Chapter 16
Research Related to Roads in USDA Experimental Forests

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Abstract Forest roads are essential in experimental forests and rangelands (EFRs) to allow researchers and the public access to research sites and for fire suppression, timber extraction, and fuel management. Sediment from roads can adversely impact watershed health. Since the 1930s, the design and management of forest roads has addressed both access issues and watershed health. Road design and management practices developed from research on roads in EFRs in the 1950s are applied throughout the USA and the world. Long-term data sets on watersheds with and without roads have helped us better understand the role of roads in runoff processes. Data collected from roads in EFRs have contributed to the development of hydrology and erosion models used throughout the world. As forest management and utilization practices change, such as gas abstraction, wind energy generation, and off-road vehicle recreation, research will be necessary to address the watershed impacts of roads and other access networks to support those new uses.

Keywords Forest roads · Erosion · Runoff · Watershed health · Forest access

16.1 Introduction

Our nation's forests provide many ecosystem services, including wood products (timber for construction and fuel); recreation (hiking, camping, fishing, and hunting); and gathering of wood, mushrooms, wild flowers, and other forest commodities. The public relies on a widespread road network in order to obtain these services. However, road networks can cause problems such as adverse impacts on water resources (erosion) and habitat fragmentation (Gucinski et al. 2001). Roads in experimental forests have played an important role in our understanding of these

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Fig. 16.1 Building a road in Deception Creek Experimental Forest in the 1930s. (From photo collection of R.T. Graham)

problems and in identifying management practices to minimize them. From the very beginning of experimental forests, roads have allowed managers and researchers access to research sites, aided in fire suppression, and allowed the public to view ongoing research projects (Fig. 16.1; Wellner and Foiles 1951). Through research that started in experimental forests (Patric 1977), roads are now recognized as a major source of sediment in forested watersheds, with sediment from roads exceeding that from any other source in the absence of wildfire (Elliot 2010). This chapter contains examples of research related to roads in experimental forests: (1) using roads to aid in forest management, (2) identifying roads as a sediment source in forests, (3) predicting the effects of roads on runoff, (4) evaluating the effects of reopening roads that have been closed, and (5) developing predictive models.

Road design in experimental forests often consisted of two categories of roads—climbing roads and contour roads (Hewlett and Douglass 1968). Evidence of this design approach is still apparent in many experimental forests, such as Priest River and Deception Creek in Idaho, although many of the contour roads are now closed and overgrown (Fig. 16.2).

16.2 Background

16.2.1 Using Roads to Aid in Forest Management

Historically, the public needed timber for construction and fuel, and access roads were necessary to extract these products from forests. Between 1920 and 1970, one of the common logging tools in the northern Rocky Mountain Forests was the Idaho jammer, a cable logging machine that was only able to reach logs within

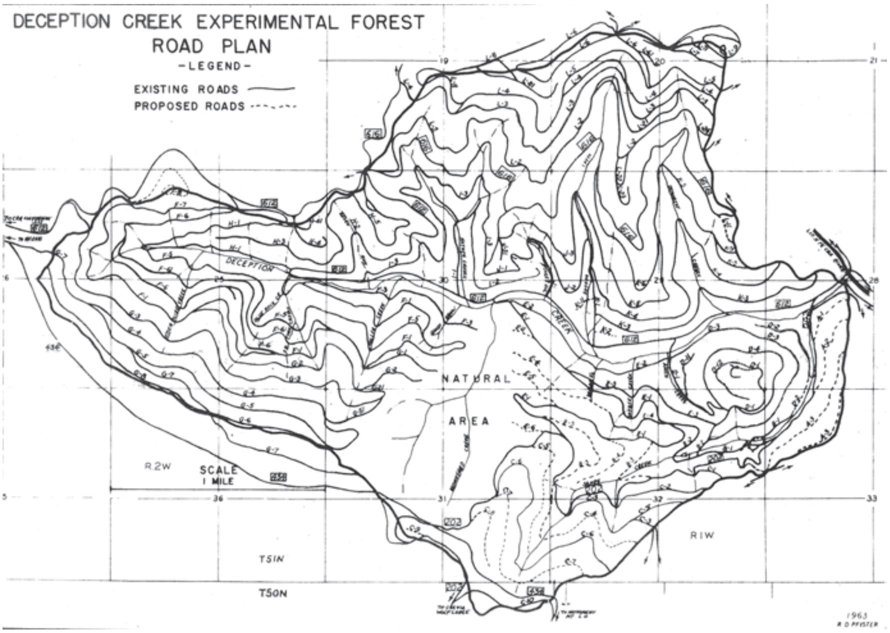

Fig. 16.2 High-density road network within the Deception Creek Experimental Forest drawn in 1963. Several of the proposed roads (*dotted lines*) were subsequently constructed to support forest management research. Note the unroaded research natural area that is still free from roads. (From R.T. Graham)

about 125 m of the road (Fig. 16.3; Stenzel et al. 1985). Yarder logging is necessary on slopes with greater than about 30 % steepness, which is typical in many US forests. The Deception Creek Experimental Forest in northern Idaho was a model of a steep forest where the road network was designed so that every tree in the forest was within 250 m of a road (Fig. 16.2). Many of these roads were originally built in the 1930s with the Civilian Conservation Corps program or with funds from timber sales (Wellner and Foiles 1951). Wellner and Foiles (1951) noted that "Development of an intensive utilization road system has been stressed on the Deception Creek Experimental Forest since its establishment." The dense road network (more than 6 km of road in a square kilometer of forest) allowed researchers to carefully select and remove specific trees and evaluate the long-term effects of intensive forest management. The road network was considered a model for the National Forest Systems to follow for forest management (R. Graham, pers. comm., Sept. 2009). Within a decade, however, other managers concluded that not all forests could sustain such a high road density. The climate and geology of many western forests resulted in unstable road segments that led to excessive road failures through mass wasting. Current road densities in this region are about 2.5 km of road in a square kilometer of forest (Elliot 2009).

Modern yarders can reach much further than 250 m, so there is no longer need for such a high road density. In the coming decades, many of the mid-slope roads in

Fig. 16.3 An "Idaho jammer" cable yarder at work in Deception Creek Experimental Forest, December 1935. (From photo collections of D. Ferguson and R.T. Graham)

the Deception Creek Experimental Forest will likely be removed (Fig. 16.2). Watershed researchers are now working with silviculturalists to plan a research project that will evaluate changes in watershed health associated with road removal (R.T. Graham pers. comm., Sept. 2009).

In the 1970s and 1980s, society began to place higher values on water quality and other environmental attributes. Research showed the adverse impacts of roads in watersheds, and the density of roads was considered one measurement of watershed health (Gucinski et al. 2001). In the 1990s, an interagency group carried out an assessment of natural resources in the Interior Columbia Basin (ICB) that included a basin-wide analysis of erosion risk. The assessment revealed that the road density in Deception Creek Experimental Forest far exceeded that of anywhere else in the basin (Quigley et al. 1996). Watershed health was an emerging concept, as was treating watersheds as complex ecosystems and considering multiple ecosystem services along with watershed function (Hascic and Wu 2006; Moryc 2009). The ICB analysis tools were programmed to link road density to watershed health, so it became apparent that the well-intentioned road network created in the 1930s had its drawbacks in the post-1990 era when managing forests for watershed health became as important as managing for timber production.

16.2.2 *Identifying Roads as Major Sources of Sediment*

As the ecosystem services from forests desired by the public have shifted from timber to other products, in particular clean water, researchers have begun to focus on the impacts of roads on water resources. Experimental forests, particularly those in the eastern USA, played an important role in identifying the role of roads in generating sediment in forested watersheds (Hursh 1935). Much of the research on roads in the eastern USA was carried out in experimental forests or watersheds, whereas road research in the western USA tended to be associated with public or commercial forest operations (Gucinski et al. 2001).

16.3 Road Research on EFRs

16.3.1 *Road Research on the Fernow Experimental Forest*

Forest products from the steep Appalachian Mountains were critical to the development of the USA. Unplanned and unmanaged trails were constructed throughout these steep forests to meet the needs of a growing US population. The trails were mainly from widespread horse logging in the late nineteenth and early twentieth centuries (Fig. 16.4). The trails resulted in scars on the landscape from soil compaction and erosion (Trimble and Weitzman 1953) and an increase in stream sedimentation (Weitzman 1952a). In the 1930s, forest road studies became an important focus of the research program on the Fernow Experimental Forest in West Virginia. Initially, this research concentrated on skid roads. Because horses were being replaced by mechanical skidding operations (Fig. 16.5) in the 1930s–1950s (Weitzman 1952a), there was a need to study the effects of mechanized skidding and to develop practices to reduce those impacts so that problems of the past erosion and watershed degradation would not be repeated. Given its infancy, initial skid road research on the Fernow was surprisingly sophisticated and broad. Studies focused on quantifying erosion losses from skid roads built to a variety of standards; practices to improve location and construction of skid roads; and time studies and economic analyses of skid road construction, maintenance, and use efficiencies.

These studies showed that preplanning the skid road system was the most important activity needed to reduce the length, cost, and adverse effects of skid roads on water resources. Preplanning skid road location reduced the per area lengths by an average of 37 % (and as much as 75 %) and reduced the area of skid roads by 40 % while maintaining average grades one-third lower than in areas without preplanning (Mitchell and Trimble 1959; Weitzman 1952b). Erosion and water quality impacts also were substantially less from well-planned and well-constructed skid roads. For example, during the first year following skidding, erosion from well-planned roads with grade limits of 10 % and water bars installed every 40 m (two chains) was only about half that of losses from skid roads without preplanning, i.e., with no

Fig. 16.4 Horse logging in the Appalachians. (Photo courtesy P. Edwards)

Fig. 16.5 Tractor skidders had much higher capacity than horse logging but caused increased watershed disturbance. (Potlatch Corporation: Historical Photographs © 1999)

location restrictions, grade control, or water control (Weitzman and Trimble 1952; Table 16.1). Roads constructed by loggers with no restrictions or water control requirements also resulted in stream turbidities that far exceeded those from better planned skid roads (Reinhart et al. 1963). Time studies showed the advantages of

Table 16.1 Soil erosion measured from skid roads built to four different standards on the Fernow Experimental Forest. (Weitzman and Trimble 1952)

Skid road characteristics	Length of skid road per 2-ha plot (m)	Erosion per 30 m of skid road (m^3)	Total soil moved per 2-ha plot (m^3)
Skid roads ≤10 % grade except for short distances; water bars installed after logging where needed	160	1.5	7.8
Skid roads ≤20 % grade except for short distances; water bars installed after logging at 40-m (two-chain) intervals	24	1.8	14.6
No restrictions on skid road location or grade (average grade was 28 %); water bars installed after logging but at no closer than 40-m (2-chain) intervals	425	2.0	27.6
No restrictions on skid road location or grade (average grade was 34 %); no water bars or other treatments applied after logging	725	2.6	61.3

maintaining gentle grades (5–15 %) on skid roads—skidding speeds were faster and costs of construction and operation were lower than on flat or steeper roads (Hutnik and Weitzman 1957). Economic analyses also showed that skid roads were far more cost-effective for removing both low- and high-value wood from stands than even low-grade, small truck roads (Trimble et al. 1963).

Results from these early studies formed a body of recommendations for skid road construction that are still applicable today and have been repeated with few alterations numerous times via publications and other technology transfer mechanisms throughout the tenure of research at the Fernow Experimental Forest (e.g., Kochenderfer and Helvey 1989; Patric 1977; Smithson and Phillips 1970; Trimble 1959; Trimble and Weitzman 1953). In brief, these recommendations include (Dunford and Weitzman 1955; Trimble and Weitzman 1953):

- Preplan the skid road system
- Avoid trouble spots
- Keep grades low
- Provide adequate and functioning drainage on the road during use
- Avoid stream crossings if possible and stay as far as possible from streams
- Limit earth disturbance
- Stabilize and maintain skid roads with vegetation, particularly the drainage, once the timber management activity is complete

Many of these recommendations can be found in the current regulations of many state agencies, although their source from research in eastern experimental forests is seldom cited (e.g., California Department of Forestry and Fire Protection and Resource Management 2011; Seyedbagheri 1996; West Virginia Division of Forestry 2005).

Table 16.2 The first set of recommendations (early 1950s) for skid road water bar spacings in the Appalachians developed at the Fernow Experimental Forest. (Weitzman 1952a; Trimble and Weitzman 1953)

Skid road grade (%)	Distance between water bars (m)
2	76
5	40
10	24
15	18
20	14
25	12
30	11
40	9

Fig. 16.6 Water bar constructed on a modern skid trail following guidelines developed in the Fernow Experimental Forest in the 1950s. (Source: http://www.muskingumtrees.com/waterbar.jpg)

Within these studies, early Fernow Experimental Forest researchers acknowledged the important role that water control and drainage played in maintaining usable road conditions and reducing erosion. Consequently, researchers employed erosion data to develop the first set of water bar spacing recommendations for the Appalachians (Table 16.2; Trimble and Weitzman 1953; Weitzman 1952a). These spacing recommendations, along with the recommendations for skid road location, construction, and maintenance practices, formed the foundation for what eventually became the base set of road-related best management practices (BMP) for many eastern states (Fig. 16.6). In fact, West Virginia used these original water bar spacings until a BMP revision in 2005 reduced and simplified the spacing requirements.

From the start of research on the Fernow, scientists recognized the importance of technology transfer and understood target audiences. While some findings were communicated in more research-oriented outlets (e.g., Reinhart et al. 1963; Trimble and Weitzman 1953), many other publications provided descriptive summaries and resulting recommendations for audiences whose interests were in on-the-ground applications. These audiences typically included loggers and foresters whose acceptance and implementation of the recommendations was needed to reduce the adverse impacts of roads on water quality and to improve environmental conditions.

Fig. 16.7 Logging road in the 1930s. Note the lack of an inside ditch and the eroding ruts on the road surface. (Potlatch Corporation: Historical Photographs © 1999)

It is likely that the foresight of the first Fernow researchers who simultaneously studied technical, economic, and environmental outcome-based research resulted in greater and faster acceptance of the recommendations than otherwise would have occurred. They were able to show that implementation of practices to protect soil and water resources were not incompatible with reducing costs and operation times.

As Fernow skid road research developed into a rich body of information, research on haul roads became more dominant (Fig. 16.7). The studies focused on how haul roads could be built more cost-effectively while still controlling erosional losses. Many of the groups and individuals who traditionally used Fernow research (e.g., foresters, consultants, loggers, and private and industrial landowners) expressed a need for methods to develop lower-cost truck road systems. This need translated into the concept of "minimum-standard roads." These are truck roads that are built to the lowest standard necessary to achieve the road use objectives while providing environmental protection (i.e., controlling runoff and erosion) at a reasonable cost (Kochenderfer et al. 1984). Characteristics of a minimum-standard road are:

- The road is constructed from a flagged centerline but has no engineered design or construction staking.
- Bulldozer operators must have experience in forest road construction and use nothing smaller than a 200-kw bulldozer for construction.
- Machine operators are paid by the hour and only one additional, experienced helper is required on the job.
- Right-of-way clearing is done with the bulldozer during road construction by pushing or pulling trees over and off of the road.
- Cutbanks are left vertical unless they are taller than 1.5 m or have a ditchline. In those cases, they are roughly sloped back or benched.
- Culverts are used to handle all live water (streams, springs, seeps, etc.), and where seeps and springs are present on the road system, ditches must be installed.
- Broad-based dips at 60-m spacings and natural grade breaks are used as the primary water control features on the road surface.
- Exposed soil should be seeded as soon as possible and practical to control erosion.

As with the skid trail practices, many of these road practices are still recommended or required by state agencies throughout the USA (e.g., California Department of Forestry and Fire Protection and Resource Management 2011; Seyedbagheri 1996; West Virginia Division of Forestry 2005).

Erosion losses from minimum-standard roads were shown to be comparable or even less than losses from higher-standard roads at many other places in the Appalachians as well as elsewhere throughout the country (Kochenderfer and Helvey 1987). Of course, substantially greater environmental protection and improved usability, especially during wet weather conditions or with heavy traffic, were shown to be possible by graveling roads with large, clean gravel. For example, sediment yields from the road surface were reduced from an average of 20 Mg ha^{-1} to less than 2.5 Mg ha^{-1} by graveling with 75-mm clean limestone gravel 150 mm deep. Clean gravel is preferred on roads because it is has higher bearing strength after compaction than graded aggregates (Kochenderfer and Helvey 1987) and does not include fines that can be washed into streams (Wooten et al. 1999). Unfortunately, graveling a road can double construction costs (Kochenderfer and Helvey 1987), which may be unacceptable, particularly to small private landowners. Consequently, recommendations to gravel only problem areas, such as the bottom of broad-based dips, soft spots, and stream crossings, were developed to provide a compromise that improved erosion protection at acceptable costs (Kochenderfer 1979).

A large body of results concerning erosion losses from skid roads and haul roads has been compiled from the research conducted over the past 60 years by Fernow scientists. However, a major shortcoming is that the results did not include sediment contributions to streams (Kochenderfer and Helvey 1987), which, in many cases, is the problem that most concerns forest managers because of state water quality regulations. Consequently, in 1999, researchers from the Fernow and several university cooperators initiated an 8-year study to quantify sediment delivery to streams, identify the sources of delivered sediment, and identify hillside variables that controlled the delivery in a watershed that underwent road construction. Beatty et al. (2004) describe the study which was recently completed, so detailed results will be forthcoming. In addition to quantifying sediment delivery, a number of adaptive management recommendations for haul road construction are expected from this report, which could greatly reduce sediment delivery in steep Appalachian watersheds.

Roads and their related adverse effects on water resources continue to remain societal concerns, and new challenges related to road design and management continue to develop. In the nation's efforts to become energy independent, there is increasing interest and pressure to extract oil and gas reserves from Federal, state, and private lands (Adams et al. 2011). One result of this goal was the installation of a natural gas well and pipeline on the Fernow Experimental Forest in 2008/2009. Development of renewable energy sources, particularly wind power, is also increasing in the central Appalachians. These new activities require construction of access roads and road-like corridors, including pipelines and electricity transmission lines. Consequently, Fernow scientists are expanding their research to study these new types of disturbances that often are built

Fig. 16.8 Horses deliver logs to a North Carolina landing in 1903. (Source: http://www.unc.edu/~whisnant/appal/Sylfal97.htm)

to much different standards or using different practices or techniques than are traditional on forest roads. Little is known about the impacts of such development, so it is expected that the results of these new studies will be as cutting edge as the initial Fernow skid road research was in the 1950s.

16.3.2 Road Research on the Coweeta Hydrologic Laboratory

The southern Appalachians experienced watershed problems similar to those in the north as southern urban areas required forest resources to support their growth. Instability of roads was soon recognized as an undesirable impact of timber abstraction. Road stabilization research at the Coweeta Hydrologic Laboratory has been part of the research program since the 1930s (Swift 1985, 1988). More recently, Swift (1984a, 1985) carried out a series of studies to evaluate road erosion during construction and the benefits of subsequent mitigation practices.

Swift (1988) reported efforts by Hursh (1935) in the 1930s to minimize road erosion through a number of mulching practices to reduce cut and fill slope erosion risks. Hursh was also credited with some of the first studies in using vegetation to stabilize banks. His approach to stabilization research was followed by both Federal and university researchers in subsequent decades. New research methods and mitigation materials may be evaluated (e.g., Grace et al. 1998), but the basic erosion problems identified in the 1930s have not changed.

Swift (1988) went on to describe that in the 1940s and 1950s, a series of logging demonstrations were developed that required the construction of additional roads and skid trails. Much of the skidding was initially done by horses (Fig. 16.8). Road erosion from these demonstrations became so severe that roads became impassable and had to be closed, cross ditched, and reseeded. Subsequent studies were carried out with roads that were constructed and managed to much higher standards, including incorporating broad-based dips that were first described as a "Coweeeta dip" (Hewlett and Douglass 1968) and later installed in the Fernow Experimental Forest (Kochenderfer et al. 1984).

In 1984, a study at Coweeta on cut and fill slopes found that soil losses were much higher before grass establishment (Swift 1984b). The erosion processes observed were more like mass failures rather than surface erosion. One of the drivers of cut and fill slope erosion was freezing and thawing in the winter months. Another observation from this study was that limiting runoff water from bare fill slopes led to much lower fill slope erosion rates. The study also demonstrated the benefit of adding gravel to the road surface, which resulted in an 80 % reduction in erosion. This finding has become a common figure used by watershed managers everywhere to support gravel surfacing as a way to reduce road impacts on watershed health (Swift 1984b).

Swift (1985) expanded his studies to address additional road design and management practices to reduce soil erosion. Swift highlighted the importance of both long-term transportation planning and improved road management practices such as gravel addition, storm water management, and low-impact stream crossings. One of the longer-lasting implications of Swift's work was that when he reported in his findings to the interagency Water Erosion Prediction Project (WEPP) in the late 1980s, the problem of road erosion was recognized to be sufficiently severe that it was specifically identified as requiring special consideration in the development of this technology (Foster and Lane 1987). WEPP currently has the capability for a road-specific submodel, although this option has yet to be developed. Forest Service researchers, however, built on Swift's influence with the WEPP model and have developed templates for and interface to the WEPP model for forest roads that are used by forest managers throughout the world (Elliot 2004; Elliot et al. 2010).

16.4 Impact of Roads

16.4.1 Evaluating the Impacts of Roads and Timber Harvest on Runoff

One of the ecosystem services affected by forest roads is water supply. The quantity, quality, and timing of water from forests are becoming increasingly critical as social demands for water increase (Dissmeyer 2000). Experimental forests play a critical role in providing researchers and managers with long-term data sets, including watershed monitoring data. Such data are critical as scientists and managers seek to understand long-term trends and short-term implications of management practices. However, the interpretation of long-term data may not always lead to the same conclusions. Such was the case when Jones and Grant (1996) studied 34 years of runoff data, including hundreds of runoff events, to determine the effect of roads and timber harvest on peak flows leaving watersheds from the H.J. Andrews Experimental Forest and some nearby gauged watersheds. The authors concluded that "forest harvesting has increased peak discharges by as much as 50 % in small basins, and 100 % in large basins over the past 50 years. These increases are attributable to

Fig. 16.9 Road in H. J. Andrews Experimental Forest rapidly eroding because of flow diversion. (Grant and Swanson 2007)

changes in both flow routing due to roads, and in water balance due to treatment effects and vegetation succession."

However, not all hydrologists agreed with the conclusions of Jones and Grant (1996). As the watershed data were available to the public, Thomas and Megahan (1998) reached a different conclusion from the same data set. They concluded that the greatest percentage increases occurred on the smallest watersheds and for the smallest floods, and it was difficult to draw any conclusions about the effects of timber management and roads on floods in larger watersheds and with larger flood events.

Jones and Grant (2001) acknowledged the controversial nature of this issue, and analyzed the data set a third time. This time, they concluded that the greatest effects were observed with small flood events. Those events generally occurred during the fall season when untreated forest watersheds generated lower flood flows than watersheds with roads and timber harvest. The return periods for the small events were less than 0.28 years. The important message from this study, as it relates to this chapter, is that long-term data from experimental forests have played and will continue to play an important role in addressing management issues in our forest and rangeland watersheds, whether the forests have roads or not.

16.4.2 Road Location and Sediment Production

More recent work on the H.J. Andrews Experimental Forest road networks has helped to determine the effect of road location on stream interception and sediment generation (Fig. 16.9; Grant and Swanson 2007). Grant and Swanson (2007) found that ridgetop and mid-slope roads tended to generate sediment, whereas toeslope roads tended to collect the sediment generated above. Stafford (2011) found that forest roads at higher elevations tended to generate less sediment in the Kings River Experimental Watersheds than in lower-elevation forests, and the author attributed those differences to more of the precipitation falling as snow in higher elevations.

16.4.3 Evaluating Effects of Reopening Closed Roads

Historically, society believed that wildfire in forests was considered unhealthy, and considerable resources were used for fire suppression. This culture changed in the 1980s when forest managers realized that the lack of fire was leading to a buildup of fuels (dead trees and understory shrubs), resulting in an increased risk of unusually severe wildfire (Agee 1993; Elliot et al. 2010). Reducing these fuel loads while minimizing watershed impacts has become a challenge for public land managers. Fuel management includes selective harvesting and prescribed underburning, requiring access every 10–40 years instead of 50–200 years between harvesting rotations. This means that access roads that had been opened up once in a century for timber harvest could now be opened up once in a decade for fuel management (Elliot et al. 2010). One question this raised was how might runoff and erosion be affected by reopening roads that had been closed.

An ideal site to answer this question was located in the Priest River Experimental Forest where a road was built in 1955 and 1956 and then closed to traffic so that vegetation became established on it. Traffic levels associated with the timber operations could be monitored and road access could be restricted during the study. In 2004, it was opened for a timber sale and had 48 loads of logs and associated traffic pass over it. This resulted in a road condition typical of a high-trafficked forest road. Following the operation, the erodibility of the reopened road was measured with a rainfall simulator (Fig. 16.10) and compared to a nearby road that was constructed in 1976, closed following construction, covered with vegetation, and never reopened (Foltz et al. 2009). Foltz et al. (2009) found that there was little difference in hydraulic conductivity between the newly opened and the closed road, but the newly opened road generated about ten times as much sediment as the closed road. The increase in sediment was attributed to the loss of vegetative cover.

16.4.4 Building Predictive Models for Road Erosion

Rainfall simulation as described in the previous section (Fig. 16.10) has been critical in the development of predictive tools, such as the WEPP model (Laflen et al. 1991; Foltz et al. 2011). Once a model is developed and the erodibility of the soils described in the input files, it is necessary to evaluate the accuracy of model predictions in order to validate the model. Roads in experimental forests can be important sites for such validation. Elliot and Foltz (2001) used data from Swift's (1984a, 1984b) Coweeta studies and Kochenderfer and Helvey's (1987) Fernow studies for such validation. They found that the WEPP:Road tool performed reasonably well in normal years but under-predicted in years with large storm events.

Fig. 16.10 Rainfall simulator (in background under canopy) and plot from previous run (in foreground) measuring changes in forest road soil erodibility when a closed road is reopened for fuel management activities in the Priest River Experimental Forest. (Photo by W. Elliot)

16.5 Future Road Challenges

Because of changing societal needs and changing forest management practices, many roads in experimental forests have been closed as they are no longer needed to reduce their adverse watershed impacts. Most experimental forests allow unregulated public access on the open roads. One of the emerging problems associated with public access is that all-terrain vehicle (ATV) riders may bypass barriers and use closed roads for recreational riding. ATV trails generally generate more sediment than forest roads (Meadows et al. 2008), and forest managers are challenged to develop strategies to minimize ATV impacts to experimental forests and watersheds. Other recreational activities such as fishing, hunting, and berry picking depend on road access. There is scope for research on developing new environmentally neutral road designs to suit these activities rather than relying on past designs that mainly support timber harvest.

Since the mid-1990s, many National Forests have been removing old roads. Data on the immediate and long-term watershed effect of road removal are sparse. Removing roads from experimental forest watersheds with long-term data from the past and a commitment to continue to monitor into the future may provide a better understanding of the short- and long-term costs and benefits of road removal.

Recent Forest Service road network management guidelines state that all roads are assumed to be closed unless declared open (R. Graham, pers. comm., Sept. 2009). This ruling may lead to restricted access to some areas of these forests and, if the roads are not maintained, may lead to delayed response to wildfire, putting long-term vegetation research plots at risk. Experimental forests, however, still have the authority to build or replace roads, whereas the National Forest System does not. This means that there is a greater potential for scientists to carry out road-related research in experimental forests than elsewhere.

16.6 Summary and Implications for the Future

Forest road access is essential to gain many ecosystem services from our nation's forests. Experimental forests have played a critical role in evaluating the impacts of roads on watershed health. In all cases, the ability to access sites with long-term historical records coupled with onsite support for research activities have resulted in experimental forests playing a key role in our ongoing understanding of the interactions between roads and watersheds. Examples were given where changes in forest management and use have meant that new research on roads or related access was needed to support such management. Management guidelines developed from the results of these studies are now prominent in BMPs for roads used throughout the world. The past 80 years of road research in experimental forests have shown that it is important to maintain our network in experimental forests to support future research on the role of roads and on the impacts of the access network on watershed health and other forest attributes.

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