07/040 prepared by AgroChemex Ltd (Mixture with Aminopyralid TPA)

Triclopyr BEE Study

43650001   Schwab, D. (1995) Evaluating the Effects of Triclopyr BEE on the Seedling Emergence and Vegetative Vigor of Non-Target Terrestrial Plants: Lab Project Numbers: 41964: RES94090. Unpublished study prepared by ABC Labs., Inc. 152 p. PDF 2022132

123-2   850.4400 and 850.5400 Aquatic plant growth

MRID	Citation Reference

Triclopyr Acid Study

41736303   Cowgill, U.; Milazzo, D. (1989) Triclopyr Acid: Evaluation of The Five Day Toxicity to The Green Alga Selenastrum Capricornutum: Lab Project Number: ES-DR-0040-8195-8: ES-2047. Unpublished Study prepared by The Dow Chemical Co. 15 p. PDF 2035116

Triclopyr TEA Salt Studies

41633705   Dill, D.; Milazzo, D. (1987) Triclopyr Triethylamine Salt: Evalua- tion of the Toxicity to a Freshwater Green Alga, Selenastrum Ca- pricornutum Printz: Lab Project Number: ES/DR/0287/8071/2. Un- published study prepared by The Dow Chemical Co. 16 p. PDF 2045573

41633706   Hughes, J. (1987) Triclopyr Triethylamine Salt: the Toxicity to An- abaena flos-aquae: Lab Project Number: 0460/02/1100/1. Unpub- lished study prepared by Malcolm Pirnie, Inc. 25 p. PDF 2045574

41633707   Cowgill, U.; Milazzo, D. (1987) Triclopyr Triethylamine Salt: The Five Day Toxicity of Skeletonema Costatum Grev. Cleve Bacillari- ophyceae, Clone Skel, A Marine Diatom: Lab Project Number: ES/dr/0287/8071/3. Unpublished study prepared by The Dow Chemical Company. 18 p. PDF 2045575

41633708   Hughes, J. (1987) Triclopyr Triethylamine Salt: The Toxicity to Navicula pelliculosa: Lab Project Number: 0460/02/1100/2. Un- published study prepared by Malcolm Pirnie, Inc. 24 p. PDF 2045576

41633709   Cowgill, U.; Milazzo, D. (1987) Triclopyr Triethylamine Salt: The Fourteen-Day Toxicity to Lemna Gibba L. G-3 Duckweed: Lab Pro- ject Number: ES/DR/0287/8071/1. Unpublished study prepared by The Dow Chemical Company. 19 p. PDF 2045577

41736302   Cowgill, U.; Milazzo, D.; Landenberger, B. (1988) A Comparison of the Effect of Triclopyr Triethylamine Salt (Garlon 3A) on Two Species of Duckweed Examined For Seven-Day and Fourteen Day Period: Lab Project Number: ES-DR-0003-7070-2. Unpublished study prepared by Dow Chemical Co. 49 p. PDF 2045581

42090413   Mayes, M. (1991**) Response** to Phase 3 Submission on Triethylammonium Triclopyr...?Growth and Reproduction of Aquatic Plants Tier 2: Lemna gibba|: Lab Project Number: ES-970. Unpublished study prepared by Dow Chemical Co., Environmental Tox & Chem Res. Lab. 21 p.

42090414   Mayes, M. (1991) **Response t**o Phase 3 Submission on Triethylammonium Triclopyr...?Growth and Reproduction of Aquatic Plants Tier 2: Skeletonema costatum|: Lab Project Number: ES-971. Unpublished study prepared by Dow Chemical Co., Environmental Tox & Chem. Res. Lab. 11 p.

48939403   Wemhoner, U. (2006) GF-1883 - Growth Inhibition Test with Freshwater Diatom (Navicula pelliculosa). Project Number: 060393/OCR, 1072/010/440. Unpublished study prepared by Springborn Smithers Laboratories (Europe). 71p.

Triclopyr BEE Studies

41633704   Cowgill, U.; Milazzo, D. (1989) GARLON 4 Herbicide: Evaluation of the Five Day Toxicity to the Green Alga Selenastrum Capricornu- tum: Lab Project Number: ES/DR/0224/6186/1. Unpublished study prepared by The Dow Chemical company. 18 p. PDF 2022097 or 2045572

42090422   Mayes, M. (1991) **Response** to Phase 3 Submission on Butoxyethyl Tri- clopyr...?Growth and Reproduction of Aquatic Plants Tier 2: Selenaestrum capricornutum|. Unpublished study prepared by Dow Chemical Co., Environmental Tox & Chem Res. Lab. 16 p.

42719101   Milazzo, D.; Servinski, M.; Weinberg, J.; et al. (1993) Triclopyr Butoxyethyl Ester: Toxicity to the Aquatic Plant, Duckweed, Lemna gibba L. G-3: Lab Project Number: ES-2592: DECO-ES-2592. Unpublished study prepared by The Dow Chemical Co. 38 p. PDF 2022120

42721101   Hughes, J.; Alexander, M. (1993) The Toxicity of Triclopyr Butoxyethyl Ester (Triclopyr BEE) to Anabaena flos-aquae: Lab Project Number: ES-DR-0133-7242: ES-2529. Unpublished study prepared by Malcolm Pirnie, Inc. 37 p. PDF 2022118

42721102   Hughes, J.; Alexander, M. (1993) The Toxicity of Triclopyr Butoxyethyl Ester (Triclopyr BEE) to Navicula pelliculosa: Lab Project Number: ES-DR-0133-7242: ES-2530. Unpublished study prepared by Malcolm Pirnie, Inc. 37 p. PDF 2022118

42721103   Hughes, J.; Alexander, M. (1993) The Toxicity of Triclopyr Butoxyethyl Ester (Triclopyr BEE) to Skeletonema costatum: Lab Project Number: ES-DR-0133-7242: ES-2531. Unpublished study prepared by Malcolm Pirnie, Inc. 38 p. PDF 2022119

42645901   Hughes, J.; Williams, T. (1993) The Toxicity of **Access** Herbicide Formulation to Selenastrum capricornutum: Lab Project Number: ES-2587: B460-152-1. Unpublished study prepared by Malcolm Pirnie, Inc. 35 p. PDF 2039127

43230301   Ward, T.; Kowalski, P.; Boeri, R. (1994) **Access** Herbicide: Toxicity to the Freshwater Diatom, Navicula pelliculosa: Lab Project Number: 430/DO: ES/2766. Unpublished study prepared by T. R. Wilbury Laboratories, Inc. 25 p. Triclopyr BEE/Picloram EHE PDF 2039127

43230304   Ward, T.; Kowalski, P.; Boeri, R. (1994**)** **Access** Herbicide: Toxicity to the Marine Diatom, Skeletonema costatum: Lab Project Number: 431/DO: ES/2767. Unpublished study prepared by T. R. Wilbury Laboratories, Inc. 25 p. PDF 2001400

43230307   Boeri, R.; Kowalski, P.; Ward, T. (1994) **Access** Herbicide: Toxicity to the Freshwater Blue-Green Alga, Anabaena flos-aquae: Lab Project Number: 432/DO: ES/2768. Unpublished study prepared by T. R. Wilbury Laboratories, Inc. 25 p. PDF 2039125

43230310   Milazzo, D.; Kirk, H.; Humbert, L.; et al. (1994) The Toxicity of **Access** Herbicide Formulation to the Aquatic Plant, Duckweed, Lemna gibba L.G-3: Lab Project Number: DECO/ES/2762. Unpublished study prepared by The Environmental Toxicology & Chemistry Research Lab. 33 p. PDF 2039124

TCP Degradate Studies

45312001   Kirk, H.; Gilles, M.; Hugo, J. et al. (1999) Effect of 3,5,6-Trichloro-2-Pyridinol (TCP) on the Growth of the Freshwater Green Alga, Selenastrum capricornutum, PRINTZ: Lab Project Number: 991194. Unpublished study prepared by The Dow Chemical Company. 43 p. PDF 2082443

45312002   Kirk, H.; Gilles, M.; McClymont, E. et al. (2000) 3,5,6-Trichloro-2-Pyridinol (TCP): Growth Inhibition Test with the Freshwater Aquatic Plant, Duckweed, Lemma gibba L. G-3: Lab Project Number: 001148. Unpublished study prepared by The Dow Chemical Company. 39 p. PDF 208244

45312003   Kirk, H.; Gilles, M.; McClymont, E. et al. (2000) 3,5,6-Trichloro-2-Pyridinol (TCP): Growth Inhibition Test with the Bluegreen Alga, Anabaena flos-aquae: Lab Project Number: 001149. Unpublished study prepared by The Dow Chemical Compamy. 38 p. PDF 2082445

141-1   850.3020   Honey bee acute contact

MRID   **Citation Reference**

Triclopyr Acid Studies

40356602   Dingledine, J. (1985) Triclopyr Acid: An Acute Contact Toxicity Study with Honey Bees: Final Report: Laboratory Project ID 103-239. Unpublished study prepared by Wildlife International, Ltd. 14 p. PDF 2035115

Triclopyr TEA Salt

No data

Triclopyr BEE Studies

41219109   Dingledine, J. (1985) Triclopyr BE Ester: An Acute Contact Toxicity Study with Honey Bees: Final Report: Project Study ID: 103-240. Unpublished study prepared by Wildlife International Ltd. 15 p. PDF 2022104

42625901   Hoxter, K.; Bernard, W.; Smith, G. (1992) **Access** Herbicide: An Acute Contact Toxicity Study with the Honey Bee: Lab Project Number: ES-2602: 103-389. Unpublished study prepared by Wildlife International Ltd. 20 p. PDF 2039123

Honeybee Non-Guideline Studies

MRID	Citation Reference

Triclopyr Acid Studies

49992409   Hahne, R. (2001) Triclopyr Acid: Acute Oral Toxicity Test with the Honeybee (Apis mellifera). Project Number: 46610, 011100. Unpublished study prepared by ABC Laboratories, Inc. 20p

50673902   Moore, S.; Leonard, J. (2018) Triclopyr: A Repeated- Exposure Laboratory Toxicity Study in Larvae, Pupae and Emergent Adults of the Honey Bee Apis mellifera Linnaeus. (Hymenoptera: Apidae): Final Report. Project Number: 014SRUS17C0057

50673903   Leonard, J.; Moore,S. (2018) Triclopyr: A Laboratory Study to Determine the Chronic Oral Toxicity to the Adult Worker Honey Bee Apis mellifera L. (Hymenoptera: Apidae). Project Number: 014SRUS17C0064, 170089 by SynTech Research Laboratory

Non-Guideline Selections

MRID	Citation Reference

151964   Batchelder, T. (1975) Environmental Analysis and Special Fish Toxicities of Two Triclopyr Formulations. Unpublished study pre- pared by Dow Chemical Co. 20 p. **ACC 259512**

42305500
42305501   Texas Dept. of Agriculture (1992) Submission of a Report of the Investigation of a Complaint of Adverse Effects of Garlon 3A and Rodeo on Horses and Property in Accordance with FIFRA 6(a)2 Requirements. Transmittal of 1 study.   **Incident Report**

151957   Batchelder, T.; Milazzo, D. (1981) Evaluation of Garlon 3A Herbi- cide in the Aquatic Environment: ES-362. Unpublished study pre- pared by Environmental Sciences Research Laboratory, Dow Chemi- cal U.S.A. 46 p.   **General summary**

42411805   Woodburn, K. (1992) Fish Metabolism Study on Triclopyr Requested by EPA for Aquatic Registration: Lab Project Number: KBW-792. Unpublished study prepared by DowElanco. 5 p.

43474200   DowElanco (1994) Submission of DERBI Numbers for Adverse Effect Incidents in Support of FIFRA 6(a)(2) for Chlorpyrifos and Other Chemicals. Transmittal of 1 Study.

44292003   Wolt, J.; Weglarz, T.; Wright, J.; et al. (1997) Triclopyr Non-Target Plant Risk Assessment: Lab Project Number: GH-C 4357. Unpublished study prepared by DowElanco. 95 p.

44385901   Eisenbrandt, D.; Nolan, R.; McMaster, S. et al. (1997) Triclopyr: An Assessment of Common Mechanism of Toxicity: Lab Project Number: HET K-042085-097. Unpublished study prepared by The Dow Chemical Co. 15 p.

44015101
44456102
44456103   Triclopyr in Fish and Shellfish: Evaluation of
44456104   Residue Data and Analytical Methods.
44456108
44456112   HED Studies listed on FOIA website
45170901

45022501   Ward, T.; Boeri, R. (1999) 3,5,6-Trichloro-2-pyridinol (TCP): Acute Toxicity to the Earthworm, Eisenia foetida: Lab Project Number: 1860-DO: 990149. Unpublished study prepared by T.R. Wilbury Laboratories, Inc. 32 p.

47164601   Moore, D.; Breton, R.; Rodney, S.; et al. (2007) Generic Problem Formulation for California Red-Legged Frog. Project Number: 89320, 05232007. Unpublished study prepared by Cantox Environmental Inc. 87 p. Registrant assessment

47164602   Holmes, C.; Vamshi, R. (2007) Data and Methodology Used for Spatial Analysis of California Red Legged Frog Observations and Proximate Land Cover Characteristics. Project Number: 3152007, WEI/252/03. Unpublished study prepared by Waterborne Environmental, Inc. (WEI). 19 p. ESA report from consulting firm

47164600   Croplife America (2007) Submission of Environmental Fate and Exposure and Risk Data in Support of the Preservation of the California Red Legged Frog. Transmittal of 2 Studies. Registrant assessment

48216801   Patterson, B. (2010) Co-Occurrence of 2,4-D and Triclopyr in Water Monitoring Samples within Threatened and Endangered Salmonid: Evolutionarily Significant Units. Project Number: 102388/F. Unpublished study prepared by Stone Environmental, Inc. 70 p.

48216802   Patterson, B. (2010) Land Cover Characterization and Water Monitoring Data Summaries for Triclopyr Butoxyethyl Ester Within Threatened or Endangered Salmonid Evolutionarily Significant Units. Project Number: 102388/G. Unpublished study prepared by Stone Environmental, Inc. 112 p.

48304701   Gelis, C. (2008) (Green S): Measurement of Ground Contamination Underneath Brushwood Canopies: Final Report. Project Number: DOW/GRE/07001. Unpublished study prepared by ADME Bioanalyses. 170 p.

APPENDIX A. Residue of Concern Justification, Detailed Fate and Transport Data, and ROCKS Table

I. Other Lines of Evidence to Support the Decision for NOT Including Triethanolamine, 2-Butoxyethanol and Choline Moieties in the Residues of Concern (ROC)

As described in the **Introduction Section** of this document and **Figure 5-1**, dissociation of TEA and COLN forms of triclopyr and hydrolysis of the BEE form are expected to produce, in addition to the ACID moiety, TEA, BEE and COLN moieties, respectively. These products were claimed, by the registrant, to dissipate rapidly by microbial degradation and/or of no toxicological concern. Hereunder the other lines of evidence for their expected behavior in the environment.

Triethylamine[26]	
Physical/Chemical Properties	**Structure**
CAS No.: 121-44-8 **Smiles Code:** CCN(CC)CC **Molecular Weight:** 101.2 g mole^{-1} **Vapor Pressure:** 52 torr @ 20 °C (High) **pKa:** 10.75 (Present as protonated moiety in environmentally relevant pHs) **Solubility in Water:** 112 g L^{-1} (High)	
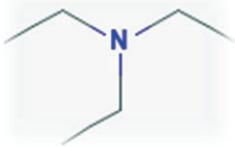
Table A-1 contains a summary of available fate data for the triethanolamine moiety of TEA form of triclopyr. In these studies, labeled ($[^{14}C$-l-ethyl]triethylamine hydrochloride was used to avoid loss due to the high volatility of the chemical.
https://www.epa.gov/ccl/contaminant-candidate-list-3-ccl-3#chemical-list

Table A-1 Summary of Environmental Degradation Data for Triethanolamine moiety.

Study	System Details	Half-life (days)/Other Data	Source (MRID)/ Study Classification
Aerobic Soil Metabolism	Harford Sandy Loam soil (pH 7.4; OC= 0.99%) (End of study= EOS= 182 d @ 25 °C) Commerce Silty Loam Soil (pH 7.6; OC= 0.49%) (EOS= 182 d @ 25 °C)	**5.6 and 13.7 d** Degrades to CO_2 to a Max of Max of 70.2% and 69.5% @ EOS, respectively. Unknown non-persistent metabolite was also observed with Max concentrations of 8% at 7 d declining to non-detect at 14 d in Harford soil. A more persistent Unknown metabolite was also observed in Commerce soil with Max concentrations of 37% at 24 d declining to 2% at 91 d	438375-01 (Acceptable)[1]

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[26] https://pubchem.ncbi.nlm.nih.gov/compound/8471#section=2D-Structure

Study	System Details	Half-life (days)/Other Data	Source (MRID)/ Study Classification
Aerobic Aquatic Metabolism	**System 1:** Silt Loam sediment from a Pond in Wayside, MS (pH= 5.8, O.C= 0.95%): Water (pH 6.7) (EOS= 30 d @ 25 ºC)	**9.3 d** Degrades to CO_2 and unextractable residues to a Max of Max of 67.7% and 18%, respectively @ EOS. No degradation products were observed	438375-03 (Acceptable)[2]
Anaerobic Aquatic Metabolism	**Same System 1** MRID 438375-03, above (EOS= 184 d @ 25 ºC)	**2 Years** Minimal degradation to a Max CO_2 of 0.3% @ EOS) with formation of 19% unextractable residues and No degradation products were observed	438375-02 (Acceptable)[3]

[1] **MRID 438375-01** Merrit, D. A. 1995. Aerobic Soil Metabolism of ^{14}C Triethylamine an unpublish study performed by North American Environmental Chemistry Laboratory, Indiana and submitted by DowElanco.

[2] **MRID 438375-03** Merrit, D. A. 1995. Aerobic Aquatic Metabolism of ^{14}C Triethylamine an unpublish study performed by North American Environmental Chemistry Laboratory, Indiana and submitted by DowElanco.

[3] **MRID 438375-02** Wolt, J. D. 1995. Anaerobic Aquatic Metabolism of ^{14}C Triethylamine an unpublish study performed by North American Environmental Chemistry Laboratory, Indiana and submitted by DowElanco.

Data in **Table A-1** indicates that triethanolamine moiety of TEA is non-persistent in aerobic soil and aquatic systems (Goring et al., 1975)[27] as it mineralizes ultimately to CO_2. In contrast, it is highly persistent in anaerobic aquatic system. Based on this fate data, exposure concern due to the triethanolamine moiety of TEA is low when it forms in aerobic soil/aquatic systems due to non-persistent. Persistence is expected for the triethanolamine moiety when it forms in anaerobic aquatic systems.

It is noted that triethylamine may reach the environment from many sources other than the application of the herbicide triclopyr. The chemical is used as catalytic solvent in chemical synthesis; accelerator activators for rubber; wetting, penetrating, and waterproofing agents of quaternary ammonium types; curing and hardening of polymers; corrosion inhibitor; propellant[28]. The chemical is among the EPA's third contaminant candidate list (CCL 3)[29].

2-Butoxyethanol [30]	
Physical/Chemical Properties	**Structure**
CAS No.: 111-76-2 **Smiles Code:** CCCCOCCO **Molecular Weight:** 118.2 g mole^{-1} **Vapor Pressure:** 0.88 torr @ 25 ºC (High) **Solubility in Water:** $\geq$100 mg L^{-1} (High)	

[27] *Goring et al. (1975) provides the following persistence scale for aerobic soil metabolism half-lives:*
- *Non-persistent less than 15 days*
- *Slightly persistent for 15-45 days*
- *Moderately persistent for 45-180 days, and*
- *Persistent for greater than 180 days.*

[28] https://toxnet.nlm.nih.gov/cgi-bin/sis/search/a?dbs+hsdb:@term+@DOCNO+896
[29] https://www.epa.gov/ccl/contaminant-candidate-list-3-ccl-3#chemical-list
[30] https://pubchem.ncbi.nlm.nih.gov/compound/2-Butoxyethanol

2-butoxyacetic acid: The main degradation product of butoxyethanol in aerobic soil/aquatic systems as well as anaerobic aquatic system (refer to Table I-2, below CAS No.: 2516-93-0
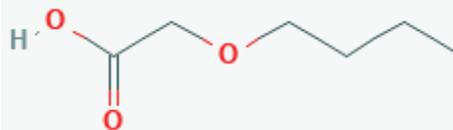
Table A-2 contains a summary of available fate data for the butoxyethanol moiety of BEE form of triclopyr. These studies we submitted in support of registration of 2,4-D butoxyethyl ester (2,4-D BEE) with the understanding that it would be referenced for other DowElanco products as appropriate.

Table A-2 Summary of Environmental Degradation Data for Butoxyethanol moiety.

Study	System Details	Half-life (days)/Other Data	MRID)/ Study Classification
Aerobic Soil	Harford SL soil (pH 7.4; OC= 0.99%) (EOS= 4 d @ 25 °C) Commerce SiL Soil (pH 7.6; OC= 0.49%) (End of study= EOS= 4 d @ 25 °C)	**0.9 and 1.4 Hours** Degrades to 2-butoxyacetic acid Max 85 & 101% @ 4 &24 hours declining with an observed t ½= 0.6 & 1.5 d, respectively producing CO_2 and unextracted residues (50% and 19%, respectively in both soils @ EOS)	**437991-01** (Acceptable)[1]
Aerobic aquatic	**System 1:** Silt Loam sediment from a Pond in Wayside, MS (pH= 5.8, O.C= 0.95%): Water (pH 6.7) (EOS= 10 d @ 25 °C)	**0.6 to 3.4 d** Degrades to 2-butoxyaceticacid Max 54% @ 3 d declining with an observed t ½ = 1.3 d producing CO_2 (69% @ EOS) and 10% of unextracted residue	**437991-06** (Acceptable)[2]
Anaerobic aquatic	**Same System 1** MRID 437991-06, above (EOS= 193 d @ 25 °C)	**1.4 d** Degrades to 2-butoxyaceticacid Max 72% @ 7 d declining with an observed t ½ = 73 d producing CO_2 (57% @ EOS) and 10% of unextracted residue	**437991-03** (Acceptable)[3]

[1] **MRID 437991-01** Batzer, F.R, 1995. Aerobic Soil Metabolism of ^{14}C-2-Butoxyrthanol, Laboratory Study ID ENV94094. Unpublished study performed and submitted by DowElanco, Indianapolis, Indiana.
[2] **MRID 437991-06** Batzer, F.R, 1995. Aerobic Aquatic Metabolism of ^{14}C-2-Butoxyrthanol, Laboratory Study ID ENV94096. Unpublished study performed and submitted by DowElanco, Indianapolis, Indiana.
[3] **437991-03** Batzer, F.R, 1995. Anaerobic Aquatic Metabolism of ^{14}C-2-Butoxyrthanol, Laboratory Study ID ENV94095. Unpublished study performed and submitted by DowElanco, Indianapolis, Indiana.

Data in **Table A-1** indicates that butoxyethanol moiety of BEE is non-persistent in aerobic soil systems (Goring et al., 1975) as it first degrades almost completely to 2-butoxyacetic acid within hours. The degradate 2-butoxyacetic acid is also non-persistent as it mineralizes to CO_2 within days (t ½= 0.6 day in one soil and 1.5 day in another soil). Similarly, butoxyethanol moiety of BEE is non-persistent in an aerobic aquatic system (Goring et al., 1975) as it first degrades to 2-butoxyacetic acid within 3 days into the degradate 2-butoxyacetic acid which is also non-persistent as it mineralizes to CO_2 within days (t ½= 1.3 days). In anaerobic aquatic system, butoxyethanol moiety of BEE degrades within days (t ½= 1.4 days) into the degradate 2-butoxyacetic acid which is moderately persistent (Goring et al., 1975). Based on this fate data, exposure concern due to the butoxyethanol moiety of BEE is low when it forms in aerobic soil/aquatic systems due to non-persistent. Although butoxyethanol moiety of BEE is non-

persistent in anaerobic aquatic systems, it degrades into a moderately persistent degradate; 2-butoxyaceticacid.

It is noted that 2-butoxyethanol may reach the environment from many sources other than the application of the herbicide triclopyr. Reported main use of 2-butoxyethanol is as a solvent in paints and surface coatings, followed by cleaning products and inks. Other products which contain 2-butoxyethanol include acrylic resin formulations, asphalt release agents, firefighting foam and others. 2-Butoxyethanol is a primary ingredient of various whiteboard cleaners, liquid soaps, cosmetics, dry cleaning solutions, lacquers, varnishes, herbicides, and latex paints[31].

Choline

Choline is a ubiquitous water-soluble essential nutrient that is grouped with the B-vitamins and is not considered a xenobiotic. It is considered essential for overall health and function of both terrestrial and aquatic organisms. Furthermore, choline, as choline hydroxide (CAS Reg No. 123-41-1), is listed in 40CFR §180.920 as an approved inert ingredient for pre-harvest use with an exemption from the requirement of a tolerance[32]. For these reasons, exposure resulting from formation of choline is not of concern.

II.   Detailed Fate and Transport Data

Table A-3 Detailed Fate and Transport Data for Triclopyr

Study	System Details	Half-life (days)/Other Data	Source (MRID)/ Study Classification
Hydrolysis	Sterile buffer solutions	**Stable** @ pHs 5, 7 and 9	418796-01 (A)
Aqueous photolysis	Sterile buffered aqueous solution @ pH 7 under xenon arc lamp @25 °C (End of study= EOS= 30 d)	**0.4** days **Major Degradates:** 29% [(3-Chloro,5,6-dihydroxy-2-pyrindinyl)oxy]acetic acid @ 1 d declining to non-detect @ EOS; 27 to 28% mixture of Chloromaleamic acid, Fumaric acid, and Chlorofumaric amide @ 6 d to EOS; 10% Maleamic acid @ 0.5 d declining to 6% @EOS; and 60% CO_2 @ EOS **Minor Degradates:** 8% Fumaric amide; <1% TMP and Mixture of succinamic succinic acids	499924-01[N] (A)
Aerobic soil	**Soil 1:** Commerce soil, SiL from MS (pH 6.6; O.C= 0.86%) **Soil 2:** Flanagan soil, SiCL from GA (pH 5.2; O.C= 2.1%) (EOS= 56 d representing the aerobic phase with acceptable moisture content for an aerobic soil system @25 °C)	**20** days (SFO) in **soil 1**; and **11** days (SFO) in **soil 2** **Major Degradate:** Max 11% **TCP** @ 28 d declined to 3.8% @ EOS in **soil 1**; and 25% @ 14 d declined to 8% @ 28 d in **soil 2** **Minor Degradate:** Max 8% **TMP** @ EOS in **soil 1**; and 5% @ 28 d declined to 3% @EOS in **soil 2**. CO_2= 50% and 62% @EOS in soil1 and 2, respectively	403463-04 (A)

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[31] https://pubchem.ncbi.nlm.nih.gov/compound/2-Butoxyethanol
[32] Choline hydroxide; Exemption from the Requirement of a Tolerance. 2010. EPA–HQ–OPP–2010–0233; FRL–8841–6. Federal register, Vol 75, No 169, 53577-81

Study	System Details	Half-life (days)/Other Data	Source (MRID)/ Study Classification
	Soil 1: SiL soil from MO, USA (pH 4.7, 1.6% O.C) **Soil 2:** SCL soil from TX (pH 7.6, 0.65% O.C) **Soil 3:** SL soil from ND (pH 6.2, 1.7% O.C) **Soil 4:** CL soil from CA (pH 6.4, 1.3% O.C) (EOS=120 d @ 20 °C)	8 days (SFO) in **soil 1**; 6 days @25 °C **29** days (SFO) in **soil 2**; 21 days @25 °C **25** days (SFO) in **soil 3**; 18 days @25 °C **18** days (SFO) in **soil 4**; 13 days @25 °C **Major Degradate: TCP in soil 1/2/3/4:** Max 35/19/28/24% @ 14/59/59/30 d declined to 4/3/19/2% @ EOS. t ½ for **TCP in soil 1/2/3/4: 34 d** (SFO)/**23 d** (SFO)/**70 d** (SFO)/**20 d** (SFO); Approximated for **soils 2** and **3** (only three data points) **Minor Degradate: Max in Soil 1/2/3/4, respectively:** **TMP:** 3/<1/4/4% @ 3/14/EOS/30 d then to 1/<1/5/1% @ EOS; **MTCP:** 6/1/5/4% @ 59/59/EOS/90 d then to 5/<1/4/1% @ EOS; **3,5 DCMP:** 1/1/<1/1% @ EOS/EOS/90/59 d then to 1/1/0/1% @ EOS **5,6 DCMP:** Max <1/<1/<1/1% @ EOS CO_2= 58/58/51/53% @EOS in **soil1/2/3/4**	90th %= 18.4 Day 499924-02 [N] (A)
Anaerobic Phase Only	**Soil 1:** Clay soil from WY, USA (pH 7.6, 0.8% O.C) **Soil 2:** SiL soil from Derbyshire, UK (pH 6.6, 3.5% O.C) **Soil 3:** SL soil from , Longwoods, Lincolnshire, UK (pH 6.9, 2.2% O.C) **Soil 4:** CL soil from South Witham, Lincolnshire, UK (pH 7.1, 3.1% O.C) **Aerobic phase** length (% average of undegraded ACID): 30 d (74.5%); 9 d (50.9%); 30 d (25.9%); and 12 d (44.7%), respectively **Anaerobic phase** length= 122 days for **soils 1** to **3** and 120 days for **soil 4**, respectively conducted @20 °C)	162 days (SFO) in **soil 1**; 115 days @25 °C **133** days (IORE) in **soil 2**; 94 days @25 °C **240** days (Slow DFOP) in **soil 3**; and 170 days @25 °C 98 days (SFO) in **soil 4** 69 days @25 °C **Major Degradate: TCP in soil 1/2/3/4:** Max 54/40/43/33% @ EOS/90/60/7 d then to 54/27/18/13% @ EOS. t ½ for **TCP in soil 1/2/3/4: Stable/Slight degradation/29 d** (SFO)/**70 d** (SFO); and **3,6-DCP in soil 1/2/3/4:** Max 0/11/32/21% all soils @ EOS **Minor Degradate: Max in Soil 1/2/3/4, respectively:** **TMP:** 4/8/6/5% all soils @ 7 d then declined to 0/2/1/0% @ EOS; **X124085:** detected only in soils 2 at Max 4% @ 60 d with slight decline and in soil 3 at a Max of 2% @ 7 d declining to no detection @ EOS; **[(5,6-Dichloropyridin-2-yl)oxy]acetic acid:** Detected in one soil (soil 4) at a Max of 2.5% @ 60 d with no apparent decline @ EOS; and **X79402:** Detected in one soil (soil 3) at a Max of 0.7% @ 60 d declining to no detection @ EOS	499924-03 [N] (A)

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Study	System Details	Half-life (days)/Other Data	Source (MRID)/ Study Classification
Aerobic Aquatic	**System 1:** L sediment from Italy (pH 7.3; O.C= 4.89%) : water (pH 7.9) **System 2:** S sediment from France (pH 5.3; O.C= 2.43%) : water (pH 6.2) (EOS= 106 d @20 °C)	Test substance for this study is **BEE,** However, **BEE** degraded into the **ACID** with a half-life of **0.7** day in **system 1**; and **0.6** day in **system 2**. Data for the **ACID** is taken from the 7-day maximum formation of 98% in **System 1** and 90% in **system 2**. This data is used to represent the degradation profile of the **ACID** in these two aerobic aquatic systems **32 days** (SFO) in **System 1**; **23** days @25 °C **36 days** (SFO) in **System 2**; **26** days @25 °C **Major Degradate: TCP** Max in **System 1 & 2**= 33 & 24% @ 59 d decreasing to 19 & 24% @ EOS (persistent); **3,6-DCP** Max 52% @ EOS in **system 1** & 34% @ 59 d in **system 2** decreasing to 30% @ EOS; and **5-CLP** Max 26% in **system 1** only @ 59 d decreasing to 21% @ EOS **Minor Degradates: 6-CLP** Max 1% @EOS in **system 2** only; and **TMP** Max 2% @ 29 Minutes in both systems decreasing to 0.04% @ EOS CO_2= <1-2% @EOS.	90th %= 29.1 Day 499924-04 [N] (S)
Anaerobic Aquatic	**System 1:** SL Cecil soil from GA (pH 5.7; O.C= 0.95%) amended with alfalfa: water (possibly tap water, not characterized) **System 2:** SL Norfolk soil from VA (pH 6.3; O.C= 0.65%) amended with alfalfa: water (not characterized) (EOS= 365 d @25 °C)	Test substance for this study is **BEE,** However, **BEE** degraded into 99 to 100% **ACID** within a day (t ½ = < **1** day in both **systems**. Data for the **ACID** from the maximum formation is used to represent the degradation profile of the **ACID** in these two anaerobic aquatic systems **1,433 days** (SFO) in **System 1**; **1,339 days** (SFO) in **System 2** **Major Degradate: TCP** Max. 26% @ EOS in system 1 and 43% @ 201 d declining to 22% @ EOS CO_2= 0.01 to 0.01% @ 14 and 20 days	90th %= 1,531 Day 001519-67 [N] (S)

III The ROCKS Table

Table A-4 contains available chemical structures while **Table A-5** contains fate information for the major and minor degradates for triclopyr acid.

Table A-4. A Summary of Available Data on the Major/Minor Degradation Products of Triclopyr Acid Observed in Laboratory Fate Studies.

Acronym (M Weight)	IUPAC Name (Formula)	CAS No	SMILES Code	Structure
TCP (198 *g mol⁻¹*)	3,5,6-Trichloro-2-pyridinol **($C_5H_2Cl_3NO$)**	6515-38-4	Oc1nc(Cl)c(Cl)cc1Cl	
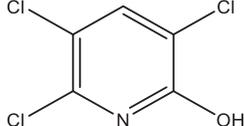
Acronym (M Weight)	IUPAC Name (Formula)	CAS No	SMILES Code	Structure
3,6-DCP (164 $g\ mol^{-1}$)	3,6-Dichloro-2-pyridinol ($C_5H_3Cl_2NO$)	57864-39-8	ClC1=CC=C(Cl)N=C1O	
MTCP (213 $g\ mol^{-1}$)	N-methyl-3,5,6-trichloro-2(1H)-pyridinone ($C_6H_4Cl_3NO$)		ClC1=C(Cl)N(C)C(C(Cl)=C1)=O	
TMP (213 $g\ mol^{-1}$)	2,3,5-Trichloro-6-methoxypyridine ($C_6H_4Cl_3NO$)	31557-34-3	n1c(OC)c(Cl)cc(Cl)c1Cl	
3,5 DCMP (178 $g\ mol^{-1}$)	3,5-Dichloro-1-methylpyridin-2(1H)-one ($C_6H_5Cl_2NO$)	NR	ClC1=CN(C)C(C(Cl)=C1)=O	
5,6 DCMP (178 $g\ mol^{-1}$)	5,6-Dichloro-1-methylpyridin-2(1H)-one ($C_6H_5Cl_2NO$)	NR	ClC1=C(Cl)N(C)C(C=C1)=O	
X124085 (222 $g\ mol^{-1}$)	[(3,6-Dichloropyridin-2-yl)oxy]acetic acid ($C_7H_5Cl_2NO_3$)	NR	ClC1=CC=C(Cl)N=C1OCC(O)=O	
[(3,6-Dichloropyridin-2-yl)oxy]acetic acid (222 $g\ mol^{-1}$)	2-[(5,6-Dichloropyridin-2-yl)oxy]acetic acid ($C_7H_5Cl_2NO_3$)		ClC1=C(Cl)C=CC(OCC(O)=O)=N1	
[(5,6-Dichloropyridin-2-yl)oxy]acetic acid (222 $g\ mol^{-1}$)	2-[(3,6-Dichloropyridin-2-yl)oxy]acetic acid ($C_7H_5Cl_2NO_3$)	NR	ClC1=CC=C(Cl)N=C1OCC(O)=O	
X79402 (270 $g\ mol^{-1}$)	(Methyl (3,5,6-trichloro-2-oxopyridin-1(2H)-yl)acetate ($C_8H_6Cl_3NO_3$)	NR	ClC1=CC(Cl)=C(Cl)[N](CC(OC)=O)C1=O	

Acronym (M Weight)	IUPAC Name (Formula)	CAS No	SMILES Code	Structure
5-CLP (130 $g\ mol^{-1}$)	5-Chloropyridin-2-ol **(C$_5$H$_4$ClNO)**	4214-79-3	OC1=NC=C(Cl)C=C1	
6-CLP (130 $g\ mol^{-1}$)	6-Chloropyridin-2-ol **(C$_5$H$_4$ClNO)**	73018-09-4	OC1=NC(Cl)=CC=C1	
Maleamic acid (115 $g\ mol^{-1}$)	4-Amino-4-oxobut-2-enoic acid **(C$_4$H$_5$NO$_3$)**	557-24-4	O=C(O)C=CC(=O)N	
[(3-Chloro,5,6-dihydroxy-2-pyrindinyl)oxy] acetic acid or isomer (220 $g\ mol^{-1}$)	[(3-Chloro,5,6-dihydroxy-2-pyrindinyl)oxy]acetic acid **(C$_7$H$_6$ClNO$_5$)**	NR	O=C(O)COC1=C(Cl)C=C(O)C(O)=N1	
Chloromaleamic acid (150 $g\ mol^{-1}$)	(2Z)-2-amino-2-chloro-4-oxo-2-butenoic acid **(C$_4$H$_4$ClNO$_3$)**	NR	NC(/C(Cl)=C([H])\C(O)=O)=O	
Fumaric acid (116 $g\ mol^{-1}$)	(2E)-But-2-enedioic acid **(C$_4$H$_4$O$_4$)**	110-17-8	O=C(O)C=CC(=O)O	
Chlorofumaric amide (150 $g\ mol^{-1}$)	(2Z)-4-amino-2-chloro-4-oxo-2-butenoic acid **(C$_4$H$_4$ClNO$_3$)**	NR	O=C(O)/C(Cl)=C(C(N)=O)\[H]	
Fumaric amide (115 $g\ mol^{-1}$)	(2E)-4-amino-4-oxobutenoic acid **(C$_4$H$_5$NO$_3$)**	NR	O=C(O)/C(Cl)=C(C(N)=O)\[H]	
Succinamic acid (117 $g\ mol^{-1}$)	4-Amino-4-oxobutanoic acid **(C$_4$H$_7$NO$_3$)**	638-32-4	NC(=O)CCC(O)=O	
Succinic acid (118 $g\ mol^{-1}$)	Butanedioic acid **(C$_4$H$_6$O$_4$)**	110-15-6	O=C(O)CCC(=O)O	

Acronym (M Weight)	IUPAC Name (Formula)	CAS No	SMILES Code	Structure
Carbon dioxide (44 *g mol^-1*)	Carbon dioxide **(CO_2)**	NR	C(=O)=O	O$=$C$=$O

Table A-5. The ROCKS Table for Triclopyr (ACID) and Its Environmental Transformation Products. [A]

Code Name/ Synonym	Study Type	MRID	Maximum %AR (day)		Final %AR (SL)
PARENT					
Triclopyr (Triclopyr Acid)	835.2240 Aqueous photolysis	49992401	PRT		
MAJOR (>10%) TRANSFORMATION PRODUCTS					
Maleamic acid (Unk 1)	835.2240 Aqueous photolysis	49992401	pH 7	**10.3%** (0.5 d)	5.9% (30 d)
[(3-Chloro,5,6-dihydroxy-2-pyrindinyl)oxy]acetic acid or isomer (Unk 4)	835.2240 Aqueous photolysis	49992401	pH 7	**29.4%** (1 d)	ND (30 d)
Mixture of Chloromaleamic acid, Fumaric acid, and Chlorofumaric amide (Unk 6)	835.2240 Aqueous photolysis	49992401	pH 7	**27.8%** (6 d)	**26.5%** (30 d)
	835.2240 Aqueous photolysis	49992401	pH 7		
	835.2240 Aqueous photolysis	49992401	pH 7		
Carbon dioxide	835.2240 Aqueous photolysis	49992401	pH 7	**60.2%** (30 d)	**60.2%** (30 d)
MAJOR (>10%) TRANSFORMATION PRODUCTS					
TMP	835.2240 Aqueous photolysis	49992401	pH 7	0.8% (0.25 d)	ND (30 d)
Fumaric amide (Unk 2)	835.2240 Aqueous photolysis	49992401	pH 7	8.4% (14 d)	7.8% (30 d)
Mixture of succinamic acid and succinic acid (Unk 3)	835.2240 Aqueous photolysis	49992401	pH 7	8.8% (1 d)	2.1% (30 d)
	835.2240 Aqueous photolysis	49992401	pH 7		

Triclopyr (ACID) and Its Environmental Transformation Products. [A]

Code Name/ Synonym	Study Type	MRID	System	Maximum %AR	Final %AR (SL)
PARENT					
Triclopyr	835.4100 Aerobic soil metabolism	49992402	PRT		
MAJOR (>10%) TRANSFORMATION PRODUCTS					
TCP	835.4100 Aerobic soil metabolism	49992402	Silt loam	**34.5%** (14 d)	4.4% (120 d)
			Sandy clay loam	**19.4%** (59 d)	3.2% (120 d)
			Sandy loam	**27.8%** (59 d)	**19.0%** (120 d)
			Clay loam	**24.2%** (30 d)	1.7% (120 d)
Carbon dioxide	835.4100	49992402	Silt loam	**58.2%** (120 d)	**58.2%** (120 d)

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Code Name/ Synonym	Study Type	MRID	System	Maximum %AR	Final %AR (SL)
	Aerobic soil metabolism		Sandy clay loam	**57.7%** (120 d)	**57.7%** (120 d)
			Sandy loam	**51.1%** (120 d)	**51.1%** (120 d)
			Clay loam	**53.2%** (120 d)	**53.2%** (120 d)
Unextractable residues	835.4100 Aerobic soil metabolism	49992402	Silt loam	**17.8%** (59 d)	**16.4%** (120 d)
			Sandy clay loam	**23.9%** (120 d)	**23.9%** (120 d)
			Sandy loam	**17.6%** (120 d)	**17.6%** (120 d)
			Clay loam	**26.6%** (59 d)	**23.0%** (120 d)
MINOR (<10%) TRANSFORMATION PRODUCTS					
TMP	835.4100 Aerobic soil metabolism	49992402	Silt loam	2.8% (30 d)	0.5% (120 d)
			Sandy clay loam	0.6% (14 d)	0.3% (120 d)
			Sandy loam	4.8% (120 d)	4.8% (120 d)
			Clay loam	4.4% (30 d)	1.2% (120 d)
MTCP	835.4100 Aerobic soil metabolism	49992402	Silt loam	5.6% (59 d)	4.9% (120 d)
			Sandy clay loam	0.4% (59 d)	0.1% (120 d)
			Sandy loam	4.4% (120 d)	4.4% (120 d)
			Clay loam	3.7% (90 d)	1.2% (120 d)
3,5 DCMP	835.4100 Aerobic soil metabolism	49992402	Silt loam	1.2% (120 d)	1.2% (120 d)
			Sandy clay loam	1.4% (120 d)	1.4% (120 d)
			Sandy loam	0.2% (90 d)	ND (120 d)
			Clay loam	1.3% (59 d)	0.9% (120 d)
5,6 DCMP	835.4100 Aerobic soil metabolism	49992402	Silt loam	0.3% (120 d)	0.3% (120 d)
			Sandy clay loam	0.4% (120 d)	0.4% (120 d)
			Sandy loam	0.4% (120 d)	0.4% (120 d)
			Clay loam	0.8% (90, 120 d)	0.8% (120 d)

Triclopyr (ACID) and Its Environmental Transformation Products. [A]

Code Name/ Synonym	Study Type	MRID	System	Maximum %AR	Final %AR (SL)
PARENT					
Triclopyr (Triclopyr Acid)	835.4200 Anaerobic soil metabolism	49992403	PRT		
MAJOR (>10%) TRANSFORMATION PRODUCTS					
TCP (3,5,6-TCP)	835.4200 Anaerobic soil metabolism	49992403	Clay	**54.0%** (152 d)	**54.0%** (152 d)
			Silt loam	**40.4%** (99 d)	**27.3%** (131 d)
			Sandy loam	**43.4%** (90 d)	**17.9%** (152 d)
			Clay loam	**32.8%** (19 d)	**12.5%** (132 d)
3,6-DCP	835.4200 Anaerobic soil metabolism	49992403	Silt loam	**10.6%** (131 d)	**10.6%** (131 d)
			Sandy loam	**31.8%** (152 d)	**31.8%** (152 d)
			Clay loam	**21.4%** (132 d)	**21.4%** (132 d)
Carbon dioxide	835.4200 Anaerobic soil metabolism	49992403	Clay	4.4% (90 d)	4.0% (152 d)
			Silt loam	**20.4%** (131 d)	**20.4%** (131 d)
			Sandy loam	**19.4%** (61 d)	**17.8%** (152 d)
			Clay loam	7.3% (72 d)	6.5% (132 d)
Unextractable residues	835.4200 Anaerobic soil metabolism	49992403	Silt loam	**21.5%** (131 d)	**21.5%** (131 d)
			Sandy loam	**14.3%** (120 d)	**13.3%** (152 d)
			Clay loam	**32.2%** (103, 132 d)	**32.2%** (132 d)
MINOR (<10%) TRANSFORMATION PRODUCTS					
TMP (X163004)	835.4200 Anaerobic soil metabolism	49992403	Clay	4.4% (37 d)	ND (152 d)
			Silt loam	8.1% (16 d)	1.7% (131 d)
			Sandy loam	6.4% (37 d)	1.2% (152 d)
			Clay loam	5.0% (19 d)	ND (132 d)
[(3,6-Dichloropyridin-2-yl)oxy]acetic acid (X124085) OR [(5,6-Dichloropyridin-2-yl)oxy]acetic acid	835.4200 Anaerobic soil metabolism	49992403	Silt loam	3.9% (69 d)	3.3% (131 d)
			Sandy loam	1.8% (30, 37 d)	ND (152 d)
			Clay loam	2.5% (72 d)	2.1% (132 d)
X79402	835.4200 Anaerobic soil metabolism	49992403	Sandy loam	0.7% (90 d)	ND (152 d)

Triclopyr BEE and Its Environmental Transformation Products. [A]

Code Name/ Synonym	Study Type	MRID	System	Maximum %AR	Final %AR (SL)
PARENT					
Triclopyr Butoxyethyl Ester (Triclopyr BEE)	835.4400 Anaerobic aquatic metabolism	00151967	PRT		
MAJOR (>10%) TRANSFORMATION PRODUCTS					
Triclopyr	835.4400 Anaerobic aquatic metabolism	00151967	Georgia Water: sandy loam	**100.5%** (1 d)	**75.3%** (365 d)
			Virginia Water: sandy loam	**98.1%** (1 d)	**86.5%** (365 d)
TCP	835.4400 Anaerobic aquatic metabolism	00151967	Georgia Water: sandy loam	**26.0%** (365 d)	**26.0%** (365 d)
			Virginia Water: sandy loam	**42.7%** (201 d)	**22.0%** (365 d)
MINOR (<10%) TRANSFORMATION PRODUCTS					
Carbon dioxide	835.4400 Anaerobic aquatic metabolism	00151967	Georgia Water: sandy loam	0.05**%** (14 d)	0.0% (365 d)
			Virginia Water: sandy loam	0.01**%** (14, 20 d)	0.0% (365 d)

Triclopyr BEE and Its Environmental Transformation Products. [A]

Code Name/ Synonym	Study Type	MRID	System	Maximum %AR	Final %AR (SL)
PARENT					
Triclopyr Butoxyethyl Ester (Triclopyr BEE)	835.4300 Aerobic aquatic metabolism	49992404	PRT		
MAJOR (>10%) TRANSFORMATION PRODUCTS					
Triclopyr	835.4300 Aerobic aquatic metabolism	49992404	Water: Loam	**98.4%** (7 d)	**11.0%** (106 d)
			Water: Sand	**89.7%** (7 d)	5.3% (106 d)
TCP	835.4300 Aerobic aquatic metabolism	49992404	Water: Loam	**33.4%** (59 d)	**18.7%** (106 d)
			Water: Sand	**23.7%** (106 d)	**23.7%** (106 d)
3,6-DCP **(3,6-Dichloro-2-pyridinol)**	835.4300 Aerobic aquatic metabolism	49992404	Water: Loam	**52.4%** (106 d)	**52.4%** (106 d)
			Water: Sand	**33.7%** (59 d)	**30.0%** (106 d)
5-CLP & 6-CLP **(5- & 6-Chloro-2-pyridinol)**	835.4300 Aerobic aquatic metabolism	49992404	Water: Loam	**25.5%** (59 d)	**20.6%** (106 d)
			Water: Sand	1.2% (106 d)	1.2% (106 d)
Unextractable residues	835.4300 Aerobic aquatic metabolism	49992404	Water: Loam	**13.0%** (106 d)	**13.0%** (106 d)
			Water: Sand	**11.2%** (106 d)	**11.2%** (106 d)
MINOR (<10%) TRANSFORMATION PRODUCTS					
TMP	835.4300 Aerobic aquatic metabolism	49992404	Water: Loam	2.08% (0.02 d)	0.04% (106 d)
			Water: Sand	1.87% (0.02 d)	0.04% (106 d)
Carbon dioxide	835.4300 Aerobic aquatic metabolism	49992404	Water: Loam	0.5% (106 d)	0.5% (106 d)
			Water: Sand	1.6% (106 d)	1.6% (106 d)

Triclopyr BEE and Its Environmental Transformation Products. [A]

Code Name/ Synonym	Study Type	MRID	System	Maximum %AR	Final %AR (SL)
PARENT					
Triclopyr Butoxyethyl Ester (Triclopyr BEE)	835.4400 Anaerobic aquatic metabolism	00151967	PRT		
MAJOR (>10%) TRANSFORMATION PRODUCTS					
Triclopyr	835.4400 Anaerobic aquatic metabolism	00151967	Georgia Water: sandy loam	**100.5%** (1 d)	**75.3%** (365 d)
			Virginia Water: sandy loam	**98.1%** (1 d)	**86.5%** (365 d)
TCP	835.4400 Anaerobic aquatic metabolism	00151967	Georgia Water: sandy loam	**26.0%** (365 d)	**26.0%** (365 d)
			Virginia Water: sandy loam	**42.7%** (201 d)	**22.0%** (365 d)
MINOR (<10%) TRANSFORMATION PRODUCTS					
Carbon dioxide	835.4400 Anaerobic aquatic metabolism	00151967	Georgia Water: sandy loam	0.05**%** (14 d)	0.0% (365 d)

[A]**AR**= Applied radioactivity; **PRT**= Parent; **SL**= Study length; **ND**= Not detected; **NA**= Not applicable

APPENDIX B. Calculations of Half-lives for the Residue of Concern; Calculations of Exposure EECs for TCP Degradate Using the Formation and Decline (F/D) Approach; and Examples for Aquatic Modeling Inputs and Outputs

I. **Calculations of half-lives for the Residue of Concern (ROC)**

Aerobic soil

Aerobic metabolism of Triclopyr ROC in silt loam soil

Days	% AR
0	96.0
0	96.7
1	93.1
1	92.6
3	91.2
3	89.1
7	80.3
7	77.0
14	62.1
14	58.3
30	32.9
30	37.6
59	13.6
59	14.5
90	6.20
90	6.20
120	5.10
120	4.00

	DT_{50}	DT_{90}	χ^2	C_0	Parameters
SFO	21.2	70.3	2.2	97.1	$k = 0.0327$
DFOP	20.8	71.1	1.8	97.4	$f = 0.999$, $k_0 = 0.0335$, $k_1 = -0.0272$
IORE	20.7	73.2	2.1	97.6	$N = 1.08$, $k = 0.0242$

S_C	69.8
S_{SFO}	65.9
Slow $t_{1/2}$	-25.5
$t_{R\ IORE}$	22

137
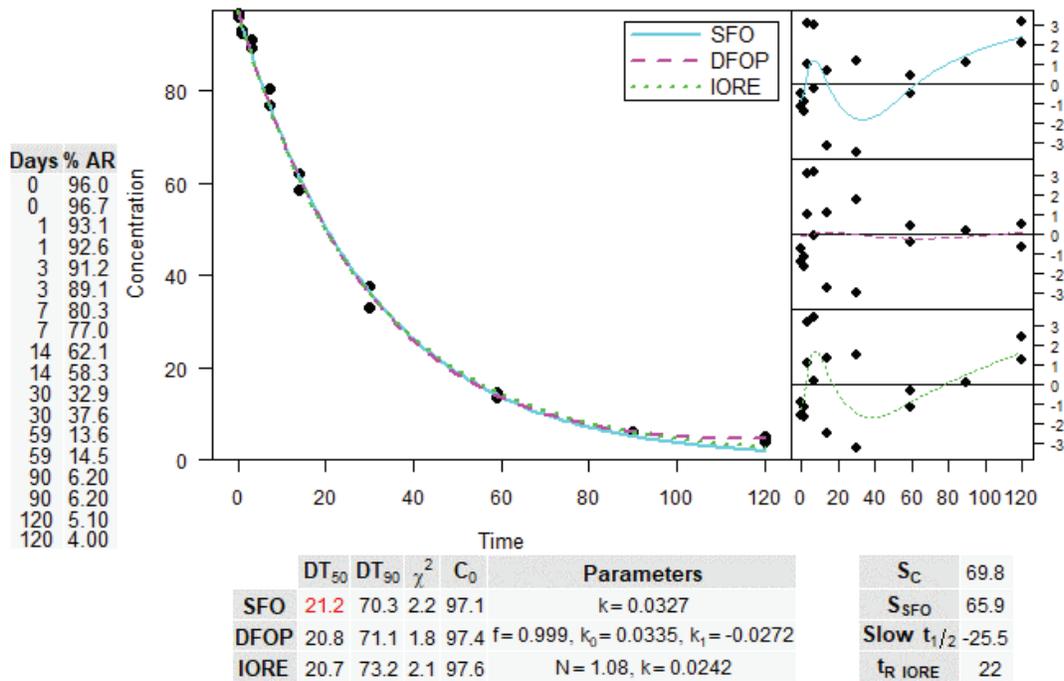
Aerobic metabolism of Triclopyr ROC in sandy clay loam soil

Days	% AR
0	94.3
0	94.6
1	92.3
1	92.8
3	92.3
3	90.8
7	84.6
7	90.1
14	84.0
14	83.6
30	69.6
30	70.8
59	41.0
59	43.4
90	9.80
90	9.10
120	3.60
120	3.20

	DT_{50}	DT_{90}	χ^2	C_0	Parameters
SFO	41	136	9	98.3	$k = 0.0169$
DFOP	41	136	10	98.3	$f = 0.821, k_0 = 0.0169, k_1 = 0.0169$
IORE	50.2	100	4.2	95.5	$N = 0.219, k = 0.375$

S_C	234
S_{SFO}	951
Slow $t_{1/2}$	41
$t_{R\ IORE}$	30.1
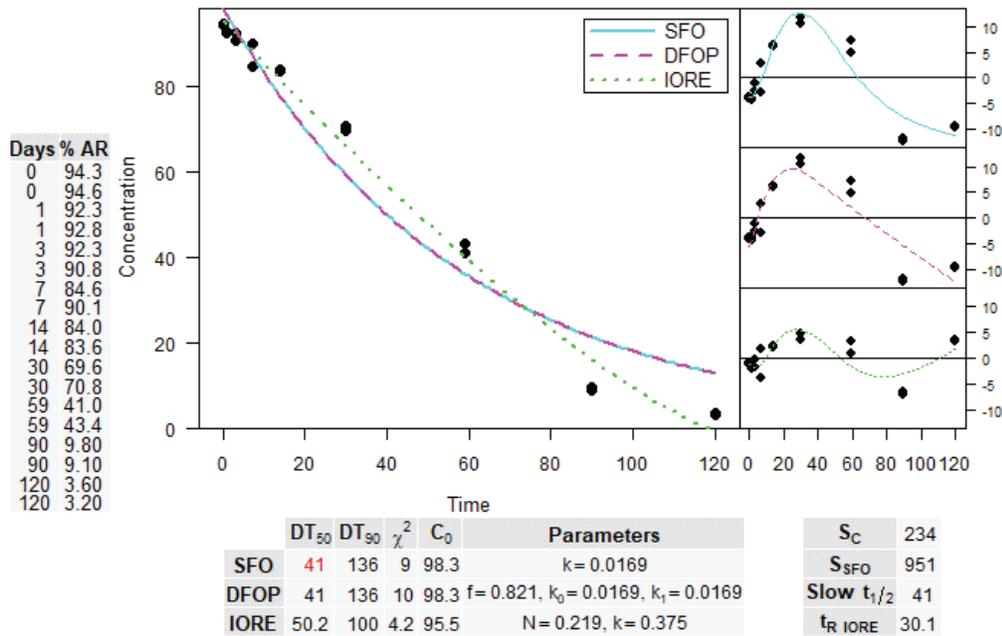
Aerobic metabolism of Triclopyr ROC in sandy loam soil

Days	% AR
0	95.7
0	95.7
1	94.2
1	86.4
3	95.4
3	94.6
7	94.0
7	93.0
14	85.5
14	87.4
30	66.7
30	68.8
59	40.7
59	40.5
90	17.5
90	21.0
120	14.7
120	21.0

	DT_{50}	DT_{90}	χ^2	C_0	Parameters
SFO	47.2	157	5.4	98.8	$k = 0.0147$
DFOP	47.2	157	6.1	98.8	$f = 0.524, k_0 = 0.0147, k_1 = 0.0147$
IORE	50.8	131	5	97.5	$N = 0.651, k = 0.06$

S_C	400
S_{SFO}	429
Slow $t_{1/2}$	47.2
$t_{R\ IORE}$	39.3

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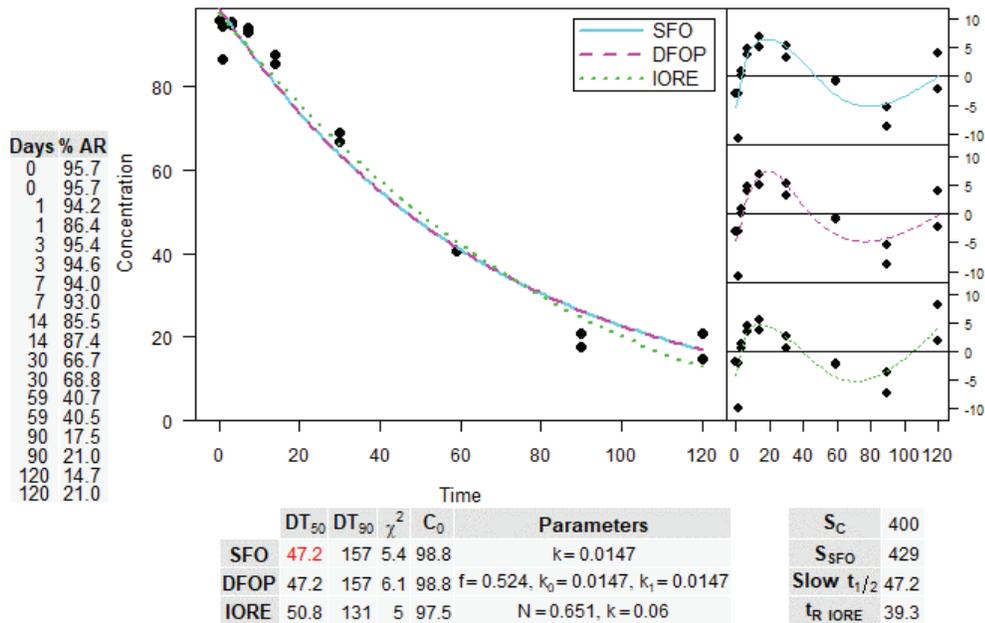
Aerobic metabolism of Triclopyr ROC in clay loam soil

Days	% AR
0	95.7
0	96.6
1	90.9
1	94.8
3	95.8
3	90.4
7	93.9
7	92.2
14	88.7
14	93.2
30	35.5
30	34.6
59	11.6
59	5.80
90	4.60
90	5.80
120	1.60
120	2.30

	DT_{50}	DT_{90}	χ^2	C_0	Parameters
SFO	24.1	80.1	14	103	$k = 0.0287$
DFOP	24.1	80.1	15	103	$f = 0.867$, $k_0 = 0.0287$, $k_1 = 0.0287$
IORE	26.3	67.3	13	102	$N = 0.645$, $k = 0.121$

S_C	1.59e+03
S_{SFO}	1.75e+03
Slow $t_{1/2}$	24.1
$t_{R\ IORE}$	20.2
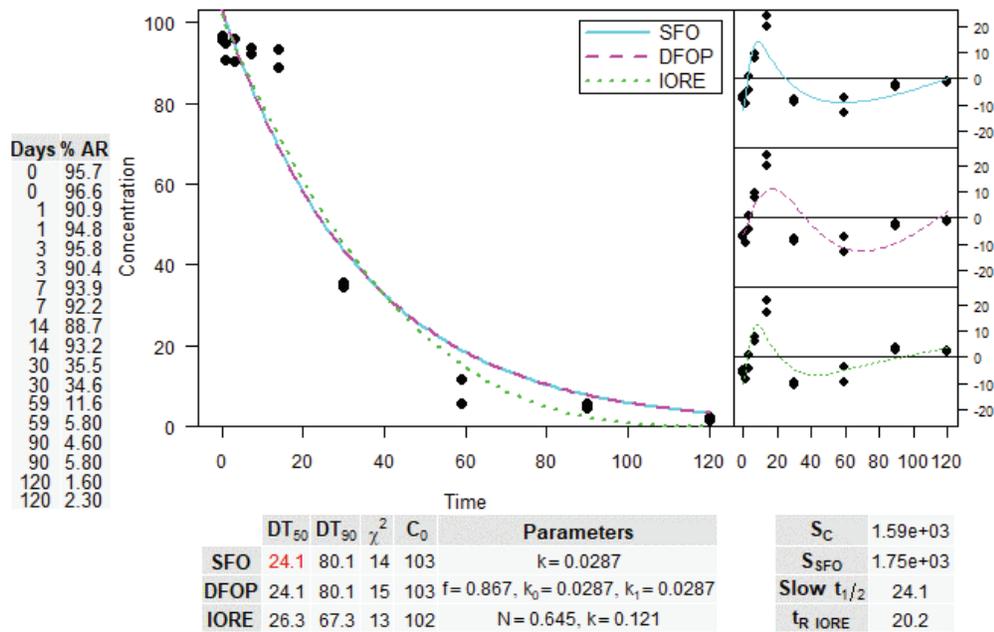
The 90 percent upper confidence bound on the mean of 4 values

(21.2; 41; 47.2 and 24.1 d @ 20 °C) Or (14.9; 29; 33.4 and 17 @ 25 °C) = **31 days** @ 25 °C

Triclopyr ROC in aerobic water:loam sediment

Days	%AR
7	99.6
7	87.9
14	86.6
14	94.6
30	83.9
30	84.6
59	73.9
59	81.2
106	63.0
106	81.7

	DT_{50}	DT_{90}	χ^2	C_0	Parameters
SFO	259	861	1.8	93.5	$k = 0.00267$
DFOP	2617	13959	0.13	97.8	$f = 0.275$, $k_0 = 0.0223$, $k_1 = 0.000142$
IORE	1213	26280601	0.34	99.4	$N = 7.19$, $k = 4.06e-15$

S_C	416
S_{SFO}	337
Slow $t_{1/2}$	4.88e+03
$t_{R\ IORE}$	7.91e+06
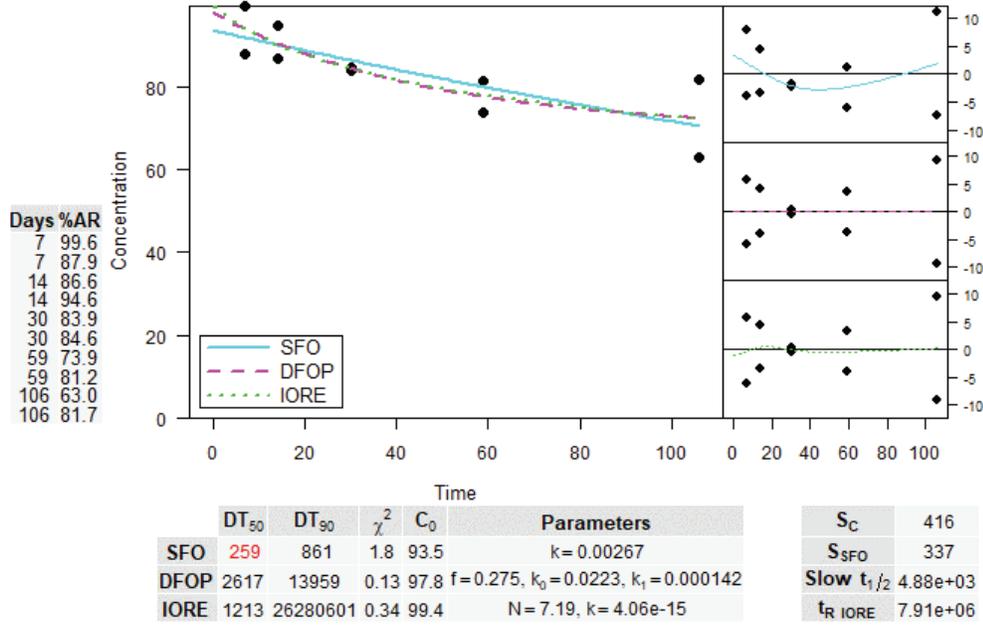
Triclopyr ROC in aerobic water:sand sediment

Days	%AR
2	89.2
7	88.5
7	92.8
14	81.9
14	90.4
30	79.7
30	81.5
59	79.9
59	80.3
106	56.4
106	58.9

	DT_{50}	DT_{90}	χ^2	C_0	Parameters
SFO	180	598	3.3	92.2	$k = 0.00385$
DFOP	153	378	3.4	89.1	$f = -0.847$, $k_0 = 0.0161$, $k_1 = 0.00765$
IORE	192	839	3.8	92.3	$N = 1.32$, $k = 0.000963$

S_C	250
S_{SFO}	180
Slow $t_{1/2}$	90.6
$t_{R\ IORE}$	253
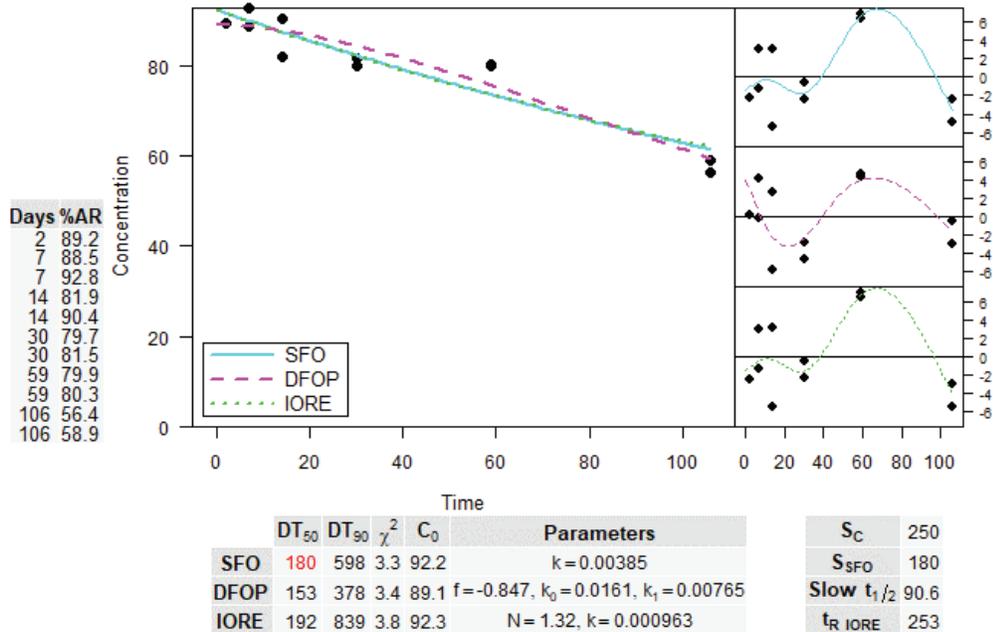
The 90 percent upper confidence bound on the mean of two values (259 & 180 d @ 20 °C or (183.1 & 127.3 d @ 25 °C) = **241 days** @ 25 °C

II. Examples for Aquatic Modeling Inputs and Outputs

Use on Rice

Scenario: ECO MO noWinter

Inputs

Chemical (ROC)
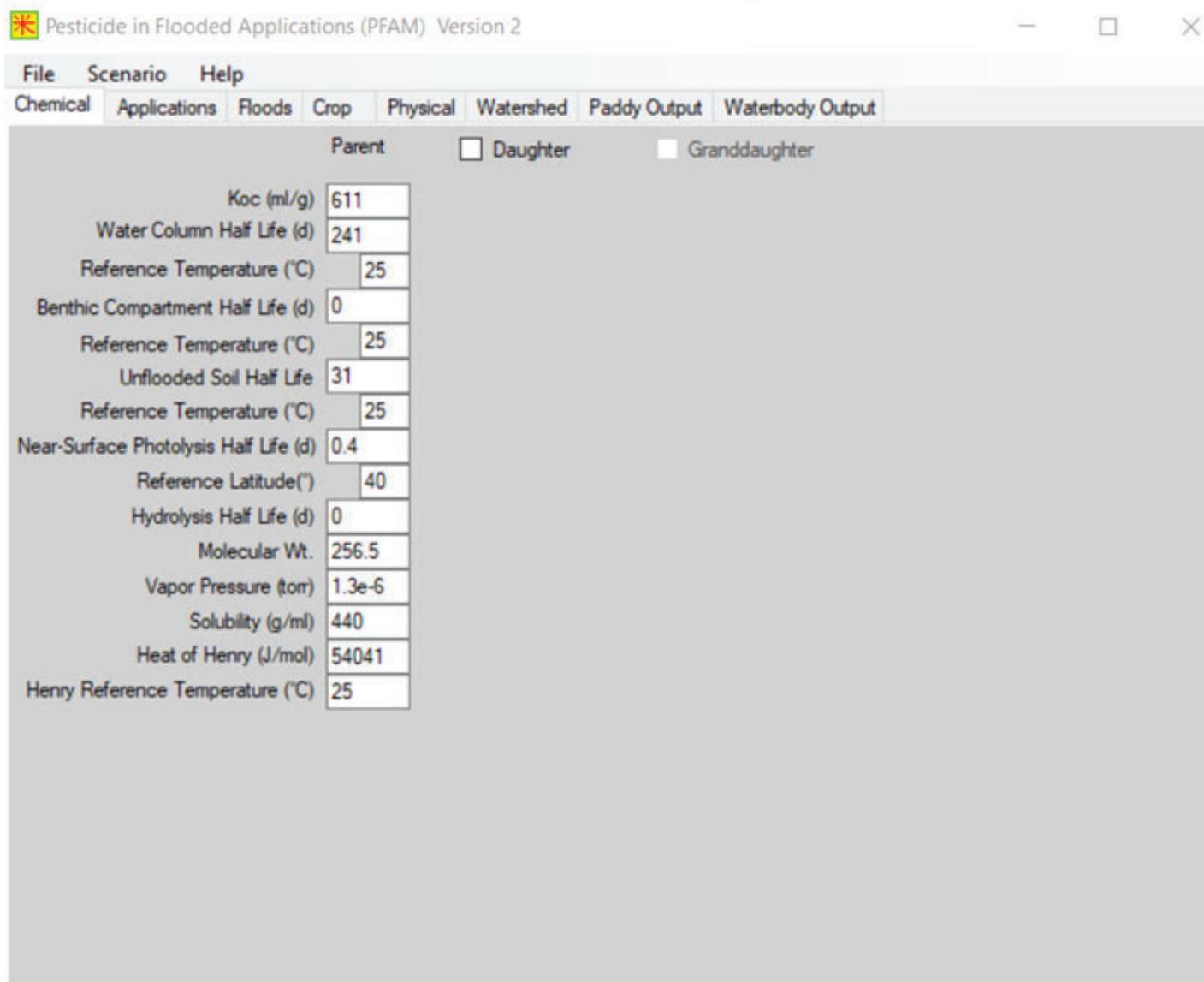
Applications

Floods

Output

Paddy Concentrations

Pesticide in Flooded Applications (PFAM) Version 2   — ☐ ✕

File   Scenario   Help

Chemical Applications Floods Crop Physical Watershed **Paddy Output** Waterbody Output

Highest Released Concentration [ppb] =   0.164E+04

1-in10 Year Paddy Values [ppb]:

	Water Column	Benthic Pore Water	Total/(Dry Mass)
Peak =	420.	--	--
1-day avg =	369.	38.8	251.
4-day avg =	261.	38.7	251.
21-day avg =	84.0	36.7	238.
60-day avg =	54.9	31.2	202.
90-day avg =	39.6	27.4	177.
365-day avg =	9.93	10.9	70.4

Holding Time Calculator

Number of Days After Last Application: 0

	highest	90th	average
Find the Concentration (ppb)			

Run completed at 7/12/2019 11:50:21 AM

Run

Working Directory: C:\Users\mruhman\Desktop\Trclopyr-Rice-1\ECO-2\MO-NoW\

IO Family Name: MO-ECO

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Use on Forestry (ACID, TEA and COLN represented by ROC)

Scenario: CAForestryRLF (6 lbs. a.e./A= 6.73 kg/ha; 11-Apr; A)

Inputs

Chemical

wc. Pesticide Water Calculator (PWC), Version 1.52   — □ ✕

File   Scenario   Help

| Chemical | Applications | Crop/Land | Runoff | Watershed | Batch Runs | More Options | Out: Pond | Out: Reservoir | Out: Custom | Out:GW | Advanced |

Chemical ID (optional)   Triclopyr

	Parent	Daughter
○ Koc ◉ Kd Sorption Coeff (mL/g)	0.6	
Water Column Metabolism Halflife (day)	241	
Water Reference Temperature (°C)	25	
Benthic Metabolism Halflife (day)	0	
Benthic Reference Temperature (°C)	25	
Aqueous Photolysis Halflife (day)	0.4	
Photolysis Ref Latitude (°)	40	
Hydrolysis Halflife (day)	0	
Soil Halflife (day)	31	
Soil Reference Temperature(°C)	25	
Foliar Halflife (day)		
Molecular Weight (g/mol)	256.5	
Vapor Pressure (torr)	1.3e-6	
Solubility (mg/L)	440	
[Push to Estimate Henry] Henry's Constant	0.0	
Air Diffusion Coefficient (cm²/day)	0.0	
Heat of Henry (J/mol)	0.0	

Q10   2

Ready...

Working Directory: J:\Triclopyr\ModelingResults\ECO-TTR\FORST-CA-H\

IO Family Name: STD-6-A

[Run]

Applications

Crop-Land

Output
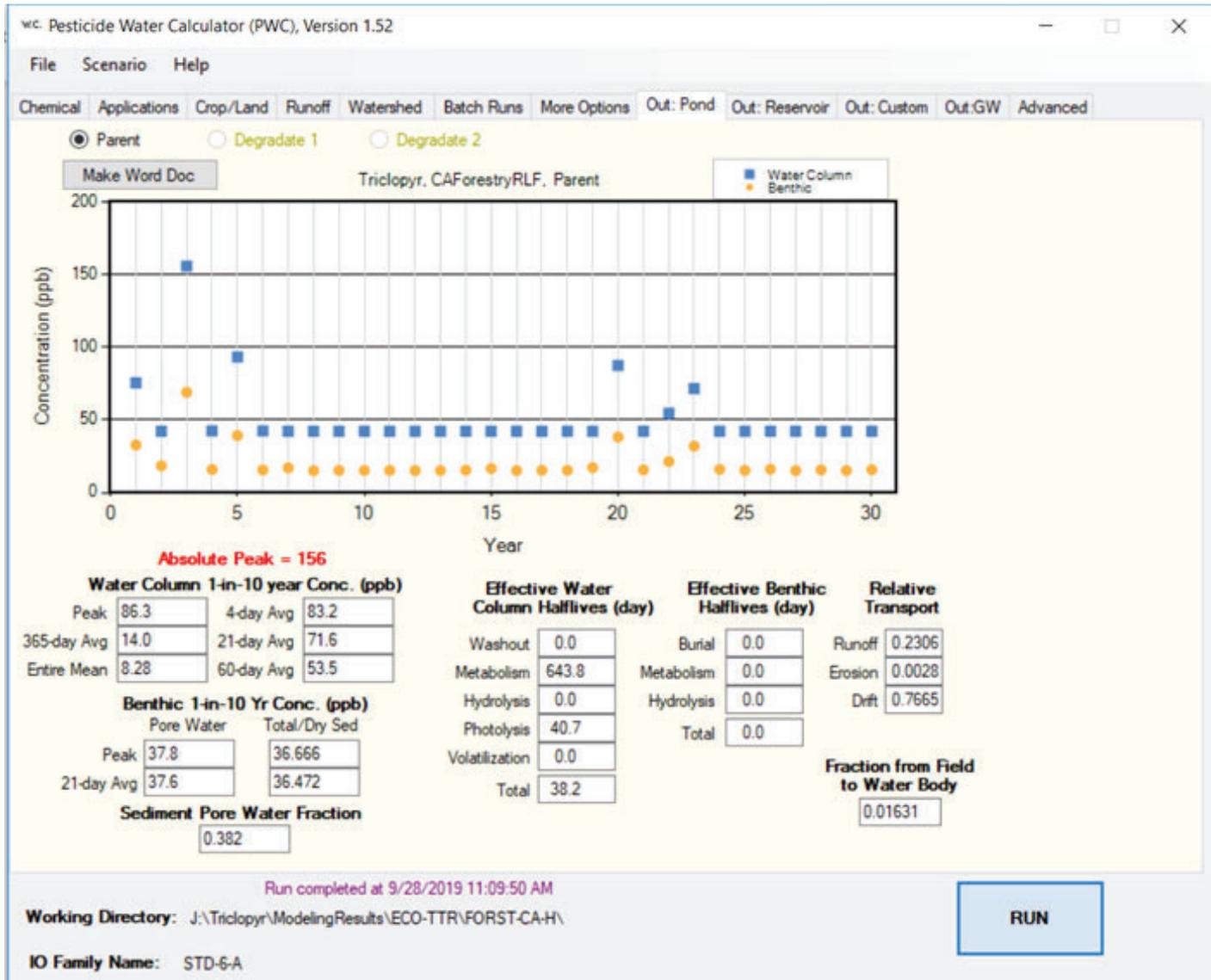
1-day EEC= 85.5 ppb (from out file)

Use on Forestry (BEE)

Scenario: CAForestryRLF (6 lbs. a.i./A= 9.35 kg /a.i/ha; 11-Apr; A)= a.i= BEE

Inputs

Chemical

Applications

Crop/Land

Output
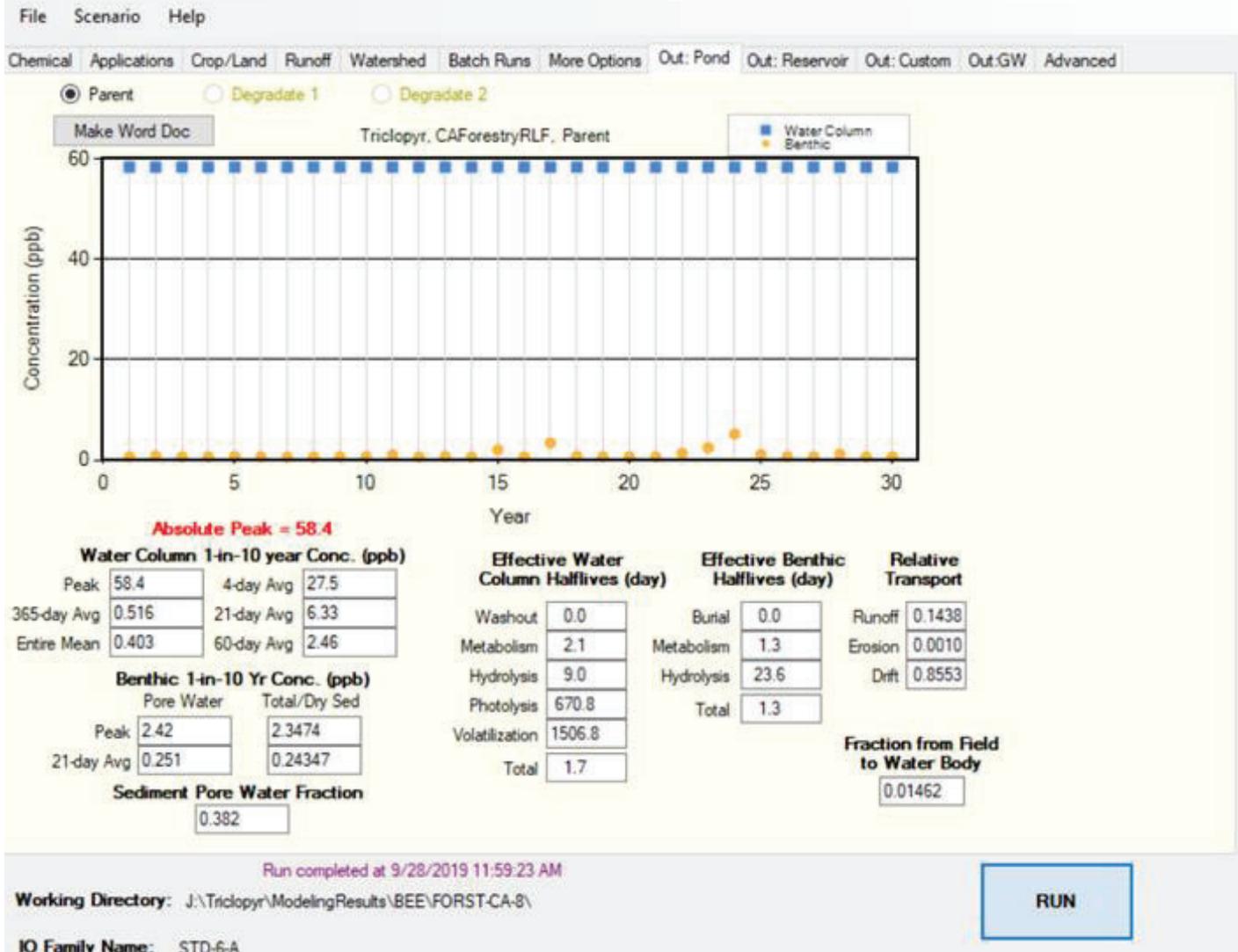
1-day EEC= 47.3 ppb (from out file)

III. Calculations of Exposure EECs for TCP Degradate Using the Formation and Decline (F/D) Approach

The EECs for the TCP degradate, forming from applications of triclopyr ACID and BEE, were estimated according to the formation and decline method guiding principles presented in Attachment 2 for Methods for Assessing Aquatic Exposure to Residue(s) of Concern, EFED division Director Memo dated June 20, 2019. The exercise requires the following:

(1) Identification of chemical species and degradation pathway associated with the formation of TCP from ACIC and from BEE

(2) Preparation of fate and transport data for TCP and all the chemical species associated with its formation;

(3) Identification of all fate processes involved in TCP formation (i.e., water column metabolism, benthic metabolism, photolysis, hydrolysis, soil metabolism and foliar degradation represented by aerobic/ anaerobic aquatic metabolism, aqueous photolysis, hydrolysis, aerobic soil metabolism and foliar degradation, respectively);

(4) Collection of data for each of the fate processes identified in 3 above (from submitted fate studies) in order to calculate the Molar Formation/Decline Ratio (MFDR) for each of the identified fate process (Note: depending on the number of submitted fate studies, multiple MFDR may result for some of the fate processes;

(5) Calculation of MFDR(s) for the fate processes involved in formation of TCP; and

(6) Collection of input parameters required for execution of special PWC runs.

Chemical species and degradation pathway associated with the formation of TCP from ACID and BEE

Based on data presented in the fate and transport summary (section 5 of this document), TCP is a major degradate of the ACID and BEE. The chemical species associated with TCP formation are: Triclopyr ACID and BEE.

Fate and transport data for TCP and all the chemical species associated with its formation

Table B-1 includes a summary of fate and transport data for TCP. Additionally, fate and transport parameters required for PWC modeling following the F/D approach, are summarized in Table B-2; that is fate and transport parameters for the ACID, BEE and TCP.

Table B-1 Summary of Environmental Degradation Data forTCP[1].

Study	System Details	Representative Half-life[2] Or Kd value*	Source/ Study Classification
K_d (mL/g) [1]	Sandy soil: pH 7.0 and O.C 0.22%	0.53	MRID 42493901, Chlorpyriphos study
	Sandy loam soil: pH 7.8and O.C 2.54%	0.6	
	Silt loam: pH 7.1 and O.C 0.31%	1.69	
	Clay loam: pH 6.9 and O.C 2.08%	1.95	
Aerobic Soil Metabolism (days)	MO: Boone Silt loam, 25°C	34.1 (SFO)	MRID 499924-02[N] (A)
	TX: Raymondville Sandy clay loam, 25°C	20.4 (SFO)	

Study	System Details	Representative Half-life[2] Or Kd value*	Source/ Study Classification
	ND: MSL-PF Sandy loam, 25°C	22.9 (SFO)	
	CA: Tehama Clay loam, 25°C	70.3 (SFO)	
Anaerobic Soil Metabolism (days)	WY: LAD-SCL-PF Clay, 25°C	Stable	MRID 499924-03 [N] (A)
	UK: Brierlow Silt Loam, 25°C	52.2 (SFO)	
	UK: Longwood Sandy Loam, 25°C	29.4 (SFO)	
	UK: South Witham Clay, 25°C	70.4 (SFO)	
Aerobic Aquatic Metabolism[3] (days)	Italy loam sediment: Water, 25°C	Stable	MRID 499924-04 [N] (S)
	French Sand Sediment: Water, 25°C		
Anaerobic Aquatic Metabolism[4] (days)	GA Sandy Loam, 25°C	271 (SFO)	MRID 001519-67 [N] (S)
	VA Sandy loam, 25°C	Stable	

[1] **General Notes:** Studies submitted since the Problem Formulation was completed are designated with an [N] in association with the MRID number; **Studies classification:** A= Acceptable, S= Supplemental; N/A= Not applicable

[2] **Half-lives:** SFO=single first order; DFOP=double first order in parallel; DFOP slow DT_{50}=slow rate half-life of the DFOP fit

[4] The test substance is the 3,5,6-trichloro-2-pyridinyloxyacetic acid, butoxyethyl ester (BEE) form of triclopyr. BEE was a transient species transforming relatively quickly into the 3,5,6-trichloro-2-pyridinyloxyacetic acid (ACID) form of triclopyr. ACID maximums reached 98 & 90% in seven days. Therefore, starting from the 7-day time interval, the study can be considered to represent the fate of the ACID form of triclopyr in an aerobic aquatic system

[5] The test substance is the BEE form of triclopyr. BEE transformed completely into the ACID form of triclopyr. ACID maximums reached 101 & 98% in one-day. Therefore, the study can be considered to represent the fate of the ACID form of triclopyr in an aerobic aquatic system

Table B-2. Aquatic Modeling Input Parameters for Chemical Tabs of BEE, the ACID and TCP.

Parameter (units)	ACID & BEE Values[1]		TCP Value(s)	
	ACID	BEE	TCP	Comments and Referenced MRID
K_d (mL/g)	0.6	0.6	1.2	Average (n= 4); Chlorpyriphos study[2]
Water Column Metabolism t ½ (days) @ 25°C	29.1	0.8	Stable	MRID 00151967
Benthic Metabolism t ½ (days) @ 25°C	1,531	0.5	Stable	MRID 49992404
Aqueous Photolysis t ½ (days)@ pH 5; 40°N	0.4	6.6	0.4	Assumed to equal parent noting that this low value is expected because reported absorption spectra in MRID 001547-16 shows two high absorption peaks in the visible light (wave length between 200-400 nm)
Hydrolysis Half-life @ pH 7 (days)	Stable	9	Stable	Assume to be the same as parent
Soil Half-life (days) at 25°C	20	1.0	55.8	Represents the 90 percent upper confidence bound on the mean (n=4); MRID 499924-02
Molecular Weight (g/mol)	256.5	356.6	198	Chemical profile; MRID 42493901
VP (Torr) at 25°C	1.3×10^{-6}	3.6×10^{-6}	1.3×10^{-6}	Assume to be the same as ACID
Solubility in Water (mg/L)	440	7.4	170	Chemical profile
Heat of Henry (J/mol) @ 25°C	54,041	37,892	54,041	Same as triclopyr ACID from EPIWEB 4.1

[1] **Value(s) for the ACID and BEE** are those presented in the Aquatic Exposure Assessment, Modeling (Section 8.11 of this document)

[2] Kd value was Kd value was used in modeling to match that used for the ACID noting that CV value for Koc was slightly lower than that for Kd (56 versus 61%).1999 Chlorpyrifos RED; Memo from EFED (Barrett, Michael R.) to HED (Steve Knizer), both of OPP/EPA, dated November 20, 1998

Fate processes involved in TCP formation from the ACID and BEE

Based on the fate and transport data, the following processes are identified:

(a) From the ACID: The processes involved are water column metabolism, benthic metabolism and soil metabolism noting that photolysis, hydrolysis and foliar degradation processes are not involved; and

(b) From BEE: The processes involved in transformation of BEE to the ACID are water column metabolism, benthic metabolism, hydrolysis and soil metabolism noting that photolysis and foliar degradation processes are not involved. Furthermore, the processes involved in transformation of the ACID to TCP are those stated in (a), above.

Collection of data for each of the fate processes (from submitted fate studies)
This data is needed to calculate the Molar Formation/Decline Ratio (MFDR) for each of the identified fate process

ACID to TCP data
(1) Water column metabolism data (Source: aerobic aquatic study, MRID 49992404)

Water: loam sediment from Italy			Water: sand sediment from France		
Day	ACID	TCP	Day	ACID	TCP
2	85.1	0.0	2	88.8	0.3
2	85.5	0.9	7	80.4	7.8
7	98.4	0.9	7	89.7	3.1
7	86.0	1.7	7	87.9	3.1
7	90.8	2.6	14	62.1	19.0
14	80.0	5.7	14	78.2	11.9
14	88.7	5.1	30	57.9	19.7
30	58.6	20.8	30	60.7	19.3
30	57.5	23.1	59	31.8	18.2
59	24.0	14.1	59	33.4	13.2
59	36.6	33.4	106	2.9	22.3
106	11.0	4.8	106	5.3	23.7
106	10.1	18.7			

(2) Benthic metabolism data (Source: anaerobic aquatic study, MRID 00151967)

System 1: Flooded Cecil sandy loam soil			System 2: Flooded Norfolk sandy loam soil		
Day	ACID	TCP	Day	ACID	TCP
0	99.0	0.04	0	96.4	0
1	100.5	0.4	1	98.1	0.2
7	91.2	1.8	7	89.9	2.9
14	77.1	4.0	14	93.7	2.8
20	76.3	4.1	20	91.1	4.6
60	94.1	6.1	60	95.2	7.0
100	88.3	15.2	100	90.6	10.2

System 1: Flooded Cecil sandy loam soil			System 2: Flooded Norfolk sandy loam soil		
201	74.8	25.9	201	86.6	14.0
365	75.3	25.7	365	86.5	15.3
365	74.7	26.0	365	79.4	22.0

(3) Aerobic soil data (Source: aerobic soil study, MRID 49992404)

Soil 1: Aerobic Boone silt loam soil, MO			Soil 2: Aerobic Raymondville sandy clay loam soil, TX			Soil 3: Aerobic MSL-PF sandy loam soil, ND			Soil 4: Aerobic Tehama clay loam soil, CA		
Day	ACID	TCP	Day	ACID	TCP	Day	ACID	TCP	Day	ACID	TCP
0	95.1	0.9	0	93.7	0.6	0	94.6	1.1	0	95.1	0.6
0	96.0	0.7	0	93.9	0.7	0	94.8	0.9	0	96.0	0.6
1	87.6	5.5	1	91.0	1.3	1	91.4	2.8	1	88.4	2.5
1	87.4	5.2	1	91.6	1.2	1	84.2	2.2	1	92.1	2.7
3	79.3	11.9	3	89.6	2.7	3	92.1	3.3	3	92.1	3.7
3	77.5	11.6	3	88.1	2.7	3	90.8	3.8	3	87.4	3.0
7	60.4	19.9	7	80.2	4.4	7	86.9	7.1	7	86.2	7.7
7	52.4	24.6	7	85.0	5.1	7	84.8	8.2	7	81.7	10.5
14	27.6	34.5	14	75.7	8.3	14	70.8	14.7	14	82.1	6.6
14	27.1	31.2	14	74.4	9.2	14	74.7	12.7	14	91.1	2.1
30	5.9	27.0	30	50.6	19.0	30	43.9	22.8	30	13.6	21.9
30	7.1	30.5	30	52.3	18.5	30	47.7	21.1	30	10.4	24.2
59	0.8	12.8	59	22.6	18.4	59	12.9	27.8	59	1.2	10.4
59	1.0	13.5	59	24.0	19.4	59	13.8	26.7	59	1.4	4.4
90	0.0	6.2	90	3.0	6.8	90	0.9	16.6	90	0.9	3.7
90	1.0	5.2	90	1.3	7.8	90	3.3	17.7	90	0.9	4.9
120	0.7	4.4	120	0.4	3.2	120	1.6	13.1	120	0.2	1.4
120	0.3	3.7	120	0.4	2.8	120	2.0	19.0	120	0.6	1.7

BEE to ACID data

Based on examination of the transformation process of BEE to the ACID, it can be assumed that nearly 100% of BEE transforms into the ACID (1 to 1 transformation) in all processes involved (water column metabolism, benthic metabolism, hydrolysis and soil metabolism). For example, BEE hydrolyze in aqueous systems and transforms in aerobic soil systems and aerobic/anaerobic aquatic systems into the ACID only within <day.

Calculation of the Formation and Decline ratios (FDR) for all fate processes involved in formation ACID from BEE and formation of TCP from the ACID

As stated earlier, FDR is considered to equal 1 all processers involved in transformation of BEE to the ACID. Therefore, what is left is calculation of FDRs for transformation of the ACID to TCP. As stated earlier, FDRs are to be calculated for the following processes water column

metabolism, benthic metabolism and soil metabolism from fate data collected in the previous step. For this a **Solver Tool** is used. The Tool calculates the formation rate of TCP from ACID along with the decline rate of the ACID simultaneously. Inputs for the tool are the fate data for chosen process and outputs include the formation rate of TCP from ACID and the decline rate of the ACID for each fate process (designated as **K1fa** and **Kp**, respectively; **Table B-3**). Additionally, the output includes graphs representing the formation and decline data (Figures B-2 and B-3)

Table B-3. Formation/Decline Values for the Various Transformation Processes Producing the Degradate TCP.

Study (MRID)	System	K1fa (TCP Formation Rate)	Kp (Acid Decline Rate	Formation/Decline Ratio (FDR)[1]	Molecular Formation/ Decline Ratio (MFDR)[2]
Decline of ACID and Formation of TCP
Aerobic Soil	USA Boone silt loam soil, Missouri (20°C, pH 4.7)	0.050093373	0.083599303	0.59921	**0.46255**
	Raymondville sandy clay loam soil, TX (20°C, pH 7.6)	0.012816393	0.024026057	0.53344	**0.41178**
	MSL-PF Sandy loam soil, ND (20°C, pH 6.2)	0.013908826	0.027348302	0.50858	**0.39259**
	Tehama clay loam soil, CA (20°C, pH 6.4)	0.014250641	0.038564986	0.36952	**0.28525**
Anaerobic Aquatic	Flooded Cecil sandy loam soil	1	1	1	**0.74600**
	Flooded Norfolk sandy loam soil	1	1	1	**0.74600**
Aerobic Aquatic	Water: loam sediment from Italy	0.009996	0.018495	0.540469	**0.41720**
	Water: loam sediment from France	0.007895	0.019697	0.400827	**0.30941**
Decline of BEE and Formation of ACID
Aerobic Soil	MS Loamy soil (pH 8; O.C= 0.5%) and GA Sandy loam soil (MRID 472938-01)	1	1	1	**0.71929**
Hydrolysis	Sterile buffered solutions @ pH 7	1	1	1	**0.71929**
Anaerobic Aquatic	Flooded Cecil sandy loam and Norfolk sandy loam soils	1	1	1	**0.71929**
Aerobic Aquatic	Water: loam sediment from Italy and Water: loam sediment from France	1	1	1	**0.71929**

Equation for calculating FDR = $\dfrac{k1fa \text{ (metabolite A formation)}}{Kp \text{ (parent P decline)}}$

Equation for calculating MFDR = $\dfrac{FDR \times \text{M.Wt. metabolite}}{\text{M.Wt. parent}}$

M. Wt.= Molecular weight g mol^{-1}= ACID: 256.5; **TCP:** 198; **BEE:** 356.6

Example MO soil: FDR= $\dfrac{0.050093373}{0.083599303}$ = 0.59921

MFDR= $\dfrac{0.59921 \times 198}{256.5}$ = 0.46255
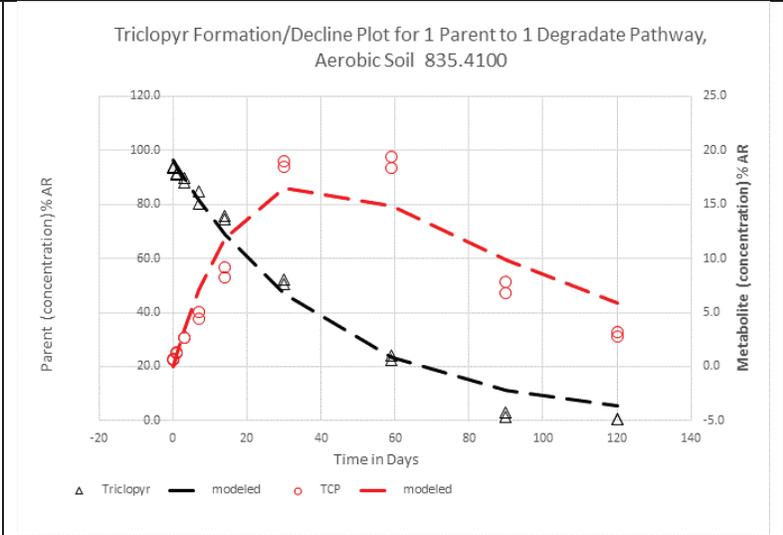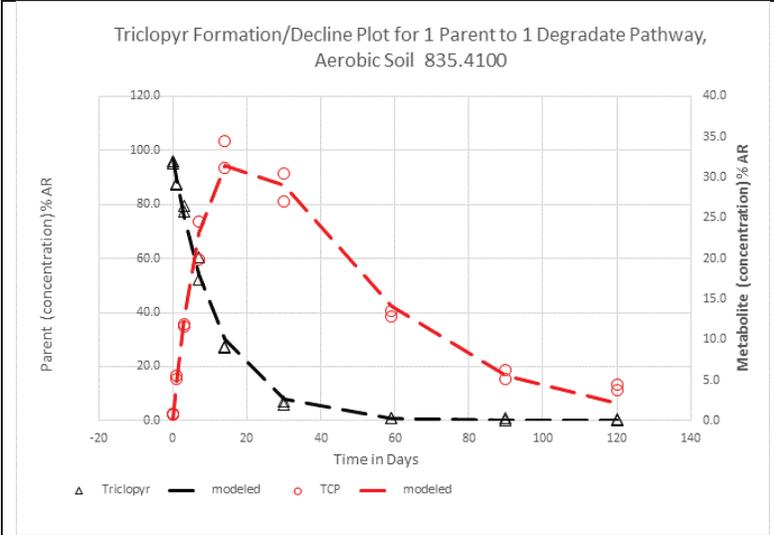
USA Boone silt loam soil, MO
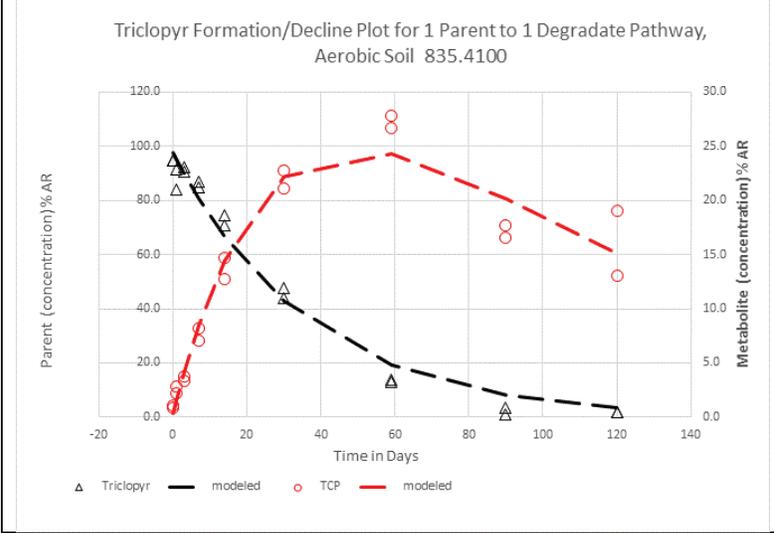
Raymondville sandy clay loam soil, TX
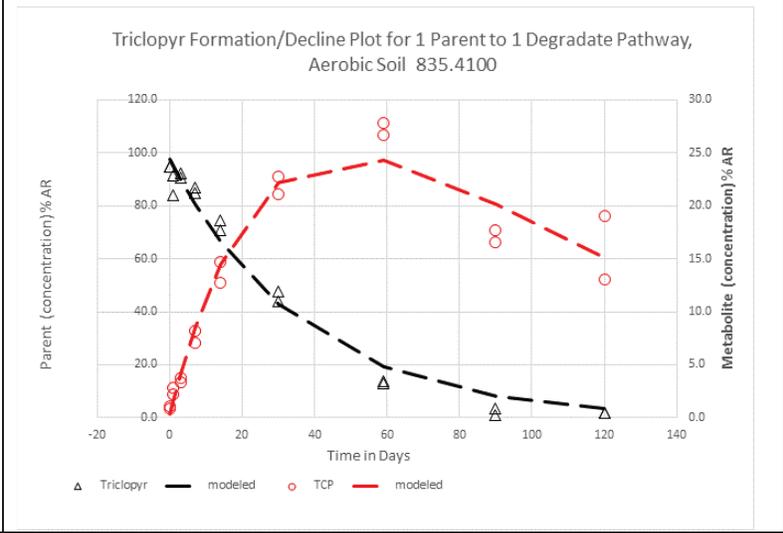
MSL-PF Sandy loam soil, ND

Tehama clay loam soil, CA

Figure B-1 Graphs Representing the Formation and Decline Data for Four Aerobic Soil Systems.

Aerobic Water: loam sediment from Italy

Aerobic Water: loam sediment from France

Flooded Cecil sandy loam soil

Flooded Norfolk sandy loam soil
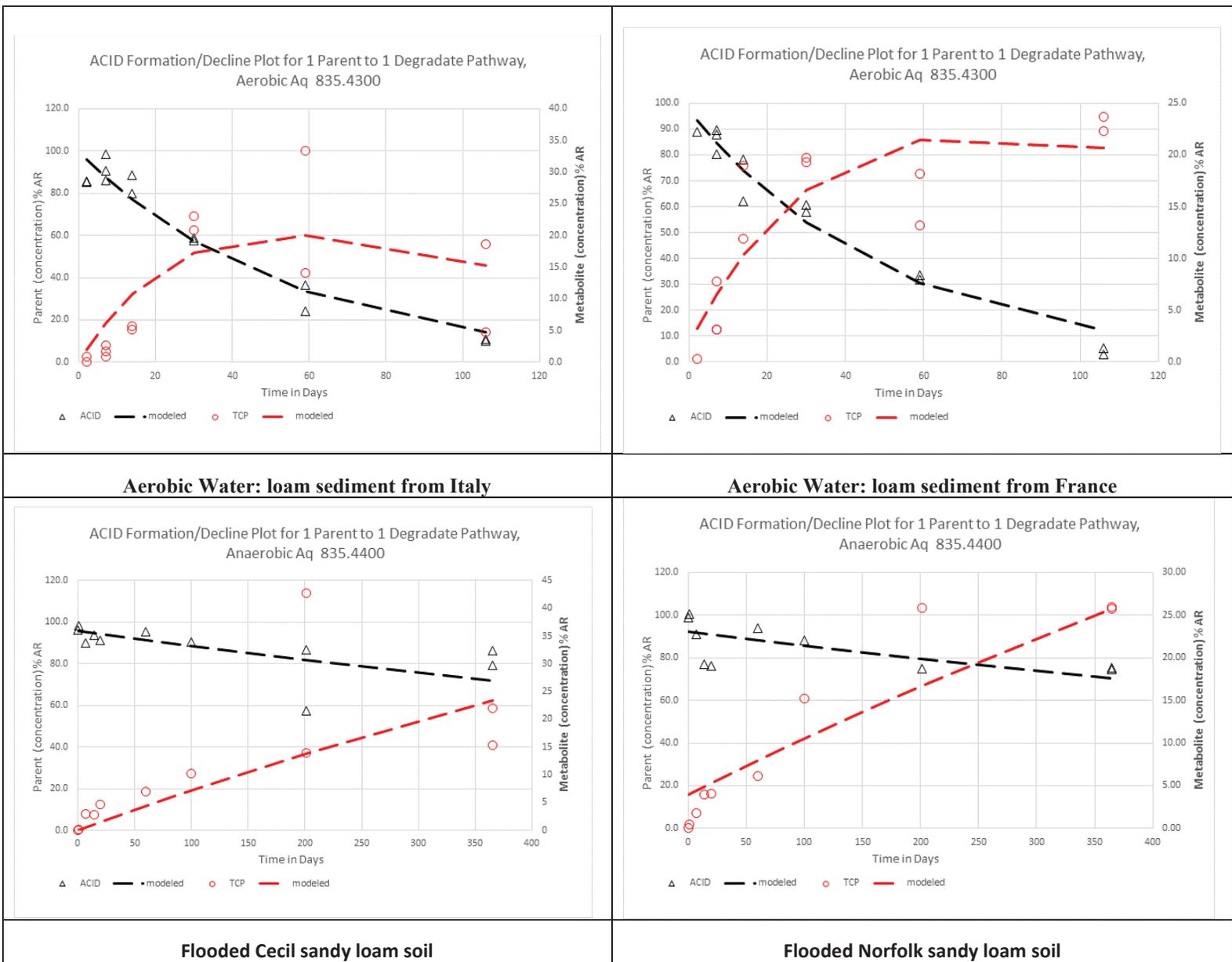
Figure B-2 Graphs Representing the Formation and Decline Data for Aerobic/Anaerobic Aquatic Systems (Two Systems Each).
Collection of input parameters required for execution of special PWC runs

Two transformation pathways are recognized for the required calculations of concentrations for each individual stressor present in these pathways, namely:

For the first pathway: ACID (referred to in PWC as parent) → TCP (referred to in PWC as Daughter); and

For the second pathway: BEE (referred to in PWC as parent) → ACID (referred to in PWC as daughter) → TCP (referred to in PWC as Granddaughter)

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One PWC run is needed for the first pathway with its associated inputs and another separate PWC run with its associated inputs (**Figure B-3**).

Left panel:

Chemical | Applications | Crop/Land | Runoff | Watershed | Batch Runs | M

Chemical ID (optional) Triclopyr

	Parent	Daughter	G
○ Koc ● Kd Sorption Coeff (mL/g)	0.6	1.2	
Water Column Metabolism Halflife (day)	29.1	0	
Water Reference Temperature (°C)	25	25	
Benthic Metabolism Halflife (day)	1531	0	
Benthic Reference Temperature (°C)	25	25	
Aqueous Photolysis Halflife (day)	0.4	0.4	
Photolysis Ref Latitude (°)	40	40	
Hydrolysis Halflife (day)	0	0	
Soil Halflife (day)	20	55.8	
Soil Reference Temperature(°C)	25	same	
Foliar Halflife (day)			
Molecular Weight (g/mol)	256.5	198	
Vapor Pressure (torr)	1.3e-6	1.3e-6	
Solubility (mg/L)	440	170	
[Push to Estimate Henry] Henry's Constant	4.08E-08	8.14E-08	
Air Diffusion Coefficient (cm²/day)	0.0	0.0	
Heat of Henry (J/mol)	54041	54041	

Molar Formation:Decline Ratio

Water Column Metabolism	0.30941
Benthic Metabolism	0.7460
Photolysis	0
Hydrolysis	0
Soil	0.28525
Foliar	0

Right panel:

Pesticide Water Calculator (PWC), Version 1.52

File   Scenario   Help

Chemical | Applications | Crop/Land | Runoff | Watershed | Batch Runs | More Options

Chemical ID (optional) Triclopyr

	Parent	Daughter	Granddaughter
○ Koc ● Kd Sorption Coeff (mL/g)	0.6	0.6	1.2
Water Column Metabolism Halflife (day)	0.8	29.1	0
Water Reference Temperature (°C)	25	25	25
Benthic Metabolism Halflife (day)	0.5	1531	0
Benthic Reference Temperature (°C)	25	25	25
Aqueous Photolysis Halflife (day)	6.6	0.4	0.4
Photolysis Ref Latitude (°)	40	40	40
Hydrolysis Halflife (day)	9	0	0
Soil Halflife (day)	1	20	55.8
Soil Reference Temperature(°C)	25	same	same
Foliar Halflife (day)			
Molecular Weight (g/mol)	356.6	256.5	198
Vapor Pressure (torr)	3.6e-6	1.3e-6	1.3e-6
Solubility (mg/L)	7.4	449	170
[Push to Estimate Henry] Henry's Constant	9.33E-06	3.99E-08	8.14E-08
Air Diffusion Coefficient (cm²/day)	0.0	0.0	0.0
Heat of Henry (J/mol)	37892	54041	54041

Molar Formation:Decline Ratio

Water Column Metabolism	0.71929	0.4170
Benthic Metabolism	0.71929	0.74600
Photolysis	0	0
Hydrolysis	0.71929	0
Soil	0.71929	0.46255
Foliar	0	0

Inputs for the first PWC run: ACID → TCP	Input for the second PWC run: BEE → ACID → TCP

Figure B-3 Chemical Input Parameters for the F/D runs; all other parameters needed for the run is the same as those used for the ROC runs.

Output from the first run calculates exposure EECs for the ACID and TCP separately (**Table B-4**) while output for the second run calculates exposure EECs for BEE, the ACID and TCP (**Table B-5**). It is noted that outputs from the ROC runs are also included in **Table B-4**.

Table B-4. Range of Surface and Pore Waters Estimated Environmental Concentrations (EECs) for the ROC; ACID; and TCP Representing the Use of ACID, TEA and COLN Forms of Triclopyr (Estimated Using PWC version 1.52 and PFAM).

Use Site	Range	PWC Scenario (1st Application Date; Yearly Rate; Application Type)[1]	Chemical Species[2]	1-in-10-year Mean EECs				
				Water Column (µg/L)			Pore-Water (µg/L)	
				1-day	21-day	60-day	1-day	21-day
Aquatic Weed Control	Min	Applied @ 400 ppb	ROC (acid equivalent= a.e.)	396	343	255	152	151
			ACID	384	308	200	116	117
			TCP (Low MFDR)	20.1	20.2	18.6	13.3	12.1
			TCP (High MFDR)	27.6	27.7	25.5	18.1	16.6
		Applied @ 2,500 ppb	ROC (a.e.)	2,480	2,140	1,590	949	943
			ACID	2,400	1,930	1,250	723	730
			TCP (Low MFDR)	125	126	116	83.0	75.5
			TCP (High MFDR)	173	173	159	113	104
	Max	Applied @ 5,000 ppb	ROC (a.e.)	4,950	4,290	3,180	1,900	1,890
			ACID	4,810	3,850	2,500	1,450	1,460
			TCP (Low MFDR)	251	253	233	166	151
			TCP (High MFDR)	346	347	319	226	208
Citrus (FL)	Min	FLcitrusSTD (6; 3-Sep; G)	ROC (a.e.)	67	53.6	37.3	22.4	22.2
			ACID	23.9	15.3	8.19	4.97	4.90
			TCP (Low MFDR)	1.81	1.77	1.58	1.10	1.11
			TCP (High MFDR)	2.44	2.39	2.13	1.47	1.48
	Max	FLcitrusSTD (6; 26-May; G)	ROC (a.e.)	297	242	164	99	98.2
			ACID	281	194	104	66.9	65.9
			TCP (Low MFDR)	21.2	20.9	18.8	13.2	13.2
			TCP (High MFDR)	28.6	28.2	25.3	17.7	17.6
Forestry	Min	CAForestryRLF (6; 4-Aug; A)	ROC (a.e.)	46	39.0	29.9	25	24.6
			ACID	42.3	32.8	23.7	19.0	18.9
			TCP (Low MFDR)	2.73	2.70	2.56	2.09	2.12
			TCP (High MFDR)	3.78	3.73	3.53	2.85	2.88
	Max	CAForestryRLF (6; 11-Apr; A)	ROC (a.e.)	86	71.6	53.5	38	37.6
			ACID	82.9	65.0	45.5	32.8	32.5
			TCP (Low MFDR)	3.22	3.19	3.05	2.37	2.36
			TCP (High MFDR)	4.35	4.32	4.12	3.17	3.16
Grass: Range/ Pasture/ Non-crop Lands	Min	CArangelandhayRLF (9; 4-Apr; A)	ROC (a.e.)	99	84.1	62.7	38	37.5
			ACID	92.8	77.1	52.3	31.1	30.8
			TCP (Low MFDR)	5.58	4.78	4.36	3.52	3.51
			TCP (High MFDR)	8.80	7.53	5.97	4.82	4.81
	Max	RangeBSS (9; 15-May; A)	ROC (a.e.)	403	336.0	232.0	138	137.0
			ACID	384	284	157	96.4	95.1
			TCP (Low MFDR)	27.0	26.7	24.4	17.5	17.4
			TCP (High MFDR)	36.6	36.2	33.1	23.5	23.4
Grass: Meadow	Min	MeadowBSS (9; 13-Aug; A)	ROC (a.e.)	132	106.0	75.1	71	76.0
			ACID	113	72.6	48.0	29.9	29.5
			TCP (Low MFDR)	16.3	15.5	13.4	11.8	11.7
			TCP (High MFDR)	25.0	23.4	18.5	15.9	15.8
	Max	MeadowBSS (9; 15-May; A)	ROC (a.e.)	346	289.0	200.0	118	117.0
			ACID	332	245	136	82.8	81.6
			TCP (Lowest MFDR)	22.9	22.6	20.7	14.8	14.8

| Use Site | Range | PWC Scenario (1st Application Date; Yearly Rate; Application Type)[1] | Chemical Species[2] | 1-in-10-year Mean EECs | | | | |
| | | | | Water Column (µg/L) | | | Pore-Water (µg/L) | |
				1-day	21-day	60-day	1-day	21-day
			TCP (Highest MFDR)	30.9	30.5	27.9	19.9	19.7
Orchards (CA)	Min	CAcitrus_WirrigSTD (6; 6-Apr; G)	ROC (a.e.)	21	17.7	12.5	8	7.9
			ACID	20.9	15.7	9.67	5.72	5.65
			TCP (Lowest MFDR)	1.10	1.09	1.01	0.754	0.750
			TCP (Highest MFDR)	1.48	1.47	1.36	1.01	1.00
	Max	CAalmond_WirrigSTD (6; 11-May; G)	ROC (a.e.)	29	25.4	18.5	11	11.0
			ACID	29	22.7	13.9	8.30	8.20
			TCP (Lowest MFDR)	1.90	1.88	1.76	1.30	1.30
			TCP (Highest MFDR)	2.59	2.57	2.40	1.76	1.75
Premises	Min	CAresidentialRLF/ CAImperviousRLF (9; 1-May; G)	ROC (a.e.)[3]	12	10.1	7.5	5	4.5
	Max	ResidentialBSS/ ImperviousBSS (9; 21-May; G)	ROC (a.e.)[3]	32	26.1	18.5	12	11.9
Rice	Min	1st Scenario	ECO MS noWinter: ROC (a.e.)[3]	254	67.5	31.2	97	84.7
		2nd Scenario	ECO MS noWinter: ROC (a.e.)[3]	256	72.5	47.9	33	31.5
		Ratoon Rice	Ratoon Rice, TX: ROC (a.e.)[3]	334	60.1	32.5	25	22.8
		1st Scenario	ECO MO noWinter: ROC (a.e.)[3]	366	78.2	36.1	99	88.9
	Max	2nd Scenario	ECO MO noWinter: ROC (a.e.)[3]	369	84.0	54.9	39	36.7
Rights-of-Way	Min	CArightofwayRLF_V2/CAImperviousRLF (9; 21-May; A)	ROC (a.e.)[3]	17	14.9	11.4	7	7.0
	Max	RightOfWayBSS/ ImperviousBSS (9; 1-May; A)	ROC (a.e.)	259	214	147.5	89	88.7
			ACID	184	131	80.9	50	45.9
			TCP (Lowest MFDR)	Not Calculated				
			TCP (Highest MFDR)	23.9	23.6	21.9		
Turf	Min	CATurfRLF (4; 16-Apr; A)	ROC (a.e.)	15	12.6	11.1	9	8.8
			ACID	12.1	9.29	8.12	6.51	6.45
			TCP (Lowest MFDR)	1.09	1.08	1.01	0.832	0.829
			TCP (Highest MFDR)	1.48	1.46	1.36	1.11	1.11
	Max	TurfBSS (4; 11-Apr; A)	ROC (a.e.)	23	18.2	15.0	11	10.9
			ACID	18.3	12.8	9.97	6.76	6.67
			TCP (Lowest MFDR)	2.13	2.09	1.90	1.54	1.53
			TCP (Highest MFDR)	2.87	2.82	2.57	2.06	2.05
Christmas Trees	Min	ORXmasTreeSTD (6; 16-May; G)	ROC (a.e.)	21	17.5	13.1	8	7.8
			ACID	20.6	16.2	10.6	6.24	6.18
			TCP (Lowest MFDR)	1.28	1.20	1.07	0.856	0.853
			TCP (Highest MFDR)	1.81	1.68	1.48	1.17	1.17
	Max	ORXmasTreeSTD (6; 24-Aug; G)	ROC (a.e.)	24	20.8	16.2	10	10.7
			ACID	21.7	17.9	11.8	6.94	6.88

Use Site	Range	PWC Scenario (1st Application Date; Yearly Rate; Application Type)[1]	Chemical Species[2]	1-in-10-year Mean EECs				
				Water Column (µg/L)			Pore-Water (µg/L)	
				1-day	21-day	60-day	1-day	21-day
			TCP (Lowest MFDR)	1.85	1.78	1.61	1.33	1.40
			TCP (Highest MFDR)	2.27	2.24	2.06	1.76	1.83

[1] *PWC Scenario (1st Application Date; Yearly Rate; Application Type):* Scenario (Yearly application rate in lbs. a.e/A/Year; 1st application date in the window; Ground (if A= Aerial). **Example**: FLcitrusSTD (6; 3-Sep; G) = FL citrus scenario with an application rate of 6 lbs. a.e/A/Year applied on September 3 using ground equipment

[2] **ROC** (acid equivalent= a.e.) = Total concentrations in µg/L of **ACID + TCP + 3,6 DCP + 5-CLP + 6-CLP** in acid equivalent; **ACID=** Triclopyr acid concentrations in µg/L; **TCP** (Lowest MFDR)= TCP degrade concentrations in µg/L based on the lowest Molecular formation and decline ratio obtained from varied soil and aquatic systems; **TCP** (Highest MFDR)= TCP degrade concentrations in µg/L based on the highest Molecular formation and decline ratio obtained from varied soil and aquatic systems[33]

[3] **ROC (a.e.)** = Concentrations of the residue of concern in µg/L of **ACID + TCP + 3,6 DCP + 5-CLP + 6-CLP** in acid equivalent were only estimated and due to the **low ROC** concentrations, no values were estimated for the **ACID or TCP**

Table B-5. Maximum Surface and Pore Waters Estimated Environmental Concentrations (EECs) for the BEE; ACID; and TCP Representing the Use of BEE Form of Triclopyr (Estimated Using PWC version 1.52)

Use Site	PWC Scenario (1st Application Date; Yearly Rate; Application Type)[1]	Chemical Species[2]	1-in-10-year Mean EECs				
			Water Column (µg/L)			Pore-Water (µg/L)	
			1-day	21-day	60-day	1-day	21-day
Citrus (FL)	FLcitrusSTD (8.342; 26-May; G)	BEE	140	11.30	3.94	5.4	0.33
		ACID	193	142	76.6	49.9	49.2
		TCP (Lowest MFDR)	15.2	15.0	13.5	9.52	9.47
		TCP (Highest MFDR)	20.5	20.2	18.2	12.7	12.6
Forestry	CAForestryRLF (8.342; 4-Aug; A)	BEE	47	6.33	2.46	2.4	0.25
		ACID	25.9	22.6	16.7	14.2	14.2
		TCP (Low MFDR)	1.89	1.87	1.78	1.48	1.49
		TCP (High MFDR)	2.61	2.57	2.44	2.00	2.02
Grass: Range/ Pasture/Non-Crop Lands	RangeBSS (12.512; 15-May; A)	BEE	267	28.00	9.79	3.2	0.48
		ACID	259	201	113	72.4	71.4
		TCP (Low MFDR)	19.4	19.1	17.5	12.6	12.5
		TCP (High MFDR)	26.2	25.9	23.7	16.8	16.7
Grass: Meadow	MeadowBSS (12.512; 15-May; A)	BEE (acid Equivalent)	264	27.50	9.64	2.8	0.43
		ACID	223	172	97.2	62.2	61.3
		TCP (Low MFDR)	16.5	16.3	14.9	10.7	10.6
		TCP (High MFDR)	22.3	22.0	20.1	14.3	14.2
Premises	ResidentialBSS/ImperviousBSS (12.512; 21-May; G)	BEE[3]	10	0.90	0.30	0.1	0.13
Right-of-Way	RightOfWayBSS/ImperviousBSS (12.512; 21-May; A)	BEE[3]	57	6.64	2.41	0.8	0.12
Turf	TurfBSS (5.561; 11-Apr; A)	BEE	9.3	1.50	0.97	0.12	0.03
		ACID	11.9	9.18	7.14	5.09	5.02
		TCP (Low MFDR)	1.53	1.51	1.38	1.11	1.11

[33] Estimated according to the formation and decline method guiding principles presented in Attachment 2 for Methods for Assessing Aquatic Exposure to Residue(s) of Concern, EFED division Director Memo dated June 20, 2019

Use Site	PWC Scenario (1st Application Date; Yearly Rate; Application Type)[1]	Chemical Species[2]	1-in-10-year Mean EECs				
			Water Column (µg/L)			Pore-Water (µg/L)	
			1-day	21-day	60-day	1-day	21-day
		TCP (High MFDR)	2.06	2.03	1.86	1.49	1.48
Christmas Trees	ORXmasTreeSTD (8.342; 24-Aug; G)	BEE	22	2.32	0.81	0.24	0.05
		ACID	16.2	12.9	8.54	5.21	5.17
		TCP (Low MFDR)	1.30	1.27	1.12	0.95	0.99
		TCP (High MFDR)	1.88	1.82	1.57	1.31	1.38

[1] *PWC Scenario (1st Application Date; Yearly Rate; Application Type):* Scenario (Yearly application rate in lbs. a.e/A/Year; 1st application date in the window; Ground (if A= Aerial). **Example**: FLcitrusSTD (6; 3-Sep; G) = FL citrus scenario with an application rate of 6 lbs. a.e/A/Year applied on September 3 using ground equipment

[2] **BEE** = Concentrations in µg/L of BEE; **ACID=** Triclopyr acid concentrations in µg/L; **TCP** (Lowest MFDR)= TCP degradate concentrations in µg/L based on the lowest Molecular formation and decline ratio obtained from varied soil and aquatic systems; **TCP** (Highest MFDR)= TCP degradate concentrations in µg/L based on the highest Molecular formation and decline ratio obtained from varied soil and aquatic systems[34]

[3] **BEE** = Concentrations in µg/L of BEE were only estimated and due to the **low BEE** concentrations, no values were estimated for the **ACID or TCP.**

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[34] Estimated according to the formation and decline method guiding principles presented in Attachment 2 for Methods for Assessing Aquatic Exposure to Residue(s) of Concern, EFED division Director Memo dated June 20, 2019

APPENDIX C. Ecological Incident Summary for Triclopyr Active Ingredients

Table C-1. Triclopyr Acid, TEA, BEE Incidents from the Incident Data System (IDS)

Incident Number	Product and /or Additional Active Ingredients involved/ Cause	Year/State/Use Site Species affected Magnitude/Other Notes- Legality- Certainty Index
Triclopyr Acid Plant Incidents		
I003147-001	Triclopyr	1996 Agricultural Area-Company response to FIFRA REGS compliance. Registered Use. Agricultural area-plant damage.
I012786-005	Triclopyr Adsorption	Scotts Chemical reported a 2001 complaint that Garlon D 12 damaged 10 ornamental trees. The symptom was listed simply as "phytotoxicity." Undetermined.
I014404-018	Triclopyr Adsorption or drift	The Annual Report 1991 from the State of Washington included a 1990 incident in Yakima County in which the complainant alleges that an application of triclopyr damaged poplar trees and other ornamentals in her yard. It is not clear whether this was a direct application or as the result of spray drift of the pesticide. Undetermined.
I020459-019	Triclopyr Drift	A 2000 case that involved alleged drift of triclopyr sprayed in a vacant field that was across the street from neighboring property in Clark County, WA. There was damaged to unknown plants on the property. Residue analysis were positive for triclopyr. The owner of the lot, and the unlicensed applicator who made the application, accepted full responsibility for the plant damage. From the Washington State Department of Agriculture 2002 PIRT Report.
I020627-032	Triclopyr Drift	2001 incident involve drift of triclopyr from a Right of Way application that damaged pear trees. The WSDA concluded that there was evidence of drift. Damage was estimated at $6,750. From The Office of Environmental Health and Safety, Washington State Department of Agriculture Annual report in 2003
I024272-364	Triclopyr Direct	In June of 2012 in Dukes County, MA it was alleged a ground application of the product Max Poison IVY & Tough Brush Killer (a.i. triclopyr) adversely affected the customer's Kiwi plants.
Multi active Plant Incidents which include Triclopyr acid		
I020459-016	Triclopyr, Dicamba, and MCPA Possible Drift	The Washington State Department of Agriculture reported in the 2002 PIRT Report a 2000 case that involved commercial application of herbicides sprayed on broadleaf weeds in turf that damaged numerous broad leaf ornamental plants.
I013883-026	Triclopyr / 2,4-D Drift	1997 in Kitsap County, WA. Cypress trees dying along a fence line. Residue found in plants. Neighbor had used the product. Site of application not given. Incident is from the 1998 Annual Report from the Washington State Department of Health Pesticide Incident Reporting and Tracking Review Panel.
I014409-009	Triclopyr/ 2,4-/ Glyphosate Drift	This 1992 incident in King County, WA. was reported in the Washington State Dept. of Health Annual Report 1993, Pesticide Incident Reporting Review Panel, April 1994, prepared by the Washington State Department of Agriculture. Alleged that glyphosate, 2,4-D and triclopyr drifted into a garden. The drift/over spray was confirmed by lab. results. No analysis and State sent a warning letter. Accidental misuse.
I014404-019	Triclopyr and 2,4-D Drift	The Annual Report 1991 from the State of Washington included a 1990 incident in Spokane County in which shrubs in a yard were dying. The State Extension Office suspected herbicide drift of 2,4-D and triclopyr from an application made along a fence line in the vicinity. Individual was charged with a violation of label and state law.

Incident Number	Product and /or Additional Active Ingredients involved/ Cause	Year/State/Use Site Species affected Magnitude/Other Notes- Legality- Certainty Index
I015748-035	Triclopyr and Propanil (STAM) at 2 pts/acre Direct to Crop	Dow reported a 2004 incident in Dewitt, AR, in which Grandstand (0.66 pt/acre) damaged 80 acres of a 160-acre crop of rice. Dow admitted that the rice showed signs of injury. A number of authorities in the field felt that Grandstand could not be related to the injury. Rice production in AR and LA has been diminished by a disease that has not been identified, but the thinking is that Grandstand amplifies the symptoms. Yield losses have been around 50%. Registered Use.
I015921-002	Picloram, Triclopyr and Tebuthiuron Drift	Dow reported a multi-year incident in Cleveland, OK, in which the plaintiff suffered damage to real property including the deaths of hundreds of trees of desirable variety as the result of conduct in January 2001 and June/July, 2002, and over spraying in December, 2003 and spring of 2004. Products that were sprayed included Spike 20P(tebuthiuron), Remedy (triclopyr), and Grazon™ P+D Herbicide (Picloram). In addition to the deaths of the trees, the plaintiff alleges that the contamination of the land and water resources have diminished the property's use for deer hunting and fishing. Legality Undetermined.
I016962-005	Triclopyr, 13 oz/acre Cyhalofop-butyl 13oz/acre Direct to Rice	In 2004 a California farmer claimed that the used Clincher CA (cyhalofop-butyl) and Grandstand CA (triclopyr) aerial application resulted in yield loss on 560 acres of rice. Apparently, the same incident (same date, same town, and same pesticides) was reported in three different claims (I016962-005, -006, and -007) by different people. The three incidents were combined into I016962-005 and the acreage of the three reported areas affected were summed.
I020459-015	Triclopyr (116001)/ 2,4-D Drift	In 2002 the Washington State Department of Agriculture reported a case that involved alleged drift of a spray application of the herbicides 2,4-D and triclopyr to property next door in Clark County, WA. Tree limbs that were hanging over the property line were damaged. Accidental exposure.
I020627-017	Triclopyr and 2,4-D Drift	A 2001 case that involve alleged drift of a commercial application of herbicides sprayed on blackberries in adjacent property that damaged plants in a residential yard in Kitsap County, WA. Triclopyr and 2,4-D were sprayed. The report did not describe the types of plants effected or the type of damage, but it did say that the herbicides were verified as the cause by symptoms and residue analysis. Office of Environmental Health and Safety, Washington State Department of Agriculture Annual report 2003
I020627-018	Triclopyr and 2,4-D Drift	Incident involved a 2001 application of herbicides on weeds in a blackberry field in Gray Harbor County, WA that drifted to neighboring property and damaged shrubs and trees. The herbicides applied were triclopyr and 2.4-D. The report stated that the damage was probably due to volatilization. From the Office of Environmental Health and Safety, Washington State Department of Agriculture Annual report 2003
I020627-021	Triclopyr and 2,4-D Drift	2001 incident involved alleged drift of triclopyr and 2,4-D from an application on blackberries in Cowlitz County, WA that damaged plants on neighboring property. The application was made contrary to the label. From the Office of Environmental Health and Safety, Washington State Department of Agriculture Annual report in 2003.
I020998-014	Triclopyr, Glyphosate and 2,4-D Drift	2002 incident involved pesticide application in Clark County, WA. that drifted to neighboring yard and garden and caused plant damage. From the Office of Environmental Health and Safety, Washington State Department of Agriculture Annual report 2002

Incident Number	Product and /or Additional Active Ingredients involved/ Cause	Year/State/Use Site Species affected Magnitude/Other Notes- Legality- Certainty Index
I020998-015	Triclopyr, Glyphosate Drift	2002 Incident involves drift from application of herbicides on weeds that caused damage to vineyard in Skamania County. From the Office of Environmental Health and Safety, Washington State Department of Agriculture Annual report in 2002
I020998-043	Triclopyr and 2,4-D Drift	This 2002 incident in Washington state involved pesticide application sprayed on weeds on property line that drifted to neighboring property and caused plant damage. Incident from The Office of Environmental Health and Safety, Washington State Department of Agriculture Annual report 2002
I021457-013	2,4-D and Triclopyr (detected) Drift	On 06/13/2006 Washington State Department of Health, Division of Environmental Health documented a pesticide related incident involving herbicide 2, 4-D that was sprayed onto a grass field and drifted onto a neighbor's property damaging plants. 2, 4-D and triclopyr were detected in the residue.
I024123-001	Triclopyr and Glyphosate Direct Injection intentional misuse	In West Australia in June of 2012 it was reported that five river red gums were poisoned in West Beach and Woodville. Arborists' tests have found traces of (a.i. glyphosate and triclopyr) in the trees' leaves. These trees are dying because someone drilled holes in their trunks and filled them with the herbicide glyphosate. Intentional misuse.
I029622-004	Triclopyr and Aminopyralid Drift	On December 19, 2016 it was reported that a small garden in Felding, Manawatu, New Zealand was damaged. Aminopyralid and Triclopyr were contained in product used, Tordon™ PastureBoss. Garden was adjacent to a neighbor's lawn that was sprayed with product.
Triclopyr TEA Product Plant Incidents		
I002507-001	Triclopyr TEA Drift	Year – N.R. Reportedly, a fence line was treated with **Garlon-3** (Triclopyr) a herbicide with a backpack sprayer. Allegedly, a neighboring cotton field experienced patches of injury caused by the drifting effect at the time of spraying the fence line.
I003377-027	Triclopyr TEA Drift	In 1993 a California pest control operator applied a pesticide to a railroad right-of-way by ground application. Owners of grapevines adjacent to the railroad noted damage to their crops; preliminary estimates of monetary damage were placed at $6,000,000. The pesticide operator (Asplundh) agreed to plead guilty to 2 misdemeanors (lack of supervision, and failure to evaluate surrounding conditions). A total of $10,000 was imposed in fines ($5,000 paid and $5,000 suspended). Triclopyr was detected as a residue on the plants. Misuse.
I004846-001	Triclopyr TEA Direct to Rice	In 1997 in Texas, Grandstand R applied to a rice field, allegedly caused twisting and knotting up in the rice.
I006846-001	Triclopyr TEA Direct to Rice	In 1998 in Arkansas a rice crop demonstrated yield loss, when grown on a field that had been treated with the pesticide.
I006846-002	Triclopyr TEA Direct to Rice	In 1998 in Arkansas a Rice crop demonstrated yield loss, when grown on a field that had been treated with the a Triclopyr TEA product.
I006846-003	Triclopyr TEA Direct to Rice	In 1998 in Arkansas a rice crop demonstrated yield loss, when grown on a field that had been treated with the Triclopyr TEA product.
I007340-707	Triclopyr TEA Direct Contact	From Aggregate report. Under 6(a)2 Solaris reported that ornamentals were alleged to have been damaged in New Jersey on May 27, 1998, as the result of using Ortho Brush-B-Gon.
I007875-001	Triclopyr TEA	In 1991 in Oregon, Wisconsin, garden and ornamental plants of homes bordering 55 treated acres allegedly were injured by drift (physical) and drift of Crossbow

Incident Number	Product and /or Additional Active Ingredients involved/ Cause	Year/State/Use Site Species affected Magnitude/Other Notes- Legality- Certainty Index
	Drift	Herbicide due to volatilization. The incident was being investigated by the Wisconsin Dept. of AG Trade and Consumer Protection, for spraying effected under conditions that were too windy.
I008003-001	Triclopyr TEA- Grandstand Direct to Rice	In a 1998 6(a)2 report. Grower alleged that 58 acres of rice in Eunice, LA, were damaged by Grandstand at 1 pt/acre by ground. Description: "Oversprayed portions of the field exhibited severe root fish-hooking and dead tellers. Grower took the acreage to yield and compared this yield with other acreage that was treated with other products. He noted a 11.4 barrel deficiency in this treated rice compared to the untreated."
I008188-001	Triclopyr TEA Direct to Rice	Dow AgroSciences reported that 125 acres of rice were alleged to have been damaged by Grandstand in Biggs, CA. 8 days after July 8, 1998 application. Rice 49 days old when applied. Rice showed symptoms of root twisting and color change. Variety M-202. After application was made temperatures exceeded 100 degrees F."
I008188-002	Triclopyr TEA Direct to Rice	Dow AgroSciences reported that 82 acres of rice in Biggs, CA, were alleged to have been damaged by Grandstand on November 3, 1998. There was a decreased yield.
I008188-003	Triclopyr TEA Direct to Rice	Dow AgroSciences reported a November 1998 complaint alleging that 202 acres of rice in Chico, CA, were damaged by Grandstand. The description in the reports states: "Color change noticed on 8/26/98. Rice was 47 days old at application. Variety L-204. Yield at 69 dry. Average 72 dry for all M fields."
I008571-027	Triclopyr TEA Direct to turf	In 1999 in Boynton Beach, FL, nearly 5 acres of lawn were sprayed with Brush-B-Gon from a 24 oz bottle with sprayer to control weeds. The label specifically states against this. At the recommendation of a local store, the customer now has alleged property damage from use on his entire St. Augustine lawn and wants compensation.
I008639-001	Triclopyr TEA Direct to Rice	In 1998 106 acres of rice in Bastrop, LA, allegedly endured 100% crop injury after pesticide application at planting time. Decreased yield was the salient crop injury demonstrated.
I008884-001	Triclopyr TEA Direct to Rice	Dow AgroSciences reported a 1999 incident in which Grandstand was allegedly aerially applied to a rice field in McGehee, AK, but drifted onto a nearby tree plantation area where it destroyed 95.6 acres of cottonwood and 27.9 acres of oak trees.
I009262-093	Triclopyr TEA Direct to turf	As part of its August 1999 report of pesticide incidents, Scotts Co. included a complaint from a resident of Ladysmith, WI, who claimed that the parts of her lawn that she treated with Weed-B-Gon Chick, Clover were burned.
I009262-094	Triclopyr TEA Direct to turf	August 1999 incident report, Scotts Co. included a complaint from a resident of Orland Park, IL, who alleged that Weed-B-Gon Chick Killer damaged his lawn. The temperature was in the low 80s and he sprayed a 10 x 12 area with a solution of 4 oz/20 gallons.
I009513-001	Triclopyr TEA Direct to Rice	Gueydan, LA in May 1999. Dow Agrosciences reported a claim made that GRANDSTAND at 1 pt/acre adversely affected 120 acres of rice. Triclopyr is the active ingredient of the product and it caused fish-hooking on roots, aborted tillers, and reduced stand.
I009513-002	Triclopyr TEA Direct to Rice	1999 in Texas 6(a)2 report: Dow AgroSciences reported the claim that GRANDSTAND damaged 150 acres of rice in Katy, TX. Rice is twisted at the roots and tillers are falling off.

Incident Number	Product and /or Additional Active Ingredients involved/ Cause	Year/State/Use Site Species affected Magnitude/Other Notes- Legality- Certainty Index
I009513-003	Triclopyr TEA Direct to Rice	11/02/1999 6(a)2 report: Dow AgroSciences reported a complaint alleging that GRANDSTAND had damaged all 153 acres of rice in Gridley, CA. An inspector reported that there was visible tip burn and damage to the rice tillers.
I012366-048	Triclopyr TEA Direct to Rice	Dow Chemical reported a 2000 complaint from Princeton, CA, that GRANDSTAND HERBICIDE damaged 90.3 acres of rice. The description in the Dow report reads: "Application made at 10 oz for the control of redstem - noticed tip burn 10 days after application."
I010927-035	Triclopyr TEA Direct to Rice	Dow reported a 1999 complaint from Biggs, CA, that Grandstand damaged all 156.9 acres of rice plants in Butte County, CA. The Dow report is as follows: "Looked at field on 7/13/99. Notice tip burn and overlap areas from application. Yellowing and white spots on the rice and in severely damaged areas. Burned down tillers and also necrotic spots on leaf. Looked at field again on 7/23/99. Small buffer strip on the east side.
I010927-036	Triclopyr TEA Direct to Rice	Dow reported a 1999 complaint from Princeton in Colusa County CA, that Grandstand damaged a 213-acre crop of rice. The Dow report states: "Noticed burn on rice shortly after application. Looked at crop on 7/21/99. Noticeable burn and some overlap areas. Application made during hot weather, with hot surfactant."
I010927-037	Triclopyr TEA Direct to Rice	Dow reported a 1999 complaint from Willows in Glenn County, CA, that Grandstand herbicide damaged all 52 acres of a rice crop at 10 oz ai/acre. The aerial application was made during very hot weather, on May 28. The field was inspected on August 4 and on December 23 when there had been a low yield and the plants were then dead.
I010927-038	Triclopyr TEA Direct to Rice	Dow reported a 2000 complaint from Princeton in Colusa County, CA that aerial application of Grandstand damaged all 145 acres of a rice crop. The report of the problem by Dow said: "Alleged crop injury and non-performance due to Grandstand. Application made late at 45 days after planting. Application made against label 2 applications 20 days apart. Application made only 15 days apart."
I010927-039	Triclopyr TEA Direct to Rice	In 2000 Dow reported a complaint from Woodland in Yolo County, CA, that aerial application of Grandstand at 6 oz ai/acre damaged all 132 acres of a rice crop. Dow's report of the incident follows: "Application of Grandstand took place late in the season resulting in damage to the rice. Yield by grower allegedly reduced. Variety m-204."
I016962-008	Triclopyr TEA Direct to Rice	A farming business in Texas sued Helena Chemical Company alleging that the Grandstand herbicide (triclopyr) they sold them caused "various damage" to their rice crop in 2003.
I024071-185	Triclopyr TEA Drift	In Trumbull County OH, during the spring of 2012 it was alleged that an application of the product Max Poison Ivy & Tough Brush Killer Conc (a,i. triclopyr) to poison ivy killed a dogwood and an unknown tree.
Multi Active Plant Incidents including Triclopyr TEA products		
I006871-001	Triclopyr TEA and Picloram mixture Runoff	From a 6(a)(2) report. In Ohio a mixture of Garlon™ 3A (Triclopyr) and Tordon (Picloram) was applied to an electric power line right-of-way. A 1.5 inches of rain occurred the next evening moving product into an adjacent soybeans field which resulted in cupped leaves and absent plants. No other data, name of county or the location was reported.
I009969-006	Triclopyr TEA and Azoxystrobin	Dow Chemical reported a 1999 complaint from Yuba City, CA, that GRANDSTAND™ applied at 14 oz/acre had damaged 142 acres of rice. Dow inspector's report: 7/23/99 noted a 3 inch height difference. Visual symptoms of

Incident Number	Product and /or Additional Active Ingredients involved/ Cause	Year/State/Use Site Species affected Magnitude/Other Notes- Legality- Certainty Index
	Direct to Rice	rice tip burn, aerial roots, crooked neck on roots. Quadris™ application made 7/21/99. Stemrot. Stated 3-4 inches of water in rice during application. Panicle and head cut in rice-some roughseed through."
I023044-034	Triclopyr TEA, Sulfometuron, and Glyphosate Drift	On May 11, 2011 in San Luis Obispo County, CA a pesticide company applied the products Garlon 3A (a.i. triclopyr), Roundup (a.i. glyphosate), and Oust (a.i. sulfometuron methyl) to a PG&E substation adjacent to a nursery. The nursery alleged about 2,800 plants were damaged due to the herbicide applications. The California Department of Pesticides suspects pesticide application violations. Waiting for lab results.
I012701-001	Triclopyr TEA and Clopyralid In Compost	In 2002 a DuPont reported a problem concerning the Columbus, OH, Compost Facility which conducted a bioassay to investigate the toxicity of their compost to tomato seedlings. The seedlings showed stunted growth and splitting of terminal leaves. There had been similar problems with composts in other areas.
I016962-043	Triclopyr TEA and Propanil Direct to Rice	In 2005 a grower in Sunflower County, MS applied Stam M-4 at 1 gal/acre and Grandstand R at 0.67 pints/acre to rice, to control broadleaf weeds, and curly indigo. 70 out of the 405 treated rice field acres experienced injury in the form of tillers erupting from the stalk. This decreased the yield by 17.9 bushels/acre compared to the uninjured 335 acres of rice field.
I017837-003	Triclopyr TEA and 2,4-D Drift	In 2004 a Minnesota nursery grower filed a lawsuit against MN Valley power alleging Garlon 3A and DMA-4 herbicides applied to their right-of-way 100 feet from the property killed nursery trees and greenhouse annuals. Leaf tissue samples of tree showed .017 ppm of 2-4-D and no detectable triclopyr.
I020725-057	Aminopyralid TPA salt, Triclopyr TEA Drift	Ain 2009 a California grower reported tomato crop loss due to pesticide drift to the Yolo County Deputy Agricultural Commissioner office. The application of pesticide Milestone VM Plus at 6 pts /acre was conducted by the Department of Water Resources to the levee banks adjacent to the tomato field and 30 acres of tomato crops were destroyed. Samples of both soil and vegetation have been collected and sent to laboratory
I023832-026	Triclopyr TEA+Dicamba DMA Adsorption	During the winter of 2012 in Brazoria County, TX an application of the product Weed-B-Gon Max Weed Killer RS 32oz Disc 715490410 (a.i. dicamba, dimethylamine salt and triclopyr, triethylamine salt) allegedly damaged a tree.
I023931-075	Triclopyr TEA + MCPA DMA + Dicamba DMA Direct	During 2012 Greene County, TN a resident alleged an application of the product Weed B Gon Killer for Lawns Conc (a.i. dicamba dimethylamine salt, MCPA, dimethylamine salt and triclopyr, triethylamine salt) killed her lilies.
I024071-326	Triclopyr TEA + MCPA DMA + Dicamba DMA Direct	In St Louis county. MO in April 2012 it was alleged an application of the product Weed B Gon Weed Killer for Lawns (a.i. MCPA dimethylamine salt, triclopyr triethylamine salt and dicamba, dimethylamine salt) damaged some Hosta plants.
I024071-335	Triclopyr TEA + MCPA DEA + Dicamba Al Direct	In Sangamon County, MO in April 2012 it was alleged an application of the product Weed B Gon Max Weed Killer RS (a.i. MCPA diethanolamine salt, triclopyr triethylamine salt and dicamba aluminum salt) killed outdoor ornamental plants.
I024071-350	Triclopyr TEA, Dicamba DEA salt Drift to trees	In April, 2012 in Utah it was alleged an application of the product Weed B Gon Max Weed Killer RS (a.i. dicamba diethanolamine salt, triclopyr triethylamine salt) may have killed a dogwood, plum and cherry trees. Two days after the application the owner noticed the trees starting to wilt and looking like they may die.

Incident Number	Product and /or Additional Active Ingredients involved/ Cause	Year/State/Use Site Species affected Magnitude/Other Notes- Legality- Certainty Index
I024071-364	Triclopyr TEA, MCPA DMA, and Dicamba DMA Direct	In Dupage County, Illinois during April 2012 it was alleged an application of the product Weed B Gon Max Weed Killer RS (a.i. MCPA, triclopyr & dicamba) killed three hydrangea bushes
I024179-104	Triclopyr TEA, MCPA DMA, and Dicamba DMA Direct	In May 2012 in Paulding County, GA it was alleged an application of the product Weed-B-Gon Weed Killer for Lawn (a.i. dicamba, dimethylamine salt; MCPA, dimethylamine salt and triclopyr, triethylamine salt) damaged a customer's tree.
I024179-177	Triclopyr TEA, MCPA DMA, and Dicamba DMA Adsorption	In May 2012 in Hennepin County, MN it was alleged an application of the product Weed B Gon Max Weed Killer (a.i. MCPA, dimethylamine salt; triclopyr, triethylamine salt and dicamba dimethylamine salt) killed an oak tree.
I024179-217	Triclopyr TEA, MCPA DMA, and Dicamba DMA Direct	In May 2012 in Middlesex County, MA it was alleged an application of the product Weed B Gon Max Weed Killer (a.i. dicamba, dimethylamine salt; MCPA, dimethylamine salt and triclopyr, triethylamine salt) damaged a bed of black eye susan plants causing the flowers to wilt.
I024179-243	Triclopyr TEA, MCPA DMA, and Dicamba DMA Direct	In May, 2012 in Paulding County, GA it was alleged an application of the product Weed B Gon Weed Killer for Lawn (a.i. MCPA , dimethylamine salt; triclopyr, triethylamine salt and dicamba, dimethylamine salt) killed a 50 ft tree with a 4 foot diameter.
I024179-257	Triclopyr TEA, MCPA DMA, and Dicamba DMA Adsorption	In Laramie County Wyoming a 2012 application of the product Weed B Gon Max Weed Killer Conc (a.i. MCPA, dimethylamine salt; triclopyr, triethylamine salt, dicamba and dimethylamine salt) was reported to have damaged trees turning leaves yellow and then black.
I024179-313	Triclopyr TEA, MCPA DMA, and Dicamba DMA Adsorption	In May, 2012 in Fayette County, KY it was alleged an application of the product Weed B Gon Weed Killer for Lawn Conc (a.i. MCPA, dimethylamine salt; triclopyr, triethylamine salt and dicamba, dimethylamine salt) killed a plum tree.
I024272-164	Triclopyr TEA, MCPA DMA, and Dicamba DMA Adsorption	During the spring of 2012 in Monroe County, NY it was alleged an application of the product Weed B Gon Max Weed Killer (a.i. MCPA, dimethylamine salt, triclopyr, triethylamine salt and dicamba, dimethylamine salt) killed a customer's bushes
I024272-170	Triclopyr TEA, MCPA DMA, and Dicamba DMA Drift	In June of 2012 Montgomery County, MO it was alleged an application of the product Weed B Gon Max Weed killer (a.i. MCPA, dimethylamine salt, triclopyr, triethylamine salt and dicamba, dimethylamine salt) blew onto zinnia and bean plants resulting in their death.
I024272-178	Triclopyr TEA, MCPA DMA, and Dicamba DMA Direct to lawn	During June of 2012 in Cuyahoga County, OH it was alleged an application of the product Weed B Gon Max Weed Killer (a.i. MCPA, dimethylamine salt, triclopyr and triethylamine salt and dicamba, dimethylamine salt) killed some flowers.
I024272-320	Triclopyr TEA, MCPA DMA, and Dicamba DMA Adsorption	During June of 2012 in Suffolk County, NY it was alleged an application of the product Weed B Gon Max Weed Killer (a.i. MCPA dimethylamine salt, triclopyr triethylamine salt and dicamba, dimethylamine salt) around some hostas and hydrangeas killed the plants
I024272-339	Triclopyr TEA, MCPA DMA, and Dicamba DMA	During June of 2012 in Renesselaer County, NY it was alleged an application of the product Weed B Gon Max Weed Killer (a.i. MCPA dimethylamine salt, triclopyr, triethylamine salt and dicamba dimethylamine salt) killed 3 shrubs.

Incident Number	Product and /or Additional Active Ingredients involved/ Cause	Year/State/Use Site Species affected Magnitude/Other Notes- Legality- Certainty Index
	Adsorption	
I029601-007	Triclopyr TEA, Dicamba DMA, and MCPA DMA salt Adsorption	In winter of 2016 tree damage was reported in El Rio, Texas from use of Weed B Gon Max Ready Spray (Registration Number 228-424-239). Homeowner reported one dead ornamental tree from use of herbicide containing Triclopyr and Dicamba active ingredients.
I031341-160	Triclopyr TEA mixture Direct	In 2018 in Downers Grove, Illinois a homeowner sprayed Weed-B-Gon on privet hedges, roses and hibiscus plants and 3 weeks later 45% of the plants were wilted
Triclopyr BEE Product Plant Incidents		
I003581-001	Triclopyr BEE Drift	It was reported that pastureland, adjacent to a vineyard, was treated with Garlon 4. Some of the aerially-applied Garlon drifted onto the vineyard and resulted in brown or dead leaves, decreased growth, and several dead vines.
I004712-001	Triclopyr BEE Drift	The County treated a right-of-way near a 10-acre site of plants which allegedly showed growth regulatory type injury in 0.92 acres after pesticide treatment.
I004721-001	Triclopyr BEE Drift	The Power & Light Company treated a right-of-way with pesticide near a planted field. Allegedly, the crop showed signs of growth regulatory type injury.
I005004-001	Triclopyr BEE Drift	Dow Elanco 6(a)2 report. Garlon 4(Triclopyr) aerial drift contaminated an adjacent pond thus, causing damage to some aquatic vegetation. No other details were reported.
I005082-001	Triclopyr BEE (Turflon ester) Direct-Unintentional	6(a)(2). A owner of a rose tree nursery had a malfunction on his spray rig. A valve shutting off the tank containing Turflon ester did not completely close when he switched to a tank containing Triforine and Mavrik. The operator proceeded with the treatment and two days later he noted damage to roses.
I005413-001	Triclopyr BEE Drift	A California roadside median was treated with Garlon 4 (triclopyr) on a relatively windy day and the spray injured several wine grape fields that were adjacent. Dow Agrosciences reported that the litigation has been voluntarily dismissed with prejudice, no other details were given
I007834-039	Triclopyr -BEE Garlon Drift	Aggregate report: On April 23, 1998, personnel of the CA Dept. of Transportation applied Garlon on weeds alongside Highway 111, in Coachella, CA. This application was made adjacent to grape vineyards. On April 24, the vineyard owner notified the Riverside County Agricultural Commissioner's Office that the pesticide had drifted onto his vineyards. On May 27 the Southern Regional Office was notified by the grower that the crop loss was estimated at $500,000. Misuse accidental
I008077-001	Triclopyr BEE Drift	Alleged damage to a vineyard occurred in ST. Helena, CA over a period of three years: April 1994, 1995, and 1996 from drift of pesticide applied to an adjacent horse pasture. The injury consisted of damage to vines, severe stunting, death of shoot tips and entire shoots which resulted in low fruit, shot berries, withering and dead clusters and loss of crop yield (grapes) and budding grape plants. 13.99 use site acres affected two different owners (1) with 8.02 acres; (2) with 5.97 acres.
I013645-010	Triclopyr BEE (Garlon 4) Drift	In 1998 the CA Department of Pesticide Regulation reported an incident in Coachella that resulted in severe damage to two grape vineyards. Personnel of the CA Department of Transportation applied GARLON 4 alongside Highway 111 on April 23, 1998. The next day, the Riverside County Agricultural Commission

Incident Number	Product and /or Additional Active Ingredients involved/ Cause	Year/State/Use Site Species affected Magnitude/Other Notes- Legality- Certainty Index
		Office was notified of pesticide damage to two vineyards; it was alleged that the damage sustained was $1,000,000. Soil and foliage samples were then collected, and the analyses established that GARLON 4 had drifted onto the vineyards and was responsible for the damage that had been sustained. On May 26 a Violation Notice was issued to Cal Trans for its use of a pesticide in conflict with its registered labeling, and on Dec. 30 an assessment of $1,000 was levied for violating FAC, Section 12973.
I025619-019	Triclopyr BEE Drift	In 2013 in San Luis Obispo County, California an application of Garlon 4 (a.i. triclopyr) allegedly drifted onto a vineyard damaging several hundred grapevines. The grapevine tissue tested positive for triclopyr from ranges of 120 ppb to 1,200 ppb. The inspector also suspects glyphosate was in the tank due to the "witches broom" symptoms on the vines. No testing for glyphosate was performed.
Multi-active Incidents which include Triclopyr BEE products		
I001944-001	Triclopyr BEE and Picloram mixture Drift	DowElanco 6(a)2 report: A pest control operator applied Garlon 4 and Tordon K on a right-of-way in Oklahoma on a day when the wind speed was between 10 and 16.1 mph. The homeowner of property adjacent to the right-of-way alleged that 332 oak, 44 walnut, 234 grafted walnut, 50 hickory, 30 hickory grafted to pecan, 30 sassafras, 12 redbud, 5 dogwood, 3 black cherry, 1 Chinese chestnut, 3 apple, 3 pear, 5 sycamore, and 1 ornamental pear were damaged. Also, damage was claimed to have occurred to numerous vegetable plantings and to animals. The State Dept. of Agriculture investigated and concluded there was no herbicidal effect to the trees.
I010927-014	Triclopyr BEE (Remedy) and Glyphosate Aerial Drift	Dow reported a 1999 complaint from Carson County, TX, involving triclopyr damaged an entire 300 acre field of soybeans. The problem was that the operator of a flying service applied Remedy to mesquite trees in Armstrong County, TX, then flushed the chemical out of the plane before filling the sprayer, through a rubber hose, with Round Up. When he sprayed 300 acres of soybeans, they all died. Plastic tubing should have been used to transfer the chemical because Remedy penetrates the inner lining of rubber hosing.
I011622-003	Triclopyr BEE (Garlon) and Remedy Drift	Dow submitted report in June 15, 2001, that reported the judgment made by a court concerning a prior damage claim. The case was made by a tomato farmer in California that Garlon was sprayed by the State of California Department of Water Resources, and this spraying damaged 300 acres of tomato plants which were adjacent. The result was the cupping and curling of the plants, and the Court's finding was in favor of the tomato farmer. Garlon and Remedy are registered for a number of uses but they do not include tomatoes.
I012209-003 I012209-012 - update	Triclopyr BEE and Glyphosate/Acetochlor(Roundup Pro) Drift	An August 2001 report from the CA Dept. of Pesticide Regulation stated that the owner of a grape vineyard in Kenwood in Sonoma County called the Sonoma County Agricultural Commissioner's office to report a crop loss and symptoms of herbicide exposure in his 8 acre vineyard. An investigation was made and it was found that on May 24-25, 2001, the owner of a winery in Glen Ellen applied GARLON 4 and ROUNDUP PRO on his property to control blackberries. Samples were taken from the vineyard and found positive. It was found that some of the pesticides had drifted onto the grape vines causing damage valued at $84,380. A Notice of Violation was filed and a fine of $675 was levied. The action was closed on May 21, 2002
I016940-015	Garlon 4 and Glyphosate-	In 2004 the CA Dept. of Pesticide Regulation reported through EPA Region 9 that there were several applications of Garlon herbicide made by State Park employees

Incident Number	Product and /or Additional Active Ingredients involved/ Cause	Year/State/Use Site Species affected Magnitude/Other Notes- Legality- Certainty Index
	isopropylammonium (Roundup) Drift	in Napa County to control weeds. The herbicide drifted on to a grape vineyard, olive trees and ornamental plants. The vineyard was 8.63 acres valued at $148,170.00. The grapes were refused at the winery because it had been contaminated with a pesticide that was not approved for use on grapes.
I021421-001	Triclopyr BEE and 2,4-D, BEE (Crossbow Herbicide) Drift	In Nov. 2009 a report submitted to N.C. Dept. of Agriculture & Consumer Services Pesticide Board documents that a landscaping company in Sylva, (Jackson County, N.C.) agreed to pay $1,000 for using pesticide Crossbow Specialty Herbicide, inconsistent with label instructions. The pesticide damaged grapevines and its label states it shouldn't come into direct contact with grapes.
I025974-014	Triclopyr BEE, Picloram P Salt, and Aminopyralid TIPA salt Direct to grasses	In spring of 2016 in Jackson County, TX, the products Garlon 4 Ultra Herbicide (a.i. Triclopyr, butoxyethyl ester), Tordon K Herbicide (a.i. picloram, potassium salt) and Milestone VM Herbicide (a.i. aminopyralid, triisopropanolamine salt) were applied to a right-of-way. The exposure occurred in a field/pasture to five bulls that were allowed into an adjacent pasture after the application. Two of the bulls died and the others displayed malaise.
Pollinator Incidents which include Triclopyr Products		
I028969-001	Triclopyr BEE and Impel Direct	On Jan. 20 to Feb. 1, 2016 a spoil island (Travatine Island) in Pinellas County, FL was treated with Garlon 4 and Impel Red (oil dispersant). Bees started walking away from the hives in a disoriented manner, unable to fly. No wing or other observed deformities are reported. Loss of six of eleven hives reported.
I031717-001	Triclopyr (116001) and Glyphosate (detected in honey?)	Based on a 2018 phone conversation with EPA , a beekeeper in Pinellas County, Florida reporting loss of 9 of 12 colonies due to application of triclopyr herbicide application by the county for invasive plant control. Beekeeper claimed presence of RoundU™p (glyphosate)in honey and feels this contributes to the chronic bee loss. FDACS investigated the losses and did not find triclopyr or other pesticides residues in the collected samples and also indicated that FDAcs believes her colonies are Africanized and in poor health.
I029045-011	Triclopyr BEE, Imazapyr IPA, Glyphosate IPA Drift possible	From April 1 to June 30, 2016 a bee keeper reported a continuing loss of bees in Ridge Spring, SC. A local utility had used products containing triclopyr (Boulder and Alligare), glyphosate (Glyphosate 4 Plus), Imazapyr (Alligare) in right of ways near his property. None of these herbicides are considered acutely toxic to bees.
I030739-001	Triclopyr BEE (Garlon 4 Ultra) Direct ingestion	IN 2018 a Florida beekeeper reporting a loss of bees in February 2018 related to Garlon 4 Ultra (active ingredient Triclopyr BEE) that the county applied near St Petersburg, FL. Product is rated as nearly non-toxic to bees but caller reported the bees gather pollen that has the active ingredient in it and then the bees starve to death. Caller reported problems related to the herbicide on four separate occasions. Caller lost 7 of 12 hives in one instance, three of her twelve hives in s second, nine out of twelve in a different instance. Triclopyr acid, a breakdown product of Triclopyr BEE has been shown to display low oral toxicity to adults. Acute and chronic larval dietary studies are still being reviewed for the Triclopyr acid by the Agency.
I030739-002	Triclopyr BEE (Garlon 4) Drift to hives	This record is similar in content to an NPIC report in incident I02969-00001. It relates to 2017 bee kill reported by beekeeper near St. Petersburg Florida regarding application of Garlon 4 (Triclopyr BEE) herbicide by County seven times over 2-weeks to control non-native plants. Caller noticed multiple instances of bee kill in significant numbers and various behavior impairment behavior of bees. According to current studies evaluated by the Agency this active ingredient is nearly non-toxic to adult honeybees from direct contact.

Incident Number	Product and /or Additional Active Ingredients involved/ Cause	Year/State/Use Site Species affected Magnitude/Other Notes- Legality- Certainty Index
I029211-003	Triclopyr TEA Milestone (Aminopyralid TPA) salt, and Streamline Drift	In 2016, an Illinois beekeeper had noticed problems with 2 hives in a state park of 4000 acres within range of her bee hives. Herbicides were sprayed along park roads and under power lines near her home. The bee hives at her home are 15 miles from the state bee yard where the bee keeper first noticed some-thing wrong with her bees. She had a mild chemical exposure on her home hives. The one damage hive was isolated, and the bees were put on all new equipment. Milestone, Garlon3A and Streamline were used for vegetation control.
I029211-004	Triclopyr TEA and Aminopyralid TPA salt- Drift	In 2016 was reported by an Illinois beekeeper reported that honey bees were effected in hives located within a state park where herbicide spraying was conducted along roads and utility right of ways. This report has multiple individual reports within it. Milestone and Garlon 3 A had been used in the park.
I029211-005	Triclopyr TEA, Aminocyclopyr, and Metsulfuron and Aminopyralid herbicides and been used in the area Possible Drift	Addendum to Incident 029186 001 more bee kills were reported in Murphysboro, Illinois as well. returned to the bee yard from the park half to 1/4 of the bees in the bee yard remained alive. But by the next day they were all dead. The beekeeper checked the hives 2 miles away and they looked good. Then next day two hives were found dead in the other bee yard. The other hives exposed showed bees acting drunk and disoriented. Due to the weakened hives, and loss of adult foragers, small hive beetles have moved in to the weak hives. Another beekeeper who had 70 hives was now down to 30 hives. No lab results were given.
I029385-006	Triclopyr TEA (Pro-Health and Fumaglin-B, Kem-Tek Supershock, Kem-Tek Power 99, and Phos-Free) Undetermined	On 24 May 2016 it was reported to Indiana authorities that 4 of his bee hives were found dead of possible poisoning. Less than a hundred dead frozen bees were taken for analysis, which may be insufficient for testing due to low quantity. The complainant's residence is surrounded by densely populated area with a mix of residential, industrial, school, and golf course properties which were neatly groomed and it is highly likely there were many pesticides products used by the various property owners. Pro-Health and Fumaglin-B, Kem-Tek Supershock, Kem-Tek Power 99, and Phos-Free were used by the beekeeper to treat hives placed in the area. None of these listed actives known to have been used in the area are considered toxic to bees.
Aquatic Incidents which include Triclopyr Products		
I000925-001	Triclopyr and 2,4-D mixed	In 1993 a fish kill was reported in area below a railroad crossing and above a low retention dam on Blueston River near Bluefield in Mercer County, WV from possible drift. Mixed species- 23,000 fish died.
I008883-001	Triclopyr TEA and Propanil	In 1999 Dow AgroSciences reported an allegation that 45,000 pounds of catfish had been destroyed in a catfish farm in St. Martinsville, LA, by triclopyr. An adjacent rice field had been sprayed with Grandstand R at the rate of 3.0 lbs/gallon, and with Stam M-4 (Propanil), a product not made by Dow. The manager of the catfish farm contends that the spray drift of Grandstand R had killed the fish as the consequence of oxygen starvation. There were no analyses made to support the allegation which is presumed to have been based on the herbicidal action of Grandstand R (triclopyr) that might kill the plankton in the fish pond.

APPENDIX D. Summary of Summitted Ecological Effects Studies

Newly Submitted Studies

MRID 49992406: *Lifecycle Chronic Toxicity for Daphnia magna exposed to Triclopyr BEE.*
Significantly increased parental mortality was observed during the 21-day study at the ≥ 520 ug a.i./L. Live offspring production and successful birth rate were negatively impacted at the 1600 and 5100 ug ai/L levels (p<0.05). Additionally, survival of offspring was negatively impacted at the highest dose, 5100 ug ai/L (p<0.05). There was no effect on time to first brood. The most sensitive endpoint from this study was parental survival, resulting in an overall NOAEC and LOAEC of 170 ug ai/L and 520 ug ai/L, respectively. Study was considered supplemental as no growth parameters were measured, but reproduction and survival data were considered valid.

MRID 50673901: *Lifecycle Chronic Toxicity for Mysid exposed to Triclopyr BEE.*
The 28-day chronic toxicity of Triclopyr butoxyethyl ester (BEE) to mysids (*Americamysis bahia*) was studied under flow-through conditions. Mysids were exposed to nominal concentrations of 0 (negative and solvent control), 19, 38, 75, 150, and 300 µg ai/L. The time-weighted average (TWA) concentrations based on analytical measurements were <6.25 (<LOQ, controls), 10.9, 20.4, 38.7, 86.9, and 153 µg ai/L. No significant treatment-related effects were observed for pre- or post-pairing first generation or second generation survival, as well as time to first brood. Female and male length and dry weight and numbers of offspring/female were significantly affected by the test material. The most sensitive endpoints were female and male dry weight, resulting in a NOAEC and LOAEC of 10.9 and 20.4 µg ai/L, respectively.

MRID 49992407: *Early Lifestage Testing with TCP on Rainbow trout.*
The 91-day chronic toxicity of 3,5,6-trichloro-2-pyridinol (TCP) to the early life-stage of the rainbow trout *(Oncorhynchus mykiss)* was studied under flow-through conditions. Fertilized eggs/embryos (200/level, 3 hours old) were exposed to TCP at nominal concentrations of 0 (negative control), 0 (solvent control), 58.3, 97.2, 162, 270, 450, and 750 µg ai/L. The mean-measured concentrations <20 (<LOQ, controls), 58.6, 106, 178, 278, 479, and 825 µg ai/L, respectively. The LOAEC for swim-up time was determined to be 825 ug ai/L where a 4% change was noted. The most sensitive NOAEC was determined by the Agency to be 178 µg ai/L, based on significant reductions in weight and length at 278 ug ai/L. No significant treatment-related differences were observed for hatching success, days-to-mean hatch, post-hatch survival, or percent normal at hatch and termination.

MRID 49992409: *Acute Oral Toxicity Testing with Honeybee exposed to Triclopyr Acid.*
A limit test was conducted with triclopyr acid using 30 bees tested at a nominal concentration of 100 ug ai/bee. The actual intake was 99 µg ai/bee. At 48 hours, mortality was 0% in the negative control and treatment group. Dimethoate was used as the positive control. No abnormal effects or other sublethal effects were observed in the Triclopyr control or treatment group.

MRID 50673902: *Chronic Repeat Dose Toxicity to Honeybee Larvae exposed to Triclopyr acid*
Larval and pupal mortality and adult emergence of honey bees were significantly affected in this 22-day experiment. Day 15 mortality NOAEL and LOAEL are determined to be 0.58 and 1.5 ug ai/larvae/day, respectively. The 22-day NOAEC for % emergence of surviving larvae slightly higher and determined to be 38.4 mg ai/kg diet.

MRID 50673903: *Chronic Oral Toxicity to Adult Honey bee exposed to Triclopyr acid.*
After 10 days oral exposure of adult honey bees, mortality averaged 3% in the negative and solvent controls, as compared to mortality averaging 10, 13, 0, 0, and 37% in the measured 150, 255, 490, 973, and 2091 mg ai/kg diet groups, respectively. Mortality in the positive control (Dimethoate technical) was at 100% at ten days. Behavioral abnormalities were not reported. The NOAEC was 973 mg ai/kg diet, respectively. This corresponds to a NOAEL of 22.3 µg ai/bee/day. Food consumption was adversely affected at a lower concentration than mortality, resulting in a NOAEC of 490 mg ai/kg diet. This value corresponds to a NOAEL of 14.3 µg ai/bee/day.

All Submitted Studies

Tables D-1 and **D-2** identify ecological effects studies by MRID that offer data for each guideline requirement as well as study classifications

Table D-1. Submitted Aquatic Ecological Effects Data for triclopyr Acid, TEA salt, BEE, and TCP.OSCSPP Guideline	Submitted Studies (MRID)	Test Material	Study Classification and Results
850.1010 **Acute FW Invertebrate**	40346504 Water flea*, Daphnia magna*	99.5% Technical acid	Acceptable EC_{50}= 132.9 ppm[1]
	00151959 Water flea*, Daphnia magna*	44.9 % TEA	Acceptable EC_{50}=1496 ppm
	00159956 Water flea*, Daphnia magna*	64.7 % TEA	Acceptable EC_{50} = 775 ppm
	00151963 Water flea*, Daphnia magna*	96.4 % Technical BEE	Supplemental EC_{50} = 1.7 ppm
	00151965 Water flea*, Daphnia magna*	96.4 % Technical BEE	Acceptable EC50=12 ppm
	43442603 Water flea*, Daphnia magna*	62.3% Garlon 4 TEP	Acceptable EC_{50} = 0.35 ppm
	41205408 Water flea*, Daphnia magna*	TCP Degradate	**Report ES-83L 1978**
	41829005 Water flea*, Daphnia magna*	99.9 % TCP Degradate	Acceptable EC_{50} = 10.4 ppm

Table D-1. Submitted Aquatic Ecological Effects Data for triclopyr Acid, TEA salt, BEE, and TCP.OSCSPP Guideline	Submitted Studies (MRID)	Test Material	Study Classification and Results
850.1025 **Acute estuarine mollusc**	42646101 Oyster spat, *Crassostrea virginica*	46% TEA	Acceptable Formulated EC_{50}=58 ppm
	00062623 40346606 Oyster spat, *Crassostrea virginica*	43.8 % TEA	Acceptable Larvae EC_{50} = 55.7 ppm Spat EC_{50}=58 PPM
	41971602 Oyster spat, *Crassostrea virginica*	96.1 % BEE technical	Acceptable EC_{50} = 0.46 ppm
	41969903 Oyster spat, *Crassostrea virginica*	62.9 % Garlon 4	Acceptable EC_{50} =0.32 ppm
	42245903 Oyster spat, *Crassostrea virginica*	99.9% TCP Degradate	Acceptable EC_{50} = 9.3 ppm
850.1035 **Acute Estuarine /Marine Crustacea**	00062623 40346406 Pink shrimp, *Penaeus duorarum*	43.8 % TEA	Supplemental LC = 895 ppm
	00062623 40346406 Fiddler crab, *Uca pugilator*	43.8 % TEA	Supplemental EC_{50} > 1000 ppm
	42646102 Grass shrimp, *Palaemonetes pugio*	46 % TEA	Acceptable LC_{50} = 327 ppm
	41971601 Grass shrimp, *Palaemonetes pugio*	96.1 % BEE technical	Acceptable LC_{50} = 2.48 ppm
	41969902 Grass shrimp, *Palaemonetes pugio*	62.4 % Garlon 4	Acceptable LC_{50} = 1.7 ppm
	42245902 Grass shrimp, *Palaemonetes pugio*	99.9% TCP Degradate	Acceptable EC_{50} = 83 ppm
850.1075 **Freshwater Fish Acute**	00049637 Rainbow trout, *Oncorhynchus mykiss* and Bluegill sunfish, *Lepomis macrochirus*	Technical acid	Acceptable LC_{50} = 148 ppm –Bluegill And 117 ppm for Rainbow trout
	40098001 Rainbow trout, *Oncorhynchus mykiss* and Bluegill sunfish, *Lepomis macrochirus*	43.5 % acid formulation	Supplemental LC_{50} > 100 ppm both species

Table D-1. Submitted Aquatic Ecological Effects Data for triclopyr Acid, TEA salt, BEE, and TCP.OSCSPP Guideline	Submitted Studies (MRID)	Test Material	Study Classification and Results
	00151956 Fathead minnow, *Pimephales promelas;* Rainbow trout, *Oncorhynchus mykiss* and Bluegill sunfish, *Lepomis macrochirus*	64.7 % TEA	Supplemental $LC_{50}S = 891$ ppm Bluegill, 947 [[m Fathead minnow, and 552 ppm Rainbow trout
	00151958 Fathead minnow, *Pimephales promelas*	44.9 % TEA	Supplemental $LC_{50} = 279$ ppm
	00062622 Bluegill sunfish, *Lepomis macrochirus*	47.8 % TEA	Acceptable $LC_{50} = 240$ ppm
	00151963 Fathead minnow, *Pimephales promelas*	BEE technical	Supplemental $LC_{50} = 2.4$ ppm
	00151965 Fathead minnow, *Pimephales promelas*	BEE Technical	Supplemental $LC_{50} = 2.31$ ppm
	41736304 Coho salmon (fry and fingerling), *Oncorhynchus kisutch*	99 % BEE technical	Supplemental data Not conducted to guideline standards
	41971603 Rainbow trout, *Oncorhynchus mykiss*	62.9 % Garlon 4	Supplemental $LC_{50} < 2.7$ ppm
	41971604 Bluegill sunfish, *Lepomis macrochirus*	62.9 % Garlon 4	Supplemental $LC_{50} = 1.3$ ppm
	42884501 Rainbow trout, *Oncorhynchus mykiss*	97 % BEE technical	Acceptable $LC_{50} = 0.65$ ppm
	42917901 Bluegill sunfish, *Lepomis macrochirus*	97 % BEE technical	Acceptable $LC_{50} = 0.36$ ppm
	43442601 Bluegill sunfish, *Lepomis macrochirus*	62 % Garlon 4	Acceptable $LC_{50} = 0.44$ ppm
	43442602 Rainbow trout, *Oncorhynchus mykiss*	62 % Garlon 4	Acceptable $LC_{50} = 0.98$ ppm

Table D-1. Submitted Aquatic Ecological Effects Data for triclopyr Acid, TEA salt, BEE, and TCP.OSCSPP Guideline	Submitted Studies (MRID)	Test Material	Study Classification and Results
	ACC 229783 Rainbow trout, *Oncorhynchus mykiss* and Bluegill sunfish, *Lepomis macrochirus*	42 % TEA and BEE formulation	Acceptable LC$_{50}$ = 1.46 ppm for Bluegill and 1.29 ppm for Rainbow trout
	41205402 Rainbow trout, *Oncorhynchus mykiss* and Bluegill sunfish, *Lepomis macrochirus*	TCP Degradate	Supplemental information
	41829003 Bluegill sunfish, *Lepomis macrochirus*	99.9 % TCP Degradate	Acceptable LC$_{50}$ = 12.5 ppm
	41829004 Rainbow trout, *Oncorhynchus mykiss*	99.9 % TCP Degradate	Acceptable LC$_{50}$ = 12.6 ppm
	44585404 Pacific salmon-several species	Garlon 3A, Garlon 4, BEE, TCP and TMP Degradates	Open lit supplemental data
	00028766 Rainbow trout, *Oncorhynchus mykiss*, Bluegill sunfish, *Lepomis macrochirus* and Goldfish, *Carassius auratus*	TCP degradate	Not useable-incomplete
850.1075 Estuarine/ Marine Fish Acute	41633703 Inland silverside, *Menidia beryllina*	44.7 % TEA	Acceptable LC$_{50}$ = 130 ppm
	41969901 Inland silverside, *Menidia beryllina*	62.9 % Garlon 4	Acceptable LC$_{50}$ = 0.45 ppm
	42053901 Inland silverside, *Menidia beryllina*	96.1% BEE technical	Acceptable LC$_{50}$ = 0.76 ppm
	42245901 Atlantic silverside, *Menidia menidia*	99.9 % TCP Degradate	Acceptable LC$_{50}$ = 58.4 ppm
850.1400 Fish Early Life Stage	00151958 Fathead minnow, *Pimephales promelas*	44.9 % TEA	Acceptable LOAEC= 162 ppm NOAEC= 104 ppm
	43230201 Rainbow trout, *Oncorhynchus mykiss*	97% BEE Technical	Acceptable LOAEC = 0.048 ppm NOAEC = 0.026 ppm

Table D-1. Submitted Aquatic Ecological Effects Data for triclopyr Acid, TEA salt, BEE, and TCP.OSCSPP Guideline	Submitted Studies (MRID)	Test Material	Study Classification and Results
	44997301 and 46033201 amended Rainbow trout, *Oncorhynchus mykiss*	99.7% TCP Degradate	Unacceptable
850.1300 **Freshwater Aquatic Invertebrate Chronic**	00151959 Waterflea, *Daphnia magna*	44.9 % TEA	Acceptable LOAEC= 149 ppm NOAEC= 80.7 ppm
	45861301 Waterflea, *Daphnia magna*	TCP Degradate	In review
	Waterflea, *Daphnia magna*	Triclopyr BEE	No data
850.1350 **Estuarine/ Marine Invertebrate Lifecycle Toxicity**	50673901 *Americamysis bahia*	Triclopyr BEE 92.4%	Acceptable LOAEC=20.4 ug ai/L NOAEC=10.9
850.4400 **Aquatic Plant Vascular**	41633709 Duckweed, *Lemna gibba*	45 % TEA	Supplemental EC_{50} = 19.5 ppm
	41736302 Duckweed, *Lemna gibba*	45 % TEA Garlon 3	Acceptable EC_{50} = 24.4 ppm
	42719101 Duckweed, *Lemna gibba*	97 % BEE technical	Acceptable EC_{50} = 0.88 ppm
	43230310 Duckweed, *Lemna gibba*	Access BEE 9%/ Picloram IOE 4.7% mix	Acceptable EC_{50} = 99.8 ppm
	45312002 Duckweed, *Lemna gibba*	99.7 % TCP Degradate	Acceptable EC_{50} = 8.2 ppm
850.4500 **Aquatic Plant Non-Vascular**	41736303 Green algae, *Selenastrum capricornutum*	98.8% Technical acid	Supplemental EC_{50} = 32.5 ppm NOEC = 7.0 ppm
	41633705 Green algae, *Selenastrum capricornutum*	45 % TEA	Acceptable EC_{50} = 39.1 ppm
	41633704 Green algae, *Selenastrum capricornutum*	61.3 % BEE Garlon 4	Acceptable EC_{50} = 5.6 ppm
	42645901 Green algae, *Selenastrum capricornutum*	Access =Triclopyr BEE 9%/ Picloram IOE 4.7% mix	Supplemental EC_{50} = 4.86 ppm

Table D-1. Submitted Aquatic Ecological Effects Data for triclopyr Acid, TEA salt, BEE, and TCP.OSCSPP Guideline	Submitted Studies (MRID)	Test Material	Study Classification and Results
	45312001 Green algae, *Selenastrum capricornutum*	99% TCP Degradate	Acceptable EC_{50} = 2.9 ppm
	45312003 Bluegreen algae, *Anabaena flos-aquae*	99% TCP degradate	Acceptable EC_{50} = 2.0 ppm
	42721101 Bluegreen algae, *Anabaena flos-aquae*	97% Technical BEE	Supplemental EC_{50} = 1.97 ppm
	41633706 Bluegreen algae, *Anabaena flos-aquae*	45 %TEA	Acceptable EC_{50} = 5.9 ppm
	43230307 Bluegreen algae, *Anabaena flos-aquae*	Access = BEE 9% Picloram IOE 4.7%	Not Acceptable
	41633708 Freshwater diatom, *Navicula pelliculosa*	45 % TEA	Acceptable EC_{50} = 15.3 ppm
	42721102 Freshwater diatom, *Navicula pelliculosa*	97% Technical BEE	Supplemental 24 hr EC_{50} = 0.10 ppm
	43230301 Freshwater diatom, *Navicula pelliculosa*	Access =Triclopyr BEE 9%/Picloram IOE 4.7%	Not Acceptable
	41633707 Marine diatom, *Skeletonema costatum*	45 % TEA	Supplemental EC_{50} = 14.9 ppm
	42721103 Marine diatom, *Skeletonema costatum*	97% Technical BEE	Supplemental EC_{50} = 1.17 pp,
	43230304 Marine diatom, *Skeletonema costatum*	Access =Triclopyr BEE 9%/ Picloram IOE 4.7% mix	Not acceptable

[1]ppm = mg ai/L
* considered a data gap pending review of the submitted study.

Table D-2. Submitted Terrestrial Ecological Effects Data for Triclopyr Acid, TEA, BEE and TCP.

OSCPP Guideline	Submitted Studies (MRID)	Test Material	Study Classifications and results
850.2100 **Avian Oral Acute**	40346401 Mallard duck, *Anas platyrhynchos*	Technical acid	Acceptable LD_{50}=1698 Mg ai/Kg bw
	00134178 Mallard duck, *Anas platyrhynchos*	64.7 TEA	Supplemental LD_{50}=3175 Mg ai/Kg bw
	40346501 Mallard duck, *Anas platyrhynchos*	64.7 TEA	Acceptable LD_{50}=3176 Mg ai/Kg bw
	41902002 Bobwhite quail, *Colinus virginianus*	96.1 % BEE technical	Acceptable LD_{50}=735
	41902003 Bobwhite quail, *Colinus virginianus*	62.9 % Garlon 4	Acceptable LD_{50}=849.2
	41829001 Bobwhite quail, *Colinus virginianus*	TCP Degradate	Acceptable LD_{50} > 2000 mg ai/Kg
	00028759 Domestic chicken	TCP Degradate	Supplemental LD_{50} > 1000 Mg ai/Kg
	Passerine Species	Triclopyr Acid	No Data
850.2300 **Avian Acute Dietary**	00031249 Mallard duck, *Anas platyrhynchos*	99 % Technical acid	Acceptable LC_{50} >5620 ppm
	40346403 Bobwhite quail, *Colinus virginianus*	Technical acid	Acceptable LC_{50} = 2934 pm
	00049638 Coturnix quail, *Coturnix coturnix*	TEA technical	Supplemental LC_{50} = 3272 ppm
	40346502 Mallard duck, *Anas platyrhynchos*	64.7 % TEA	Acceptable LC_{50} >10,000 ppm
	40346503 Bobwhite quail, *Colinus virginianus*	64.7 % TEA	Acceptable LC_{50} >10,000 ppm
	00134179 Mallard duck, *Anas platyrhynchos*	93 % BEE technical	Acceptable LC_{50} >10,000 ppm
	00134180 Bobwhite quail, *Colinus virginianus*	93 % BEE technical	Acceptable LC_{50}= 9026 ppm
	41905501 Bobwhite quail, *Colinus virginianus*	96.1% BEE technical	Acceptable LC_{50} =5401 ppm
	41905502 Mallard duck, *Anas platyrhynchos*	96.1 % BEE technical	Acceptable LC_{50}>5401 ppm
	41829002 Mallard duck, *Anas platyrhynchos*	TCP degradate	Supplemental LC_{50} > 5620 ppm
850.2300 **Avian Reproduction**	00031250 Mallard duck, *Anas platyrhynchos*	99% Technical acid	Acceptable LOAEL=200 ppm
	00031251 Bobwhite quail, *Colinus virginianus*	99% Technical acid	Supplemental LOAEL>500 ppm
850.3020 **OECD 213** **Honeybee Acute**	40356602 Honeybee, *Apis mellifera*	99.2% Technical acid	Acceptable >100 ug ai/bee
	41219109 Honeybee, *Apis mellifera*	97.7% Technical BEE	Acceptable > 100 ug ai/bee
	42625901 Honeybee, *Apis mellifera*	Access = triclopyr BEE 9% + Picloram EHE 4.7%	Acceptable >25 ug form./bee

OSCPP Guideline	Submitted Studies (MRID)	Test Material	Study Classifications and results
850.3030 Honeybee Residues on Foliage	N.A.	N.A.	No data
OECD 214 Honeybee Oral Acute	49992409 Honeybee, *Apis mellifera*	Triclopyr acid (99%)	Acceptable LD_{50}>99 ug ai/bee
OECD 245 Honeybee Chronic Oral Toxicity Test	50673803 Honeybee, *Apis mellifera*	Triclopyr acid (99.4%)	Acceptable LOAEL=33.4 NOAEL=22.3 ug ai/bee/day
OECD 239 Honeybee Larvae Chronic Toxicity	50673902 Honeybee, *Apis mellifera*	Triclopyr acid (99.4%)	Acceptable LOAEL = 1.5 NOAEL = 0.58 ug ai/larvae/day
850.3040, **Higher Tier Bee Studies ***	N.A.	N.A.	
850.4400 Terrestrial Plants Tier I or Tier II Seedling Emergence	41734301 Ten Species Tier I Seedling Emergence	63.7 % BEE	Acceptable EC25 < 9.0 lb ai/A all species
	41734301 Ten Species Tier I Seedling Emergence	45.2 % TEA	Acceptable EC25 < 8.0 lb ai/A all species
	41296501 Species Tier I Seedling Emergence	Access 9% Triclopyr BEE with 4.7% Picloram	Supplemental Drybean EC25 = 0.000004 lb ai/A
850.4550 Terrestrial Plants Tier I or Tier II Vegetative Vigor	41784401 Ten Species Tier I Vegetative Vigor	45.2 % TEA	Acceptable EC25<9.0 lb ai/A all species
	41734301 Ten Species Tier I Vegetative Vigor	63.7 % BEE	Acceptable EC25<8.0 lb ai/A all species
	41296501 Species Tier I Vegetative Vigor	Access 9% Triclopyr BEE with 4.7% Picloram	Supplemental Soybean EC25 = 0.0002 lb ai/A
	43129801 Ten Species Tier II Seedling Emergence	46.5 % TEA salt	Acceptable Corn EC25>0.333 lb ai/A
	43276601 Tier II Seedling Emergence	Access 9% Triclopyr BEE with 4.7% Picloram	Acceptable Lima bean EC25 0.00042 lb ai/A
	43650001 Ten Species Tier II Seedling Emergence	62.2% Garlon 4 Triclopyr BEE	Acceptable Alfalfa EC25=0.062 lb ai/A

OSCPP Guideline	Submitted Studies (MRID)	Test Material	Study Classifications and results
850.4150	43129801 Ten Species Tier II Vegetative Vigor	46.5 % TEA salt	Acceptable Sunflower EC25 = 0.0076 lb ai/A
	43650001 Ten Species Tier II Vegetative Vigor	62.2% Garlon 4 Triclopyr BEE	Acceptable Sunflower EC25 =0.0089 lb ai/A
Non-Guideline	ACC 235248 Tier III Veg vigor- foliar application-in field	Garlon 3A	Acceptable

APPENDIX E. Sample Runs for Terrestrial Models Used in this assessment

1. TREX Example Run Input and Output: Pasture/Range land use with Triclopyr ACID

Chemical Identity and Application Information

Chemical Name:	**Triclopyr Acid** FALSE
Seed Treatment? (Check if yes)	☐
Use:	hay or pasture, all or unspecified ▼
Product name and form:	**Garlon**
% A.I. (leading zero must be entered for formulations <1% a.i.):	**100.00%**
Application Rate (lb ai/acre)	**9**
Half-life (days):	**35**
Application Interval (days):	
Number of Applications:	**1**
Are you assessing applications with variable rates or intervals?	**no**

Endpoints

Avian	**Mallard duck**	**LD50 (mg/kg-bw)**	**1698.00**
	Bobwhite quail	**LC50 (mg/kg-diet)**	**2934.00**
	Mallard duck	**NOAEL(mg/kg-bw)**	**0.00**
	Mallard duck	**NOAEC (mg/kg-diet)**	**100.00**
Mammals		**LD50 (mg/kg-bw)**	**630.00**
		LC50 (mg/kg-diet)	**0.00**
		NOAEL (mg/kg-bw)	**25.00**
		NOAEC (mg/kg-diet)	**500.00**

Upper Bound Kenaga, Acute Avian Dose-Based Risk Quotients													
Size Class (grams)	Adjusted LD50	Short Grass		Tall Grass		Broadleaf Plants		Fruits/Pods/Seeds		Arthropods		Granivore	
		EEC	RQ	EEC	RQ	EEC	RQ	EEC	RQ	EEC	RQ	EEC	RQ
20	882	2460	2.79	1128	1.28	1384	1.57	154	0.17	964	1.09	34	0.04
100	1122	1403	1.25	643	0.57	789	0.70	88	0.08	549	0.49	19	0.02
1000	1585	628	0.40	288	0.18	353	0.22	39	0.02	246	0.16	9	0.01

Upper Bound Kenaga, Subacute Avian Dietary Based Risk Quotients										
	EECs and RQs									
	Short Grass		Tall Grass		Broadleaf Plants		Fruits/Pods/Seeds		Arthropods	
LC50	EEC	RQ	EEC	RQ	EEC	RQ	EEC	RQ	EEC	RQ
2934	2160	0.74	990	0.34	1215	0.41	135	0.05	846	0.29

Upper Bound Kenaga, Chronic Avian Dietary Based Risk Quotients										
	EECs and RQs									
NOAEC (ppm)	Short Grass		Tall Grass		Broadleaf Plants		Fruits/Pods/Seeds		Arthropods	
	EEC	RQ	EEC	RQ	EEC	RQ	EEC	RQ	EEC	RQ
100	2160	21.60	990	9.90	1215	12.15	135	1.35	846	8.46

Upper Bound Kenaga, Acute Mammalian Dose-Based Risk Quotients													
		EECs and RQs											
Size Class (grams)	Adjusted LD50	Short Grass		Tall Grass		Broadleaf Plants		Fruits/Pods/Seeds		Arthropods		Granivore	
		EEC	RQ	EEC	RQ	EEC	RQ	EEC	RQ	EEC	RQ	EEC	RQ
15	1385	2059	1.49	944	0.68	1158	0.84	129	0.09	807	0.5825	29	0.0207
35	1120	1423	1.27	652	0.58	801	0.71	89	0.08	557	0.4976	20	0.0176
1000	485	330	0.68	151	0.31	186	0.38	21	0.04	129	0.2667	5	0.0095

Upper Bound Kenaga, Chronic Mammalian Dietary Based Risk Quotients										
	EECs and RQs									
NOAEC (ppm)	Short Grass		Tall Grass		Broadleaf Plants		Fruits/Pods/Seeds/Large Insects		Arthropods	
	EEC	RQ	EEC	RQ	EEC	RQ	EEC	RQ	EEC	RQ
500	2160	4.32	990	1.98	1215	2.43	135	0.27	846	1.69

Upper Bound Kenaga, Chronic Mammalian Dose-Based Risk Quotients													
		EECs and RQs											
Size Class (grams)	Adjusted NOAEL	Short Grass		Tall Grass		Broadleaf Plants		Fruits/Pods/Seeds		Arthropods		Granivore	
		EEC	RQ	EEC	RQ	EEC	RQ	EEC	RQ	EEC	RQ	EEC	RQ
15	55	2059	37.48	944	17.18	1158	21.08	129	2.34	807	14.68	29	0.52
35	44	1423	32.02	652	14.67	801	18.01	89	2.00	557	12.54	20	0.44
1000	19	330	17.16	151	7.87	186	9.65	21	1.07	129	6.72	5	0.24

II. BEE REX Example Model Run (4.0 lbs ai/A Triclopyr Acid)

Table 1. User inputs (related to exposure)

Description	Value
Application rate	1
Units of app rate	lb a.i./A
Application method	foliar spray
Are empirical residue data available?	no

Table 2. Toxicity data

Description	Value (µg a.i./bee)
Adult contact LD50	100 (>100)
Adult oral LD50	99 (>99)
Adult oral NOAEL	22.3
Larval LD50	4.3
Larval NOAEL	0.58

Table 3. Estimated concentrations in pollen and nectar

Application method	EECs (mg a.i./kg)	EECs (µg a.i./mg)
foliar spray	110	0.11
soil application	NA	NA
seed treatment	NA	NA
tree trunk	NA	NA

Table 4. Daily consumption of food, pesticide dose and resulting dietary RQs for all bees

Life stage	Caste or task in hive	Avg age (in days)	Jelly (mg/day)	Nectar (mg/day)	Pollen (mg/day)	Total dose (µg a.i./bee)	Acute RQ	Chronic RQ
Larval	Worker	1	1.9	0	0	0.002	#DIV/0!	0.004
		2	9.4	0	0	0.010	#DIV/0!	0.02
		3	19	0	0	0.021	#DIV/0!	0.04
		4	0	60	1.8	6.798	#DIV/0!	11.72
		5	0	120	3.6	13.596	#DIV/0!	23.44
	Drone	6+	0	130	3.6	14.696	#DIV/0!	25.34
	Queen	1	1.9	0	0	0.002	#DIV/0!	0.00
		2	9.4	0	0	0.010	#DIV/0!	0.02
		3	23	0	0	0.025	#DIV/0!	0.04
		4+	141	0	0	0.155	#DIV/0!	0.27

Adult	Worker (cell cleaning and capping)	0-10	0	60	6.65	7.33	0.07	0.51
	Worker (brood and queen tending, nurse bees)	6 to 17	0	140	9.6	16.46	0.17	1.15
	Worker (comb building, cleaning and food handling)	11 to 18	0	60	1.7	6.79	0.07	0.47
	Worker (foraging for pollen)	>18	0	43.5	0.041	4.79	0.05	0.33
	Worker (foraging for nectar)	>18	0	292	0.041	32.12	0.32	2.25
	Worker (maintenance of hive in winter)	0-90	0	29	2	3.41	0.03	0.24
	Drone	>10	0	235	0.0002	25.85	0.26	1.81
	Queen (laying 1500 eggs/day)	Entire lifestage	525	0	0	0.58	0.006	0.040

III. TerrPlant Model Run: 6.0 lbs ai/A for Forestry Use

TerrPlant v. 1.2.2
Green values signify user inputs (Tables 1, 2 and 4).
Input and output guidance is in popups indicated by red arrows.

Table 1. Chemical Identity.	
Chemical Name	Triclopyr TEA as acid
PC code	116001
Use	Forestry
Application Method	Aerial
Application Form	Spray
Solubility in Water (ppm)	440

Table 2. Input parameters used to derive EECs.			
Input Parameter	Symbol	Value	Units
Application Rate	A	6	lbs ai/A
Incorporation	I	1	none
Runoff Fraction	R	0.05	none
Drift Fraction	D	0.05	none

Table 3. EECs for Triclopyr TEA as acid. Units in lbs ai/A.		
Description	Equation	EEC
Runoff to dry areas	(A/I)*R	0.3
Runoff to semi-aquatic areas	(A/I)*R*10	3
Spray drift	A*D	0.3
Total for dry areas	((A/I)*R)+(A*D)	0.6
Total for semi-aquatic areas	((A/I)*R*10)+(A*D)	3.3

Table 4. Plant survival and growth data used for RQ derivation. Units are in lbs ai/A.				
	Seedling Emergence		Vegetative Vigor	
Plant type	EC25	NOAEC	EC25	NOAEC
Monocot	0.33	0.333	0.166	0.111
Dicot	1	0.333	0.0076	0.0041

Table 5. RQ values for plants in dry and semi-aquatic areas exposed to Triclopyr TEA as acid through runoff and/or spray drift.*				
Plant Type	Listed Status	Dry	Semi-Aquatic	Spray Drift
Monocot	non-listed	1.82	10.00	1.81
Monocot	listed	1.80	9.91	2.70
Dicot	non-listed	0.60	3.30	39.47
Dicot	listed	1.80	9.91	73.17
*If RQ > 1.0, the LOC is exceeded, resulting in potential for risk to that plant group.				

APPENDIX F. Endocrine Disruptor Screening Program (EDSP)

As required by FIFRA and the Federal Food, Drug, and Cosmetic Act (FFDCA), EPA reviews numerous studies to assess potential adverse outcomes from exposure to chemicals. Collectively, these studies include acute, subchronic and chronic toxicity, including assessments of carcinogenicity, neurotoxicity, developmental, reproductive, and general or systemic toxicity. These studies include endpoints which may be susceptible to endocrine influence, including effects on endocrine target organ histopathology, organ weights, estrus cyclicity, sexual maturation, fertility, pregnancy rates, reproductive loss, and sex ratios in offspring. For ecological hazard assessments, EPA evaluates acute tests and chronic studies that assess growth, developmental and reproductive effects in different taxonomic groups. As part of the Draft Ecological Risk Assessment for Registration Review, EPA reviewed these data and selected the most sensitive endpoints for relevant risk assessment scenarios from the existing hazard database. However, as required by FFDCA section 408(p), triclopyr ACID, TEA, COLN and BEE are subject to the endocrine screening part of the Endocrine Disruptor Screening Program (EDSP).

EPA has developed the EDSP to determine whether certain substances (including pesticide active and other ingredients) may have an effect in humans or wildlife similar to an effect produced by a "naturally occurring estrogen, or other such endocrine effects as the Administrator may designate." The EDSP employs a two-tiered approach to making the statutorily required determinations. Tier 1 consists of a battery of 11 screening assays to identify the potential of a chemical substance to interact with the estrogen, androgen, or thyroid (E, A, or T) hormonal systems. Chemicals that go through Tier 1 screening and are found to have the potential to interact with E, A, or T hormonal systems will proceed to the next stage of the EDSP where EPA will determine which, if any, of the Tier 2 tests are necessary based on the available data. Tier 2 testing is designed to identify any adverse endocrine-related effects caused by the substance, and establish a dose-response relationship between the dose and the E, A, or T effect.

Under FFDCA section 408(p), the Agency must screen all pesticide chemicals. Between October 2009 and February 2010, EPA issued test orders/data call-ins for the first group of 67 chemicals, which contains 58 pesticide active ingredients and 9 inert ingredients. A second list of chemicals identified for EDSP screening was published on June 14, 2013[1] and includes some pesticides scheduled for registration review and chemicals found in water. Neither of these lists should be construed as a list of known or likely endocrine disruptors. Triclopyr ACID, TEA, COLN and BEE are not on List 1. For further information on the status of the EDSP, the policies and procedures,

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[1] See http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OPPT-2009-0477-0074 for the final second list of chemicals.

the lists of chemicals, future lists, the test guidelines and Tier 1 screening battery, please visit our website[2].

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[2] Available: http://www.epa.gov/endo/

APPENDIX G. Listed Species

In November 2013, the EPA, along with the Services and the United States Department of Agriculture (USDA), released a summary of their joint Interim Approaches for assessing risks to endangered and threatened (listed) species from pesticides. The Interim Approaches were developed jointly by the agencies in response to the National Academy of Sciences' (NAS) recommendations and reflect a common approach to risk assessment shared by the agencies as a way of addressing scientific differences between the EPA and the Services. The NAS report[1] outlines recommendations on specific scientific and technical issues related to the development of pesticide risk assessments that EPA and the Services must conduct in connection with their obligations under the ESA and FIFRA.

EPA received considerable public input on the Interim Approaches through stakeholder workshops and from the Pesticide Program Dialogue Committee (PPDC) and State-FIFRA Issues Research and Evaluation Group (SFIREG) meetings. As part of a phased, iterative process for developing the Interim Approaches, the agencies will also consider public comments on the Interim Approaches in connection with the development of upcoming Registration Review decisions. The details of the joint Interim Approaches are contained in the white paper *Interim Approaches for National-Level Pesticide Endangered Species Act (ESA) Assessments Based on the Recommendations of the National Academy of Sciences April 2013 Report (NRC, 2013)*[2], dated November 1, 2013.

Given that the agencies are continuing to develop and work toward implementation of the Interim Approaches to assess the potential risks of pesticides to listed species and their designated critical habitat, this ecological risk assessment for triclopyr ACID, TEA, COLN and BEE does not contain a complete ESA analysis that includes effects determinations for specific listed species or designated critical habitat. Although EPA has not yet completed effects determinations for specific species or habitats, this assessment assumed, for all taxa of non-target wildlife and plants, that listed species and designated critical habitats may be present in the vicinity of the application of triclopyr ACID, TEA, COLN and BEE. This assessment will allow EPA to focus its future evaluations on the types of species where the potential for effects exists once the scientific methods being developed by the agencies have been fully vetted. Once the agencies have fully developed and implemented the scientific methodology for evaluating risks for listed species and their designated critical habitats, these methods will be applied to subsequent analyses for triclopyr ACID, TEA, COLN and BEE as part of completing this registration review.

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[1] *Assessing Risks to Endangered and Threatened Species from Pesticides.* Available at http://www.nap.edu/catalog.php?record_id=18344
[2] Available at http://www2.epa.gov/endangered-species/assessing-pesticides-under-endangered-species-act#report