BIOLOGICAL EFFECTS OF SEDIMENT ON BULL TROUT AND THEIR HABITAT –

GUIDANCE FOR EVALUATING EFFECTS

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Anthropogenic sediment input into water bodies can have a variety of impacts to fish species from behavioral effects such as avoidance or abandonment of cover to lethal effects. The Washington Fish and Wildlife Office reviews numerous projects where sediment is generated during construction. A scientific approach was needed to determine the concentration and duration of sediment input where adverse effects of project-related sediment would occur.

The following document addresses the biological effects of sediment on bull trout and their habitat. The document is divided into two sections:

1. A literature review on the biological effect of sediment on fish (Page 3).
2. Effects analysis for project related sediment input (Page 23).

The literature review addresses the different types of sediment and the biological effects on bull trout. Direct effects include gill trauma and impacts to spawning, redds, eggs, and alevins. Indirect effects include impacts to macroinvertebrates, feeding efficiency, habitat, physiological stress, and behavioral changes.

The effects analysis section provides a step-by-step process to determine the concentration and duration of sediment input to a stream where adverse affects occur. Newcombe and Jensen (1996) and Anderson et al (1996) provide the basis for the analyzing sediment effects to bull trout and their habitat.

Introduction

As a stream or river flows downslope, it transports sediment and dissolved matter (Skinner and Porter 2000, p. 252). A stream has a natural amount of sediment that is transported through the system that varies throughout the year in response to natural hydrological changes (Galbraith et al. 2006, p. 2488). The amount of sediment that a stream can transport annually is based on numerous factors: precipitation, surface water transport, erosion, topography, geology, streamflow, riparian vegetation, stream geomorphologic characteristic, human disturbance, atmospheric deposition, etc. (Bash et al. 2001o, p. 7;Berry et al. 2003, p. 7). Therefore, different watersheds will have different levels or concentrations of turbidity and suspended sediment. A glaciated stream will have higher sediment levels than a spring fed stream (Uehlinger et al. 2002, p. 1;Ahearn 2002, p. 2).

Many watersheds are subject to anthropogenic disturbances that can produce substantial inputs of sediments into streams (Barrett et al. 1992, p. 437). Turbidity, suspended solids, sediment, and siltation have been consistently listed as impairments in the U.S. Environmental Protection Agency's (EPA) 305(b) water quality reports in rivers and streams, lakes, reservoirs, ponds, wetlands, and oceans shoreline waters (Berry, Rubinstein, Melzian, and Hill 2003, p. 4). The EPA's 305(b) list provides the U.S. Congress and the public a means of determining or assessing the current condition of water quality within each individual state. Excessive sedimentation, natural and anthropogenic, has been estimated to occur in 46 percent of all streams and rivers in the U.S. and is considered the most important factor limiting fish habitat and causing water quality impairment (Judy et al. 1984 as cited in Henley et al. 2000, p. 126;Berry, Rubinstein, Melzian, and Hill 2003, pp. 4, 7). One of the most pervasive influences of land-use activities on stream ecosystems is an increase in sediment yield resulting from point source discharges associated with in-stream activities (Suren and Jowett 2001, p. 725).

Aquatic organisms have adapted to the natural variation in sediment load that occurs seasonally within the stream (ACMRR/IABO Working Party on Ecological Indices of Stress to Fishery Resources 1976, pp. 13, 15;Birtwell 1999, p. 7). Field experiments have found a thirty-fold increase in salmonids' (coho salmon) tolerance to suspended solids between August and November when naturally occurring concentrations are expected to be high (Cederholm and Reid 1987, p. 388).

The introduction of sediment in excess of natural amounts can have multiple adverse effects on bull trout and their habitat (Rhodes et al. 1994, pp. 16-21;Berry, Rubinstein, Melzian, and Hill 2003, p. 7). The effect of sediment beyond natural background conditions can be fatal at high levels. Embryo survival and subsequent fry emergence success have been highly correlated to percentage of fine material within the streambed (Shepard et al. 1984, pp. 146, 152). Low levels of sediment may result in sublethal and behavioral effects such as increased activity, stress, and emigration rates; loss or reduction of foraging capability; reduced growth and resistance to disease; physical abrasion; clogging of gills; and interference with orientation in homing and migration (McLeay et al. 1987a, p. 671;Newcombe and MacDonald 1991, pp. 72, 76, 77;Barrett, Grossman, and Rosenfeld 1992, p. 437;Lake and Hinch 1999, p. 865;Bash et al. 2001n, p. 9;Watts et al. 2003, p. 551;Vondracek et al. 2003, p. 1005;Berry, Rubinstein, Melzian, and Hill

2003, p. 33). The effects of increased suspended sediments can cause changes in the abundance and/or type of food organisms, alterations in fish habitat, and long-term impacts to fish populations (Anderson et al. 1996, pp. 1, 9, 12, 14, 15;Reid and Anderson 1999, pp. 1, 7-15). No threshold has been determined in which fine-sediment addition to a stream is harmless (Suttle et al. 2004, p. 973). Even at low concentrations, fine-sediment deposition can decrease growth and survival of juvenile salmonids.

Aquatic systems are complex interactive systems, and isolating the effects of sediment to fish is difficult (Castro and Reckendorf 1995d, pp. 2-3). The effects of sediment on receiving water ecosystems are complex and multi-dimensional, and further compounded by the fact that sediment flux is a natural and vital process for aquatic systems (Berry, Rubinstein, Melzian, and Hill 2003, p. 4). Environmental factors that affect the magnitude of sediment impacts on salmonids include duration of exposure, frequency of exposure, toxicity, temperature, life stage of fish, angularity and size of particle, severity/magnitude of pulse, time of occurrence, general condition of biota, and availability of and access to refugia (Bash et al. 2001m, p. 11). Potential impacts caused by excessive suspended sediments are varied and complex and are often masked by other concurrent activities (Newcombe 2003, p. 530). The difficulty in determining which environmental variables act as limiting factors has made it difficult to establish the specific effects of sediment impacts on fish (Chapman 1988, p. 2). For example, excess fines in spawning gravels may not lead to smaller populations of adults if the amount of juvenile winter habitat limits the number of juveniles that reach adulthood. Often there are multiple independent variables with complex inter-relationships that can influence population size.

The ecological dominance of a given species is often determined by environmental variables. A chronic input of sediment could tip the ecological balance in favor of one species in mixed salmonid populations or in species communities composed of salmonids and nonsalmonids (Everest et al. 1987, p. 120). Bull trout have more spatially restrictive biological requirements at the individual and population levels than other salmonids (USFWS (U.S. Fish and Wildlife Service) 1998, p. 5). Therefore, they are especially vulnerable to environmental changes such as sediment deposition.

Bull trout are apex predators that prey on a variety of species including terrestrial and aquatic insects and fish (Rieman and McIntyre 1993, p. 3). Fish are common in the diet of individual bull trout that are over 110 millimeters or longer. Large bull trout may feed almost exclusively on fish. Therefore, when analyzing impacts of sediment on bull trout, it is very important to consider other fish species that are part of their prey base. While sediment may not directly impact bull trout, the increased sediment input may affect the spawning and population levels of Chinook and coho salmon, cutthroat trout, and steelhead, or other species that are potential prey for bull trout. The following effects of sediment are not specific to bull trout alone. All salmonids can be affected similarly.

This document identifies the biological effects of sediment on fish and their habitat including the different life stage(s) affected by sediment input. It also provides an analysis to determine the level of sediment concentrations and duration that results in adverse effects to bull trout (and all salmonids) and their habitat.

Sediment Classifications and Definitions

Sediment within a stream can be classified into a variety of categories: turbidity, suspended sediment, bedload, deposited sediment, and wash load (Waters 1995, pp. 13-14;Bash et al. 2001l, pp. 3-4). Sediment category definitions include:

- Turbidity - Optical property of water which results from the suspended and dissolved materials in the water. This causes light to be scattered rather than transmitted in straight lines. Turbidity is measured in nephelometric turbidity units (NTUs). Measurements of turbidity can quickly estimate the amount of sediment within a sample of water.
- Suspended sediment - Represents the actual measure of mineral and organic particles transported in the water column. Suspended sediment is measured in mg/L and is an important measure of erosion, and is linked to the transport of nutrients, metals, and industrial and agricultural chemicals through the river system.
- Bedload - Consists of larger particles on the stream bottom that move by sliding, rolling, or saltating along the substrate surface. Bedload is measured in tons/day, or tons/year.
- Deposited sediment - The intermediate sized sediment particles that settle out of the water column in slack or slower moving water. Based on water velocity and turbulence, these intermediate size particles may be suspended sediment or bedload.
- Wash load - Finest particles in the suspended load that are continuously maintained in suspension by the flow turbulence. Therefore significant quantities are not deposited in the bed.

Suspended sediment, turbidity, and deposited sediment are not associated with specific particle sizes, as there will be considerable overlap depending on velocity, turbulence, and gradient (MacDonald et al. 1991, p. 98;Waters 1995, p. 14). Turbidity cannot always be correlated with suspended solid concentrations due to the effects of size, shape and refractive index of particles (Bash et al. 2001k, p. 5). Turbidity and suspended sediment affect the light available for photosynthesis, visual capability of aquatic animals, gill abrasion, and physiology of fish. Suspended and deposited sediment affect the habitat available for macroinvertebrates, the quality of gravel for fish spawning, and the amount of habitat for fish rearing (Waters 1995, p. 14).

The size of particles within the stream is also important. The quantity of "fines" within a stream ecosystem is usually associated with the degree of fish population declines (Castro and Reckendorf 1995c, p. 2). Particle diameters less than 6.4 mm are generally defined as "fines" (Bjornn et al. 1977c, p. 1;Shepard, Leathe, Waver, and Enk 1984, p. 148;Hillman et al. 1987, p. 185;Chapman 1988, p. 14;Bjornn and Reiser 1991, p. 103;Rieman and McIntyre 1993, p. 6;Castro and Reckendorf 1995b, p. 2;MBTSG (The Montana Bull Trout Scientific Group) 1998a, p. 8).

Biological Effects of Sediment on Bull Trout

Classification of Sediment Effects

In the absence of detailed local information on population dynamics and habitat use, any increase in the proportion of fines in substrates should be considered a risk to the productivity of an environment and to the persistence of associated bull trout populations (Rieman and McIntyre 1993, p. 6). Specific effects of sediment on fish and their habitat can be put into three classes that include (Newcombe and MacDonald 1991, pp. 72-73;Waters 1995, pp. 81-82;Bash et al. 2001j, p. 10):

Lethal:	Direct mortality to any life stage, reduction in egg-to-fry survival, and loss of spawning or rearing habitat. These effects damage the capacity of the bull trout to produce fish and sustain populations.
Sublethal:	Reduction in feeding and growth rates, decrease in habitat quality, reduced tolerance to disease and toxicants, respiratory impairment, and physiological stress. While not leading to immediate death, may produce mortalities and population decline over time.
Behavioral:	Avoidance and distribution, homing and migration, and foraging and predation. Behavioral effects change the activity patterns or alter the kinds of activity usually associated with an unperturbed environment. Behavior effects may lead to immediate death or population decline or mortality over time.

Direct Effects

Gill trauma

High levels of suspended sediment and turbidity can result in direct mortality of fish by damaging and clogging gills (Curry and MacNeill 2004, p. 140). Fish gills are delicate and easily damaged by abrasive silt particles (Bash et al. 2001i, p. 15). As sediment begins to accumulate in the gill filaments, fish excessively open and close their gills to expunge the silt. If irritation continues, mucus is produced to protect the gill surface, which may impede the circulation of water over the gills and interfere with fish respiration (Bash et al. 2001h, p. 15). Gill flaring or coughing abruptly changes buccal cavity pressure and is a means of clearing the buccal cavity of sediment. Gill sediment accumulation may result when fish become too fatigued to continue clearing particles via the cough reflex (Servizi and Martens 1991a, p. 495).

Fish are more susceptible to increased suspended sediment concentrations at different times of the year or in watersheds with naturally high sediment such as glaciated streams. Fish secrete protective mucous to clean the gills (Erman and Ligon 1985, p. 18). In glaciated systems or during winter and spring high flow conditions when sediment concentrations are naturally high, the secretion of mucous can keep gills clean of sediment. Protective mucous secretions are inadequate during the summer months, when natural sediment levels are low in a stream system. Consequently, sediment introduction at this time may increase the vulnerability of fish to stress and disease (Bash et al. 2001g, p. 12).

Spawning, redds, eggs, and alevins

The effects of suspended sediment, deposited in a redd and potentially reducing water flow and smothering eggs or alevins or impeding fry emergence, are related to sediment particle sizes of the spawning habitat (Bjornn and Reiser 1991, p. 98). Sediment particle size determines the pore openings in the redd gravel. With small pore openings, more suspended sediments are deposited and water flow is reduced compared to large pore openings.

Survival of eggs is dependent on a continuous supply of well oxygenated water through the streambed gravels (Cederholm and Reid 1987, p. 384;Anderson, Taylor, and Balch 1996, p. 13). Eggs and alevins are generally more susceptible to stress by suspended solids than are adults. Accelerated sedimentation can reduce the flow of water and, therefore, oxygen to eggs and alevins. This can decrease egg survival, decrease fry emergence rates (Cederholm and Reid 1987, p. 384;Chapman 1988, pp. 12-16;Bash et al. 2001f, pp. 17-18), delay development of alevins (Everest, Beschta, Scrivener, Koski, Sedell, and Cederholm 1987, p. 113), reduce growth and cause premature hatching and emergence (Birtwell 1999, p. 19). Fry delayed in their emergence are also less able to compete for environmental resources than fish that have undergone normal development and emergence (intra- or interspecific competition) (Everest, Beschta, Scrivener, Koski, Sedell, and Cederholm 1987, p. 113). Sedimentation fills the interstitial spaces and can prevent alevins from emerging from the gravel (Anderson, Taylor, and Balch 1996, p. 13;Suttle, Power, Levine, and McNeely 2004, pp. 971-972).

Several studies have documented that fine sediment can reduce the reproductive success of salmonids. Natural egg-to-fry survival of coho salmon, sockeye and kokanee has been measured at 23 percent, 23 percent and 12 percent, respectively (Slaney et al. 1977, p. 33). Substrates containing 20 percent fines can reduce emergence success by 30-40 percent (MacDonald, Smart, and Wissmar 1991, p. 99). A decreases of 30 percent in mean egg-to-fry survival can be expected to reduce salmonid fry production to extremely low levels (Slaney, Halsey, and Tautz 1977, p. 33).

Indirect Effects

Macroinvertebrates

Sedimentation can have an effect on bull trout and fish populations through impacts or alterations to the macroinvertebrate communities or populations (Anderson, Taylor, and Balch 1996, pp. 14-15). Increased turbidity and suspended sediment can reduce primary productivity by decreasing light intensity and periphytic (attached) algal and other plant communities (Anderson, Taylor, and Balch 1996, p. 14;Henley, Patterson, Neves, and Lemly 2000, p. 129;Suren and Jowett 2001, p. 726). This results in decreased macroinvertebrates that graze on the periphyton.

Sedimentation also alters the habitat for macroinvertebrates, changing the species density, diversity and structure of the area (Waters 1995, pp. 61-78;Anderson, Taylor, and Balch 1996, pp. 14-15;Reid and Anderson 1999, pp. 10-12;Shaw and Richardson 2001, p. 2220). Certain groups of macroinvertebrates are favored by salmonids as food items. These include mayflies, caddisflies, and stoneflies. These species prefer large substrate particles in riffles and are negatively affected by fine sediment (Everest, Beschta, Scrivener, Koski, Sedell, and Cederholm

1987, p. 115;Waters 1995, p. 63). Increased sediment can affect macroinvertebrate habitat by filling of interstitial space and rendering attachment sites unsuitable. This may cause invertebrates to seek more favorable habitat (Rosenberg and Snow 1975, p. 70). With increasing fine sediment, invertebrate composition and density changes from available, preferred species (i.e., mayflies, caddisflies, and stoneflies) to non-preferred, more unavailable species (i.e., aquatic worms and other burrowing species) (Reid and Anderson 1999, p. 10;Henley, Patterson, Neves, and Lemly 2000, pp. 126, 130;Shaw and Richardson 2001, p. 2219;Suren and Jowett 2001, p. 726;Suttle, Power, Levine, and McNeely 2004, p. 971). The degree to which substrate particles are surrounded by fine material was found to have a strong correlation with macroinvertebrate abundance and composition (Birtwell 1999, p. 23). At an embeddedness of one-third, insect abundance can decline by about 50 percent, especially for riffle-inhabiting taxa (Waters 1995, p. 66).

Increased turbidity and suspended solids can affect macroinvertebrates in multiple ways through increased invertebrate drift, feeding impacts, and respiratory problems (Cederholm and Reid 1987, p. 384;Shaw and Richardson 2001, p. 2218;Berry, Rubinstein, Melzian, and Hill 2003, pp. 8, 11). The effect of turbidity on light transmission has been well documented and results in increased invertebrate drift (Waters 1995, p. 58;Birtwell 1999, pp. 21, 22). This may be a behavioral response associated with the night-active diel drift patterns of macroinvertebrates. While increased turbidity results in increased macroinvertebrate drift, it is thought that the overall invertebrate populations would not fall below the point of severe depletion (Waters 1995, p. 59). Invertebrate drift is also an important mechanism in the repopulation, recolonization, or recovery of a macroinvertebrate community after a localized disturbance (Anderson, Taylor, and Balch 1996, p. 15;Reid and Anderson 1999, pp. 11-12).

Increased suspended sediment can affect macroinvertebrates by abrasion of respiratory surface and interference with food uptake for filter-feeders (Anderson, Taylor, and Balch 1996, p. 14;Birtwell 1999, p. 21;Shaw and Richardson 2001, p. 2213;Suren and Jowett 2001, pp. 725-726;Berry, Rubinstein, Melzian, and Hill 2003, p. 11). Increased suspended sediment levels tend to clog feeding structures and reduce feeding efficiencies, which results in reduced growth rates, increased stress, or death of the invertebrates (Newcombe and MacDonald 1991, p. 73). Invertebrates living in the substrate are also subject to scouring or abrasion which can damage respiratory organs (Bash et al. 2001e, p. 25).

Feeding Efficiency

Increased turbidity and suspended sediment can affect a number of factors related to feeding for salmonids, including feeding rates, reaction distance, prey selection, and prey abundance (Barrett, Grossman, and Rosenfeld 1992, pp. 437, 440;Henley, Patterson, Neves, and Lemly 2000, p. 133;Bash et al. 2001d, p. 21). Changes in feeding behavior are primarily related to the reduction in visibility that occurs in turbid water. Effects on feeding ability are important as salmonids must meet energy demands to compete with other fishes for resources and to avoid predators. Reduced feeding efficiency would result in lower growth and fitness of bull trout and other salmonids (Barrett, Grossman, and Rosenfeld 1992, p. 442;Sweka and Hartman 2001, p. 138).

Distance of prey capture and prey capture success both were found to decrease significantly when turbidity was increased (Berg and Northcote 1985, pp. 1414-1415;Sweka and Hartman 2001, p. 141;Zamor and Grossman 2007, pp. 168, 170, 174). Waters (1995, p. 83) states that loss of visual capability, leading to reduced feeding, is one of the major sublethal effects of high suspended sediment. Increases in turbidity were reported to decrease reactive distance and the percentage of prey captured (Sweka and Hartman 2001, p. 141;Bash et al. 2001c, pp. 21-23;Klein 2003, pp. 1, 21). At 0 NTUs, 100 percent of the prey items were consumed; at 10 NTUs, fish frequently were unable to capture prey species; at 60 NTUs, only 35 percent of the prey items were captured. At 20 to 60 NTUs, significant delay in the response of fish to prey was observed (Bash et al. 2001b, p. 22). Loss of visual capability and capture of prey leads to depressed growth and reproductive capability.

To compensate for reduced encounter rates with prey under turbid conditions, prey density must increase substantially or salmonids must increase their active searches for prey (Sweka and Hartman 2001, p. 144). Such an increase in activity and feeding rates under turbid conditions reduces net energy gain from each prey item consumed (Sweka and Hartman 2001, p. 144).

Sigler et al. (1984, p. 150) found that a reduction in growth occurred in steelhead and coho salmon when turbidity was as little as 25 NTUs. The slower growth was presumed to be from a reduced ability to feed; however, more complex mechanisms such as the quality of light may also affect feeding success rates. Redding et al. (1987, p. 742) found that suspended sediment may inhibit normal feeding activity, as a result of a loss of visual ability or as an indirect consequence of increased stress.

Habitat Effects

Compared to other salmonids, bull trout have more specific habitat requirements that appear to influence their distribution and abundance (Rieman and McIntyre 1993, p. 7). All life history stages are associated with complex forms of cover including large woody debris, undercut banks, boulders, and pools. Other habitat characteristic important to bull trout include channel and hydrologic stability, substrate composition, temperature, and the presence of migration corridors (Rieman and McIntyre 1993, p. 5).

Increases in sediment can alter fish habitat or the utilization of habitats by fish (Anderson, Taylor, and Balch 1996, p. 12). The physical implications of sediment in streams include changes in water quality, degradation of spawning and rearing habitat, simplification and damage to habitat structure and complexity, loss of habitat, and decreased connectivity between habitat (Anderson, Taylor, and Balch 1996, pp. 11-15;Bash et al. 2001a, pp. 1, 12, 18, 30). Biological implications of this habitat damage include underutilization of stream habitat, abandonment of traditional spawning habitat, displacement of fish from their preferred habitat, and avoidance of habitat (Newcombe and Jensen 1996, p. 695).

As sediment enters a stream it is transported downstream under normal fluvial processes and deposited in areas of low shear stress (MacDonald and Ritland 1989, p. 21). These areas are usually behind obstructions, near banks (shallow water) or within interstitial spaces. This episodic filling of successive storage compartments continues in a cascading fashion downstream until the flow drops below the threshold required for movement or all pools have reached their storage capacities (MacDonald and Ritland 1989, p. 21). As sediment load increases, the stream compensates by geomorphologic changes in increased slope, increased channel width, decreased depths, and decreased flows (Castro and Reckendorf 1995a, p. 21). These processes contribute to increased erosion and sediment deposition that further degrade salmonid habitat.

Loss of acceptable habitat and refugia, as well as decreased connectivity between habitats, reduces the carrying capacity of streams for salmonids (Bash et al. 2001p, p. 30). This loss of habitat or exclusion of fish from their habitat, if timed inappropriately, could impact a fish population if the habitat within the affected stream reach is critical to the population during the period of the sediment release (Anderson, Taylor, and Balch 1996, p. 12;Reid and Anderson 1999, p. 13). For example, if summer pool habitat used by adults as holding habitat prior to spawning is a limiting factor within a stream, increased sediment and reduced pool habitat during the summer can decrease the carrying capacity of the stream reach and decrease the fish population. In systems lacking adequate connectivity of habitats, fish may travel longer distances or use less desirable habitats, increasing biological demands and reducing their fitness.

The addition of fine sediment (less than 6.4 mm) to natural streams during summer decreased abundance of juvenile Chinook salmon in almost direct proportion to the amount of pool volume lost to fine sediment (Bjornn et al. 1977b, p. 31). Similarly, the inverse relationship between fine sediment and densities of rearing Chinook salmon indicates the importance of winter habitat and high sediment loads (Bjornn et al. 1977a, pp. 26, 38, 40). As fine sediments fill the interstitial spaces between the cobble substrate, juvenile Chinook salmon were forced to leave preferred habitat and to utilize cover that may be more susceptible to ice scouring, predation, and decreased food availability (Hillman, Griffith, and Platts 1987, p. 194). Deposition of sediment on substrate may lower winter carrying capacity for bull trout (Shepard, Leathe, Waver, and Enk 1984, p. 153). Food production in the form of aquatic invertebrates may also be reduced.

Juvenile bull trout densities are highly influenced by substrate composition (Shepard, Leathe, Waver, and Enk 1984, p. 153;Rieman and McIntyre 1993, p. 6;MBTSG (The Montana Bull Trout Scientific Group) 1998b, p. 9). During the summer, juvenile bull trout hold positions close to the stream bottom and often seek cover within the substrate itself. When streambed substrate contains more than 30 percent fine materials, juvenile bull trout densities drop off sharply (Shepard, Leathe, Waver, and Enk 1984, p. 152). Any loss of interstitial space or streambed complexity through the deposition of sediment would result in a loss of summer and winter habitats (MBTSG (The Montana Bull Trout Scientific Group) 1998c, p. 9). The reduction of rearing habitat will ultimately reduce the potential number of recruited juveniles and therefore reducing population numbers (Shepard, Leathe, Waver, and Enk 1984, pp. 153-154). In fact, Johnston et al. (2007, p. 125) found that density-dependent survival during the earliest of the juvenile stages (between egg and age-1) regulated recruitment of adult bull trout in the population.

Although an avoidance response by fish to increased sediment may be an initial adaptive survival strategy, displacement from cover could be detrimental. It is possible that the consequences of fish moving from preferred habitat, to avoid increasing levels of suspended sediment, may not be beneficial if displacement is to sub-optimal habitat, because they may be stressed and more vulnerable to predation (Birtwell 1999, p. 12).

In addition to altering stream bed composition, anthropogenic input of sediment into a stream can change channel hydrology and geometry (Owens et al. 2005, pp. 694-695). Sediment release can reduce the depth of pools and riffle areas (Anderson, Taylor, and Balch 1996, p. 12). This can reduce available fish habitat, decrease fish holding capacity, and decrease fish populations (Anderson, Taylor, and Balch 1996, pp. 12, 14).

Physiological Effects

Sublethal levels of suspended sediment may cause undue physiological stress on fish, which may reduce the ability of the fish to perform vital functions (Cederholm and Reid 1987, p. 388, 390). Stress is defined as a condition perceived by an organism which threatens a biological function of the organism, and a set of physiological and behavioral responses is mounted to counteract the condition (Overli 2001, p. 7). A stressor is any anthropogenic or natural environmental change severe enough to require a physiological response on the part of a fish, population, or ecosystem (Anderson, Taylor, and Balch 1996, pp. 5-6;EPA (U.S. Environmental Protection Agency) 2001a, pp. 1-2;Jacobson et al. 2003, p. 2). At the individual level, stress may affect physiological systems, reduce growth, increase disease, and reduce the individual's ability to tolerate additional stress (Anderson, Taylor, and Balch 1996, p. 7;Bash et al. 2001q, p. 17). At the population level, the effects of stress may include reduced spawning success, increased larval mortality, reduced recruitment to succeeding life stages and, therefore, overall population declines (Bash et al. 2001r, p. 17).

Upon encountering a stressor, the fish responds through a series of chemical releases in its body. These primary chemical and hormonal releases include catecholamine (e.g. epinephrine, norepinehprine) in the circulatory system, corticosteroids (e.g. cortisol) from the interregnal tissue, and hypothalamic activation of the pituitary gland (Gregory and Wood 1999, p. 286;Schreck et al. 2001, p. 5;Barton 2002, p. 517;Davis 2006, p. 116). Primary chemical releases result in secondary releases or changes in plasma, glucose, tissue ion, metabolite levels, and hematological features. These secondary responses relate to physiological adjustments in metabolism, respiration, immune and cellular function (Mazeaud et al. 1977, p. 201;Barton 2002, p. 517;Haukenes and Buck 2006, p. 385). After secondary responses, continued stress results in tertiary stress responses which affect whole-animal performance such as changes in growth, condition, resistance to disease, metabolic scope for activity, behavior, and ultimately survival (Pickering et al. 1982, p. 229;Barton 2002, p. 517;Portz et al. 2006, pp. 126-127).

Stress in a fish occurs when the homeostatic or stabilizing process in the organism exceed the capability of the organism to compensate for the biotic or abiotic challenge (Anderson, Taylor, and Balch 1996, p. 5). The response to a stressor is an adaptive mechanism that allows the fish to cope with the real or perceived stressor in order to maintain its normal or homeostatic state (Barton 2002, p. 517). Acclimation to a stressor can occur if compensatory physiological responses by the fish are able to re-establish a satisfactory relationship between the changed environment and the organism (Anderson, Taylor, and Balch 1996, p. 5). The ability of an individual fish to acclimate or tolerate the stress will depend on the severity of the stress and the physiological limits of the organism (Anderson, Taylor, and Balch 1996, p. 5). In a natural system, fish are exposed to multiple chemical and physical stressors which can combine to cause adverse effects (Berry, Rubinstein, Melzian, and Hill 2003, p. 4). The chemical releases from each stressor results in a cumulative or additive response (Barton et al. 1986, pp. 245, 247;EPA (U.S. Environmental Protection Agency) 2001b, pp. 3, 25;Cobleigh 2003, pp. 16, 39, 55;Milston et al. 2006, p. 1172).

Stress in fish results in extra cost and energy demands. Elevated oxygen consumption and increased metabolic rate result from the reallocation of energy to cope with the stress (Barton and Schreck 1987, pp. 259-260;Contreras-Sanchez et al. 1998, pp. 439, 444;McCormick et al. 1998, pp. 222, 231). An approximate 25 percent increase in metabolic cost, over standard metabolism requirements, is needed to compensate for a perceived stress (Barton and Schreck 1987, p. 260;Davis 2006, p. 116). Stressed fish would thus have less energy available for other life functions such as seawater adaptation, disease resistance, reproduction, or swimming stamina (Barton and Schreck 1987, p. 261;Contreras-Sanchez, Schreck, Fitzpatrick, and Pereira 1998, p. 444).

Tolerance to suspended sediment may be the net result of a combination of physical and physiological factors related to oxygen availability and uptake by fish (Servizi and Martens 1991b, p. 497). The energy needed to perform repeated coughing (see Gill trauma section) increases metabolic oxygen demand. Metabolic oxygen demand is related to water temperature. As temperatures increase, so does metabolic oxygen demand, but concentrations of oxygen available in the water decreases. Therefore, a fish's tolerance to suspended sediment may be primarily related to the capacity of the fish to perform work associated with the cough reflex. However, as sediment increases, fish have less capability to do work, and therefore less tolerance for suspended sediment (Servizi and Martens 1991c, p. 497).

Once exposed to a stressor, the primary chemical releases can take one-half to twenty-four hours to peak (Schreck 1981, p. 298;Barton 2002, p. 520;Quigley and Hinch 2006, p. 437). Recovery or return of the primary chemical release to normal or resting levels can take two hours to two weeks (Mazeaud, Mazeaud, and Donaldson 1977, pp. 205-206;Schreck 1981, p. 313). In a study of handling stress, chemical release of cortisol peaked at two hours and returned to normal in four hours. However, complete recovery took 2 weeks (Pickering, Pottinger, and Christie 1982, pp. 236, 241). Fish exposed to two or more stresses require longer recovery times than fish exposed only to one stressor indicating the cumulative effects of stress (Sigismondi and Weber 1988, pp. 198-199).

Redding el al.(1987, pp. 740-741) observed higher mortality in young steelhead trout exposed to a combination of suspended sediment (2500 mg/L) and a bacteria pathogen, than when exposed to the bacteria alone. Physiological stress in fishes may decrease immunological competence, growth, and reproductive success (Bash et al. 2001s, p. 16).

Behavioral effects

Increased turbidity and suspended sediment may result in behavior changes in salmonids. These changes are the first effects evoked from increased levels of turbidity and suspended sediment

(Anderson, Taylor, and Balch 1996, p. 6). These behavioral changes include avoidance of habitat, reduction in feeding, increased activity, redistribution and migration to other habitats and locations, disruption of territoriality, and altered homing (Anderson, Taylor, and Balch 1996, p. 6;Bash et al. 2001t, pp. 19-25;Suttle, Power, Levine, and McNeely 2004, p. 971). Many behavioral effects result from changes in stream habitat (see Habitat effects section). As suspended sediment concentration increases, habitat may be lost which results in abandonment and avoidance of preferred habitat. Stream reach emigration is a bioenergetic demand that may affect the growth or reproductive success of the individual fish (Bash et al. 2001u, p. 12). Pulses of sediment result in downstream migration of fish, which disrupts social structures, causes downstream displacement of other fish and increases intraspecific aggression (McLeay et al. 1987b, pp. 670-671;Bash et al. 2001v, pp. 12, 20;Suttle, Power, Levine, and McNeely 2004, p. 971). Loss of territoriality and the breakdown of social structure can lead to secondary effects of decreased growth and feeding rates, which may lead to mortality (Berg and Northcote 1985, p. 1416;Bash et al. 2001w, p. 20).

Downstream migration by bull trout provides access to more prey, better protection from avian and terrestrial predators, and alleviates potential intraspecific competition or cannibalism in rearing areas (MBTSG (The Montana Bull Trout Scientific Group) 1998d, p. 13). Benefits of migration from tributary rearing areas to larger rivers or estuaries may be increased growth potential. Increased sedimentation may result in premature or early migration of both juveniles and adults or avoidance of habitat and migration of nonmigratory resident bull trout.

High turbidity may delay migration back to spawning sites, although turbidity alone does not seem to affect homing. Delays in spawning migration and associated energy expenditure may reduce spawning success and therefore population size (Bash et al. 2001x, p. 29).

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DETERMINING EFFECTS FOR SECTION 7 CONSULTATIONS

There are numerous factors that can influence project-specific sediment effects on bull trout and other salmonids. These factors include the concentration and duration of sediment input, existing sediment conditions, stream conditions (velocity, depth, etc.) during construction, weather or climate conditions (precipitation, wind, etc.), fish presence or absence (bull trout plus prey species), and best management practice effectiveness. Many of these factors are unknown.

Newcombe and Jensen (1996) and Anderson et al. (1996) provide the basis for analyzing sediment effects to bull trout and other salmonids and their habitat. Newcombe and Jensen (1996) conducted a literature review of pertinent documents on sediment effects to salmonids and nonsalmonids. They developed a model that calculated the severity of ill effect (SEV) to fish based on the suspended sediment dose (exposure) and concentration. No data on bull trout were used in this analysis. Anderson et al. (1996), using the methods used by Newcombe and Jensen (1996), developed a model to estimate sediment impacts to salmonid habitat.

A 15-point scale was developed by Newcombe and Jensen (1996, p. 694) to qualitatively rank the effects of sediment on fish (Table 1). Using a similar 15-point scale, Anderson et al. (1996)

Table 1 – Scale of the severity (SEV) of ill effects associated with excess suspended sediment on salmonids.

SEV	Description of Effect
	Nil effect
0	No behavioral effects
	Behavioral effects
1	Alarm reaction
2	Abandonment of cover
3	Avoidance response
	Sublethal effects
4	Short-term reduction in feeding rates; short-term reduction in feeding success
5	Minor physiological stress; increase in rate of coughing; increased respiration rate
6	Moderate physiological stress
7	Moderate habitat degradation; impaired homing
8	Indications of major physiological stress; long-term reduction in feeding rate; long-term reduction in feeding success; poor condition
	Lethal and paralethal effects
9	Reduced growth rate; delayed hatching; reduced fish density
10	0-20% mortality; increased predation; moderate to severe habitat degradation
11	> 20 – 40% mortality
12	> 40 – 60% mortality
13	> 60 – 80% mortality
14	> 80 – 100% mortality

ranked the effects of sediment on fish habitat (Table 2).

We analyzed the effects on different bull trout life history stages to determine when adverse effects of project-related sediment would occur. Table 3 shows the different ESA effect calls for bull trout based on severity of ill effect.

The effect determination for a proposed action should consider all SEV values resulting from the action because sediment affects individual fish differently depending on life history stage and site-specific factors. For juvenile bull trout, an SEV of 5 is likely to warrant a "likely to adversely affect" (LAA) determination. However, abandonment of cover (SEV 2), or an avoidance response (SEV 3), may result in increased predation risk and mortality if habitat features are limiting in the project's stream reach. Therefore, a LAA determination may be warranted at an SEV 2 or 3 level in certain situations. For subadult and adult bull trout, however, abandonment of cover and avoidance may not be as important. A higher SEV score is more appropriate for adverse effects to subadult and adult bull trout. In all situations, we assume that SEV scores associated with adverse effects are also sufficient to represent a likelihood of harm or harass[1].

Table 2 – Scale of the severity (SEV) of ill effects associated with excess suspended sediment on salmonid habitat.

SEV	Description of Effect
3	Measured change in habitat preference
7	Moderate habitat degradation – measured by a change in invertebrate community
10	Moderately severe habitat degradation – defined by measurable reduction in the productivity of habitat for extended period (months) or over a large area (square kilometers).
12	Severe habitat degradation – measured by long-term (years) alterations in the ability of existing habitats to support fish or invertebrates.
14	Catastrophic or total destruction of habitat in the receiving environment.

When evaluating impacts to habitat as a surrogate for species effects, adverse effects may be anticipated when there is a notable reduction in abundance of aquatic invertebrates, and an alteration in their community structure. These effects represent a reduction in food for bull trout and other salmonids, and correspond to an SEV of 7 – moderate habitat degradation.

Newcombe and Jensen (1996) used six data groups to conduct their analysis. These groups were 1) juvenile and adult salmonids (Figure 1), 2) adult salmonids (Figure 2), 3) juvenile salmonids (Figure 3), 4) eggs and larvae of salmonids and non-salmonids (Figure 4), 5) adult estuarine nonsalmonids (no figure provided), and 6) adult freshwater nonsalmonids (no figure provided). No explanation was provided for why juvenile and adult salmonids were combined

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[1] Harm and harass in this context refers to the FWS's regulatory definition at 50 CFR 17.3. E.g., Harm means "an act which actually kills or injures wildlife. Such an act may include significant habitat modification or degradation where it actually kills or injures wildlife by significantly impairing essential behavior patterns, including breeding, feeding, or sheltering."

for group 1. As juveniles are more adapted to turbid water (Newcombe 1994, p. 5), their SEV levels are generally lower than for adult salmonids given the same concentration and duration of sediment (Figures 1-3).

Table 3 – ESA Effect calls for different bull trout life stages in relation to the duration of effect and severity of ill effect. Effect calls for habitat, specifically, are provided to assist with analysis of effects to individual bull trout.

	SEV	ESA Effect Call
Egg/alevin	1 to 4	Not applicable - alevins are still in gravel and are not feeding.
	5 to 14	LAA - any stress to egg/alevin reduces survival
Juvenile	1 to 4	NLAA
	5 to 14	LAA
Subadult and Adult	1 to 5	NLAA
	6 to 14	LAA
Habitat	1 to 6	NLAA
	7 to 14	LAA due to indirect effects to bull trout

The figures of Newcombe and Jensen (1996) have been modified in this document. In each figure, values (in mg/L) are provided for each duration to determine when adverse effects would occur. Specific values are also given for when harm would be likely to occur. For example:

> Figure 1 – This figure is for both juveniles and adults. From Table 2, bull trout are "likely to be adversely affected" given an SEV of 5. On Figure 1, a sediment concentration of 99 mg/L for one hour is anticipated to be the maximum concentration for an SEV of 4. At 100 mg/L, an SEV of 5 occurs. In addition, one hour of exposure to 5,760 mg/L is the maximum for an SEV of 7. Exposure to 5,761 mg/L for one hour would warrant an SEV of 8. This would be the threshold between harassment and harm. An SEV of 7 would be harassment, and an SEV of 8 would be considered harm.

The following provides some guidance on use of the figures.

Definitions from Newcombe and Jensen (1996, p. 696). These definitions are provided for consultations that may have impacts to bull trout prey such as Chinook and coho salmon.

> Eggs and larvae – eggs, and recently hatched fish, including yolk-sac fry, that have not passed through final metamorphosis.
>
> Juveniles – fry, parr, and smolts that have passed through larval metamorphosis but are sexually immature.

Adults – mature fish.

Bull trout use:

Newcombe and Jensen (1996) conducted their analysis for freshwater, therefore the use of the figures within this document in marine waters should be used with caution.

Figure 1 – Juvenile and Adult Salmonids. This figure should be used in foraging, migration and overwintering (FMO) areas. In FMO areas, downstream of local populations, both subadult and adult bull trout may be found.

Figure 2 – Adult Salmonids. This figure will not be used very often for bull trout. There may be circumstances, downstream of local population spawning areas that may have just adults, but usually this would not be the case. Justification for use of this figure should be stated in your consultation.

Figure 3 – Juvenile Salmonids. This figure should be used in local population spawning and rearing areas outside of the spawning period. During this time, only juveniles and sub-adults should be found in the area. Adults would migrate to larger stream systems or to marine water. If the construction of the project would occur during spawning, then Figure 1 should be used.

Figure 4 – Eggs and Alevins. This figure should be used if eggs or alevins are expected to be in the project area during construction.

Figure 5 – Habitat. This figure should be used for all projects to determine whether alterations to the habitat may occur from the project.

Background and Environmental Baseline

In determining the overall impact of a project on bull trout, and to specifically understand whether increased sediment may adversely affect bull trout, a thorough review of the environmental baseline and limiting factors in the stream and watershed is needed. The following websites and documents will help provide this information.

1. Washington State Conservation Commission's Limiting Factors Analysis. A limiting factors analysis has been conducted on watersheds within the State of Washington. Limiting factors are defined as "conditions that limit the ability of habitat to fully sustain populations of salmon, including all species of the family Salmonidae." These documents will provide information on the current condition of the individual watersheds within the State of Washington. The limiting factors website is http://salmon.scc.wa.gov. Copies of the limiting factors analysis can be found at the Western Washington Fish and Wildlife Library.

2. Washington Department of Fish and Wildlife's (1998) Salmonid Stock Inventory (SaSI). The Washington Department of Fish and Wildlife (WDFW) inventoried bull

trout and Dolly Varden (*S. malma*) stock status throughout the State. The intent of the inventory is to help identify available information and to guide future restoration planning and implementation. SaSI defines the stock within the watershed, life history forms, status and factors affecting production. Spawning distribution and timing for different life stages are provided (migration, spawning, etc.), if known. SaSi documents can be found at http://wdfw.wa.gov/fish/sasi/index.htm.

3. U.S. Fish and Wildlife Service's (USFWS 1998a) Matrix of Diagnostics/Pathways and Indicators (MPI). The MPI was designed to facilitate and standardize determination of project effects on bull trout. The MPI provides a consistent, logical line of reasoning to aid in determining when and where adverse affects occur and why they occur. The MPI provides levels or values for different habitat indicators to assist the biologist in determining the level of effects or impacts to bull trout from a project and how these impacts may cumulatively change habitat within the watershed.

4. Individual Watershed Resources. Other resources may be available within a watershed that will provide information on habitat, fish species, and recovery and restoration activities being conducted. The action agency may cite a publication or identify a local watershed group within the Biological Assessment or Biological Evaluation. These local groups provide valuable information specific to the watershed.

5. Washington State Department of Ecology (WDOE) - The WDOE has long- and short-term water quality data for different streams within the State. Data can be found at http://www.ecy.wa.gov/programs/eap/fw_riv/rv_main.html. Clicking on a stream or entering a stream name will provide information on current and past water quality data (when you get to this website, scroll down to the Washington map). This information will be useful for determining the specific turbidity/suspended sediment relationship for that stream (more information below).

6. Washington State Department of Ecology (WDOE) - The WDOE has also been collecting benthic macroinvertebrates and physical habitat data to describe conditions under natural and anthropogenic disturbed areas. Data can be found at http://www.ecy.wa.gov/programs/eap/fw_benth/index.htm. You can access monitoring sites at the bottom of the website.

7. U.S. Forest Service, Watershed Analysis Documents - The U.S. Forest Service (USFS) is required by the Record of Decision for Amendments to the USFS and Bureau of Land Management Planning Documents within the Range of the Northern Spotted Owl to conduct a watershed analysis for watersheds located on FS lands. The watershed analysis determines the existing condition of the watershed and makes recommendations for future projects that move the landscape towards desired conditions. Watershed analysis documents are available from individual National Forests or from the Forest Plan Division.

8. U.S. Fish and Wildlife Service - Bull Trout Recovery Plans and Critical Habitat Designations. The draft Bull Trout Recovery Plan for the Columbia River Distinct

Population Segment (DPS) (also the Jarbidge River and the St. Mary-Belly River DPS) and the proposed and final critical habitat designations provide current species status, habitat requirements, and limiting factors for bull trout within specific individual recovery units. These documents are available from the Endangered Species Division as well as the Service's web page (www.fws.gov).

These documents and websites provide baseline and background information on stream and watershed conditions. This information is critical to determining project-specific sediment impacts to the aquatic system. The baseline or background levels need to be analyzed with respect to the limiting factors within the watershed.

Consultation Sediment Analysis

The analysis in this section only applies to construction-related physiological and behavioral impacts, and the direct effects of fine sediment on current habitat conditions. Longer-term effects to habitat from project-induced channel adjustments, post-construction inputs of coarse sediment, and secondary fine sediment effects due to re-mobilization of sediment during the following runoff season, are not included in the quantitative part of this effects determination. Those aspects are only considered qualitatively.

The background or baseline sediment conditions within the project area or watershed will help to determine whether the project will have an adverse effect on bull trout. The following method should be followed to assist in reviewing effects determinations and quantifying take in biological opinions.

1) Determine what life stage(s) of bull trout will be affected by sedimentation from the project. Life history stages include eggs and alevins, juveniles, and sub-adults and adults. If projects adhere to approved work timing windows, very few should be constructed during periods when eggs and alevins are in the gravels. However, streambed or bank adjustments may occur later in time and result in increased sedimentation during the time of the year when eggs and alevins may be in the gravels and thus affected by the project.

2) Table 4 (Page 45) provides concentrations, durations, and SEV levels for different projects. This table will help in analyzing similar projects and to determine sediment level impacts associated with that type of project. Based on what life history stage is in the project area and what SEV levels may result from the project, a determination may be made on effects to bull trout.

3) Once a "likely to adversely affect" determination has been made for a project, the figures in Newcombe and Jensen (1996) or Anderson et al. (1996) are used to determine the concentration (mg/L) at which adverse effects[2] and "take" will occur (see Figures 1-5). For example, if a project is located in FMO habitat, Figure 1 would be used to determine the concentrations at which adverse effects will occur. Since Figure 1 is used for both adults and juveniles, an SEV of 5 (for juveniles) is used (see Table 2). For (a.) the level

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[2] For the remainder of the document, references to "adverse effects" also refer to harm and harass under 50 CFR 17.3.

when instantaneous adverse effects occur, find the SEV level of 5 in the one hour column. The corresponding concentration is the instantaneous value where adverse affects occur. In this example, it is 148 mg/L. For (b), (c), and (d), adverse effects will occur when sediment concentrations exceed SEV 4 levels. The exact concentrations for this have been provided. For each category, find the SEV 4 levels and the corresponding concentration levels are the values used.

For impacts to individual bull trout, adverse effects would be anticipated in the following situations:

a. Any time sediment concentrations exceed 148 mg/L over background.
b. When sediment concentrations exceed 99 mg/L over background for more than one hour continuously.
c. When sediment concentrations exceed 40 mg/L over background for more than three hours cumulatively.
d. When sediment concentrations exceeded 20 mg/L over background for over seven hours cumulatively.

For habitat effects, use Figure 5 and the same procedure as above for individual bull trout. For example, adverse effects would be expected to occur in the following situations:

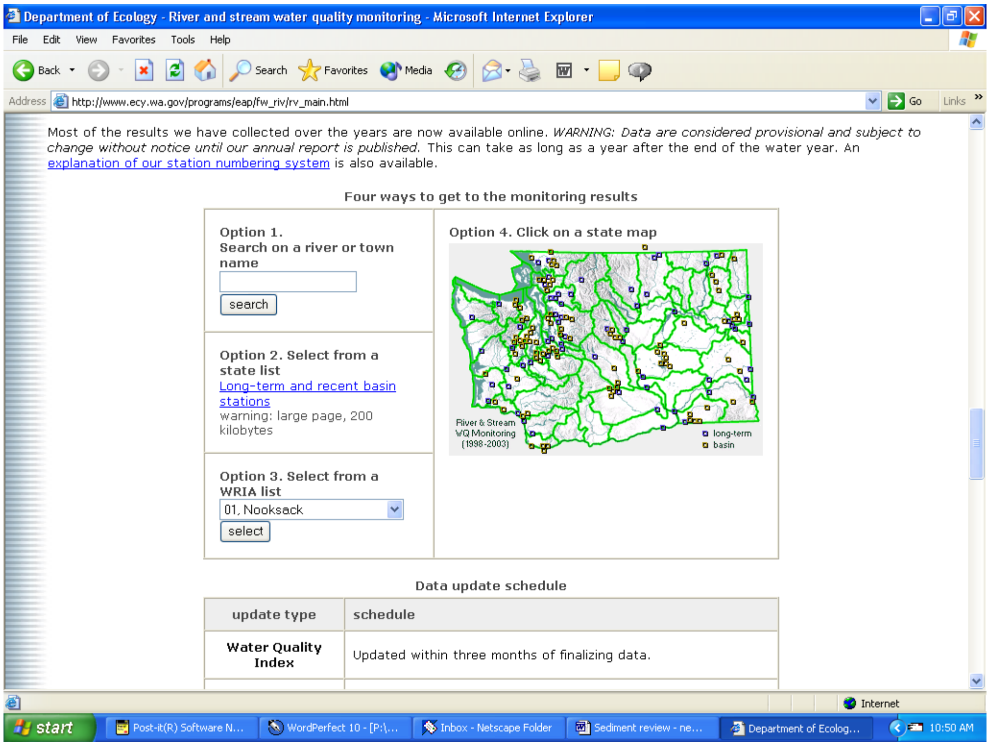
a. Any time sediment concentrations exceed 1,097 mg/L over background.
b. When sediment concentrations exceed 885 mg/L over background for more than one hour continuously.
c. When sediment concentrations exceed 345 mg/L over background for more than three hours cumulatively.
d. When sediment concentrations exceeded 167 mg/L over background for over seven hours cumulatively.

4) Because sediment sampling for concentration (mg/L) is labor intensive, many applicants prefer to monitor turbidity as a surrogate. To do this, the sediment concentration at which adverse effects to the species and/or habitat occurs is converted to NTUs. Two methods, regression analysis and turbidity to suspended solid ratio, are available for this conversion. The regression analysis method should be used first. If not enough data are available then the turbidity to suspended solid ratio method should be used.

   a. Data – as described above in Background and Environmental Baseline, an attempt should be made to find turbidity and suspended solid information from the project area, action area, or the stream in which the project is being constructed. This information may be available from the Tribes, watershed monitoring groups, etc. Try to obtain information for the months in-water construction will occur, which is usually during the fish timing window (in most cases, July through September). If you are unable to find any data for the action area, use the WDOE water quality monitoring data. The following are the steps you need to go through to locate the information on the web and how to download the data:

i. Go to the WDOE webpage (http://www.ecy.wa.gov/programs/eap/fw_riv/rv_main.html).

ii. When you get to the website, the page will state “River and Stream Water Quality Monitoring.” If you scroll down the page, you will see the following text and map.



http://www.ecy.wa.gov/programs/eap/fw_riv/rv_main.html

Most of the results we have collected over the years are now available online. *WARNING: Data are considered provisional and subject to change without notice until our annual report is published.* This can take as long as a year after the end of the water year. An explanation of our station numbering system is also available.

Four ways to get to the monitoring results

Option 1.
Search on a river or town name
search

Option 2. Select from a state list
Long-term and recent basin stations
warning: large page, 200 kilobytes

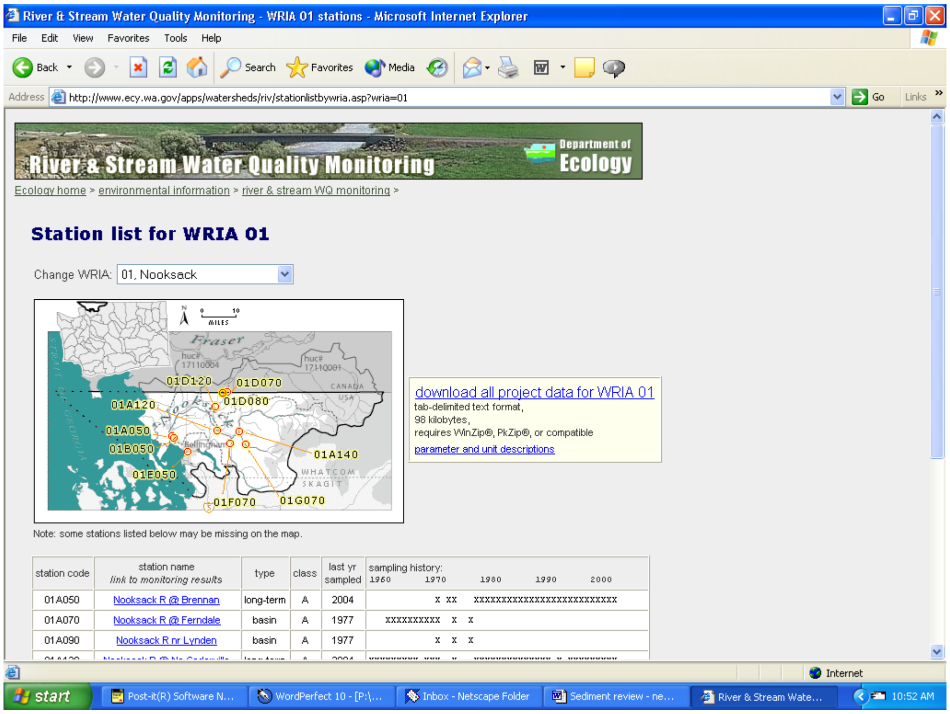
Option 3. Select from a WRIA list
01, Nooksack
select

Option 4. Click on a state map

Data update schedule

update type	schedule
Water Quality Index	Updated within three months of finalizing data.

iii. The map shows all the water quality monitoring stations in Washington. You can click on a watershed, or go to Option 3, click on the down arrow and find your watershed. You will then get the following webpage. This is an example for the Nooksack River.



Station list for WRIA 01

Change WRIA: 01, Nooksack

download all project data for WRIA 01
tab-delimited text format,
98 kilobytes,
requires WinZip®, PkZip®, or compatible
parameter and unit descriptions

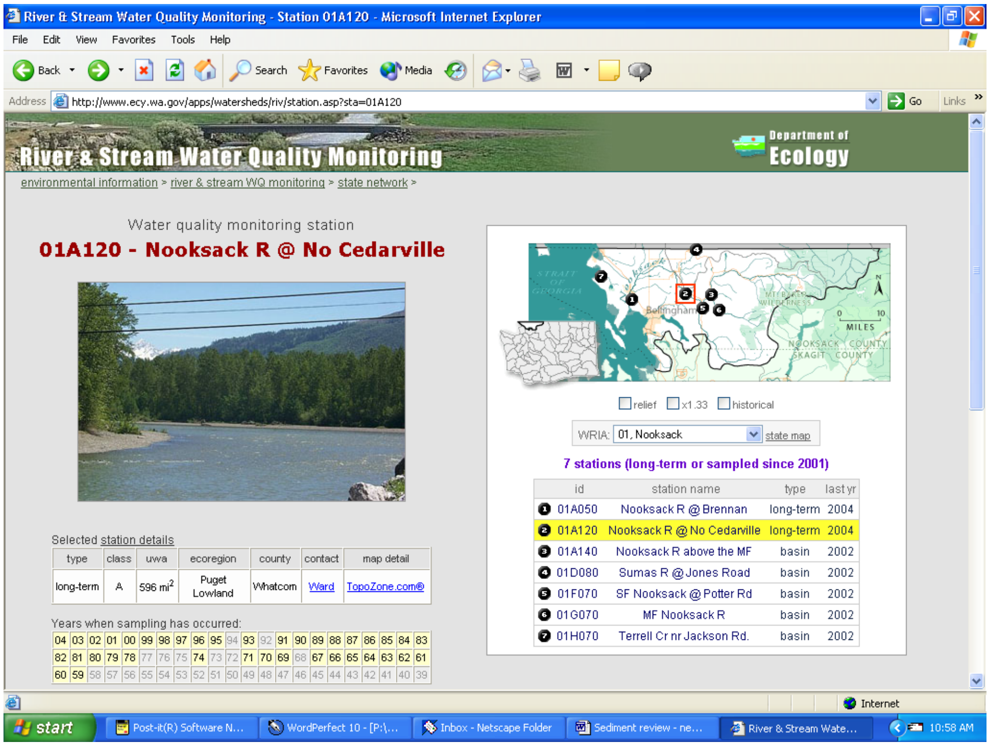
Note: some stations listed below may be missing on the map.

station code	station name *link to monitoring results*	type	class	last yr sampled	sampling history: 1960 1970 1980 1990 2000
01A050	Nooksack R @ Brennan	long-term	A	2004	x xx xxxxxxxxxxxxxxxxxxxxxxxxxx
01A070	Nooksack R @ Ferndale	basin	A	1977	xxxxxxxxxx x x
01A090	Nooksack R nr Lynden	basin	A	1977	x x x

iv. This webpage shows you all the monitoring stations in this watershed. Scrolling down a little on the webpage, you get a list of the monitoring stations and the years that data were collected. The more years in which data were collected the better; however, you want to pick the monitoring station closest to the project site. If a project is located on a tributary, do not use data from the main river in the watershed. Find a monitoring station on a tributary and use that data. **Justification for the use of the data needs to be made in the BO.** The following language was used in the Anthracite Creek Bridge Scour BO. Changes to this paragraph to represent regression analysis are not italicized.

"*The guidance of Newcombe and Jensen (1996) requires a measurement of the existing suspended sediment concentration levels (mg/L) and duration of time that sediment impacts would occur. The Service used data available on the Washington Department of Ecology (WDOE) website to determine a ratio of turbidity (NTU) to suspended solids (mg/L)*(website to find the correlation between turbidity and suspended solids) *in Anthracite Creek. No water quality data was available for Anthracite Creek, so the Service used water quality monitoring data from a different tributary within the Snohomish River watershed. Patterson Creek, which is a tributary to the Snoqualmie River, was used to determine the ratio of turbidity to suspended solids* (correlation between turbidity and suspended solids). *The Service believes that Patterson Creek would have very comparable water quality data as Anthracite Creek. The turbidity to suspended solid ratio for Patterson Creek is 1:2.4 during the proposed months of construction (July through September).*" Delete the last sentence for regression analysis or put in the equation used for analysis and the R^2.

v. When you select the monitoring station, the following webpage appears. This monitoring station is on the Nooksack River at North Cedarville.



http://www.ecy.wa.gov/apps/watersheds/riv/station.asp?sta=01A120

environmental information > river & stream WQ monitoring > state network >

Water quality monitoring station

01A120 - Nooksack R @ No Cedarville

Selected station details

type	class	uwa	ecoregion	county	contact	map detail
long-term	A	596 mi^2	Puget Lowland	Whatcom	Ward	TopoZone.com®

Years when sampling has occurred:

04	03	02	01	00	99	98	97	96	95	94	93	92	91	90	89	88	87	86	85	84	83
82	81	80	79	78	77	76	75	74	73	72	71	70	69	68	67	66	65	64	63	62	61
60	59	58	57	56	55	54	53	52	51	50	49	48	47	46	45	44	43	42	41	40	39

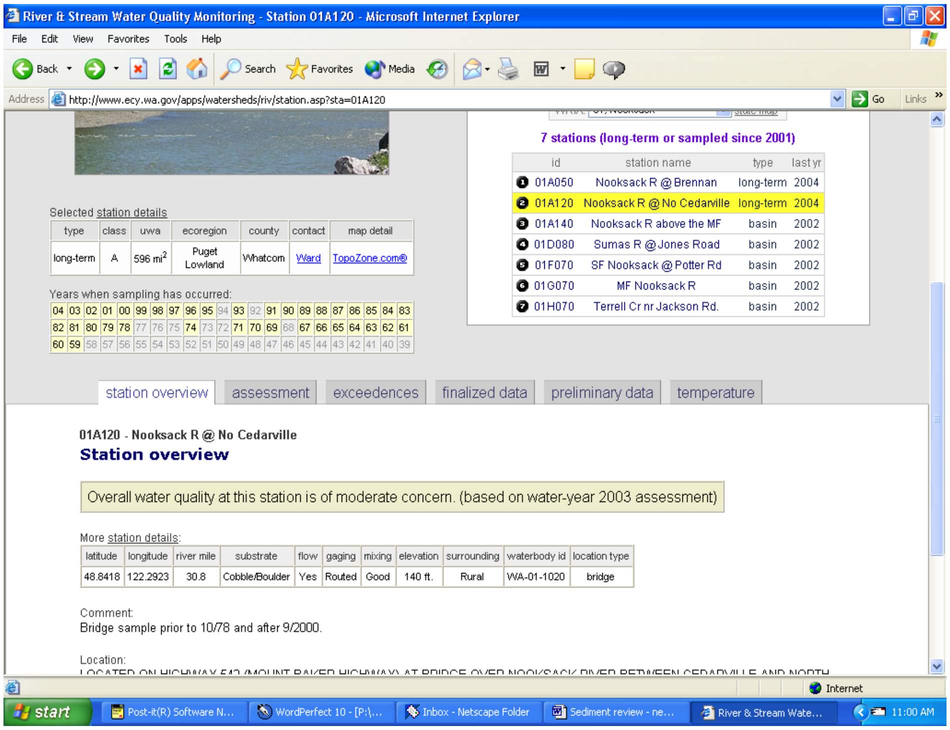
☐ relief ☐ x1.33 ☐ historical

WRIA: 01, Nooksack state map

7 stations (long-term or sampled since 2001)

	id	station name	type	last yr
❶	01A050	Nooksack R @ Brennan	long-term	2004
❷	01A120	Nooksack R @ No Cedarville	long-term	2004
❸	01A140	Nooksack R above the MF	basin	2002
❹	01D080	Sumas R @ Jones Road	basin	2002
❺	01F070	SF Nooksack @ Potter Rd	basin	2002
❻	01G070	MF Nooksack R	basin	2002
❼	01H070	Terrell Cr nr Jackson Rd.	basin	2002

vi. Moving down the webpage, you find the following. The page shows the years data were collected and 4 to 6 tabs that provide different information. Click on the finalized data tab.



River & Stream Water Quality Monitoring - Station 01A120 - Microsoft Internet Explorer

http://www.ecy.wa.gov/apps/watersheds/riv/station.asp?sta=01A120

7 stations (long-term or sampled since 2001)

	id	station name	type	last yr
❶	01A050	Nooksack R @ Brennan	long-term	2004
❷	01A120	Nooksack R @ No Cedarville	long-term	2004
❸	01A140	Nooksack R above the MF	basin	2002
❹	01D080	Sumas R @ Jones Road	basin	2002
❺	01F070	SF Nooksack @ Potter Rd	basin	2002
❻	01G070	MF Nooksack R	basin	2002
❼	01H070	Terrell Cr nr Jackson Rd.	basin	2002

Selected station details

type	class	uwa	ecoregion	county	contact	map detail
long-term	A	596 mi^2	Puget Lowland	Whatcom	Ward	TopoZone.com®

Years when sampling has occurred:

04	03	02	01	00	99	98	97	96	95	94	93	92	91	90	89	88	87	86	85	84	83
82	81	80	79	78	77	76	75	74	73	72	71	70	69	68	67	66	65	64	63	62	61
60	59	58	57	56	55	54	53	52	51	50	49	48	47	46	45	44	43	42	41	40	39

01A120 - Nooksack R @ No Cedarville

Station overview

Overall water quality at this station is of moderate concern. (based on water-year 2003 assessment)

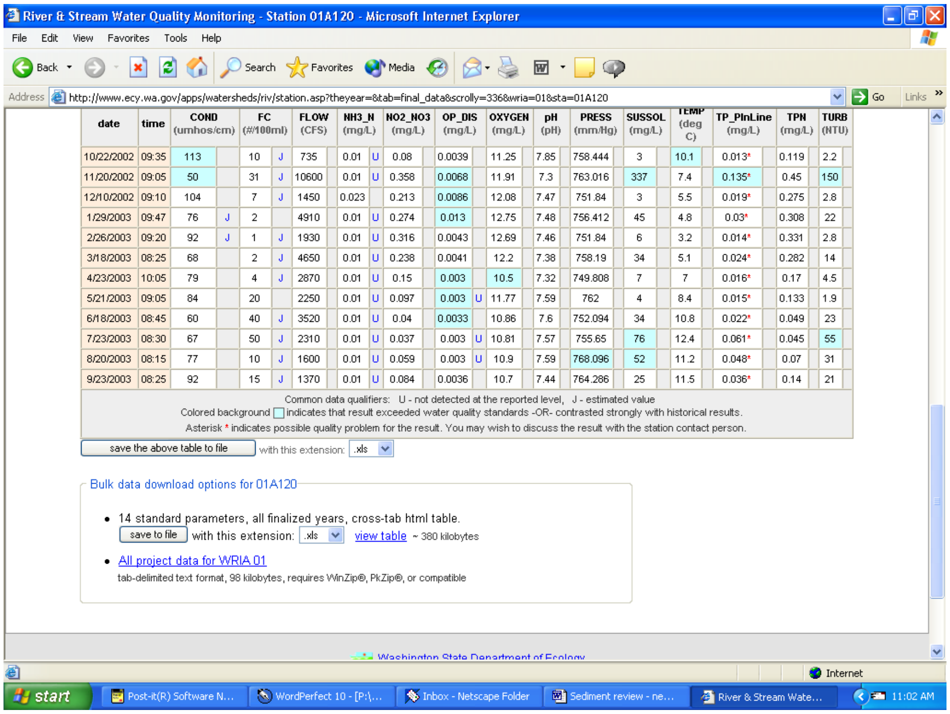
More station details:

latitude	longitude	river mile	substrate	flow	gaging	mixing	elevation	surrounding	waterbody id	location type
48.8418	122.2923	30.8	Cobble/Boulder	Yes	Routed	Good	140 ft.	Rural	WA-01-1020	bridge

Comment:
Bridge sample prior to 10/78 and after 9/2000.

Location:
LOCATED ON HIGHWAY 542 (MOUNT BAKER HIGHWAY) AT BRIDGE OVER NOOKSACK RIVER BETWEEN CEDARVILLE AND NORTH

vii. Selecting the finalized data, a new page comes up; scrolling down that page you see the following. The top part of the page shows the finalized data for the most recent year data were collected. Below the data is a box that says “Bulk data download options...” Click on the “save to file” button for the 14 standardized data parameters. Follow the instructions to save this file. This saves all the data from that monitoring station so the regression analysis can be conducted.



date	time	COND (umhos/cm)		FC (#/100ml)		FLOW (CFS)	NH3_N (mg/L)		NO2_NO3 (mg/L)	OP_DIS (mg/L)		OXYGEN (mg/L)	pH (pH)	PRESS (mm/Hg)	SUSSOL (mg/L)	TEMP (deg C)	TP_PlnLine (mg/L)	TPN (mg/L)	TURB (NTU)
10/22/2002	09:35	113		10	J	735	0.01	U	0.08	0.0039		11.25	7.85	758.444	3	10.1	0.013*	0.119	2.2
11/20/2002	09:05	50		31	J	10600	0.01	U	0.358	0.0068		11.91	7.3	763.016	337	7.4	0.135*	0.45	150
12/10/2002	09:10	104		7	J	1450	0.023		0.213	0.0086		12.08	7.47	751.84	3	5.5	0.019*	0.275	2.8
1/29/2003	09:47	76	J	2		4910	0.01	U	0.274	0.013		12.75	7.48	756.412	45	4.8	0.03*	0.308	22
2/26/2003	09:20	92	J	1	J	1930	0.01	U	0.316	0.0043		12.69	7.46	751.84	6	3.2	0.014*	0.331	2.8
3/18/2003	08:25	68		2	J	4650	0.01	U	0.238	0.0041		12.2	7.38	758.19	34	5.1	0.024*	0.282	14
4/23/2003	10:05	79		4	J	2870	0.01	U	0.15	0.003		10.5	7.32	749.808	7	7	0.016*	0.17	4.5
5/21/2003	09:05	84		20		2250	0.01	U	0.097	0.003	U	11.77	7.59	762	4	8.4	0.015*	0.133	1.9
6/18/2003	08:45	60		40	J	3520	0.01	U	0.04	0.0033		10.86	7.6	752.094	34	10.8	0.022*	0.049	23
7/23/2003	08:30	67		50	J	2310	0.01	U	0.037	0.003	U	10.81	7.57	755.65	76	12.4	0.061*	0.045	55
8/20/2003	08:15	77		10	J	1600	0.01	U	0.059	0.003	U	10.9	7.59	768.096	52	11.2	0.048*	0.07	31
9/23/2003	08:25	92		15	J	1370	0.01	U	0.084	0.0036		10.7	7.44	764.286	25	11.5	0.036*	0.14	21

Common data qualifiers: U - not detected at the reported level, J - estimated value
Colored background ☐ indicates that result exceeded water quality standards -OR- contrasted strongly with historical results.
Asterisk * indicates possible quality problem for the result. You may wish to discuss the result with the station contact person.

save the above table to file with this extension: .xls

Bulk data download options for 01A120

- 14 standard parameters, all finalized years, cross-tab html table.
  save to file with this extension: .xls view table ~ 380 kilobytes
- All project data for WRIA 01
  tab-delimited text format, 98 kilobytes, requires WinZip®, PkZip®, or compatible

viii. Open Excel and open the file that was just downloaded. Verify that all data appear to be available. After you have worked with these files, you will get an idea if something appears wrong. If the data looks like something is wrong, verify it by comparing the data to the finalized data on the webpage (look at each year's finalized data). After the file is open, delete all columns except the date, sussol (mg/L) and turb (NTU).

ix. Next delete the rows that do not need to be included. Only save the months in which the project will be constructed. For example, if work will be conducted during the work timing window of July 15 through August 31, delete all rows except those that contain data for July and August. The data consist of one data collection point each month. In addition, delete any values that have a "U" or "J" in the column to the right of the NTU value. This data may not be accurate; data may not be detectable at reported level or is an estimated value. The blue cells indicate the value exceeds water quality standards or contrasted strongly with historical results.

x. After deleting the unnecessary columns and rows, your data should contain 5 columns. You can now delete the columns to the right of the values. This will give you 3 columns. The first being the date, the second column contains the suspended solid data (mg/L) and the third column the turbidity (NTU) data.

b. Regression analysis. Once you have the data reduced to the months construction will occur, you can determine the relationship between turbidity and suspended solids using regression. The following steps will provide the regression equation using the data obtained above. These steps are for Excel 2007.

i. With your mouse, highlight both columns of data (suspended solid and turbidity), but do not include the heading information.

ii. Then click on “Insert”, “Scatter” and then the graph that does not have any lines on it (should be the upper left graph).

iii. The graph is placed on your Excel sheet, so move it over so you can see all the data and the graph.

iv. Now add the trendline to the graph. This is done by clicking (left button) once on any of the points on the graph. Then right click. A window pops open and click on “Add Trendline.” A “Format Trendline” window appears. Make sure Linear is checked, and down on the bottom, check Display Equation on chart and Display R-squared value on chart. Click on close.

    1. The X and Y data are opposite of what you want so you need to swap the values. This is done by left clicking once anywhere on the graph and then right click and click on “select data.” A window pops open and you want to click on Edit. An Edit Series window appears and you want to click on the little red arrow next to Series X values. This allows you to select the data in the table. Upon clicking the red arrow, you will see the column under sussol (mg/L) being selected by a moving line around the cells. Select the data under Turb (NTU) by left clicking and holding the button down and drag all the way down to the last cell in that column. The whole column should have the moving line around all the cells. Click on the little red arrow in the Edit Series window. That will expand out the window and you will do the same for the Series Y values. Click on the red arrow next to that, then left click and hold and select all the cells in the column under Sussol (mg/L), and then click on the red arrow again. When the Edit Series window expands, click on OK, and then click on OK.

v. The equation that you want to use for your conversion from NTUs to suspended solids is now on the graph. Hopefully, your R-squared value is also high. This gives you an indication of how well your data fits the line. A one (1) is perfect. If this number is low (and a ballpark figure is less than 0.60) then you may want to consider using the ratio method to determine your conversion from NTUs to suspended solids.

    1. Outliers – sometimes there will be data that will be far outside the norm. These values can be deleted and that will help increase your R-squared value. If you are good at statistics there are ways of

determining outliers. If not, you will probably just use the data as is, unless you think something is really not right, then you may want to delete those data points.

vi. Using the equation for the regression analysis, convert the sediment concentrations found for when adverse affects occur to bull trout and their habitat (number 3 above) to NTUs. For our example, let's say our NTU to suspended solid equation is: $y = 1.6632x - 0.5789$. Adverse effects would then occur at (solve for x):

For impacts to the species adverse effect would occur in the following situations:

a. Any time sediment concentrations exceed 89 NTU over background.
b. When sediment concentrations exceed 60 NTU over background for more than one hour continuously.
c. When sediment concentrations exceed 24 NTU over background for more than three hours cumulatively.
d. When sediment concentrations exceeded 12 NTU over background for over seven hours cumulatively.

For impacts to habitat

a. Any time sediment concentrations exceed 660 NTU over background.
b. When sediment concentrations exceed 532 NTU over background for more than one hour continuously.
c. When sediment concentrations exceed 208 NTU over background for more than three hours cumulatively.
d. When sediment concentrations exceeded 101 NTU over background for over seven hours cumulatively.

c. Turbidity:suspended solid ratio: To calculate the turbidity to suspended solid ratio you need to download the same data off the Ecology website as described above. Sometimes the monitoring stations have limited amount of data and by running the regression analysis it is possible to get a negative slope (an increase in turbidity results in a decrease in suspended solids). This is very unlikely to occur in a stream. Other times you have so few data points that the R^2 value shows that the correlation between suspended solid and turbidity is not very good. When R^2 values are below 0.60, determine the turbidity to suspended solid ratio. The following are the steps needed to calculate the turbidity to suspended solid ratio.

i. After you deleted all the columns and rows of data you do not need, you should have 3 columns of data. The first being the date, the second column contains the suspended solid data (mg/L) and the third column the turbidity (NTU) data.

ii. Calculate the average turbidity and suspended solid value for all data. Average the turbidity column and average the suspended solid column.

iii. Calculate the turbidity to suspended solid value for the average turbidity and average suspended solid value obtained in ii. Divide the average suspended solid value by the average turbidity value.

iv. If any outliers are identified, they should be deleted. Recalculate the turbidity:suspended solid ratio if outliers have been removed (should automatically be done when values are deleted).

vii. Using the turbidity to suspended solid ratio, convert the sediment concentrations found for when adverse effects occur to bull trout and their habitat (number 3 above) to NTUs. For our example, let's say our NTU to suspended solid ratio is 2.1. Adverse effects to the species would then occur in the following situations:

   a. Any time sediment concentrations exceed 70 NTU over background.
   b. When sediment concentrations exceed 47 NTU over background for more than one hour continuously.
   c. When sediment concentrations exceed 19 NTU over background for more than three hours cumulatively.
   d. When sediment concentrations exceeded 10 NTU over background for over seven hours cumulatively.

   Adverse effects to the species through habitat impacts would occur in the following situations:
   a. Any time sediment concentrations exceed 522 NTU over background.
   b. When sediment concentrations exceed 421 NTU over background for more than one hour continuously.
   c. When sediment concentrations exceed 164 NTU over background for more than three hours cumulatively.
   a. When sediment concentrations exceeded 80 NTU over background for over seven hours cumulatively.

5) Determine how far downstream adverse effects and take will occur. There is no easy answer for determining this. Table 4 provides some sediment monitoring data for a variety of projects. These data can be used to determine the downstream extent of sediment impacts for a project. Note that in Table 4 there is not a single downstream point that can always be used because sediment conveyance and mixing characteristics are different for each stream. **An explanation of how the distance downstream was determined needs to be included in each BO.**

Figure 1 – Severity of ill effect scores for juvenile and adult salmonids. The individual boxes provide the maximum concentration for that SEV. The concentration between 4 and 5 represents the threshold for harassment, and the concentration between 7 and 8 represents the threshold for harm.

Juvenile and Adult Salmonids
Average severity of ill effect scores

Concentration (mg/L)	Hours			Days			Weeks		Months		
	1	3	7	1	2	6	2	7	4	11	30
162755	10	11	11	12	12	13	14	14	-	-	-
59874	9	10	10	11	12	12	13	13	14	-	-
22026	8	9	10	10	11	11	12	13	13	14	-
8103	8	8	9	10	10	11	11	12	13	13	14
2981	$\boxed{5760}$ 7	8	8	9	9	10	11	11	12	12	13
1097	6	$\boxed{2335}$ 7	$\boxed{1164}$ 7	8	9	9	10	10	11	12	12
403	5	6	7	$\boxed{491}$ 7	8	9	9	10	10	11	12
148	5	5	6	7	$\boxed{214}$ 7	8	8	9	10	10	11
55	$\boxed{99}$ 4	5	5	6	6	$\boxed{95}$ 7	8	8	9	9	10
20	3	$\boxed{40}$ 4	$\boxed{20}$ 4	5	6	6	$\boxed{42}$ 7	8	8	9	9
7	3	3	4	$\boxed{8}$ 4	5	6	6	$\boxed{18}$ 7	$\boxed{8}$ 7	8	9
3	2	2	3	4	$\boxed{4}$ 4	5	5	6	7	$\boxed{4}$ 7	8
1	1	2	2	3	3	$\boxed{2}$ 4	5	5	6	7	$\boxed{2}$ 7

Figure 2 - Severity of ill effect scores for adult salmonids. The individual boxes provide the maximum concentration for that SEV. The concentration between 5 and 6 represents the threshold for harassment, and the concentration between 7 and 8 represents the threshold for harm.

Adult Salmonids
Average severity of ill effect scores

Concentration (mg/L)	1	3	7	1	2	6	2	7	4	11	30
	Hours			Days			Weeks		Months		
162755	11	11	12	12	13	13	14	14	-	-	-
59874	10	10	11	11	12	12	13	13	14	14	-
22026	9	10	10	11	11	12	12	13	13	14	14
8103	8	9	9	10	10	11	11	12	12	13	13
2981	8	8	9	9	10	10	11	11	12	12	13
	2190										
1097	7	8	8	8	9	9	10	10	11	11	12
		1095	642								
403	6	7	7	8	8	9	9	10	10	11	11
	156			331	175						
148	5	6	6	7	7	8	8	9	9	10	10
		78				94					
55	5	5	6	6	7	7	8	8	9	9	9
			46	24			50	27			
20	4	4	5	5	6	6	7	7	8	8	9
					12				14	8	
7	3	4	4	5	5	6	6	7	7	7	8
						7	4				4
3	2	3	3	4	4	5	5	6	6	7	7
								2	1		
1	2	2	3	3	4	4	5	5	5	6	6

Figure 3 - Severity of ill effect scores for juvenile salmonids. The individual boxes provide the maximum concentration for that SEV. The concentration between 4 and 5 represents the threshold for harassment, and the concentration between 7 and 8 represents the threshold for harm.

Juvenile Salmonids
Average severity of ill effect scores

Concentration (mg/L)											
162755	9	10	11	11	12	13	14	14	-	-	-
59874	9	9	10	11	11	12	13	14	14	-	-
22026	8	9	9	10	11	11	12	13	13	14	-
	13119										
8103	7	8	9	9	10	11	11	12	13	13	14
		4448									
2981	6	7	8	9	9	10	11	11	12	13	13
			1931								
1097	6	6	7	8	9	9	10	11	11	12	13
				687							
403	5	6	6	7	8	9	9	10	11	11	12
	197				254						
148	4	5	6	6	7	8	9	9	10	11	11
		67				96					
55	4	4	5	6	6	7	8	8	9	10	11
			29				36				
20	3	4	4	5	6	6	7	8	8	9	10
				10				13			
7	2	3	4	4	5	6	6	7	8	8	9
					4				5		
3	1	2	3	4	4	5	6	6	7	8	8
						1					
1	1	1	2	3	4	4	5	6	6	8	8
	1	3	7	1	2	6	2	7	4	11	30
	Hours			Days			Weeks		Months		

Figure 4 - Severity of ill effect scores for eggs and alevins of salmonids. The individual boxes provide the maximum concentration for that SEV. The concentration between 4 and 5 represents the threshold for both harassment and harm to eggs and alevins.

Eggs and Alevins of Salmonids
Average severity of ill effect scores

Concentration (mg/L)	Hours			Days			Weeks		Months		
	1	3	7	1	2	6	2	7	4	11	30
162755	7	9	10	11	12	13	14	-	-	-	-
59874	7	8	9	10	12	13	14	-	-	-	-
22026	7	8	9	10	11	12	13	-	-	-	-
8103	7	8	9	10	11	12	13	14	-	-	-
2981	6	7	8	10	11	12	13	14	-	-	-
1097	6	7	8	9	10	11	12	14	-	-	-
403	6	7	8	9	10	11	12	13	14	-	-
148	5	6	7	9	10	11	12	13	14	-	-
55	5	6	7	8	9	10	12	13	14	-	-
20	5	6	7	8	9	10	11	12	13	-	-
7	11 4	5	7	8	9	10	11	12	13	14	-
3	4	5	6	7	8	10	11	12	13	14	-
1	4	5	6	7	8	9	10	11	13	14	-

Figure 5 - Severity of ill effect scores for salmonid habitat. The individual boxes provide the maximum concentration for that SEV. The concentration between 6 and 7 represents the threshold for anticipating adverse effects to bull trout through habitat modifications.

Salmonid Habitat
Average severity of ill effect scores

Concentration (mg/L)	Hours			Days			Weeks		Months		
	1	3	7	1	2	6	2	7	4	11	30
162755	11	12	12	13	14	-	-	-	-	-	-
59874	10	11	12	12	13	14	-	-	-	-	-
22026	9	10	11	11	12	13	14	14	-	-	-
8103	8	9	10	11	11	12	13	14	14	-	-
2981	8	8	9	10	11	11	12	13	13	14	-
1097	7	7	8	9	10	10	11	12	13	13	14
403	885 6	7	7	8	9	10	10	11	12	12	13
148	5	345 6	167 6	7	8	9	9	10	11	12	12
55	4	5	6	68 6	7	8	9	9	10	11	11
20	3	4	5	5	29 6	7	8	8	9	10	11
7	2	3	4	5	5	12 6	7	7	8	9	10
3	2	2	3	4	5	5	5 6	7	8	8	9
1	1	1	2	3	4	4	5	2 6	7	7	8

Reference List

1. Anderson, P. G., B. R. Taylor, and G. C. Balch. 1996. Quantifying the effects of sediment release on fish and their habitats.Canadian Manuscript Report of Fisheries and Aquatic Sciences 2346.

2. Newcombe, C. P. and J. O. T. Jensen. 1996. Channel suspended sediment and fisheries: synthesis for quantitative assessment of risk and impact. North American Journal of Fisheries Management 16(4): 693-727.

3. Newcombe, C. P. 1994. Suspended sediment in aquatic ecosystems: ill effects as a function of concentration and duration of exposure.Victoria, British Columbia.

ESA Consultations:

While reviewing a project for sediment related impacts, there are a couple things to think about.

1. Time frame – how does sediment affect feeding, breeding, and sheltering. This is important when thinking about the likelihood of harm (significant impairment of essential behavior…) and/or harassment (significantly disrupt normal behavior…). During ESA consultations this must always be in the back of your mind.

2. Individual fish – Throughout this document, the term bull trout and their habitat are used. Please remember to think about risks to individual bull trout. The ESA is designed to protect individuals as well as populations, but effect determination and analysis or take are both about effects to individuals. For example, on page 4 of the Sediment Template (literature review), under Biological Effects of Sediment on bull trout, the last sentence in the first paragraph states "Specific effects of sediment on fish and their habitat can be put into three classes that include:" The document then defines lethal, sublethal, and behavioral effects. These effects can be to an individual or to multiple individuals within a reach.

3. Habitat – similarly, sediment input into a stream can alter habitat, and this can impact an individual bull trout as well as multiple bull trout within a reach. The preceding discussion addresses fish habitat in general and not necessarily critical habitat or PCE's. An attempt was made to clarify this in the document. It was not possible to relate sediment input to the critical habitat PCE's. The information needed to address sediment input and impacts to the PCEs can be found within the Sediment Template document.

				regression as stated in comments column.		
Culvert Removal or Removal and Replacement						
Siegel Creek Culvert Removal, Siegel Creek – Clark Fork River Watershed (Montana) Culvert removal Channel stabilization Bank reshaping	Lolo National Forest Bankfull width: 12 ft Average discharge: 2.8 CFS Slope: 6.7% Drainage area: 9,245 acres	Grab samples No distance Provided. Assume 150 ft.	Sediment load Ave: 0.07 tons/day Peak: 0.4 tons/day	9.4 (average)* 53.7 (peak)*	24 hrs* > 3 to 7 hrs*	5 5 at 3 hrs 5 at 7 hrs
		Automatic sampling - 150 ft downstream	Sediment load Ave: 0.04 tons/day Peak: 0.3 tons/day	5.4 (average)* 40.3 (peak)*	24 hrs* > 3 to 7 hrs*	4 4 at 3 hrs 5 at 7 hrs
Sheep Creek Culvert Replacement Sheep Creek – Selway River Watershed (Idaho) Culvert replacement	Bitterroot National Forest Discharge: 1.5-2.0 CFS baseflow Channel width: 5 feet Slope: 8.9% Rosgen B4 channel	Approximately 100 ft. Distance not given, stated right below work area where water was put back in stream.	Baseline 1.69 mg/L 4.5 mg/L – 25 min 7.5 mg/L – 2 min 7.5 mg/L – 30 min 34.37 mg/L – 30 min	11..8	1.5 hrs (building diversion dam and diverting stream)	3
			164.19 mg/L – 11 min	162.5	15 min (diversion failure)	4
			15,588.6 mg/L – 30 min 677 mg/L – 30 min 105.31 mg/L – 30 min 29.17 mg/L – 30 min 17.6 mg/L – 30 min 19.74 mg/L – 30 min	2,737.9 (average)	6.5 hrs (diversion removed and stream stabilizing, exact duration unknown, stopped monitoring before sediment conc. returned to background.	8
			15,588.6 mg/L – 30 min	15,586.9 (peak)	30 min (peak during diversion removal)	8

Quinault River Watershed (Washington) Road widening Culvert installation	1.7 miles upstream of Upper Quinault Bridge Discharge: 3,200 – 3,700 cfs Slope: 0.4%	provided. Road runs along Quinault River, so assume distance was less then 50 feet. Monitoring data is at confluence.	Below new culvert: 5.5 NTUs		limited to less than two hours.	
Sulpher Creek State Route 241 Yakima County Culvert replacement	Project located approximately 1.5 miles of I-82 on SR141, near airport. Slope 3.5%	100 and 200 ft	Data provided in NTUs	100 ft 137.1 36.8 77.6 436.3 94.6 118.7 200 ft 33.8 50.0 55.5 213.0 147.2 141.0	6 hr# 1 hr# 1 hr# 6 hr# 1 hr# 1 hr# 1 hr# 1 hr# 1 hr# 6 hr# 1 hr# 1 hr#	6 4 4 7 4 5 4 4 4 6 5 5
Everett Vicinity Bridge 2/5N Seismic Retrofit Snohomish River and unnamed side channel Removal of 2 culverts of an existing temporary access road	Culverts removed in side channel Project located at Highway 2 over Snohomish River. Slope: In tidally influenced section of Snohomish River Construction occurred during low tide and channel had very little water running.	Work conducted in side channel of Snohomish River, sample taken 10 ft below confluence with river	Reading of 825 NTUs found, no background on that day, background next day was 15.6 NTUs.	713.4	2.5 hrs	6

Culvert replacement stream dewatered during construction. Water quality monitoring data for other Judd Creek project said "another stream simulation culvert replacement"	Monitoring report did not state where project was located. Drainage area: 3,292 acres. Discharge: 2.2 cfs Slope: 1.5% - used lower reach		estimated from graph	18.5 500 11.3 41.4 72.7 16.3 1800 19 41.4 9.2	13 hrs 6 hrs 7 hrs 6 hrs 14 hrs 4 hrs 7 hrs 12 hrs	5 4 5 5 5 4 5 4
Judd Creek Vashon Island Culvert Replacement stream dewatered during construction.	Judd Creek enters in NW corner of Quartermaster Harbor of Vashon Island. Drainage area: 3,292 acres. Discharge: 2.2 cfs Slope: 2.0%	100, 500, 1600 ft.	Data provided in graph format (NTUs). All values were estimated from graph	100 ft 9.6 49.7 20.6 500 ft 12 20.9 22.2 1,600 ft 10 22.5 11	 3 hrs 4 hrs 5.5 hrs 1.5 hrs 6 hrs 3.5 hrs 1 hr 2.5 hrs 2	 3 5 4 3 4 4 3 4 3
Harris Creek Snoqualmie River Culvert Replacement	Harris Cr. located approx. 2 miles north of Carnation, WA. Project in upper reaches of creek. Drainage area: 8,626 acres. Slope: 3.9% Discharge: 1.3 cfs (King County data)	Not provided	Document stated all water quality criteria were met except for one exceedance, 24 NTUs above background.	48	1 hr#	4

River Project: 300 feet long, placing rock groins, LWD, and plantings	Drainage area: 685 sq. miles. Discharge: 1,892 cfs Slope: 0.3% Bankfull width: 210 ft.			28.4 27.5 16.1 22.8 35.7 42.4 20.0 600 ft. 33.6 38.5 31.6 17.7 24.5 20.4 1,200 ft 47.6	30 min. 1.5 hrs 30 min 30 min 1.5 hrs 30 min 1 hrs$^{\#}$ 2 hrs** 2 hrs** 3 hrs** 1 hrs# 30 min 30 min 1 hrs**	3 4 3 3 4 3 3 4 4 4 3 3 3 4
MP 9.2 Oil City Road Hoh River Riprap (170 ft) and LWD placement	No project location given, Oil City Road runs along the north bank of the lower Hoh River. Discharge: 2,541 cfs Drainage area: 253 sq. miles Slope: 0.3%	300 and 600 ft downstream	Monitoring data was only for LWD placement and not riprap installation Data provided in NTUs.	300 ft. 8.4 7.7 9.4 600 ft 7.5	10 min 10 min 10 min 20 min	2 1 2 2
SR 20 – debris jam Skagit River tributary	Project located at milepost 90 on SR20. No exact location, so used tributary just east of Concrete WA. Slope: 8.1%	Data stated sampling points located upstream and downstream of project area on the Skagit River. Two additional points located on two Skagit tributaries that are culverted under SR20.	Turbidity readings taken once a week in absence of any major rainfall and more frequently during a runoff producing rain event.	Met water quality standards.	Met water quality standards.	
Emergency Bank Protection Hoh River Rock placed in stream	No information on location of project. Work conducted in December.	Samples drawn 150 - 200 ft downstream of project.	Turbidity readings taken usually after large deposit of rock was placed in the river.	Met water quality standards. NTUs were provided for project, but levels were same as background.		

South Fork Stilliguamish River Reconstructed 1,000 ft of riverbank and stabilized the bank with rock vanes, logs, and rootwad structures.	Slope: 0.4%			12.5 98.1 120.7 3.3 miles 50.1 32.8	1 hr 1 hr 10.5 hrs 4 hrs 4.5 hrs**	3 4 6 5 5
Boulder Creek Bank Stabilization Montana	No project location was given. Unable to determine any stream characteristics information.	350 and 4,300 ft	Data estimated off of graph of monitoring data – in mg/L	350 ft 77.4 334.5 4,300 ft 13.25 155.6	3.5 hrs 12.5 hrs 3.5 hrs 12.25 hrs	5 7 4 6
Saxon Bank Stabilization Project South Fork Nooksack River Construct tree revetment and 3 rock vanes. Protecting 1,400 ft. of bank.	Project located at town of Saxon, WA. Slope: 0.7% Drainage area: 129 sq. miles Discharge: 748 cfs	300 ft	Summary of data provided in email which gave NTU levels when monitoring was above 5 NTU's, WA water quality standard.	43.0	4 hrs#	5
Lower Hutchinson Creek Project South Fork Nooksack River Installation of ELJs and levee setback	Project located at confluence of Hutchinson Creek and S.F. Nooksack River near Acme, WA. LEJs installed on S.F. Nooksack and Hutchinson Creek. S.F. Nooksack Slope: 0.7% Drainage area: 129 sq. miles Discharge: 748 cfs Hutchinson Creek Slope: 1.1%	300, 1200, 3000 ft.	Daily monitoring was provided in NTU's. Most work occurred either in dewatered section of Hutchinson Creek or outside wetted channel.	300 ft. 14 12	1 hr 0.5 hr	3 2

			couple readings of the	45.5	5.25	5
Installation of in-stream gravel nourishment and construction of 2 ELJs	Drainage area: 231 sq. miles Discharge 958 cfs Slope: 0.8%		day as background.	16.6	5.0	4
				63.5	11.25**	6
				74.6	10.5#	6
				112.3	2.75**	5
				27.0	7.75**	5
				9.0	9.5**	4
				87.1	11**	6
				118.4	8.5#	6
				600		
				11.1	3.25	4
				121.9	0.75	4
				28.8	11.75#	5
				31.3	9.5**	5
				35.7	9.0#	5
				9.9	5.0	4
				58.6	11.25**	6
				67.3	10.5#	6
				10.7	2.75**	3
				23.5	7.75**	5
				9.9	9.5**	4
				121.8	11**	6
				100.6	8.5#	6
				1200		
				22.4	4.75	4
				36.7	11.75#	5
				20.6	9**	5
				23.5	11.5#	5
				20.2	2.25**	4
				48.3	11.25**	5
				130.3	6.75#	6
				19.7	7.75**	5
				18.8	11.75#	5
				143.1	11**	6
				75.6	9.0#	6
				2500		
				11.4	4.75	4
				19.1	3.0	4
				13.4	10.0**	4
				26.9	9.5	5
				12.5	2.25**	3
				33.4	11.25**	5
				67.7	2.25#	5
				48.8	4.5	5
				20.9	7.75**	5
				12.7	9.5**	4
				104.1	11**	6
				63.4	10.0#	6

Thornton Creek 2 culvert removals, 2 bridge installations, channel reconstruction with habitat enhancement, boulder clusters, porous weirs, logjams, etc.	School, above 30th St. NE bridge. S.F. Thornton Creek Drainage area: 12.1 sq. miles Discharge: 8 cfs Slope: 0.3% Bankful: 8 ft		graph. Project site was dewatered, data collected during rewatering site.	600 ft 48.1 1660 ft 40.5	3 hrs 1.5 hrs	5 4
Bridge Construction and/or Repair						
SR 90 – Wilson Creek Bridge Widening Project Wilson Creek tributary to Yakima River	Project located on Wilson Creek at I-90 Bridge at Ellensburg WA. Slope: 0.6% Drainage area: 13 sq, miles	100 and 200 ft downstream		100 ft. 55.2 21.4 20.6 200 ft. 202.3 28.2 22.5	1 hr[#] 6 hrs 1 hr 2 hrs 4.5 hrs 1 hr	4 4 3 5 4 3
SR – 12 Black River Bridge Scour Protection Black River – Tributary to Chehalis River. Placement of riprap to protect bridge column, placement of filter blanket and streambed gravel, installation of temporary work platform.	Project located on Black River, approximately 2 miles SE of Oakville, WA Slope: 0.2% Drainage area: 144 sq. miles Discharge: 162 cfs	300, 500 and 600 ft	Data provided in NTUs.	300 ft 10.6 8.8 9.6 18.8 500 ft 12.0 8.1 19.1 600 ft 12.5 6.4 12.8	0.5 hr 5 hr 5 hr 1 hr# 4.5 hr 4.5 hr 1 hr# 2.5 hr 4.5 hr 1 hr#	2 4 4 3 4 4 3 3 3 3

Removal of railroad trestle	Discharge: 3,946 cfs Drainage area: 842 sq. miles Slope: 0.2%					
Humptulips River Bridge Scour Repair Humptulips River Project involved repair and augment riprap and placement of LWD	Project located on Humptulips River at US 101 Bridge. Slope 0.4% Drainage area: 276 sq. miles, 132 Sq. miles at project location Discharge: 1,340 cfs Bankfull at project location: 80-220 ft.	300 ft.	Measurements were recorded throughout the day, 5 to 7 times. Data provided in NTUs. Because time between monitoring sampling was anywhere from one to two hours during sediment generating activities, the peak turbidity values may not have been captured.	7.6 11.0	6.5 hrs** 7 hrs#	4 4
Humptulips River Bridge Scour Repair Humptulips River Project involved installation of rock barbs and LWD in stream.	Project located on Humptulips River at US 101 Bridge. Slope 0.4% Drainage area: 276 sq. miles, 132 Sq. miles at project location Discharge: 1,340 cfs Bankfull at project location: 80-220 ft.	300 ft.	Met water quality standards.			

Project involved installing a pipeline under the NF. Stillaguamish River	Drainage area: 262 sq miles Discharge: 1,896 cfs Slope: 0.3%		from lab analysis: SS = 2.3237*NTU + 3.6702 Equation provides higher total suspended solids then Ecology data.	338.9	20 hrs	7
				76.2	4 hrs	5
				145.3	12 hrs	6
				1070.5	29 hrs	8
				676.6	6 hrs	7
				132.0	9.5 hrs	6
				93.5	5 hrs	5
				600 ft		
				25.9	1 hr	3
				16.7	0.5 hr	3
				25.4	8.5 hrs	5
				13.0	3 hrs	4
				37.4	8.5 hrs	5
				73.0	21 hrs	6
				19.8	0.5 hr	3
				135.3	20.5 hrs	7
				23.7	0.5 hr	3
				59.8	1.5 hr	4
				50.7	9.5 hrs	5
				293.1	31.5 hrs	7
				41.7	5.5 hrs	5
				122.4	10 hrs	6
				12.7	9.5 hrs	4
				12.7	9 hrs	4
				2000 ft		
				12.6	3 hrs	4
				25.9	1.5 hrs	4
				14.1	4 hrs	4
				34.7	9 hrs	5
				45.3	2 hrs	4
				212.8	18 hrs	7
				25.3	5 hrs	4
				30.4	10.5 hrs	5
				18.2	4 hrs	4
				185.7	14.5 hrs	7
				22.8	7.5	5
				75.7	5.5 hrs	5
				75.4	9.5 hrs	6
				32.0	1.5 hrs	4
				22.9	1 hrs	3
				1 mile		
				20.5	1.5 hrs	4
				16.5	1.5 hrs	3
				45.5	2.5 hrs	4
				23.1	3.5 hrs	4
				394.6	0.5 hr	5
				232.4	17 hrs	7
				22.3	4.5 hrs	4
				46.6	5.5 hrs	5
				25.3	3.5 hrs	4
				123.2	9.5 hrs	6
				30.5	6.5 hrs	5
				22.9	3.5 hrs	4
				45.4	9 hrs	5

Project involved installing a pipeline under the Pilchuck River. Used open trench method.	Pilchuck on topo map. Located SW of Machias, WA. Slope: 0.4% Drainage area: 127 sq. miles Discharge: 744 cfs			1000 ft. 34.8	51 hrs	6
Williams Pipeline – Sumas Loop		Construction method:				
Smith Creek	Trib to mainstem Nooksack River by Lawrence WA Slope: 0.8%	Dam and pump	Met water quality standards.			
Saar Creek (two locations where crossed creeks)	Trib to Frasier River, creek enters Canada, located near Sumas, WA Slope: 0.6%	#1: Open cut #2: Dam and pump	Met water quality standards. Met water quality standards.			
Kenny Creek	Unable to locate creek	Open cut	Met water quality standards.			
Unnamed trib to Sumas River	Located 2 miles SE of Nooksack, WA. Slope: 2.3%	Dam and pump	Met water quality standards.			
Breakenridge Cr.	Trib to Sumas River, located 2 miles east of Nooksack, WA Slope: 1.9%	Dam and pump	Met water quality standards.			
Williams Pipeline – Mt. Vernon Loop		Construction method:				
Armstrong Creek	Trib to mainstem Stillaguamish at Arlington, WA Slope: 0.5%	Dam and pump	Met water quality standards.			
Trib to SF Stillaguamish River	Unable to locate creek	Dam and pump	Met water quality standards.			

			standards.			
Seidel Creek – had Siedel Creek on monitoring form	Trib to Bear Creek, 1.4 miles NE of Avondale, WA, which enters Sammamish River. Slope: 1.0%	Dam and pump	Met water quality standards.			
Struve Creek	Trib to Bear Creek, 1.1 miles SE of Cottage Lake, WA, which enters Sammamish River. Slope: 3.0%	Dam and pump	Met water quality standards.			
Williams Pipeline – Ft. Lewis Loop		Construction method:				
Muck Creek	Trib to the Nisqually River. Site located on Ft. Lewis, 2.7 miles W of Rocky Ridge.	Open cut	Met water quality standards.			
South Fork Creek	Trib to the Nisqually River. Site located on Ft. Lewis, 2.7 miles W of Rocky Ridge. Just South of Muck Creek crossing.	Open cut	Met water quality standards.			
Williams Pipeline Ft. Lewis Loop Nisqually River Project involved installing a pipeline under the Nisqually River Used open trench method.	Project located 0.8 miles SW if McKenna, WA Drainage area: 517 sq. miles Discharge: 1,500 cfs Slope: 0.1%	600, 1250, 2500, 5200 ft, 2 miles, and 4 miles	Samples taken approximately every hour. Samples at 2 miles was only taken once, two samples were taken at 4 miles (4.5 hours apart). These samples were used to determine downstream extent of plume. Data provided in NTUs.	600 ft. 35.1 1,250 ft. 24.4 2500 ft. 16.2 5200 ft. 12.8 2 miles 15.5 4 miles 9.5	22 hrs 22 hrs 22 hrs 22 hrs 4.5** Used 4 miles time 4.5**	6 5 5 5 4 4

Snohomish River Clamshell and hydraulic dredging were used on the Upper and Lower Sediment Basins and the Navigational Channel. Disposal location was at Elliott Bay for clamshell dredging and Port of Everett's Riverside Business Park Disposal Site for the hydraulic dredging.	Upstream settling basin is located southeast of the I-5 Bridge.	Clamshell dredging: samples taken at 600 ft. Three samples taken, surface (2 foot depth), mid, and bottom (2 feet above bottom). Hydraulic dredging: 300 ft for dredging activities – surface, mid and bottom readings, 600 ft for disposal activities. Samples taken twice daily, once during slack tide, once during strong ebb or flood tide. --------- Ebb tide sampling at 300, 600, 1500, 2250, and 2480 ft.		Additional samples taken during ebb tide, which exceeded background levels. Not enough information provided to determine concentration and duration. Hydraulic dredging All within water quality standards.	1 hr	4
Grays Harbor Dredging.	Exact location with Grays Harbor was not provided. Project was in tidal area	Samples taken at 300 and 600 feet from dredging operation. Samples taken at surface, midwater, and bottom.	Data provided in NTUs	Met water quality standards. Midwater and bottom samples highly variable. When samples were above water quality, resampling both background and at monitoring location, showed in compliance.		
Miscellaneous Activities						
Mount Vernon Wastewater Treatment Plant Outfall Project Skagit River Project involved extending the outfall from the river bank out into the thalwag of the river.	Project located in City of Mount Vernon. Drainage area: 3,093 sq. miles Discharege: 14,000 cfs Slope: 0.1%	Monitoring occurred 100 feet upstream of project and 300 feet downstream	Data provided in NTUs	Met water quality standards for sheet pile driving (cofferdam) and dewatering, no information provided on putting water back into site and removing sheet piles.		

River. Project involved removal of 10-year-old log stringer dam about 5 ft high.	White River, near Silver Springs Campground. Approximately 3.3 miles SE of Snoquera, WA on Highway 410. Drainage area: 8.0 sq. miles Slope: 8.4% Discharege: 8.3 cfs		was not dewatered, logs pulled out of stream and sediment released.	157.0 1118 ft. 55.2	0.75 0.75	5 4

* Values calculated from monitoring report. Concentration calculated using equation tons/day = 0.0027* cfs* mg/L (USACE (U.S. Army Corps of Engineers) 1995). Ba monitoring report stated sediment concentration levels decreased to near pre-removal levels in about 24 hours (used for average values), peak values based on 8 to 10 hou

** Exact duration is unknown as monitoring stopped when work day was over. Unable to determine when concentrations returned to baseline.

Exact duration is unknown as monitoring did not provide start or stop times to be able to make accurate determination.