National Level Assessment of Water Quality Impairments Related to Forest Roads and Their Prevention by Best Management Practices

Final Report

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ATV	All-terrain Vehicle
BMP	Best Management Practices
CAL FIRE	California Department of Forestry and Fire Protection
CSBOF	California State Board of Forestry
CSES	Critical Site Erosion Study
CWA	Clean Water Act (Federal Water Pollution Control Act Amendments of 1972, PL 92-500)
CWE	Cumulative Watershed Effects
CSBOF	California State Board of Forestry and Fire Protection
BLM	Bureau of Land Management
DAT	Days After Treatment
DEC	Department of Environmental Conservation
DOF	Department of Forestry
EDC	Environmental Defense Center
ESA	Endangered Species Act
FORPRIEM	Forest Practice Rule Implementation and Effectiveness Monitoring
FPA	Forest Practices Act
FPGs	Forest Practice Guidelines
FPR	Forest Practices Regulations
FPWQ	Forest Practices Water Quality audit
FRTA	National Forest Roads and Trails Act of 1964
ICBEMP	Interior Columbia Basin Ecosystem Management Project
MCR	Modified Compliance Report
MDC	Maine Department of Conservation
MFS	Maine Forest Service
MOA	Memorandum of Agreement
NAASF	Northeastern Area Association of State Foresters
NCASI	National Center for Air and Stream Improvement
NCDFR	North Carolina Division of Forest Resources
NFS	National Forest System

NIPF	Non-industrial private forest
NMFS	National Marine Fisheries Service
GAO	Government Accountability Office
GFC	Georgia Forestry Commission
GIS	Geographic Information System
HA	Hectare (1,000 square meters)
HCP	Habitat Conservation Plan
HMP	Hillslope Monitoring Program
IMMP	Interagency Mitigation Monitoring Program
JTU	Jackson Turbidity Unit
LA	Load Allocation
LW	Large Wood
MS4	municipal separate storm sewer systems
NAASF	Northeastern Area Association of State Foresters
NAD	National Assessment Database
NFC	North Fork Caspar Creek Gauging Station
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPS	nonpoint source pollution
NTU	Nephelometric Turbidity Units
NWQI	National Water Quality Inventory
ODF	Oregon Department of Forestry
ODFW	Oregon Department of Fish and Wildlife
OHV	Off-highway Vehicle
PNW	Pacific Northwest
QAPP	Quality Assurance Project Plan
SABS	Suspended and Bedded Sediments
SFI	Sustainable Forestry Initiative
SFRA	Sustainable Forest Resources Act
SHA	Stream Habitat Assessment
SGSF	Southern Group of State Foresters

SMA	Streamside Management Area
SYP	Sustained Yield Plan
TFW	Timber/Fish/Wildlife program
TIFS	Texas Intensive Forestry Study
TH/FM	Timber Harvesting and Forest Management Guidelines
THP	Timber Harvest Plans
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids
USFS	Unites States Forest Service
USEPA	Unites States Environmental Protection Agency
USLE	Universal Soil Loss Equation
VA DOF	Virginia Department of Forestry
WLA	Wasteload Allocation
WATERS	Watershed Assessment, Tracking & Environmental Results

1. BACKGROUND AND INTRODUCTION

Most of the measures to protect water quality in the United States owe their origin to the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500), which became known as the Clean Water Act (CWA) (ee U.S.C. §1251 et seq. CWA section 301(a) generally prohibits the discharge of a pollutant from a point source to navigable waters unless in compliance with a National Pollutant Discharge Elimination System (NPDES) permit. The NPDES program requires permits for the discharge of pollutants from any point source into waters of the United States. Section 502(14) of the CWA defines point sources as “any discernible, confined, and discrete conveyance,” and includes, among other things, any pipe, ditch, channel, tunnel, or conduit from which pollutants are discharged. It follows that any source that is not a point source is a nonpoint source, although nonpoint source (NPS) pollution is not specifically defined in the CWA. This lack of definition has resulted in some confusion. For example, storm water runoff from construction sites, industrial facilities, certain municipal areas, and concentrated animal feeding operations are point sources. However, diffuse sources such as agricultural storm water runoff and irrigated agriculture return flows are specifically excluded from the definition of point source. Generally, a NPS is diffuse runoff caused, for example, by rainfall or snowmelt moving over the ground carrying pollutants into waterbodies. Atmospheric deposition and hydrologic modification are also generally considered NPS pollution.

Silvicultural operators are specifically categorized in 40 C.F.R. section 122.27(b) either as as point or nonpoint sources. Silvicultural point sources include any discernible, confined and discrete conveyance related to rock crushing, gravel washing, log sorting, or log storage facilities which are operated in connection with silvicultural activities and from which pollutants are discharged into waters of the United States. Silvicultural point sources are subject to the NPDES permit program. NPS silvicultural activities include nursery operations, site preparation, reforestation and subsequent cultural treatment, thinning, prescribed burning, pest and fire control, harvesting operations, surface drainage, or road construction and maintenance from which there is natural runoff[1]. Oversight of NPS pollution has been delegated to the states primarily through Sections 208 and 319 of the CWA. Section 208 of the CWA requires all states to identify nonpoint sources of pollution, their cumulative effects, and methods of controlling them 933. U.S.C. 208(b)(2)(F). Silviculture was one of the nonpoint sources specifically mentioned in the Act. Sediment is the primary pollutant from forestry[2] activities and forestry-related sediment is a leading source of water quality impairment to rivers and streams nationwide (USEPA, 2000 and 2002). Roads are the primary source of sediment from forest management activities in the western United States (Megahan and Ketcheson, 1996), the southern states (Prud’homme and Greis, 2002), the Midwest and the Northeast (NCASI, 2007). The dominance of road-related erosion over erosion from other forestry activities has been noted in studies since at least 1954 (Anderson, 1954).

In 1975, USEPA developed regulations to guide the states in implementing Section 208 by establishing non-regulatory nonpoint source pollution programs. States were required to develop Best Management Practices (BMPs) for the major land uses, as well as an implementation schedule. BMPs are structural and nonstructural measures used to reduce nonpoint source pollution to receiving waters (See 40 C.F.R. section 130.2(m). Forest Practice Regulations (FPRs) may be part of some state’s efforts to satisfy the requirements of Section 208 and specify the BMPs necessary to control the water quality effects of forest roads (Rice, 1992). Every state with significant silvicultural activities has some type of program (Ice et al., 1997), but they vary widely across the country due to regional, geographic, and cultural differences. Consequently, states have developed regulatory programs which require permits or mandatory BMPs; nonregulatory programs with voluntary BMPs; nonregulatory programs with enforcement where BMP use is voluntary but severe violations may lead to fines or citations; and a combination of programs that mix aspects of regulatory and nonregulatory programs. Repeated assessments have shown that compliance with state BMPs and FPRs prevents major

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[1] However, some of these activities (such as stream crossing for roads) may involve point source discharges of dredged or fill material which may require a CWA section 404 (a regulatory program for the disposal of dredged or fill materials in the waters and wetlands) permit.

[2] In this report, “silviculture” and “forestry” are used interchangeably, despite the subtle differences among the definitions of these terms.

water quality impacts under most circumstances (Ethridge and Heffernan, 2000; NCASI, 2001). However, detrimental impacts from forest roads have been documented in many water bodies and the extent of such impacts can be large (Williams, 1999).

The control of nonpoint source pollution under the CWA has been controversial. The Act originally envisioned that nonpoint sources of pollution would be dealt with at the state and local level through area waste management plans mandated by Section 208. This section requires states to engage in a planning process that, among other things, identified and controlled nonpoint sources of pollution. This planning process was not sufficient to address nonpoint source pollution (BLM, 2005).

Recognizing the continuing problem of nonpoint source pollution, Congress added Section 319 to the CWA through the 1987 amendments (33.U.S.C. section 1329). This section specifically addresses the creation of nonpoint source management programs through a three-stage process: 1) states develop nonpoint source assessment reports; 2) states adopt nonpoint source management programs; and 3) states phase in the programs with the assistance of Federal funds. States are to identify waters not attaining water quality standards without additional nonpoint source controls, identify BMPs for categories of nonpoint source problems, and develop programs to implement the BMPs. Federal grants are made available to develop and implement these measures. This nonpoint source management program is intended to operate voluntarily through financial incentives from the federal government. The voluntary approach to nonpoint source water pollution reflects Congress’s reluctance to encroach upon traditional state and local prerogatives to control land use decisions (BLM, 2005).

Although there is general consensus that Section 319 has brought about some positive steps, there is also criticism that it has not comprehensively addressed nonpoint source pollution problems (BLM, 2005). In 1988, USEPA indicated that NPS pollution had become the dominant fraction of the Nation’s remaining surface water pollution problem (EPA, 1988). Another section of the CWA, 305(b), requires the states to describe the quality of their surface waters including the extent to which water quality standards are being met; USEPA then summarizes these assessments and reports the results to Congress. Fourteen such reports have been published since 1975; the most recent National Water Quality Inventory reports[3] were published in 2000 and 2002. The 2000 report listed a number of nonpoint sources – agriculture, hydrologic modification, habitat modification, urban runoff, and silviculture - as leading sources of river and stream impairment. Silviculture was the 5th ranked source, responsible for impairment of 28,156 river miles. The 2002 report lists silviculture as the 9th leading source, responsible of impairment of 18,463 miles[4]. Significantly, USEPA noted in the 2002 report that:

> "…it is important to note that the information about specific sources and causes of impairment is incomplete. States do not always report the pollutant or source of pollutants affecting every impaired river and stream."

In 1999, USEPA provided Congress with a list of 1,040 waterbodies identified as impaired by silviculture in states without authority to regulate forest activities. This list and the National Water Quality Inventory reports were criticized by the Society of American Foresters (Ice, 2000), which contended that silviculture was a minor contributor to nonpoint source pollution nationwide. They cited numerous inconsistencies and discrepancies between data sources, pointing out that 48% of the listed waterbodies did not appear on the most recent 303(d) lists, and that an additional 37% were listed on the basis of sparse or unreliable data. In general, their critique of the list of waterbodies impaired by forestry operations pointed out the shortcomings and difficulties of assessing water quality progress using 305(b) and 303(d) lists.

In 1999, USEPA also issued the Phase II NPDES rule for stormwater dischargers. 64 Fed. Reg. 68,722 (Dec. 9, 1999) (codified at 40 C.F.R. pts. 9, 122, 123, and 124). This rule did not contain any provisions to require permits for forest roads. This rule was challenged in the Fifth, Ninth, and D.C. Circuit Courts in three separate actions ultimately consolidated before the Ninth Circuit Court. In the suit filed by the Environmental Defense Center (EDC), in cooperation with the Natural Resources

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[3] The 2000 and 2002 National Water Quality Inventory reports are discussed further in Section 2.4.

[4] Overall, more river miles were assessed in 2002; however, three states (including Washington) were not included in this latest round of reporting.

Defense Council, plaintiffs asserted that the regulations failed to meet minimum Clean Water Act statutory requirements because, among other reasons, they neglected to address stormwater runoff associated with forest roads and other significant sources of runoff pollution. EDC v. USEPA 344 F.3d 832.859 (9th Cir. 2003). In September 2003, the Ninth Circuit Court of Appeals remanded the forest road issue to the Agency. The court asked USEPA "to consider, in an appropriate proceeding, the petitioners contention that Section 402(p)(6) requires USEPA to regulate forest roads." Id. at 879.

USEPA needs a better understanding of water quality impacts associated with forest roads and the effectiveness of state programs to address these impacts. Specifically, additional research is needed to assess: (1) the extent to which runoff from forest roads has degraded water quality and aquatic habitat, and (2) the effectiveness and state of technology of state BMP programs for forestry operations to prevent water quality degradation.

At the request of USEPA, Great Lakes Environmental Center (GLEC) conducted a literature review and evaluated data to explore whether, why, and how forest roads impact water quality and the effectiveness of BMPs in preventing these impacts. The analysis was based on GLEC's review of documents provided by USEPA and a limited survey of on-line literature. This report concisely answers the following questions, based on the literature searches and evaluation of available data.

What is the nature and extent of water quality impairments due to forest roads across the country?

How are the water quality impacts from forest roads quantified and documented?

What total maximum daily loads (TMDLs) have been developed for sediment associated with forest roads?

What are the state programs that address forest roads?

Are forest roads defined differently among states?

Are voluntary or regulatory BMP programs effective?

What are the circumstances producing effective BMP implementation?

How often do states revise their BMPs?

Do existing BMPs include the most technologically up-to-date and useful practices available?

What processes are used to address and correct failing BMPs?

Are compliance and effectiveness monitoring of BMP programs actually capturing the success of these programs in addressing forest road runoff?

How representative are the results of BMP monitoring?

What are the types of BMPs and how are they maintained?

How well do Forest Road BMPs work?

What are the costs of installing and maintaining these BMPs?

What are recent promising innovations in forest road BMPs?

How can failing BMPs be improved?

The report is organized around several basic issues, which are divided into three sections, as follows:

- Section 2 describes and quantifies the impacts of forest roads on water quality and aquatic resources.
- Section 3 describes the forest road BMPs, their effectiveness and costs.
- Section 4 inventories and discusses state BMP programs for forest roads.

2. WATER QUALITY IMPACTS OF FOREST ROADS

Forests cover about 1/3 of the continental United States (Figure 2-1). Most of the headwaters of major rivers and streams arise in forested catchments (NCASI, 1994), and 80% of the nation's scarce freshwater resources originate in these forests (USFS, 2000). Various assessments show that the quality of surface water draining forested watersheds is generally among the highest in the country (NCASI, 1994). Natural geologic erosion is quite low from most forested lands. Although forests typically occur on the steepest portions of the landscape, the annual sediment yields from forested lands are lower than any other rural land use (Swank et al., 1989; Gianessi et al., 1986). Unit area loads (also called export coefficients) are routinely used to develop estimates of pollutant loads in a watershed. An export coefficient is a value expressing pollutant generation per unit area and time for a specific land use (Novotny and Olem, 1994). The use of unit area loading or export coefficients has been used extensively in estimating loading contributions from different land uses (Beaulac and Reckhow, 1982; Uttormark et al., 1974). The concept is straightforward; different land use areas contribute different loads to receiving waters. By summing the amount of pollutant exported per unit area of land use in the watershed, the total pollutant load to the receiving system can be calculated. Export coefficients for undisturbed forest lands are typically the smallest of all land uses. This is the case for sediment as well as nutrients (nitrogen and phosphorus). Thus, the quality of surface waters in forests should be excellent and in most forested watersheds the water quality usually is (Rummer et al., 1997), assuming that the integrity of the watershed and its functions are maintained.

The high quality of water supplies from forests is widely recognized as a valuable resource. In 2000, the US Forest Service (USFS) calculated the marginal value of water from all National Forest lands to be at least $3.7 billion per year (USFS, 2000). The rivers and streams in forests are also critical habitat for aquatic biota including fish species that are in decline, face significant ecological challenges, or are listed as species of concern or endangered species. According to surveys of Washington state residents, the most important use of private forestland is as "a source of clean water" as the number one priority, followed by "fish and wildlife habitat"(Reiter et al., 2004). Likewise, the most generally valued and utilized "commodity" produced by California's forest lands is clean water (Reid, 1999). In fact, the origins of the National Forest system are tied directly to watershed concerns (Ice and Whittemore, 1998). Steen (1991), writing about the early legislation that established the National Forests, concluded that "the primary driving force behind forest reserve legislation at that early time was the protection and enhancement of water supplies, including flood protection."

Forest management activities associated with timber harvesting can affect the physical, chemical, and biological properties of the soil (Swank et al., 1989). Any management activity that exposes and/or compacts the soil and reduces infiltration can concentrate surface runoff and thereby accelerate erosion. If these activities increase soil erosion, for example, then water quality may be decreased through stream sedimentation, accompanied by a loss of long-term site and stream productivity. Felling trees alone seldom causes erosion although some soil compaction and surface gouging may occur during this operation. In contrast, road building, skidding and stacking logs, and some site preparation activities, can produce major soil surface disturbance that greatly increases the erosion on a site. Soil losses are greatest during and immediately after road construction (unstabilized road prism, disturbances by heavy equipment passage). However, water quality impacts can continue throughout the active lifetime of a road and even afterwards.

Sediment is the most significant pollutant of surface waters due to forestry activities, often where there is a legacy of roads or road-related drainage issues (Rehder and Stednick, 2006**)**. Unpaved roads and stream crossings are the major source of erosion from forest lands (Anderson et al., 1976, Megahan and Kidd, 1972; Patric, 1976; Rothwell, 1983), contributing up to 90% of the total sediment production from forestry operations. Surface erosion rates from roads are typically at least an order of magnitude greater than rates from harvested areas, and as much as three orders of magnitude (1,000 times) greater than erosion rates from undisturbed forest soils (NCASI, 2001). Mass wasting events such as landslides are also frequently attributed to forest management and associated with roads in steeply sloped terrain. Both erosion and mass wasting can increase the loading of fine and/or coarse-grained sediment to surface waters in forests.

However, soil erosion and mass wasting do not necessarily represent sediment contributions to streams (Kochenderfer and Helvey, 1987). Whether eroded soil reaches a stream depends on many factors such as road location, the volume of water available for sediment transport, effectiveness of sediment traps, and slope steepness. The distance that sediment travels downslope is also an important factor in determining how much eroded soil is delivered to a water body as sediment. Soil losses and erosion occurring closer to a stream have greater potential to deliver sediment and lead to water quality impairment. In this regard, stream crossings have the greatest potential to adversely impact water quality on the forest landscape (Grace, 2002).

Effects of sedimentation on stream water quality are numerous and the extent of such impacts is large (Williams, 1999). Among all pollutants measured in streams, sediment has the largest effect on stream biota (Aitken, 1936; Trautman, 1933). Sediment delivery from improperly constructed or maintained forest roads can adversely affect stream water quality and associated beneficial uses (Furniss et al., 1991; Megahan et al., 1992). As discussed below in Section 2.2, sediment loading can degrade water quality and impair numerous physical and biological functions.

2.1 What Are Forest Roads?

Roads are vital components of the human use of forested systems (Gucinski et al., 2001). Without roads, development of the economic activity critical to the quality of modern life would have been difficult, and roads remain central to many forest uses today. Roads provide access for people to extract resources from natural and modified ecosystems, as well as providing access to forests for other activities such as fire suppression and recreation. Figure 2-2 provides a cross-sectional diagram of a forest road.

Different kinds of roads comprise the forest road network. Primary or mainline roads are the most heavily traveled forest roads and generally originate from paved county or state highways (NCASI, 2001). They are generally graveled roads, are built for use throughout the year, and easily accommodate two-way traffic. Secondary roads generally depart from primary roads and may or may not be graveled. These roads are commonly closed during at least part of the year. Two-way traffic is usually accommodated by turnouts spaced along the route. Temporary roads are generally unsurfaced, although gravel surfacing of temporary roads is a common practice in particularly wet areas of the West Coast and Alaska. These roads are generally closed to traffic immediately after completion of log hauling and/or silvicultural activities such as slash disposal, thinning, and tree planting. Temporary roads are used to access individual sites and landings, where logs are processed and stacked before loading onto log trucks.

Road networks differ greatly in development through time and layout over terrain, and they carry this history into their present performance and environmental impacts (Gucinski et al., 2001). In many parts of the National Forest system, the major roads were built in the 1950s and 1960s, with secondary and tertiary feeder roads following as the road networks expanded into watersheds. In other areas, logging roads developed from previous road systems used for mining in the Rocky Mountain and southwestern states or agriculture in the southern Appalachians, Ozarks, and New England. Thus, changes in road standards through time (for example, width, construction methods, position in the landscape) have affected different parts of road networks. Consequently, each road network commonly contains a collection of old and new types and standards of roads designed for various purposes that cross terrain of differing sensitivities. This mosaic of road segments has implications for how the road network will interact with the forest watershed, streams, and other downstream aquatic resources.

While the term ‘forest road’ is not defined in the CWA or in EPA regulations States have developed many definitions of forest roads. Not surprisingly, there is no one, clear definition of a “forest road”. This may be one of the problems with the issue because forest road BMPs are only required for roads meeting the definition. Although the definition of a road may seem self-evident, definitions of forest roads have been constructed that confuse rather than clarify the relationships of roads and streams (NCASI, 2001). Many different definitions of forest roads are included in the individual states’ forest practice rules. Here are several examples of definitions of forest roads:

- A forest road is used principally for forest management activities and includes any road used by truck or pick-up since 1972 and that has not been formally vacated. (Oregon)

- "Forest road," as it applies to the operation of the road maintenance and abandonment plan element of the forest practices rules on small forest landowners, means a road or road segment that crosses land that meets the definition of forest land, but excludes residential access roads. (Washington)

- Roads, skid trails and landings are all part of a forest transportation system. Roads connect the forest land to existing public roads. They provide forest access for such activities as managing timber, improving fish and wildlife habitat, fighting fires, and recreation. (Wisconsin)

- Active Road: a road that can be either temporary or permanent that allows vehicle movement in and out of forestland. Forest Road: an access route for vehicles into forestland. (Arkansas)

- “Road” refers to truck or haul roads.

- Unpaved pathway in a forested landscape used at one time or another by vehicles in a logging operation.

- A road built through natural habitat, typically to access resource extraction or recreation activities.

- Roads are smooth-surfaced corridors for truck and automobile transportation (NCASI, 2001).

States’ Forest Practice Rules also define different types and categories of forest roads. Depending on the state, many different forest road categories may be defined, including: mainline, primary, secondary, temporary, permanent seasonal, permanent all-season forest, collector, spur, administrative, abandoned, vacated, active and inactive. These definitions often tend to overlap. The forest road definitions usually exclude state and county roads that may cross forestlands. The definitions also exclude skid trails, which are addressed as timber harvesting operations. However, skid trails involve many of the same issues (lack of soil stabilization, inadequate stream crossings, poor placement), impacts and BMPs as forest roads. These distinctions among types of forest roads are more than academic, because forest practice rules and forest road BMPs apply to specific roads. For example, a county road crossing state forests in Oregon is not subject to the Oregon Forest Practices Act, because it is not a road owned by a public or private forest manager (T. Lorenson, ODF; letter to A. Wiedeman, USEPA, December 12, 2007).

There is a rich variety of road standards and road jurisdictions within the National Forests; Figure 2-3 summarizes the legal basis and definitions relative to forest roads in the National Forest System (NFS). The USFS definition of a forest road is “any road wholly or partly within, or adjacent to, and serving the NFS and which is necessary for the protection, administration, and utilization of the NFS and the use and development of its resources” (Coghlan and Sowa, 1998).

A recent controversy involving negotiations between the USFS and Plum Creek Timber Company over road access in Montana illustrates how changing land use, driven by economic development, can complicate forest road management issues. Negotiations between the USFS and the nation's largest private landowner over use of Montana forest roads could set a precedent for commercial development near forests nationwide, according to the Government Accountability Office (Bontrager, E. 2008).

Until January 5, 2009, the USFS and Plum Creek Timber Co. were engaged in private negotiations for nearly two years to amend shared access easements on forest roads. The easements were conveyed to Plum Creek and its predecessors under the National Forest Roads and Trails Act of 1964 (FRTA), 16 U.S.C. sections 532-538, for large tracts of land in western Montana. According to the Government Accountability Office (GAO), the negotiations between the USFS and the nation's largest private landowner over use of Montana forest roads could have set a precedent for commercial development near forests nationwide.

The proposed amendment would have allowed the company, which owns 8 million acres nationwide and 1.2 million in Montana alone, to use federal timber roads on national forests to develop the company's private holdings adjacent to the forests. Critics of the plans said a road-sharing deal would have made it easier for Plum Creek to sell timberland for development. They contend the roads were intended for logging only.

The controversy began after a forest ranger informed a potential buyer of Plum Creek land that the easement did not allow access for residential use. That opinion was echoed in a regional forest memorandum in 2007 that stated that the FRTA easements "were not developed for residential use and the roads were rarely designed to accommodate it safely." (memorandum from Regional Foresters to Forest Supervisors June 18, 2007But the USFS overruled the ranger following discussions with Plum Creek, agreeing that the company could use certain NFS roads for any purpose, according to the GAO report. The proposed agreement being hammered out between the agency and Plum Creek would allow for the company to use the roads for any future development. GAO found that the property value of many Plum Creek lands would have a significantly higher value if the amendment is finalized.

2.2 What is the Nature, Extent and Severity of Water Quality Impairments Due to Forest Roads Across the Country?

Roads can have very different effects on water resources depending on road size, design, location, construction, access, usage and maintenance techniques. Although most roads will have some effect on their watersheds, a small percentage of road area (or length) is often responsible for most of the erosion. For example, in a study of road-related erosion, Rice and Lewis (1986) found only 0.6% of the road length had events displacing significant quantities (greater than 15 m^3, approximately 2 dump trucks) of eroded material. Roads creating significant erosion impacts may not be completely controllable (McCashion and Rice, 1983).

Forest roads can severely and permanently harm streams and their biota. The water quality impairments due to forest roads include physical, biological and ecological impacts. Forest roads degrade aquatic ecosystems by increasing levels of fine sediment input to streams and by altering natural streamflow patterns. Construction, use and existence of logging roads detrimentally affects stream health and aquatic habitat by increasing sediment delivery and stream turbidity which adversely affects the survival of dozens of sensitive aquatic biota (salmon, trout, other native fishes, amphibians and macroinvertebrates). Even when well-located and carefully designed, adverse impacts can result from forest roads if they are not properly operated and maintained. Increased fine sediment deposition in streams and altered streamflows and channel morphology result in increased adult and juvenile salmonid mortality, a decrease in aquatic amphibian and invertebrate abundance or diversity, and decreased habitat complexity.

Some degree of environmental impairment is an inevitable consequence of forest roads. Although the impacts of forest roads are widespread, the severity of the resulting impairments vary considerably between locations. In fact, the extent and severity of water quality impairments due to forest roads is debated by various interest groups. This may in part reflect the spatial variability of impairments attributed to forest roads. The variations in rates of erosion, sediment delivery, and the intensity of forestry activities (as measured by road density and traffic levels) lead to vastly different impacts in different locations and watersheds. The issue is further complicated because:

- The impairments can be difficult to detect and/or measure;
- Erosion only usually occurs during wet weather;
- There are no reliable data at the national level to use for such an assessment; and
- Many studies in the peer reviewed literature were conducted 10 or 20 years ago and may not represent present conditions.

This latter point is relevant because, to some degree, the water quality impairments from forest roads have been, and continue to be, a consequence of past forestry practices and activities. In some states, such as Connecticut and New Mexico, BMP regulations have changed greatly within a single decade. In other states, including Idaho and Washington, FPRs are almost continuously evolving. Changes in logging systems, reforestation techniques, and environmental protection requirements have meant that the concepts of best forest management practices have always been evolving (Bisson et al., 1992). The broad changes in road management practices that managers have enacted are a result of the gradual development of water quality and environmental objectives over the past 40 years or more (NCASI, 2001). Thus, the issue of forest roads and their water quality impacts is both dynamic and spatially variable.

In the sections that follow, specific water quality impairments attributable to forest roads are discussed, along with factors that cause these impairments to vary. No attempt has been made to distinguish impairments due to historical versus modern forest management practices, although this can sometimes be inferred from the dates of specific studies.

2.2.1 Water Quality Impairments

The physical impacts of forest roads on streams, rivers, downstream water bodies and watershed integrity can be dramatic and have been well documented. Roads impact watershed integrity through three mechanisms: they intercept, concentrate, and divert water (Williams, 1999). Roads intercept water falling as rainfall directly on road surfaces and cutbanks as well as subsurface water moving underground down the hillslope. They concentrate flow on the road surface and in adjacent ditches and channels. Roads divert both surface and subsurface water from flow paths that otherwise would be taken in the absence of a road. The hydrologic and geomorphic consequences resulting from these three processes can be large, as discussed below. Roads directly affect natural sediment and hydrologic regimes by altering streamflow, sediment loading, sediment transport and deposition, channel morphology, channel stability, substrate composition, stream temperatures, water quality, and riparian conditions within a watershed (Lee et al., 1997).

Potential effects of roads on water quality include increased loading of sediment due to erosion and mass wasting, increased suspended solids and turbidity, increased sediment deposition and bed load, siltation of coarse streambed substrates, physical barriers to migration and downstream transport, altered streamflow and pollution from other chemicals associated with road use. The physical and chemical impacts of roads have detrimental effects on fish and other aquatic organisms and their habitat; these are discussed separately in Section 2.2.2.

2.2.1.1 Increased Loading of Fine and/or Coarse-Grained Sediment Due to Erosion and Mass Wasting

Roads and especially stream crossings are a major source of sediment to streams (Eaglin and Hubert, 1993; Furniss et al., 1991), and contribute more sediment to streams than any other land management activity (Gibbons and Salo, 1973; Meehan, 1991). Soil erosion rates were 30 to 300 times higher on forests with roads than undisturbed forest (Furniss et al., 1991). High rates of stream sedimentation can result from this increased erosion. Most fine sediment from surface erosion processes is delivered during common rainfall events and is relatively chronic (FPAC, 2001). A survey conducted in one watershed in the southeast revealed that 80 percent of the sources of sediment delivery to streams and rivers were from the road prism; i.e., road surface, ditches, banks (van Lear et al., 1995; Grace and Clinton, 2006). Surface erosion from forest roads affects the fine sediment budget and may impose a chronic condition of sediment inputs to streams directly affecting the stream substrate and the health of aquatic life (Luce et al., 2001).

Surface erosion rates from roads are typically at least an order of magnitude greater than rates from harvested areas, and three orders of magnitude greater than erosion rates from undisturbed forest soils (NCASI, 2001). For example, estimates of road surface erosion rates in California, Idaho, and Washington are generally in the range of 10 to 100 tons/acre/year (Cline et al., 1981; McCashion and Rice, 1983; WFPB, 1997), with extreme estimates as high as 480 tons/acre/year in Washington's Olympic Mountains (Reid and Dunne, 1984). These extremely high erosion rates may be contrasted with sediment yields measured on undisturbed forested lands in the eastern and western United Sates (0.09 tons/acre/year; Gianessi et al., 1986 and Patric, 1984), intact pine forests the southern US (0-0.09 tons/acre/year), clearcut forests with BMPs (0.04-0.18 tons/acre/year), and harvesting and site preparation without BMPs (1.3-6.2 tons/acre/year; Yoho, 1980).

It should be noted that some investigators have reported erosion rates for roads, ranging from 5 to 550 tons/acre/year, whereas others have reported erosion rates of watersheds containing roads in the range of 0.02 to 2 tons/acre/year. The wide range results from differences in measuring erosion (on the road or at the watershed outlet) and in the factors causing erosion, including the presence, density, and design of the road network on the watershed (Elliot, 2000). Although a wide range of erosion rates and sediment yields are reported in the literature, all sources agree that these rates are considerably higher in forests containing roads in comparison to areas without roads.

Bilby et al. (1989) studied erosion from two kinds of forest gravel roads in southwestern Washington. The sediment produced from each road segment was related to traffic rate and type of road surfacing material. The majority of the sediment produced (80%) was material finer than 0.004 mm. Steeper roads produced a higher proportion of coarser material (primarily sand). Average sediment concentrations from secondary road sites were 2,000 mg/L, with a maximum of 19,500 mg/L. Hourly concentrations from a mainline road ranged from 500-700 mg/L, occasionally exceeding 20,000 mg/L.

Roads also greatly increase the frequency of landslides, debris flows, and other mass movements (Burroughs et al., 1976; Clayton, 1983; Dunne and Leopold, 1978; Furniss et al., 1991; Hammond et al., 1988; Megahan et al., 1992). Landslides have been reported to be the predominant form of erosion from roads in several studies of steep, hazardous (as evidenced by presence of natural failures) terrain (Megahan and Kidd, 1972; O'Loughlin, 1972; Swanson and Dyrness, 1975). Landslides from road fills or sidecast are the most common type of failure, tend to form debris avalanches or debris flows (often down steep draws and small streams), and are the most destructive to downstream fish-bearing channels (Benda et al., 1997; Furniss et al., 1991; Gonsior and Gardner, 1971; O'Loughlin, 1972; Dyrness, 1967). Cutslope failures often block road ditches and divert concentrated water onto fillslopes, contributing to their failure (Dyrness, 1967). The discharge of concentrated road drainage water, usually from ditches through relief culverts, onto road fills or naturally unstable bedrock hollows also contributes to many failures (Benda et al., 1997).

Road-related landslides and stream crossing failures can result in significant sediment impacts from the volume of material in the failed fill and also by scouring headwater channels for some distance. These types of sediment inputs tend to be episodic and are often the result of large rainfall events. Landslides are typically dominant erosion mechanism in areas with steep slopes, the frequency of which can be greatly accelerated by road management practices. Prior to mid-1980s, excavated soil and rock from full-bench road construction was sidecast on very steep slopes below road prism. These steep slopes were often associated with landslides.

Weaver and Hagans (1996) found that roads were associated in an apparently causal manner with 15% to 61% of the new landslides following the February 1996 storm in the Oregon and Washington Cascades and Oregon Coast Range Mountains. That same storm resulted in a flood event in the Fish Creek watershed on Oregon's Mt. Hood National Forest that caused 236 landslides, of which 34% were attributed directly to the road system (Reeves et al., 1997). Similarly, very high associations between the road system and landslides were found in Idaho following 1997 spring storms, with 65% of landslides observed in the North Fork Clearwater Basin and 72% in the Lochsa River Basin associated with roads (Weaver et al., 1998).

McCashion and Rice (1983) investigated erosion due to forest roads and logging in northwestern California. Mass erosion was the predominant form of erosion occurring in the study sites. In steep watersheds, more sediment may be from mass wasting, which tends to deliver greater quantities of sediment to the stream. Roads caused 152 of the 171 major erosional events inventoried and 61% of the soil volume displaced by erosion was due to these road-related events. In the Clearwater National Forest in Idaho, 58 percent of the landslides that occurred were associated with roads (McClelland et al., 1998). Other studies in Oregon, however, suggest that road impacts may have been overestimated (Robinson et al., 1999), and that sediment from landslides in undisturbed areas is similar to that in areas with roads.

Soil erosion and mass wasting do not necessarily represent sediment contributions to streams (Kochenderfer and Helvey, 1987). Whether eroded soil reaches a stream depends on many factors such as road location, the volume of water available for sediment transport, effectiveness of sediment traps, and slope steepness. Sediment delivery to streams from unpaved forest roads consist of a direct component, which is the sediment delivered from road segments leading into stream crossings, and an indirect component which is the sediment delivered at constructed drainage outfalls and where road surface runoff flows off the roadway before reaching a ditch or drain (Woods et al., 2007). The sediment delivery ratio from road segments leading into stream crossings is close to 100%, so that the direct component of sediment delivery depends almost entirely on the road erosion rate. Active hauling on roads during wet periods results in particularly high erosion rates. The delivery ratio for indirect sediment delivery is less than 100% because a portion of the sediment eroded from the road is stored on the hillslope as a plume of sediment that lies on top of the natural soil profile. The delivery rate depends on the distance that sediment travels downslope. Soil losses and erosion occurring closer to a stream have greater potential to deliver sediment and lead to water quality impairment. Stream crossings have the greatest potential to adversely impact water quality on the forest landscape (Grace, 2002). Ligon et al. (1999) noted that the most common source of sedimentation was from fillslopes immediately adjacent to watercourse crossings. Plugged culverts and fill slope failures are frequent and often lead to catastrophic increases in stream channel sediment (Furniss et al., 1997).

Researchers worldwide have measured increased sedimentation from roads and similar disturbances (Elliot, 2000). The magnitude of erosion varies considerably with climate, but the relative impacts of soil, topography, and management are generally the same (Elliot et al., 1999). Erosion rates are observed to be highly variable, due to the high natural variability in the factors that cause erosion. Even a well designed erosion experiment frequently results in variations from the mean of up to 50 percent. This high variability should be considered when interpreting any research or monitoring results, or any erosion prediction value.

Road age and wet weather use are factors that strongly influence surface erosion (FPAC, 2001; Swift, 1988). Research shows newly constructed/ reconstructed roads may have 10 times more surface erosion the first winter after construction compared to subsequent years, resulting from increased erodibility because of soil disturbance during construction and lack of erosion pavement and vegetation to protect the soil surface. During periods of wet weather, road surfaces not constructed with adequate surface materials and spacing of drainage structures are a potential source of fine sediment delivery by allowing sediment laden water to enter stream channels directly. Fill failure is also a risk (FPAC, 2001).

Water quality effects of fire roads, all-terrain vehicle (ATV, also known as off-highway vehicle or OHV) trails, and public access and recreation trails have not been studied as extensively as roads built for forestry operations. Unmanaged ATV use is a “spotlight issue” representing this threat because of the unauthorized creation of roads and trails and the associated erosion, water-quality degradation, and habitat destruction. An estimated 11 million visits to National Forests involve ATV use; this constitutes about 5 percent of all recreation visits to national forests (English, 2003).

Repeated cross-country forays by ATV traffic results in the uncontrolled proliferation of trails. Unauthorized trails from motorized use currently cause much of the natural resource damage on National Forests, and are a major problem for forest managers. For example, Lewis and Clark

National Forest personnel in Montana currently estimate that the forest has 1,348 unauthorized roads and trails extending for 646 miles (Robertson, 2003). ATVs often blaze new paths through forests and these roads are typically unmonitored and unmaintained. The magnitude of effects varies depending on local characteristics of the landscape including slope, aspect, soil susceptibility to erosion, and vegetation type. Riparian areas and riparian and aquatic species are particularly vulnerable to ATV damage. Heavy use of trails can accelerate erosion, compact soils and decrease infiltration, leading to changes in discharge magnitude/timing, channel structure, sediment routing through forest streams, and habitat destruction. Impacts may be more pronounced in the case of ATV trails, where users develop improperly located trails in addition to designated ones (Chin et al., 2004).

The Ouachita National Forest in Arkansas has 67 km of designated ATV trails. Because of prevalence of off-road exploration and ease with which ATVs traverse rugged terrain, users also developed a network of unauthorized trails. These can be especially erosive and potentially exacerbate negative impacts of planned trail system on stream channel integrity. Studies of two impacted creeks (Chin et al., 2004) indicated that watersheds with ATV trails had pools with higher percentages of sands and fines, lower depths, and lower volumes. High turbidity levels were observed in surface runoff from ATV trails entering creeks after light rainstorms. Pools below ATV trail crossings were sediment-laden and turbid.

Roads provide access to a wide variety of activities within the Wilson River watershed (Duck Creek Associates, 2008). From timber harvesting and log hauling to recreating with ORVs and motorcycles, the roads within the watershed are well used and often a busy place. During a 2006 road inventory, 42 miles of ORV trails were surveyed, representing 28% of the designated trails but only ~5% of the undesignated trails. Undesignated trails are not maintained and tend to have steep gradients, high erosion, and impaired drainage. Thirteen trails hydrologically connected to streams were assessed for risk of washout. Results indicated that trail-stream and trail-road intersections were very likely to adversely affect water quality because the majority of hydrologically-connected trails violated trail construction guidelines (trail grades <10%, slope alignment < ½ sideslope grade). Many of the worst hydrologically connected trails were undesignated or user-created with no regard for design standards. Furthermore, none of the undesignated trails are maintained as they are not part of the Oregon Department of Forestry (ODF) OHV-designated trail system. These undesignated trails have high impacts on water quality and are common enough throughout the watershed to be a concern. Soil erosion estimates were made for seven sample trail segments; the results indicate that hydrologically connected OHV trails are a significant source of sediment, especially considering the year round nature of use and the back log of repair and closure facing ODF staff.

2.2.1.2 Increased Suspended Solids and Turbidity

Suspended sediment transport is generally “source limited” in rivers and streams, meaning that concentrations of suspended solids and surrogate measures (e.g., turbidity) depend on sediment loading (Beschta, 1981). In many regions, total suspended solids (TSS) concentrations are low (<5 parts per million or ppm) under dry weather condition, but increase to high peak concentrations (~100 ppm or higher) during major rainfalls. Since forest roads can increase sediment loading, it is reasonable to expect suspended solids and turbidity to increase in impacted surface waters. However, there is usually a great deal of uncertainty in determining when and how much sediment from an erosion feature was delivered to a stream channel (Lewis, 1998). It can be even more difficult to determine the origin of suspended sediment that has been measured at a stream location. To some degree, this is because the biotic and chemical variability in rivers and streams tends to mask the water quality effects of forestry activities (Jackson et al., 2004). Just as environmental characteristics (soil texture, slope, road aspect) and regional variability both significantly affect sediment loading, these and other factors can also affect the water quality response.

Forest management activities, such as road construction, often cause concentrations of suspended sediment to increase. However, this is not always the case. Figure 2-4, reproduced from Binkley and Brown (1993), plots suspended sediment concentrations in undisturbed (control) and disturbed (treatment) experimental forested watersheds. Points on the graph in Figure 2-4 that fall fairly close to the 1:1 slope line indicate similar suspended sediment concentrations in undisturbed and disturbed forested situations. Many of these cases are due to proper implementation of BMPs. Local variability in soil erosivity can also affect water quality due to sediment loading. In regions where BMPs were not imposed, substantial and variable increases in sediment concentrations occurred. These cases are also evident on the graph in Figure 2-4, as points where the disturbed suspended sediment concentrations are an order of magnitude (or more) greater than in the undisturbed forest situations.

The use of gravel-surfaced roads during wet periods has been documented as a major source of fine-grained sediment and associated stream turbidity (Mills et al., 2003; Reid and Dunne, 1984). Impacts of water quality on fish and aquatic organisms have motivated much of the research. Sediment-laden water supplies also reduce the capacity of storage reservoirs and may require additional treatment to render the water drinkable (Lewis, 1998). Sediment in irrigation water shortens the life of pumps and reduces soil infiltration capacity. Water quality is also an important issue for recreational water users and tourism.

There is also much evidence in the literature demonstrating the difficulty in evaluating the impacts of roads and other logging activities on erosion and suspended sediment transport. Monitoring and evaluating forestry impacts on stream water quality is usually complex, time consuming, and expensive (Corner et al., 1996). Monitoring projects based on instream sampling often result in incomplete or inconclusive data, especially in remote areas. This is partially due to the inability to predict the timing of sediment-producing events and the many technical problems associated with water quality sampling and analysis. For example, Corner et al. (1996) found that instream monitoring did not reveal any significant differences in total suspended solids (TSS) between clearcut and control sample locations at three sites. On each site, data for stream TSS were generally characterized by high variability and low values. The data were not significantly correlated to stream discharge. Outliers did not necessarily correspond to sample collection dates that coincided with precipitation events, nor did they occur exclusively at the clearcut and road locations. The instream monitoring indicated that clearcutting and access roads did not effect stream sediment loads in the summer after logging. Many other studies have produced similar results. Hetherington (1976), for example, found no statistical difference in suspended sediment concentration above and below logged areas in British Columbia. Sullivan (1985) demonstrated that, even with automated equipment sampling stream water at 6 hour intervals, large volumes of sediment can enter stream channels and be flushed off-site undetected. Furthermore, Beschta (1978) noted that the natural variability in the sediment-discharge relationship often makes relatively small changes in sediment concentrations very difficult to detect at a point in the stream system, even with intensive sampling.

Bilby (1985) measured the size of sediment washing from a gravel-surfaced road and its fate after entering Johnson Creek, Washington. After rainfall events, sediment input from the road frequently increased the levels of suspended sediment downstream of the culvert compared to upstream levels. Maximum turbidity reached downstream was almost three times the maximum recorded upstream. The sediment was primarily very fine particles (more than 80% less than 0.004 mm in size) and was attributed to erosion from the road surface rather than roadside ditches or banks.

In a project to monitor fine sediment delivery to streams, Mills et al. (2003) measured turbidity responses in forest streams near road crossings. For a typical site delivering sediment to streams, peak turbidity downstream from the road crossing was 110 nephelometric turbidity units (NTUs) while peak turbidity above the road was 40 NTUs (Lewis, 1998). A wide range of changes in turbidity was observed during the two winters of field monitoring. Thirty percent of the sample pairs showed no change or a decrease in turbidity downstream of road crossings. Ninety percent of the sample pairs showed a change of 20 NTUs or less. The remaining 10% of the observations ranged from an increase in turbidity of 20 to 520 NTUs. Increases in stream turbidity levels at stream crossings during periods of wet weather hauling appeared to be impacted by several factors including precipitation, surfacing material, drainage design, and traffic factors. Depending upon these site-specific factors, as well as the technical difficulties of monitoring discussed above, increases in turbidity or suspended sediment concentrations may be undetectable, even when other impacts of forest roads are taking place.

2.2.1.3 Increased Sediment Deposition and Bed Load

Sedimentation is the end result of several processes, including erosion; sediment delivery, transport and deposition; and instream morphological processes. Erosion and mass wasting associated with forest roads can deliver both fine and coarse-grained sediment to water bodies. While fine-grained sediment is usually transported suspended in the water column, coarse solids are mostly transported as bed load. Bedload transport is “flow limited”, meaning that coarse-grained sediment is usually only transported and redeposited at high flow rates (Beschta, 1981). Deposition during and following large flow events can significantly change channel characteristics in low-gradient stream reaches. Although many of these changes (e.g., filling of pools reducing pool frequency, depth and volume) are associated with negative impacts on biota, stream habitat can be potentially enhanced if mass erosion delivers material to streams where coarse sediment is limited.

The capacity of a stream to carry sediment also increases with stream velocity. At a given flow, velocity varies within channels longitudinally and in cross section. Thus, channel erosion and sedimentation occur simultaneously. The magnitude of these processes is affected by flow rate; high flows increase channel erosion, and low flows increase sedimentation, or deposition (Prud’homme and Greis, 2002). These relationships are far from straightforward, however, because in many forest stream systems, other factors such as large woody debris or bedform are the dominant controls on streambed texture (Buffington, 1995).

Methods for measuring bedload transport are relatively crude, and correctly timing bedload sampling to observe transport due to management activities is difficult (Harris et al., 2005). Data regarding bedload transport may be best captured with channel geometry and substrate measurements in depositional stream reaches. Unless a stream can be intensively monitored during high flows or a settling pond exists within a channel, bed load measurements are unreliable to the extent that they should not be monitored (Corner et al., 1996).

2.2.1.4 Siltation of Coarse Streambed Substrates

The abundance and quality of spawning substrate can be severely affected by sedimentation. Coarse gravel channel substrates are a critical habitat requirement for many stream organisms including salmonids and aquatic amphibians and invertebrates, and are considered a scarce resource. Fine sediment deposition may alter the quality of these gravel streambeds as fine sediment particles embed (cover) the larger particles and fill in the interstitial space in gravel substrates. Deposition may occur well downstream of the sediment source(s), because once fine sediment is delivered to a stream it can be transported relatively far downstream to a deposition location. In low-velocity stream reaches, excess deposition of fine sediment can completely cover suitable spawning gravel. Massive levels of fine sediment delivery can also produce changes in channel habitat by reducing pool frequency, depth and volume.

Burns (1984) found that roaded and logged watersheds in the South Fork Salmon River drainage had significantly higher channel bed substrate embeddedness ratings than undeveloped watersheds. Siltation of spawning gravels can occur rapidly in response to road impacts. Platts et al. (1989) studied the effects of fine sediment delivery to rivers from logging and road construction in habitat for Chinook salmon and steelhead. After logging ceased, there was a significant decline in the percentage of fine sediment (material <4.75 mm in diameter) on the surface of 84% of the spawning area locations. Within two years of resuming logging, however, surface fine sediments increased at all five spawning areas, with overall increases of 22.2% to 83.8%.

Although streambed siltation has been reported to be a widespread impairment of sediment from forest roads, a number of studies have found no such impact (Adams, 1994). In Johnson Creek/Deschutes River of Washington, Bilby (1985) reported that sediments eroded from road surfaces were deposited on the streambed during low flow, but were “flushed” from the system by high flows. No increase in fine sediment was found in streambed gravels. The lack of deposition was attributable to small particle sizes of road sediment. Sullivan (1985) studied the Middle Fork Santiam River of Oregon in the Cascade range. Water quality remained good during the first decade of extensive timber harvest. Sediments eroded from road construction and road surfaces contributed to instream sediment yield, but the effect on an annual timescale was not detected within the natural variability of the erosion processes.

2.2.1.5 Alteration of Stream Morphology (E.G., Reduced Pool Volume) and Channel Simplification

The increased sediment flux into streams that is associated with roads causes aggradation[5], filling of pools, and increased channel widths and width-to-depth ratios (Jackson and Beschta, 1984; Lisle, 1982; Madej, 1982). Increases in width/depth ratios in sensitive streams can result in higher summer water temperatures even when shade is not lost (Beschta et al., 1987; McCullough, 1999). With increasing road density there is a clear decline in the frequency of pools and large pools, fundamental components of high-quality fish habitat (Lee et al., 1997). Significant aggradation at channel transitions such as tributary confluences or road crossings can force streamflows subsurface.

Forest roads can have other impacts on stream morphology. Unnatural channel widths and slope and stream bed form can occur upstream and downstream of road crossings, and these alterations in channel morphology may persist for long periods of time (Williams, 1999; Heede, 1980). Concentration and diversion of flow by roads into headwater areas can cause incision of previously unchanneled portions of the landscape (Montgomery, 1994). Roads are sometimes placed partially in an existing stream channel. Riprap is placed to prevent erosion of the road fill, resulting in a dramatic change in channel form (Luce et al., 2001).

2.2.1.6 Physical Barriers to Fish Migration and Downstream Transporto Coarse Sediment and Large Wood

Structures associated with forest road crossings of streams are potential barriers to movement and migration of fish (Clancy and Reichmuth, 1990; Evans and Johnston, 1980; Furniss et al., 1991). Road crossings, especially culverts (which are also the most widely used crossing type), can pose as obstacles to the movement of fish and other aquatic biota, as well as sediment and large wood (Cupp et al., 1999). Reducing the number of road crossings of streams or using alternatives to culverts, including temporary road crossings such as portable bridges, are BMPs that can greatly reduce these impacts (see Section 3).

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[5] Aggradation is the accumulation of sediment in streams and rivers, that occurs when the supply of sediment exceeds the ability of the stream to transport the sediment.

In western streams, anadromous salmonids migrate upstream/downstream during their life cycles, usually over long distances. Many resident salmonids and other fish also move extensively upstream/downstream seeking food, shelter, water quality and spawning areas. Improper culvert placement and installations used for stream crossings may create partial or seasonal barriers to fish movement while others may reduce or eliminate fish passage year-round (Belford and Gould, 1989; Beechie et al., 1994). Culverts may also delay or deny access to seasonally critical habitats, fragment populations, and suppress the recovery of populations following disturbance.

A number of physical conditions at stream crossings create migration barriers (USEPA, 2005). The two most important fish passage considerations are maximum water velocity and minimum depth. Culverts can be insurmountable barriers to migrating fish when culvert outlet is elevated above the streambed that fish cannot enter the pipe; this is termed an outfall barrier. It is considered acceptable culvert design practice to not require conditions suitable for fish passage during the 5% of the year with highest flows (Evans and Johnston, 1980) because fish don’t normally migrate during peak flow.

The removal of large organic debris at stream crossings can eliminate important components of fish habitat (Furniss et al., 1991). Road systems also have the potential to block the downstream movement of large wood (LW). Where a stream crossing blocks the passage of LW there is potential for dam-break flood to occur. When a downstream reach depends on a supply of LW delivered during peak flows, road crossings not designed to pass LW can reduce upstream sources of wood and have a negative effect on riparian functions and habitat conditions (FPAC, 2001). Extreme sedimentation above or below road crossings can cause streamflow to become subsurface or too shallow for fish movement (Furniss et al., 1991).

Increasing numbers of culverts have been correlated with increasing amounts of fine sediment in streams and decreasing fish densities. Eaglin and Hubert (1993) studied the effects of logging and associated road construction on streams and on trout populations in the Medicine Bow National Forest, Wyoming. Both the amount of fine sediment in a stream reach and the embeddedness of fine sediment in the substrate increased as the proportion of logged area increased, and as the extent to which roads crossed watercourses increased. Trout standing stocks also decreased as the density of road culverts increased.

It should be noted that culverts and other road crossings can pose migration barriers beyond the forest landscape. A survey of county and state highways in western Oregon in 1999 found more than 1,200 culverts acted as barriers to fish passage (FPAC, 2001). These highways are typically located downstream of forestlands and therefore may limit or block access to upstream fish habitat. The relatively large network of nonforest roads in close proximity to streams that are currently providing (or have potential to provide) quality fish habitat are likely to have significant impact on salmonid maintenance and recovery.

2.2.1.7 Altered Streamflow

The most dramatic and visible effect of a road often is its effect on the flow of water through the watershed (Williams, 1999). Runoff is low from undisturbed forests, but runoff rates from rainfall and snowmelt are greater from compacted road surfaces than from less disturbed parts of watersheds (Elliot and Hall, 1997). The presence of roads in a watershed may increase the frequency and magnitude of peak runoff discharges, particularly on small watersheds. Roads may also increase total runoff and decrease the time to peak runoff from major storms or snowmelt (Elliot, 2000). Roads interrupt hillslope drainage patterns by intercepting surface and subsurface flow and concentrating and diverting it into ditches, gullies and channels, thereby effectively increasing the density of streams in the landscape and altering the timing and magnitude of peak flows and changing base stream discharge (Furniss et al., 1991; Harr et al., 1975; King and Tennyson, 1984; Wemple et al., 1996) and sub-surface flows (Furniss et al. 1991; Megahan, 1972).

In some instances, road-induced changes in watershed hydrology can have serious consequences. However, the magnitude of road effects on peak flows is debated in the literature (Ice et al., 2004). The impact may depend on the fraction of the forested watershed area occupied by roads. King and Tennyson (1984) monitored the effects of logging roads on streamflow on six headwater watersheds in Nez Perce National Forest in north central Idaho. In one watershed, with 3.9% of its area disturbed by roads, there was an increase in the 25% exceedance flows (streamflow during snowmelt runoff and summer storms), attributed to interception of subsurface flow by the roads and conversion to surface flow. Another watershed, with 4.3% of its area in roads, showed a significant decrease in the 5% exceedance flow, which represents the period of highest flow.

2.2.1.8 Pollution From Other Chemicals Associated With Roads (Spills, Deicing and Dust Control Agents, Herbicides)

Roads can also contribute to water quality degradation through runoff of applied road chemicals (Furniss et al., 1991; Norris et al., 1991; Rhodes et al., 1994) including herbicides, as well as toxic spills (Furniss et al., 1991; IDT, 1996). In recent years, the use of chemical site preparation has become increasingly common, as indicated by the establishment of BMPs for the proper use of chemicals during forest management in many states (Williams, 1999). The use of herbicides dramatically lowers the threat of sediment transport to streams compared to disking and other tillage treatments by not disturbing the soil surface. For example, Michigan’s BMP manual states that herbicides have an “…advantage over mechanical means [of site preparation] because there is no soil disturbance and can be used where steep slope prevents use of machinery “ (MI DNR & DEQ, 1994). According to NCASI (2007), the potential of impacts to water quality that result from herbicide transport to streams has been demonstrated to be small. Analyses of streamwaters associated with the Texas Intensive Forestry Study (TIFS) for hexazinone, imazapyr, and sulfometuron methyl showed maximum hexazinone concentrations in the range of 20 to 30 ppb in waters associated with storm events within approximately 30 days after treatment (DAT), dropping to approximately 1 ppb by 140 DAT (NCASI, 2007a). Maximum imazapyr concentrations in waters associated with storm events were in the range of 30 to 40 ppb within approximately 20 DAT, dropping to approximately 1 ppb by 150 DAT. Maximum sulfometuron methyl concentrations in waters associated with storm events were in the range of 2 to 3 ppb within approximately 20 DAT, dropping to approximately 1 ppb by 30 DAT. Some details of a screening analysis for determination of dissolved glyphosate to 0.2 ppb are also given, and the results from analyses of some composite samples of TIFS waters are reported. A screening analysis for determination of dissolved glyphosate indicated maximum glyphosate concentrations in water associated with storm events on the order of 10 ppb within approximately 30 DAT, dropping to approximately 1 ppb by 100 DAT. Because the water quality impact of other chemicals is discussed only incidentally in most of the literature on forest roads, it will not be a focus of this report.

2.2.2 Degradation of Habitat for Salmonids, Other Fish, Invertebrates, and Other Aquatic Organisms

The physical impacts of roads have detrimental effects on fish and fish habitat. Mechanisms through which roads exert these deleterious impacts include fine-sediment effects, changes in streamflow, changes in water temperature caused by loss of riparian cover or conversion of groundwater to surface water, and migration barriers. The physical impacts of roads discussed above have a widespread and profound effect on fish habitat and fish communities and populations across a range of environments and conditions (Lee et al., 1997).

Serious degradation of fish habitat affecting all life-stages of fishes (including migration, spawning, incubation, emergence, and rearing) can result from poorly planned, designed, located, constructed, or maintained roads, as demonstrated in numerous studies conducted in the Pacific northwest (Furniss et al., 1991; Henjum et al., 1994; MacDonald et al., 1991; Rhodes et al., 1994). Well-known native aquatic species affected by turbidity and sedimentation are salmon (coho, chinook and chum), steelhead, and trout (cutthroat and rainbow) as well as other native fishes and amphibians (salamanders, tailed frogs).

Sedimentation can have obvious consequences in stream systems, often leading to complete loss of salmonid fisheries (Berry et al., 2003). The effects of roads on salmonid habitats have been most studied, including effects on migration, spawning, incubation and juvenile rearing:

Migration- Improperly designed roads prevent and interfere with upstream migration of adult and juvenile salmon, and also impair and/or prevent macroinvertebrate movements by road-related changes to stream channels (Pearce and Watson, 1983). Culverts pose the most common migration barriers associated with road. Improperly designed and maintained culverts can be insurmountable barriers to migrating fish (Furniss et al., 1991).

Spawning- Adult salmon have exacting habitat requirements for spawning, including requirements for substrate sizes, depth and velocity. The abundance and quality of spawning substrate can be severely affected by sedimentation. In low-velocity stream reaches, excessive fine sediment can completely cover suitable spawning gravel. Gravel extraction for road construction may directly remove suitable spawning substrate.

Incubation- If gravel interstices fill with fine sediment, egg development may be slowed or halted.

Juvenile rearing- Large amounts of fine sediment reduce and/or eliminate suitable substrate producing macroinvertebrates, which comprise most of the diets of juvenile fish. Modification of stream channel configurations, decreasing the number and depth of pools, reduce the space available for rearing fish, and can lead to reduced survival.

Road construction near streams also often directly removes riparian vegetation. The essential role of large woody riparian debris in salmon streams is reviewed in Bisson et al. (1992).

Because of their great importance to the region, the majority of research on fish population abundance in the Pacific Northwest has focused on salmon and trout. Very little is known about the effects of cumulative habitat changes on the abundance of most non-salmonid species. Some may be more sensitive to habitat change than anadromous salmonids, because they spend their entire lives in freshwater and may be associated with a specific type of habitat. There have been no studies that have attempted to assess the abundance of non-salmonid populations at the scale of drainage basins in the Pacific Northwest (Bisson et al., 1992). A change in the abundance of a single species may not be a useful measure of the cumulative effects of forest practices on fish populations in a river system. Instead of using trends in designated “indicator species” to gauge the cumulative effects of forestry operations, a potentially more powerful approach is to examine the relationship between forestry-related habitat changes and the structure of fish communities in streams and rivers.

2.2.2.1 Sediment

The increased sediment flux into streams that is associated with roads causes aggradation, filling of pools, and increased channel widths and width-to-depth ratios (Jackson and Beschta, 1984; Lisle, 1982; Madej, 1982). These changes are associated with widespread and profound impacts on fish and other aquatic biota in streams, and are well documented in the scientific literature. Of all of the taxonomic groups, fishes, particularly salmonids, have received the most attention from researchers (Waters, 1995). This is because of the commercial and recreational importance of salmonids, and the obvious impact that logging and other land use activities have had on salmonid fisheries, particularly in the Pacific Northwest. In California, all species of anadromous salmon are in serious decline and many local stocks have been completely extirpated. Coho have experienced some of the most precipitous declines of all west coast salmon and are at critically low levels today (EPIC, 2002).

The effects of increased embeddedness, on salmonids in particular, have been well documented (e.g., Waters, 1995). As pools are filled by sediment they support fewer fish and the individuals that reside in them suffer higher mortality (Alexander and Hansen, 1986; Bjornn et al., 1977). Furthermore, elevated levels of fine sediment adversely affect salmonid embryo survival (Bjornn and Reiser, 1991; Chapman, 1988; Everest et al., 1987) and have been linked to decreased fry emergence, decreased juvenile densities, loss of winter carrying capacity via loss of concealment cover, and increasing predation (Bjornn et al., 1977; Chapman, 1988; Chapman and McLeod, 1987; Everest et al., 1987; Scrivener and Brownlee, 1989; Thurow, 1997; Weaver and Fraley, 1993; Young et al., 1991). Fine sediment deposition in spawning gravels smothers fish eggs. Increased fine sediment in stream gravel reduces intra-gravel water exchange, thereby decreasing oxygen concentrations, increasing metabolic waste concentrations, and restricting movements of alevins (Bjornn and Reiser, 1991; Chapman, 1988; Coble, 1961; Cordone and Kelly, 1960; Everest et al., 1987). This loss of unembedded interstitial areas in stream substrates also is correlated with a severe reduction or elimination of tailed frogs (Corn and Bury, 1989; Welsh, 1990) and benthic organism populations (Chutter, 1969; Hynes, 1970). Increased fine sediments in rearing areas are also correlated with reduced juvenile salmonid densities (Alexander and

Hansen, 1986; Bjornn et al., 1977; Chapman and McLeon, 1987; Everest et al., 1987; Shepard et al., 1984).

Numerous studies have indicated that high sediment levels can affect fish by increasing mortality, reducing growth rates, causing physiological stress, impairing homing instinct, and reducing feeding rates (FPAC, 2001). Efforts to relate sediment concentration to fish response have had mixed results (Everest et al., 1987). Some studies have found that increased sedimentation reduces egg and alevin survival. Not all sediment increases have detrimental effects; there are cases where fish have maintained large and viable fish populations in streams with high chronic loads of fine sediment. Fish appear to react most negatively when fine sediment concentrations are both high and persistent (Newcombe and MacDonald, 1991). Newcombe and Jensen (1996) reviewed 80 published studies on the response of fish to suspended sediment in streams. Adult and juvenile salmonids exposed to particle sizes of 0.5-250 µm showed an increasingly negative response as sediment dose increased, and sublethal and lethal effects occurred at high doses.

Fine grained sediment suspended in the water column contributes to turbidity (along with organic and dissolved material) which is clearly linked to fish foraging efficiency (Madej et al., 2003). For example, increased turbidity is associated with impaired salmonid sight-feeding and gill damage (Rhodes et al., 1994; Lloyd et al., 1987).

Chapman (1988) reviewed laboratory and field studies on salmonid embryo survival. The majority of studies showed that survival rates decreased as the percentage of fine sediments in stream substrate increased, as illustrated in Figure 2-5. Size of emergents was also found generally to decrease as fine sediment levels increased. Despite the variability among studies in quantitative results, they consistently showed the adverse impacts of fine sediments on salmonid survival. Extrapolation of laboratory results to natural streams was judged to be currently impossible without better sampling techniques, and that establishing thresholds was not yet feasible without more carefully controlled field experimentation.

Scrivener and Brownlee (1989) investigated the effect of logging practices on gravel composition utilized by salmonids for spawning and fry survival in Carnation Creek on the west coast of Vancouver Island. After logging, the percentage of fine sediment increased in the streambeds, although the patterns of deposition and proportion of fine sediment in the streambed varied among treatments and timing of logging. After logging and a subsequent large snowmelt event, the survival to emergence rates of coho salmon fry declined to 16.4%, compared to a prior survival rate of 29.1%. The decline was correlated to decreasing mean particle sizes in the lower layers of the streambed cores. Survival to emergence of chum salmon fry declined from a prior rate of 22.2% to 11.5% post-logging, and was correlated to decreasing mean particle size in the whole streambed core and in the top layers of the core. Peak survival occurred during years when pea gravel and sand were washed out from the top layer.

Phillips et al. (1975) conducted laboratory experiments at the Alsea Watershed Study field station. As the proportion of fine sediment in the gravel mixtures increased, coho salmon fry emerged earlier and were smaller in size. Their survival rates decreased as fine sediment percentage increased, from 96% survival in the control gravel mixture to 8% survival in the mixtures containing 70% sand. Hillman et al. (1987) investigated the effect of fine sediment on juvenile chinook salmon, particularly the impact of fine sediment deposition on winter survival. Salmon winter rearing densities increased eightfold in glide areas (slow, shallow areas) after cobble was added, compared to densities the previous year. A significantly higher density of young chinook salmon (five times higher) used interstitial spaces in the altered areas than in the unaltered areas. When the cobble subsequently became heavily embedded with fine sediment, juvenile salmon densities decreased by more than 90% and were similar to densities pre-alteration.

Survival of incubating salmonids from embryos to emergent fry has been negatively related to the proportion of fine sediment in spawning gravels (Chapman, 1988; Everest et al., 1987; Scrivener and Brownlee, 1989; Weaver and Fraley, 1993; Young et al., 1991). As a rule of thumb, a 2% reduction in survival of coho salmon fry to emergence can be expected for each 1% increase in percent fines over natural levels (Cederholm et al., 1981). Juvenile salmonid densities decline as fine sediment concentrations increase in rearing areas. Increases in fine sediment can also reduce winter carrying capacity of streams by loss of concealment cover. Pools that lose volume from sediment (Jackson and Beschta, 1984; Lisle, 1982) support fewer fish (Bjornn et al., 1977), and fish that reside in them may suffer higher mortality (Alexander and Hansen, 1986). McHenry et al. (1994) reported that no steelhead or coho eggs survived if more than 13% fine sediment intruded into the redd[6]. Fine sediment can also affect the population of aquatic insects (Hicks et al., 1991). Similarly, populations of tailed frogs can be severely reduced or eliminated by increased sedimentation. Increased sediment reduces populations of benthic organisms by reducing interstitial spaces and flow used by many species and by reducing algal production. Waters (1995) considered the effects of increased deposition of sediments on benthic invertebrates as one of the most important concerns within the sediment pollution issue, especially in regards to the dependence of freshwater fisheries on benthic productivity.

Welsh and Ollivier (1998) studied the impact of highway construction and the resulting erosion on the abundance of stream amphibians in California old-growth redwood forest. The density of Pacific giant salamanders and southern torrent salamanders was significantly lower in streams impacted by road sediment. The density of tailed frogs was lower in their preferred riffle and step run habitat in sedimented streams as opposed to control streams. Corn and Bury (1989) compared the occurrence and abundance of amphibians in streams flowing through unlogged forest versus streams flowing through forests with prior logging in Oregon's Coast Range. Results were analyzed for the four amphibian species reported to be the most common and the dominant vertebrates of small streams in the Oregon Coast Range: tailed frogs (*Ascaphus truei*), Pacific giant salamanders (*Dicamptodon ensatus*), Olympic salamanders (*Rhyacotriton olympicus*), and Dunn's salamanders (*Plethodon dunni*). All four species occurred more frequently and had higher density and biomass in the streams flowing through unlogged as opposed to logged forest stands. The only physical habitat variable found to be significantly different between stand treatment was that streams in logged stands had more fine sediment. Studies from Oregon, Idaho, British Columbia, and Alaska, for instance, showed that salmonid abundance and fry survival decreased as fine sediment levels increased after logging (Hicks et al., 1991). Fine sediment in deposits or suspension also reduced the availability of food in streams by reducing invertebrate abundance and primary production. Suspended sediment increases were shown to affect salmonids in various ways, including avoidance, cessation of feeding, and disrupted social behavior. The increased frequency of landslides and other mass erosion events due to logging and roads changed channel morphology, reducing pool area and depths and resulting in stream reaches that were wider, shallower, and more prone to bank

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[6] Redd: The depressions in a gravel streambed created by salmonids to deposit eggs.

erosion. Studies in British Columbia, for instance, showed that pool habitat was reduced by an average of 79% in streams affected by debris torrents and suitable winter cover was reduced by an average of 75%. Coho salmon winter survival averaged 1.8% in stream reaches affected by debris torrents compared to survival rates of 24.5% in unaffected streams. The authors discussed studies showing salmonid abundance initially increasing after clearcutting. They note that these increases were documented only over the short term and that over the longer term (after 10 to 15 years), other research had indicated that populations could eventually decline to levels lower than those in old-growth forest.

Several other investigations in the Pacific Northwest have also shown that timber harvest can result in increased salmonid productivity, chiefly by enhancing autotrophic production within streams (Bisson et al., 1992). Loss of complexity, if accompanied by increased light and dissolved nutrients, is likely to result in productivity increases concentrated in only a few taxa that directly benefit from the changes. A similar pattern has been observed in the structure of aquatic invertebrate communities after logging (Bisson et al., 1992). The pattern of increased production of a few taxa accompanied by a reduction in overall biodiversity may be common to all consumer trophic levels in streams where habitat has been simplified but light and nutrients are more plentiful. Suspended sediment is not always detrimental to fish, and indexes based on duration and concentration are unrealistically simplistic (Gregory et al., 1993). Turbidity, can, for example, provide cover from predators (Gregory, 1993). However, in the overall context of research conducted on the effects of sedimentation on salmonids, other fish, invertebrates, and amphibians in stream ecosystems, the impacts are overwhelmingly negative.

The effects of roads are not limited to those associated with increases in sediment delivery to streams; they can include alterations to streamflow regimes, barriers to migration, and water temperature changes (Gucinski et al., 2001).

2.2.2.2 Flows

Road-related alterations in the timing and magnitude of peak flows and changes in base stream discharge and sub-surface flows affect the predictability and stability of streamflow, factors found to strongly influence salmonid densities by influencing overwintering survival and reproductive success (McFadden, 1969; Seegrist and Gard, 1972). For example, post-spawning high flows can wash out eggs, displace fry, and otherwise increase mortality (Latta, 1962; Shetter, 1961). Montgomery et al. (1996) noted research by other authors reporting that increases in scour depths were related to increases in stream discharge and velocity and increases in fine sediment transport. Those authors therefore concluded that increases in scour due to increased sedimentation from logging or roads could significantly increase the mortality of buried salmon eggs. Other authors state that the effect of roads on peak flows is relatively modest and the issues of changing stability and predictability because of roads may be of little importance to aquatic habitat suitability (Gucinski et al., 2001).

2.2.2.3 Temperature

Increases in temperature are correlated with construction of roads along valley bottoms next to stream channels and the resultant removal of riparian vegetation and reduction in riparian canopy cover. Roads in riparian zones prevent growth of dense stands of trees shading streams, and roads that travel long distances along stream channels would be more likely to yield a measurable effect on stream temperature (Luce et al., 2001). As noted above, increases in width/depth ratios in sensitive streams due to sediment delivery can also result in higher summer water temperatures even when shade is not lost. Such temperature increases can elevate stream temperatures beyond the range for rearing, increase susceptibility of fishes to disease, reduce metabolic efficiency, shift species assemblages, and inhibit upstream migrations (Beschta et al., 1987; Hicks et al., 1991). Filling of stream pools can also result in the in loss of low-temperature refuge.

2.3 Extent and Severity of Water Quality Impairments Due to Forest Roads

As noted above, sedimentation of streams is one of the most significant nonpoint source pollution concerns in the United States. This is especially true in the Pacific Northwest (Sidle, 1980) owing to the potential for adverse effects on aquatic ecosystems, critical fish habitat, stream morphology, reservoir capacity, quality of domestic water supplies, and aesthetic and recreational values (Anderson, 1974; Bilby, 1985; Bisson and Bilby, 1982; Meehan and Swanston, 1977). Increased sediment delivery to streams after road building has also been well documented in the research literature in California, Idaho and in the Eastern United States (Gucinski et al., 2001). However, since forest roads and stream crossings are recognized as major contributors of sediment to surface waters regardless of region, the potential effects of this pollution may be found wherever silvicultural activity occurs.

Precise quantification of the impacts of forest roads and other silvicultural practices on soil and water is not possible across the wide range of forest types and regions nationwide (Swank et al., 1989). However, research is available to provide a scientific basis of general principles that indicate the relative magnitude of changes to expect in different forest types (see Figure 2-65 for a map of the major forest types in the Continental U.S.). Although differences between regional forest types are noted below, similarities in the descriptions of forest erosion and water quality impacts from forest roads should also be recognized: natural geologic erosion is quite low from most forested lands; roads and skid trails are the primary sources of additional sediment associated with harvesting practices; effective procedures and methods are available for some regions of the country that minimize sediment from harvesting practices; and, many management goals for protecting water quality can be achieved by following BMP concepts.

2.3.1 Western Inland Conifers

The western inland conifer forest region is located in the Rocky Mountains, where it extends from Canada to the Mexican border. Forest types in this region range from the Rocky Mountain subalpine forests in Colorado and Wyoming to southwestern ponderosa pine stands in Arizona and New Mexico. The northern Rocky Mountain province comprises the mountainous headwaters of the Columbia and Missouri drainages. The remaining portion of the central and southern Rocky Mountains are located mainly in the upper and lower Colorado

River basins. Geomorphology, geology, and soils vary widely throughout the western inland conifer type. Noteworthy is an area in the northern Rocky Mountains called the Idaho Batholith. The geology of this area is granitic rocks and the soils derived from them are extremely erodible and present special management problems. Accelerated surface and mass erosion are often easily caused by silvicultural practices in the inland conifer type.

The amounts of erosion and sedimentation vary widely within the inland conifer type. Landslides are a major concern in 10-12 % of national forest lands in Idaho and Montana; however, the risk and occurrence of landslides is considerably less than in Pacific Coast Range. Landslides associated with roads accounted for 57-88% of total landslide occurrence (McCleland et al., 1997; Megahan et al., 1978).

2.3.2 Pacific Coast Conifers

The Pacific coast conifer forest region extends from southwestern Alaska through the Cascade Mountains in western Washington and Oregon and southward into the Sierra Nevada Mountains in northern and central California. This forest type also includes the Pacific Coast Mountains in northern and central California. Substantial increases in sediment yields have been noted on watersheds during and following the construction of forest roads in this region. Erosion rates on roads and landings in southwestern Oregon were 100 times those on undisturbed areas. Properly constructed roads on gentle to moderate slopes on stable topography present little hazard. However, construction difficulty and erosion hazard increase rapidly when roads are pushed into steep terrain, cut into erosive soils or unstable slopes, or encroached on stream channels (Stone, 1973). Sedimentation of streams is one of the greatest nonpoint source pollution concerns in the Pacific Northwest (Sidle, 1980).

2.3.3 Northeastern Conifers

The northeastern conifer forest region supports stands of spruce, fir, and pine in the northern part of the United States between Minnesota and Maine. These species are intermingled with the maple-beech-birch forest type in New England and aspen-birch type forests in the upper Great Lakes states. Scattered islands of red spruce and white pine stands extend into the Appalachian Mountains as far south as Georgia. The sparseness of streams, porous soils, and more than 760 mm (30 inches) of precipitation create a hydrologically stable environment in the northeastern conifer region. Forest disturbances generally heal quickly. Cut slopes on roads and roads crossing streams have long been recognized as the primary sources of stream sedimentation. Some of the deep unconsolidated gravels and sands of glacial origin erode badly if disturbed by road construction. However, efforts have been made to better locate and design roads to minimize this impact (Stone, 1973). Less expensive roads, having lower standards, have been tested as a measure for reducing environmental impacts as well as construction costs (Kochenderfer et al., 1984). Such lower standard roads may be acceptable in this region when their location avoids erosion hazards and adequate riparian buffers are maintained.

2.3.4 Eastern Hardwoods

The eastern hardwood forest region is considered to encompass hardwood forest types within the Appalachian Highlands physiographic division, which extends from Maine to northern Georgia. A major concern in harvest and regeneration practices is the impact on stream sedimentation. Natural geological erosion in the moist climate of forested lands in the hardwood region averages about 0.1 ton/acre/year (Patric, 1980). The primary sources of additional sediment associated with silvicultural practices are roads and skid trails as documented in many studies (Lull and Reinhart, 1972; Anderson et al., 1976). Some temporary increases in stream turbidity are an inevitable consequence of any harvesting but can be minimized by careful layout, construction, and maintenance of roads. The most critical aspect of road construction occurs at stream crossings since soil eroded from cuts and fills has direct access to the stream. A key factor in erosion control for roads is rapid establishment of surface protection such as a grass cover (Swift, 1984a). Immediately after construction, the roadbed accounts for only 10-30 percent of the total soil loss from roads (Swift, 1984b), but after cut and fill stabilization, the roadbed may be a major source of stream sediment, particularly with continual use. Thus, the type and amount of road surfacing are important factors in controlling soil loss. In general, effective procedures that minimize sediment from logging and road construction activities are well known (Kochenderfer, 1970; Hewlett and Douglass, 1968) and need only to be judiciously applied.

2.3.5 Southern Conifers

The Piedmont and Upper Coastal Plain regions of the southeastern US have much higher suspended sediment concentrations in undisturbed forest watersheds. A baseline value of about 60 mg/L has been suggested as the average annual sediment concentration in stormflow from small, pine-covered watersheds in the south (Ursic, 1979). A more recent review of background-level data for all pine types by Ursic (1986) indicates an average annual sediment concentration of 0.006 ton per hectare-centimeter (0.007 ton per acre-inch) of flow. Much of the sediment comes from erosion of the minor channels developed during former land uses; therefore, natural sedimentation rates may vary substantially depending upon channel characteristics. The increases in stormflow from harvesting and site preparation accelerate the rates of baseline sediment losses to varying degrees depending on the nature of the disturbance, characteristics of the soil, and climatic factors. Erosion and sedimentation are noted as primary forest management concerns in 4 of 8 physiographic provinces in the southeast (Jackson et al., 2004). The duration of elevated sediment losses following road construction is related to how rapidly vegetation becomes re-established. Some studies indicate that sediment losses return to near preharvest levels within a 4 to 5 year period after disturbance.

2.3.6 How and why do Water Quality Impacts from Forest Roads Vary?

The impacts of forest road on water quality tend to be concentrated in certain regions of the country and specific locations in the forest landscape. Increased sediment delivery to streams after road building has been well documented in the research literature in the Pacific Northwest, California, Idaho and in the Eastern United States (Gucinski et al., 2001). In fact, most studies of roads have been conducted in only a few regions (the Pacific Northwest, Rocky Mountains, Appalachians, Interior Highlands, and Piedmont), so the ability to generalize to other regions is limited. Statements about the effects of roads on mass erosion are limited to those landscapes affected by such processes. This section will focus on forest roads in highly impacted locations, as these tend to be the most studied. Detrimental impacts from roads in these regions and locations can be inevitable, and the extent of such impacts is large as is the legacy of past road building (Williams, 1999). Within the range of the northern spotted owl, there are about 180,000 km (or 111,800 mi) of roads, including 250,000 stream crossings (about 1.25 per km or 2 per mile) and a significant number of culverts that are unlikely to be able to withstand a 25 year storm event (FEMAT, 1993). Within the Interior Columbia Basin Ecosystem Management Project (ICBEMP) area, there are at least 204,333 km (126,900 miles) of inventoried roads and an additional 61,300 to 102,166 km (38,100 to 63,500 miles) of uninventoried roads (Lee et al., 1997).

Representatives of the forestry industry including the NCASI contend that a few roads cause most of the problems, i.e., the so-called 80/20 rule (80% of the problems come from 20% of the roads; NCASI, 2001). Some regional studies support this view. For example, Rice and Lewis (1992) developed an objective methodology to estimate erosion risk on forest roads and in harvest areas on private land in northwestern California. It was based on 260 plots sampled from the area harvested under 415 Timber Harvest Plans (THPs) completed between 1978 and 1979. Results confirmed previous findings that most erosion related to forest management occurs on a small fraction of the managed area. Locations where the volume of eroded soil were larger than the minimum size inventoried in that study (> 13 cubic yards) occupied only 0.2 percent of the area investigated.

However, earlier assessments have found the problems associated with forest roads to be more widespread. An example is the direct connection of road drains to streams. Direct drainage connections signify likely impacts of roads on stream sedimentation, because sediment eroded from the roadway is delivered directly to the stream. A number of field studies have documented the extent of direct drainage connections in forest road networks in the Pacific Northwest. Reid and Dunne (1984) found that 75% of road drainage in a western Washington study area was discharging directly to streams; Bilby et al. (1989) reported 34% direct discharge of road drainage in southwestern Washington; and Wemple (1994) found 57% of road drainage in the western Cascades of Oregon was discharging directly to streams. A 1997 ODF study of road-sediment in the Tillamook State Forest found that 25 to 39% of the road system was delivering sediment to streams from 459 different discharge points (live stream culverts, where stormwater ditches joined flowing stream that then flowed through culvert under the road) along 42 miles of road (ODF, 1997). Skaugset and Allen (1998) reported 31 percent of the surveyed road length in 5 Oregon regions was rated as certain (25%) or possible (6%) to deliver sediment to streams.

Even in the same region, road effects differ by landscape position (Gucinski et al., 2001). Ridgetop, midslope, and valley floor roads all produce different effects, based on the topography they cross; the degree and type of interaction with stream networks; the stability and response to storms; and the effects on fire, wildlife, and vegetation.

The geographic patterns of roads in forest landscapes differ substantially from place to place, with commensurate differences in environmental effects (Gucinski et al., 2001). In the glaciated terrain of southeastern Alaska, for example, main roads were built on the broad, major valley floors, and the high-value timber that grew on lower hillslopes was brought downhill to them. In forests along the west side of the Sierra Nevada in California, on the other hand, major roads were built along broad ridges, with secondary roads leading down into headwater areas. The main roads into western Oregon forests entered watersheds along narrow stream bottoms and then climbed the adjacent steep, unstable hillslopes to access timber extending from ridge to valley floor. These configurations, combined with local geology and climate, resulted in very different effects of roads on stream and watershed processes.

Adverse environmental effects from logging roads change over time and vary with season of construction and use, age, weather, kinds and intensity of maintenance, traffic level and other factors. Understanding how and why these effects vary is critical to appreciate the extent and severity of forest road impacts on water quality, and sets the stage for considering how these impacts can be reduced using BMPs. Focusing on sediment impairments, spatial and temporal factors to consider include the following:

Geology, geomorphic location, soils and terrain - Luce and Black (1999) showed that soil type makes an important difference in terms of road erosion and BMP performance. Soils vary in erodibility, depending on their properties. Landsides in Oregon's Coast Range were concentrated in "soft sedimentary bedrock" that was geologically young, poorly consolidated, yet on steep slopes (Durgin et al., 1988). Percentage and length of slope are the most significant topographic variables affecting erosion.

Climate - Rainfall intensities are greatest along the coasts and generally decline to the interior. Road erosion in western Montana was limited by low erodibility of dominant parent materials and low rainfall (Sugden and Woods, 2007). Alternate freezing and thawing of soils also exert strong forces for the detachment of soil particles. High summer temperatures desiccate bare soil, and a layer of loose, structureless soil similar to that caused by frost heaving is produced. Thus, temperature extremes set the stage for high erosion losses from bare soils during rainstorms.

Age and density of road network - Road area distributed in "critical locations" may be a better indicator of impacts and cumulative effects than road density.

Sensitivity of designated uses – The presence of salmonids and other sensitive and endangered species in a receiving water may be much more vulnerable to sedimentation.

Roads produce geomorphic responses ranging from the chronic, long-term contributions to streams of relatively small amounts of fine sediment to the catastrophic contributions of large amounts of sediment during mass failures (Williams, 1999). Further, the results of these geomorphic changes produce cumulative consequences that can be manifest considerably downstream.

2.3.6.1 Surface Erosion

Erosion occurs when the energy for detachment and transport of soil particles exceeds the cohesive and adhesive forces which bind soil in place. The energy for erosion comes principally from rainfall and flowing water. The greatest source of energy is from falling raindrops. Rainfall intensities are greatest along the Pacific, Gulf and Atlantic Coasts and generally decline to the interior (Douglass, 1975). Rain which does not infiltrate the soil moves overland and possesses kinetic energy for detachment and transport of soils. Total energy is influenced mostly by velocity. In both detachment and transport of soil, velocity of flowing water is a key factor. Velocity of overland flow, if it occurs under forest stands, is slow. But since overland flow is concentrated in rills and gullies, the velocity of flow, depth of flow, or both are increased, the energy is concentrated, and erosion losses increase sharply.

The major effect of forests on erosion is to reduce slightly the volume of rainfall reaching mineral soil and to change greatly the energy available for detachment and transport of soil particles (Douglass, 1975). Water temporarily stored in the forest floor drains slowly, thus increasing the likelihood of infiltration. The forest floor also offers resistance to overland flow and reduces the velocity of any water which may fail to infiltrate. Increases in erosion have been associated with cutting the forest, but if the forest floor is not removed or grossly disturbed by cutting the overstory, infiltration rates remain high and overland flow is virtually absent. When the forest floor is removed by the building of roads, the skidding of logs, or wildfire, raindrop energy is dissipated on mineral soil. Infiltration rates are reduced by compaction and puddling of the soil. When infiltration rate falls below the rainfall rate, overland flow and sheet and rill erosion occur.

Chronic surface erosion from road surfaces, cutbanks, and ditches is well documented (Bilby et al. 1989; Megahan and Kidd, 1972; Reid and Dunne, 1984), and is often the dominant source of road-related sediment input to streams. In the initial years after construction, rates of surface erosion appear highest (Megahan and Kidd, 1972) and, on unpaved roads, are closely correlated to traffic volume (Reid and Dunne, 1984). However, because of maintenance problems, roadbeds and road-related ditches and channels are continuing sources of sediment long after construction is complete (Miller et al., 1985; Swift, 1984a and 1988).

Sediment erosion on forest roads in the Oregon Coastal Range was correlated to the road length between culverts, the square of the road slope, soil erosivity, and ditch cleaning (Ice et al., 2004). Other factors related to surface erosion rates include vegetative cover and climate (amount of precipitation, occurrence of freeze-thaw cycles). Roads account for 4% of the land area in Coast Range mountains, but 76% of measured erosion (Durgin et al., 1988). One third of the sediment production was from surface erosion. The most common source of sedimentation was from fillslopes immediately adjacent to watercourse crossings

Other literature shows that wet season road use can be a major source of fine sediment (Mills et al., 2003). Road surfacing and drainage practices can have a very large effect on both erosion and the delivery of sediment to streams in this situation. The use of gravel-surfaced roads during wet periods has been documented as a major source of fine-grained sediment and associated stream turbidity (Reid and Dunne, 1984). Studies by Weyerhaeuser and others (Bilby, 1985; Duncan and Ward, 1985; Bilby et al., 1989) found a good correlation between rock hardness and sediment delivery. They also found that most of the sediment delivered to streams from the road surface was very fine, clay-sized particles.

Extensive research has been conducted on road erosion and sediment travel distances in highly erodible parent materials such as the granitics of the Idaho batholith (Megahan and Kidd, 1972; Megahan et al., 2001; Burroughs and King, 1989), and the high precipitation and landslide prone climate of Oregon’s Coast Range (Wemple et al., 1996; Luce et al., 2001; Brake et al., 1997). Less research has been conducted in other parent materials. Road erosion in western Montana is limited by both low erodibility of the dominant parent materials and low rainfall. Woods et al. (2007) investigated sediment travel distances below drivable drain dips along unpaved roads in the metasedimentary Belt Series and glacial till parent materials of western Montana. The generally low sediment travel distances observed in that study indicate that most drivable dips along unpaved roads in western Montana did not deliver sediment to streams. The vast majority of the sediment introduced to streams came from relatively few drainage outfalls.

2.3.6.2 Mass Movements of Soil

In areas with steep slopes, landslides are the dominant erosional mechanism. Rates of mass movement (wasting) vary greatly across the landscape, depending on climatic, geologic, and topographic factors as well as factors associated with management practices (NCASI, 2001). Landslide frequency can be greatly accelerated by road management practices (Sidle et al. 1985). According to Megahan et al. (1992), 88% of landslides within Idaho were associated with roads. Roads have been associated with most failures and failure volume in most studies, but certainly not in all studies and all locations (NCASI, 2001). In addition to the detrimental effects on vulnerable fish species and their habitat through increased sedimentation, landslides can result in serious personal injury and downstream property damage.

Mass movement can occur as shallow debris slides, deep-seated slumps, and rapid debris flows (Williams, 1999). In areas ranging from the Pacific Northwest to New Zealand, mass movements were 30 to 300 times greater in roaded than in unroaded watersheds (Sidle et al., 1985). Erosion rates on roads and landings in the Klamath mountains of southwest Oregon were 100 times greater than those on the undisturbed area (Amaranthus et al., 1985). Total sediment production from logging roads in the Idaho batholith was 770 times higher than in undisturbed areas; approximately 71 % of the increased sediment production was due to mass erosion and 27% to surface erosion (Megahan and Kidd, 1972). Ninety-one percent of the annual sediment production by land use activities in the South Fork of the Salmon River has been attributed to roads and skid trails (Arnold and Lundeen, 1968). Increased rates of landsliding in roaded areas as compared to unroaded forested areas also have been documented in Washington (Reid, 1981) and northern California (Hagans et al., 1986). The majority of landslides associated with managed forests came from road Right-of-Ways and were often associated with specific practices such as sidecast road construction, poor location and inadequate drainage (Ice et al., 2004). Stream diversion at road crossings and landslides initiated by culvert failures are two other related road impacts.

In addition to the reported correlation between mass movement and roads, a number of geomorphic locations within a watershed are more susceptible to landsliding than are others (Williams, 1999). Most of the landslides observed in Idaho by Weaver et al. (1998) were most likely to occur in the inner gorge, swale, or break-in-slope (93%, 86%, and 68% respectively for the North Fork Clearwater, Lochsa River, and Boise River basins). These three locations also have been identified as being at higher risk of landslide during infrequent, high intensity, or long duration storm events in northwestern California by LaHusen (1984) and in Oregon and southern Washington by Weaver and Hagan (1996). The risk of landslide in these areas is even greater when these hillslope locations are roaded (Weaver et al., 1998).

2.3.6.3 Road Drainage and Sediment Delivery

Historically, logging roads were intentionally designed to discharge stormwater directly into streams. This practice also directly delivered sediment eroded from roads into the streams. More recent design standards acknowledge that direct discharges are ecologically undesirable and seek to direct drainage onto porous forest soils for infiltration. However, direct discharge into streams is still commonly reported. Runoff from roads generally follows one of several potential pathways: infiltration back into the hillslope below the road with no delivery to streams; direct delivery at channel crossings; direct delivery through gullies formed below relief drains; or indirect delivery via overland flow below the road (NCASI, 2001). Direct delivery at channel crossings is the most common and most rapid form of delivery, and occurs where roadside ditches and/or road surface runoff run directly to the stream crossing structure. The prominence of direct delivery and gullying is documented by research done in western Washington and Oregon. These studies found that 42 to 66% of road drainage points discharged to hillslopes with no delivery to streams, 28 to 35% of drains delivered directly to streams, and 17 to 28% delivered via gullies (Bilby et al., 1989; Bowling and Lettenmaier, 1997; Wemple et al., 1996). More importantly, however, these same or similar studies have found that 17 to 35% of the total road *mileage* contributes sediment to the stream system (Bowling and Lettenmaier, 1997; McGreer et al., 1997), or conversely, 65 to 83% of the road mileage did not contribute sediment to streams. Monitoring conducted in the mid-1990s shows that about one-third (29-39 %) of active and inactive roads on state and private lands in Oregon can deliver sediment to streams by ditch delivery (Skaugset and Allen, 1998). An inventory of road drainage sites in three watersheds in southwestern Washington found two thousand drainage points along 730 km of road; 34% of the drainage points directly entered streams rather than draining into the forest floor (Bilby et al., 1989).

2.3.6.4 Road Maintenance

Forest roads require significant ongoing maintenance to prevent deterioration of the roadway by grading, ditch cleaning, unplugging culverts, etc. Poorly maintained roads are subject to periodic blockage or failure as transportation systems due to both surface erosion and mass wasting events, primarily during floods. Erosion and sediment delivery associated with such failures can be extreme. In addition, roads produce chronic surface erosion impacts, particularly where poorly located and maintained. Although sediment problems are sometimes worsened by too much maintenance, it is usually the neglect of maintenance that leads to problems with road erosion and mass wasting. Road maintenanace is an ongoing expense, and economics is the primary reason that forest roads are poorly maintained.

This is well illustrated by statistics for the National Forests. The NFS road system is considerably more extensive than the Interstate Highway System (Grace and Clinton, 2006) and consists of over 600,000 km of roads of varying classes and an estimated 7,600 bridges (TetraTech, 1999). There are a variety of road standards and road jurisdictions within the National Forests. Figure 2-3 summarizes the legal basis and definitions relative to forest roads in National Forests (Coghlan and Sowa, 1998). Most of these roads were initially constructed for management activities such as harvesting and fire prevention. In recent years, road maintenance has been sharply reduced because funds for maintenance as well as maintenance by timber purchasers have declined (Williams, 1999). This has resulted in chronically poor road maintenance. In the southern Appalachians, forest roads often are not maintained at all, are subjected to maintenance that is inadequate for the level of road use, or are scheduled for maintenance in such a way that the work is poorly timed relative to storm patterns (Swift, 1984b and 1988). This pattern is not unique to the East. There has been a progressive degradation of road drainage structures and function in the Columbia River Basin (Lee et al., 1997), and about 60% of all NFS roads are not fully maintained to the planned safety and environmental standards for which they were designed (USFS, 1999). It is not clear whether the same trends are taking place for forest roads in timberland owned by the commercial forest industry and other private timberland owners, but this may be a reasonable assumption.

During the early 1970's through the 1980's the value of timber started to fluctuate (Coghlan and Sowa, 1998). A dramatic increase in the development of forest road miles also occurred between 1977 and 1987. In an attempt to reduce roading costs, access was frequently provided through temporary roads rather than the more costly permanent roads. Temporary roads have lower initial development costs than permanent roads, but their long-term management implications are more significant. The reliance on temporary as opposed to permanent roads created some unwanted impacts. These lower standard roads were also not intended to serve the purposes that they have evolved to serve, namely increased recreational use in the National Forests. There has been an eleven-fold increase in traffic in National Forests in comparison to the 1950's. Increased use and traffic has resulted in the need for significantly more maintenance, and has resulted in more erosion and sedimentation.

Revisions in the USFS timber management practices during the 1990's limited the harvest activity for which the existing roads were designed. Consequently, timber harvesting presently accounts for only 0.5% of all forest road use. Commercial users, such as timber haulers, are responsible for traffic-generated maintenance commensurate with their use, so commercial use maintenance has decreased in proportion to the decrease in timber harvest. Current funding is sufficient to maintain about 40 percent of the roads to planned service levels. The balance of the roads are maintained according to priority safety and environmental needs. Appropriated annual maintenance ranges from $300 to $600/mile for maintenance level 3–5 roads, $60 to $100/mile for maintenance level 2 roads, and $20 to $40/mile for maintenance level 1 roads. It is practically impossible to maintain roads to designed standards based on these funding levels. For comparison, in 1994, the average annual costs of maintaining a mile of gravel or loose aggregate road was $7,986 for all counties, and $1,995 for all townships (Coghlan and Sowa, 1998). The backlog of deferred maintenance on roads in the National Forests has been estimated to be $4.1 billion (Bellingham Herald, 2007). The cost to remove barriers to fish passage at 25,500 stream crossings would cost an additional $1.9 billion.

2.3.6.5 Age of Roads and Road Network

Much of the potential watershed-scale effects of roads are likely related to roads designed and constructed under older administrative rules (FPAC, 2001). These make up the majority of the roads on the landscape, often constructed with practices presenting greater risk of adverse effects to aquatic habitat. The result of over 100 years of forest access is that most of the roads needed today for management of private lands have already been built (NCASI, 2001). However, much of today's existing road system was designed and built to standards and in locations that would not be used if the system were built "from scratch" today. Road networks differ greatly in development through time and layout over terrain, and carry this history into their present performance (Gucinski et al., 2001). The geographic patterns of roads in forest landscapes also differ substantially from place to place, with commensurate differences in environmental effects (Gucinski et al., 2001). Road effects, when aggregated at the landscape scale, are dependent on road design and road location, and assessment of these effects must consider the proportion of old roads to new roads that incorporate improved engineering design (Gucinski et al., 2001).

Cederholm et al. (1981) reported that large amounts of the sediment embedded in spawning gravels in the Clearwater River of Jefferson County, Washington came from roads built before 1972. In Oregon, "old" roads are considered to be those built before 1983 (i.e., before end-hauling was introduced to eliminate the hazardous side-casting of excavated soil). Current methods of road construction and erosion prevention have vastly reduced erosion problems.

Numerous large landslides associated with the road system in the South Fork of Caspar Creek occurred in early 1998, indicating that "legacy" roads continue to be significant sources of sediment decades after they were constructed (Cafferata and Spittler, 1998). Old roads built with practices prevalent in the 1950's, 1960's, and early to mid-1970's are still significant sources of erosion. In virtually all of the studies of road failures due to mass wasting reviewed by NCASI (2001), the majority of failures observed are from roads built years ago in locations and with construction methods which later became unacceptable and/or illegal, and thus road systems pose significant potential for legacy effects.

In addition, however, it is important to note that increases in sedimentation from new roads and landings are unavoidable even using the most cautious logging and roading methods (Williams, 1999). Few studies have systematically and quantitatively evaluated the extent to which new road design, siting, construction and engineering practices have resulted in lower mass erosion rates and reduced the ecological impacts of roads (McCashion and Rice, 1983). An analysis of the effects of new road construction and siting practices in the Oregon Coast Range suggested some reduction in slide frequencies over those resulting from the old roading practices (Sessions et al., 1987). However, the new practices were not "put to the test" as no large storms occurred during the study period. McClelland et al. (1997) also reported that following intense rain-on-snow precipitation during the 1996 floods the rate of failure of roads built in the 1970s through the 1990s was approximately half the rate of failures of roads built in the 1950s and 1960s. Examination of the improved road design practiced by the Boise National Forest indicated that while the new practices were an improvement over the old roading practices, total accelerated sediment yields still were 51 % greater than natural (undisturbed) levels (Megahan et al., 1992).

2.3.6.6 Road Density and “Critical” Locations

The density and location of roads have been correlated to impairments of forested watersheds. The Interior Columbia Basin Ecosystem Management Project (ICBEMP) Assessment of Ecosystem Components in the Interior Columbia Basin of Idaho, Oregon and Washington (Quigley and Arbelbide, 1997) was one of the few examples of landscape-scale analysis of road influences. The evaluation of road density and forest and range integrity in that study serve to illustrate landscape-scale interaction of roads with their surroundings (Gucinski et al., 2001). Forest and range indices of integrity were developed that showed sub-basins having the highest forest-integrity index were largely unroaded. Of the five indicator variables used, the proportion of a subbasin composed of wilderness or roadless areas seemed most closely associated with subbasins having high integrity indices; 81 percent of the subbasins classified as having the highest integrity had relatively large proportions of wilderness and roadless areas (>50 percent). Conversely, of subbasins with the lowest integrity, 89 percent had low proportions of roadless and wilderness areas; 83 percent had relatively high proportions of at least moderate road density (0.27 miles/square mile). None of the seven subbasins having high rangeland integrity had areas of moderate or high road densities. This assessment found that increasing road densities (combined with the activities associated with roads) are correlated with declines in anadromous salmonid species (NCASI, 2001). In other words, road density and fish populations are inversely correlated across a large area in the interior Columbia basin. Linkages show that strong fish populations were more frequently found in areas with low rather than high road densities (Gucinski et al., 2001). Supplemental analysis "clearly show that increasing road densities and their attendant effects are associated with declines in the status of four nonanadromous salmonid species .... they are less likely to use highly roaded areas for spawning and rearing, and, where found, are less likely to be at strong populations levels." (Lee et al., 1997). However, the ICBEMP report also noted that the component contributions (causes) of effects associated with roads could not be identified, and that they were therefore “forced to use roads as a catch-all indicator of human disturbance.” The correlation of basin or subbasin integrity is not total, thereby suggesting that other variables and mechanisms are complex and non-uniform.

The degree of connectivity between roads and streams (that is, the number of stream crossings and areas where roads and streams are near enough to strongly interact) is recognized as a good general indicator of the interactions between the two and of the potential effects roads can exert (Wemple, 1994). Where both stream and road densities are high, the incidence of connections between roads and streams can be expected to also be high, resulting in more common and pronounced effects of roads on streams than in areas where road-stream connections are less common and dense (Gucinski et al., 2001). Eaglin and Hubert (1993) studied the effects of logging and associated road construction on streams and on trout populations in the Medicine Bow National Forest of Wyoming. The amount of fine sediment in a stream reach increased, and the embeddedness of fine sediment (its coverage of large particles) in the substrate increased as the proportion of logged area increased and as the extent to which roads crossed watercourses increased. Trout standing stocks also decreased as the density of road culverts increased. Cederholm et al. (1981) found that the percent fine sediment in spawning gravel increased above natural levels when more than 2.5% of the drainage basin was covered by roads. King and Tennyson (1984) found that the hydrologic behavior of small forested watersheds was altered when as little as 3.9% of the watershed was occupied by roads.

Other scientists looking at large scale physical variables relating to fish abundance have also noted that increased road density yields lower fish abundance (Lee et al., 1997) or occurrence (Dunham and Rieman, 1999). Luce et al. (2001) applied a predictive watershed erosion model to estimate the average annual sediment yield from surface erosion in 18 small basins. The results suggested that road density correlates poorly to sediment yield from surface erosion (Luce et al., 2001). They concluded that a strategy aimed at reducing road miles alone may not reduce sedimentation in streams.

Road area distributed in “critical locations” has been suggested as a better indicator of cumulative watershed effects than road density alone. The Critical Site Erosion Study (CSES) was a study of the occurrence of critical sites, defined as sites where more than 189 m^3/ha of soil were eroded, in harvest areas and forest roads (Lewis and Rice, 1989). The sampled site population came from areas covered by Timber Harvest Plans completed in California between November 1978 and October 1979. Because of high landowner cooperation, CSES came close to obtaining a truly random sample of the target population. The results largely confirmed previous findings (Rice, 1992). Critical sites contained 65% of the erosion but occupied only 2% of road length and 0.5% of harvested area. The CSES also confirmed the dominance of road-related erosion over harvest area erosion, which has been noted in studies since at least 1954 (Anderson, 1954). Roads yielded 70% of the total erosion volume. The erosion rate on roads was 21.5 times that in harvest areas, close to the ratio of 17 reported by McCashion and Rice (1983). These findings confirm the ubiquitous “80-20 rule,” in this case, 80% of the problems come from 20% of the roads.

2.3.6.7 Cumulative Impacts and Effects

Logging is generally conducted in large areas (tracts or parcels) that often comprise major portions of catchments or watersheds. A road network develops in forested watersheds, resulting in numerous chronic sediment sources, landslides and/or obstacles to fish passage. If a large number of such sources (possibly hundreds or thousands) deliver sediment into the streams in a watershed, they will have a cumulative impact on the sediment budget of the streams, rivers and other downstream water bodies, resulting in significant accumulation of sediment in deposition locations. Cumulative impacts from these numerous sediment sources tend to be greater downstream of larger watersheds; watersheds with more forestry activity, higher road density and/or problem roads, crossings, etc.; watersheds with older road networks and a greater percentage of legacy roads; and watersheds where the rates of chronic sediment delivery and/or mass wasting are higher due to regional and site-specific factors. Again, much of the potential for the watershed-scale effects of roads is likely related to roads designed and constructed under older administrative rules (FPAC, 2001). These make up the majority of the roads on the landscape, often constructed with practices presenting greater risk of adverse effects to aquatic habitat.

In the Caspar Creek watershed, much of the sediment measured in the tributaries has been trapped behind woody debris or otherwise stored in the channels, so that much of it has not yet been measured downstream (Lewis, 1998). Suspended sediment transport per unit watershed area tends to increase downstream in the absence of disturbance. This tendency was apparent in the pretreatment data analyses and could be reflecting the greater availability of fine sediment stored in these lower gradient channels. The relevance to cumulative effects is that downstream locations might reach water quality levels of concern with a smaller proportion of watershed disturbance than upstream locations. To the extent that larger watersheds reflect average disturbance rates and therefore have smaller proportions of disturbance than the smallest disturbed watersheds upstream, one might expect sediment loads downstream to increase by less than those in the logged tributaries, reducing the overall variability among watersheds. In addition, as mentioned before, some of the sediment may be stored for several years before reaching the lower stations. In Caspar Creek, the effects of multiple disturbances in a watershed were approximately additive. Downstream suspended load increases were no greater than would be expected from the proportion of area disturbed (Lewis, 1998). To the contrary, most of the increased sediment produced in the tributaries was apparently stored in the main stem and has not yet been measured at the main-stem stations.

Cumulative impacts are those influenced by multiple activities, as are most environmental impacts (Reid, 1999). In reality, then, almost all off-site environmental impacts are cumulative impacts. When impacts involve the transport of water, sediment, or woody debris through a watershed, they are referred to as "cumulative watershed impacts." Cumulative watershed impacts are of considerable concern because they are responsible for much of the damage to property and to public-trust resources that occurs away from the site of land-use activity.

Cumulative watershed impact influences, or is influenced by, the flow of water through a watershed (Reid 1998). Cumulative watershed effects, a phrase which has widely replaced reference to “impacts,” can be additive or synergistic and involve modification of water, sediment, nutrients, pollutants, and other watershed system components (Swanson et al., 2000). An example of such effects would be where forest roads and timber cutting contributes to increased peak streamflows and sediment loads, leading to aggradation of downstream areas, which in turn results in lateral channel migration causing streambank and floodplain erosion, which entrains additional sediment.

Reid (1993) provides a broad and detailed summary of cumulative watershed effects of diverse land-use activities, such as grazing, roads, logging, recreation, and water extraction. She also addresses alternative approaches for assessing cumulative effects (Reid 1993, 1998). Cumulative effects can be addressed by examining the changes triggered by a particular land-use activity and how these changes interact with effects of other land uses and natural processes. Such an approach is best undertaken as a long-term study with substantial focus on mechanisms of transport, transformation, and storage within the watershed.

An important development in anticipating and hopefully minimizing cumulative watershed effects has been the watershed analysis developed for use by federal (e.g., Regional Ecosystem Office, 1995) and state (WFPB, 1995) agencies in the Pacific Northwest (Swanson et al., 2000). The general objective of the federal watershed analysis procedure is to gain an understanding of present and prospective future mechanisms affecting watershed conditions.

Thus, watershed analysis provides a useful starting point for assessments of cumulative watershed effects. However, Reid (1998) asserted that neither of these "widely used watershed analysis methods provides an adequate assessment of likely cumulative effects of planned projects."

The term "cumulative effects" is intuitively appealing, as it suggests that environmental impacts of specific management activities cannot properly be viewed in isolation from a broad perspective of land management at large spatial scales and long time scales (Bisson et al., 1992). An underlying assumption has been that although individual management actions by themselves may not cause undue harm, taken collectively, such land use activities may result in unacceptable stream habitat degradation and long-term declines in fish abundance. As seemingly logical as this concept is, clear examples of cumulative effects of forest management on stream habitat have been difficult to demonstrate in all but the most severely degraded river systems. Establishing unambiguous relationships between abundance of fish populations and cumulative environmental change has been equally difficult, if not more so.

Specific changes in stream environment caused by past forest practices in the Pacific Northwest (PNW) vary according to logging and reforestation history, watershed geology, regional climate, and the degree of protection given to riparian zones during management activities (Bisson et al., 1992). The one change that appears to be consistent over all areas in which the effects of forest management on streams have been studied is a trend towards simplification of stream channels and a loss of habitat complexity (Bisson and Sedell, 1984). Simplification of stream channels involves loss of hydraulic complexity (i.e., variation in depth and velocity and obstructions), elimination of physical and biological interactions between stream and floodplain, reduction of structures that serve as cover from predators, increase in dominance of one particular substrate type, and the loss of sediment and organic matter storage capacity. This is most evident in the changes in frequency, size, and location of different types of habitat units within the channel. The most pervasive change has been a reduction in the frequency and size of pools that constitute preferred habitat of certain species and age classes. There have been two principal causes of pool reduction in PNW streams: filling of pools by sediment (Megahan, 1983) and the loss of pool-forming structures such as boulders and large woody debris. Bisson et al. (1987) cited numerous studies that have associated declines in fish abundance with the loss of pools and woody debris in PNW streams. In addition to reductions in the number and size of large scour and plunge pools, forestry and other land use practices have led to stream channel simplification by eliminating edge habitat along stream margins, although this is not necessarily an effect of roads.

2.4 How are the Water Quality Impacts From Forest Roads Quantified and Documented?

National level assessments of water quality are based on state lists of impaired waters, the so-called 305(b) and 303(d) lists. These assessments represent the only available National data on the extent and causes of impairment to rivers and streams, lakes, wetlands, and other waterbodies. Section 305(b) of the CWA requires the states to describe the quality of their surface waters including the extent to which water quality standards are being met. USEPA is also to biennially provide a prioritized list of waters that are impaired and develop pollution controls; this data is discussed separately in Section 2.5 (below). Fourteen National Water Quality Inventory (NWQI) reports have been published since 1975; the most recent reports were published in 2000 and 2002. For the 2000 report, states assessed 19% (699,946 of 3,692,830 miles) of the nation’s total river and stream miles; 43% of its lake, pond and reservoir acres; 36% of its estuarine square miles; and 92% of Great Lakes shoreline miles. This report will focus on the assessment results for rivers and streams, as these are the waterbodies most likely to reflect impairments due to forest roads. The states assessed 142,480 fewer river and stream miles in 2000 than in 1998. This 17% decrease was primarily a result of changes in assessment and reporting methods in a few states, for the most part reflecting a move toward the use of more reliable monitoring data and a greater reluctance to include qualitative information or older data in water quality assessments. The states reported that 61% of the 699,946 assessed river and stream miles fully supported all of their uses. As reported in earlier assessments, sedimentation remained one of the most widespread pollutants affecting assessed rivers and streams. Sedimentation impaired 84,503 river and stream miles (12% of the assessed river and stream and stream miles). Sources of sedimentation included agriculture, urban runoff, construction, and forestry. Alteration to river and stream habitats was reported by the states to cause impairment to 58,807 miles (8% of the assessed river and stream miles and

22% of the impaired river and stream miles). In this case, only habitat alterations that did not affect water flow were considered because states and tribes reported stream flow alterations (such as dams and irrigation) under a different category. Examples of habitat alterations that do not directly affect stream flow include the removal of woody debris or stream bottom cobblestones. Habitat modifications result from human activities such as flow regulation, logging, and land-clearing practices. The 2000 report listed nonpoint sources – agriculture, hydrologic modification, habitat modification, urban runoff, and silviculture - as leading sources of river and stream impairment. Silviculture was the 5th ranked source, responsible for impairment of 28,156 river miles; this represents 10% of impaired river miles and 4% of all assessed river miles. Ten states listed silviculture as a major source of impairment to assessed rivers and streams: Arizona, California, Kentucky, Louisiana, Maine, New Mexico, Oregon, Tennessee, Vermont and West Virginia. North Carolina listed silviculture as a major source of impairment to assessed wetlands, and Utah listed silviculture as a major source of impairment to assessed lakes.

For the 2002 NWQI, states assessed 695,540 miles (19%) of the nation’s 3.7 million miles of rivers and streams. Three states (Alabama, North Carolina, and Washington), Puerto Rico, the tribal nations, and the island territories of the Pacific did not provide data electronically in 2002. This lack of data may account, at least in part, for the fewer number of river miles, lake acres, and estuarine square miles reported as assessed in 2002 compared to 2000. Of these waterbodies, 45% were reported as impaired or not clean enough to support their designated uses. States found the remaining 55% to be fully supporting of all designated uses. Sediment, pathogens, and habitat alterations were again cited as the leading causes of impairment in rivers and streams, and top sources of impairments included agricultural activities, unknown/unspecified sources, and hydrologic modifications. The 2002 report lists silviculture as the 9th leading source, responsible for impairment of 18,463 river miles. Of the nine states that listed silviculture as a major source of impairment to assessed rivers and streams in 2000, in 2002 only California listed silviculture as a major source of impairment. California and Montana reported 9,713 forest road-related impaired miles of streams. Oregon did not report probable sources for impairments in 2002. As noted in the 2002 report:

"…it is important to note that the information about specific sources and causes of impairment is incomplete. States do not always report the pollutant or source of pollutants affecting every impaired river and stream."

In previous NWQI reports, unknown or unspecified causes and sources were included only as footnoted material to summary statistics. For the first time, the 2002 NWQI report includes unspecified causes and sources in all summary statistics to more clearly represent what states are reporting to USEPA. The ranking of "unknown or unspecified sources" as the second-leading source of river mile impairment illustrates the uncertainty inherent in the assessment data. In the 2002 NWQI report, there is additional breakdown of the silviculture source group: forest roads, forest management, silviculture, etc., in terms of affected river and stream miles. However, these sources are not defined well enough to interpret the information, and the impairments attributed to the different sources may substantially overlap. Review of the complete data presented in the current NWQI report suggests that this detailed breakdown of the silviculture source group may be misleading or even meaningless.

The most recent national summary of state information available on the USEPA Watershed Assessment, Tracking & Environmental Results (WATERS) web site is based upon data reported between 2002 and 2006. For this summary, the states assessed 822,721 river and stream miles (23% of the nation's total of 3,533,205 river and stream miles); this assessment reflected an increase of over 100,000 river and stream miles from the previous 2 reporting cycles. Of the assessed waterbodies, 47% were reported as impaired or not clean enough to support their designated uses. States found 52% to be fully supporting of all designated uses. The remaining 1% (9,793 miles) were categorized as "threatened". Pathogens, sediment, nutrients and habitat alterations were cited as the leading causes of impairment in rivers and streams, and the top sources of impairments included agriculture, unknown/sources, and hydromodification. The 2002 report lists silviculture as the 12th leading source, responsible for impairment of 19,071 river miles; this represents 5% of impaired river miles.

USEPA characterizes the information contained in the NWQI reports and the associated National Assessment Database (NAD) as useful "snapshot views" of water quality assessed by the states during each reporting cycle. Although the information in the NAD provides a picture of state assessment results, these data cannot be used to compare water quality conditions between states or to identify trends in statewide or national water quality. According to USEPA the following are reasons for this lack of comparability:

- The methods states use to monitor and assess their waters, including what and how they monitor and how they report their findings to USEPA, vary from state to state and within individual states over time.
- The science of monitoring and assessment varies over time, and many states are better able to identify problems as their monitoring and analytical methods improve.
- 2002 was a transition period between traditional 305(b) reporting and integrated 305(b)/303(d) reporting.
- Under the CWA, each state has the authority to set its own water quality standards; therefore, each state's definition of its designated uses (e.g., Warm Water Fishery or Livestock Watering) may differ from definitions used by other states, along with the criteria against which states determine impairments.

As discussed above, the 305(b) lists cannot be considered to be reliable, representative data to assess and quantify the water quality impacts from forest roads at the National level. In general, the rigorous scientific documentation of water quality impairments due to forest roads comes from site-specific studies of impacted water bodies and threatened aquatic resources, and these tend to be focused on water bodies where impairments are known or suspected. Many studies have been conducted which show the adverse impacts of soil erosion and stream sedimentation on the nation's water quality (Author et al., 1998; Binkley and Brown, 1993). A number of different scientific approaches have been used in these studies to quantify the water quality impacts from forest roads, including water quality monitoring and bioassessment approaches, stream morphology and substrate analysis, as well as watershed-scale research. The problems associated with detecting water quality impacts and attributing them to specific sources are common to all of these approaches. Results from many of these studies have been presented previously in Sections 2.2 and 2.3.

USEPA, other federal agencies, and the states have embarked on a more cost-effective approach to track trends in the quality of the Nation's waters: statistically valid, probability-based studies that complement existing monitoring and assessment programs and add to our understanding of national, regional, and local water quality conditions. Probability-based studies select a specific number of sites at random to represent the condition of waters in regions that share similar ecological characteristics. Scientists can then draw inferences for all waters with a known degree of confidence. Probability-based studies are generally characterized by standard sampling methodologies, a defined set of relevant indicators, and stringent quality assurance (QA) requirements. The Wadeable Streams Assessment, a survey of the biological health of the nation’s wadeable streams, was launched in 2004 by USEPA and the states to provide a scientific baseline of stream water quality data based on conditions at approximately 500 randomly selected sites across the central and eastern United States. With support from USEPA, state water quality agencies sampled streams between June and October 2004 using the same types of methods at all sites. Crews collected macroinvertebrates, sampled water quality conditions, and evaluated physical habitat (i.e., the condition of the streambed, streambanks, and vegetation surrounding the stream site) at each site. Data from these sites were combined with data collected by USEPA and western states in the Western Streams Pilot Study to draw conclusions about the condition of 100% of streams throughout each major ecological region of the contiguous United States. Further assessments of rivers and streams, which will include fish collection, are planned for 2008 and 2009.

2.5 What Total Maximum Daily Loads (TMDLs) Have Been Developed for Sediment Associated with Forest Roads?

The need to develop Total Maximum Daily Loads (TMDLs) for impaired waters was established by Section 303(d) of the Clean Water Act to assist in the implementation of state water quality standards to protect the designated beneficial uses (e.g. fishing, swimming, drinking water, fish habitat, aesthetics) of individual water bodies. TMDLs are developed for waters that fail to meet state water quality standards despite the application of technology-based effluent limitations. A TMDL is a calculation of the maximum quantity of a pollutant that may be added to a water body from all sources, including point sources, nonpoint sources, and natural background sources, without exceeding the applicable water quality criteria for that pollutant. A TMDL has three components: a Wasteload Allocation (WLA), a Load Allocation (LA), and a margin of safety. The WLA is the portion of a TMDL allocated to existing and future point sources, whereas the LA is the portion attributed to existing and future nonpoint sources, including natural background levels of the pollutant. Where possible, the LA must distinguish between loadings from natural sources and those from nonpoint sources. The TMDL must allow a margin of safety to account for scientific uncertainty, and it must take into consideration seasonal variations in water quality conditions. A simple formula summarizes the components of a TMDL:

$$\text{WLA} + \text{LA} + \text{margin of safety} = \text{TMDL}$$

Determining the source of a particular type of non point source pollution (e.g., sedimentation) is difficult. Sediment in a water body or watershed is typically derived from a number of both natural and man made sources. The type and amount of sediment will also fluctuate depending on short-term climatic changes. Nevertheless, the "Sources of Impairment" statistics on the 303(d) list clearly shows the significance of nonpoint source pollution. Only 10% of the impaired watersheds in the United States are impaired solely because of point source pollution alone. An estimated 43% of the nation's waterways are impaired by nonpoint source pollution only, with the remaining 47% impaired from a combination of both point source and nonpoint source pollution. Sedimentation is a leading impairment in 6,427 water bodies (9.9% of reported impairments). This picture loses some of its coherence, however, when the consistency of the state lists of impaired waters is examined. States with very similar land use patterns and environment paint a very different picture of the impairment level of their waters. For example, the State of Washington shows little impairment of their watersheds while neighboring Oregon reports a high level of impairment for their watersheds. States are required to disclose the data, modeling and assumptions used in developing their list of impaired waters. The ranking depends on the best available information, and the quality and reliability will tend to vary from state to state. Thus, TMDL tracking can be plagued by the same inconsistencies and incomplete reporting noted above for the 305(d) lists.

As mentioned in Section 2.4 above, TMDLs listed under Section 303(d) provide another way to evaluate the significance of forest roads in contributing to water quality impairments in the US. Beginning in 1992, states, territories and authorized tribes were to submit lists of impaired waters (i.e., waters that do not meet water quality standards) to USEPA every two years. The current National Section 303(d) list, which includes state electronic data submissions from 1998 through 2006, lists pathogens, mercury, other metals, sediment, nutrients, and oxygen depletion as the leading causes of impairment of all water bodies. Sediment, as well as other causes of impairment (e.g., Cause Unknown - Biological Integrity, Turbidity, Habitat Alteration), suggest that forestry and forest roads may be sources of impairment in some of these water bodies. However, the source(s) of the impairment are not identified in the current National Section 303(d) List and the associated TMDL Tracking System database[7]. Oregon lists 1,512 sedimentation-impaired water bodies (including 5,600 miles of forest streams) in the 2004/06 Integrated Report Database; Washington lists 1,110 impairments in stream and creek segments. Unfortunately, neither state reports the sources of water quality impairment.

Many impaired waters that require a TMDL budget for sediment include roads as a primary source. In Idaho, for example, nearly every TMDL created for sediment in a forested setting identifies roads as a primary source of sediment problems. TMDLs written for seven waterbodies in Idaho specifically address forest roads as a source of sediment, while implementation strategies for general sediment reduction often focus on road improvement and road removal as critical steps for reducing loads.

The involvement of the National Forest Service in developing TMDLs illustrates the possible extent of forest roads as sources of impairments. The 303(d) lists for 2005 include more than 4,300 water quality impairments in 2,600 water bodies on National Forest Service lands in 41 states. The Forest Service has supported development of more than 300 TMDLs in more than 30 National Forests. As another example, the Washington State Forest and Fish Agreement addresses Endangered Species Act listings for 660 streams included on the 303(d) list of water quality limited water bodies (NCASI, 2001b).

In California, many Northern Coastal rivers have been listed as "water quality limited" due to sediment and/or temperature impacts to fish. In the settlement of a lawsuit brought against

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[7] In the future, it may be possible to identify the source of impairment in a TMDL as forestry-related in EPA's new TMDL data system (expected to be online in the spring of 2008), but only for Integrated states and within that subset, only those states that actually identify their cause of impairment sources (N. Abdelmajid, EPA; personal communication 12/13/07).

USEPA stating that the agency was not enforcing the Clean Water Act, USEPA made a legal commitment guaranteeing that TMDLs would be established by either USEPA or the State Regional Water Quality Control Board for 18 river basins by 2007, including 10 where silviculture is a potential source of sedimentation and/or siltation:

- Garcia River (TMDL completion date: 1997)
- Redwood Creek (1998)
- Noyo River (1999)
- Eel River South Fork-above and below Garberville (1999)
- Navarro River (2000)
- Gualala River (2001)
- Mattole River (2002)
- Eel River -North Fork (2002) and Upper Main Fork (2004)
- Mad River (2007)

The state of California did not complete adoption of a TMDL for the Mad River by the deadline of December 2007, so USEPA established sediment and temperature TMDLs for the river. USEPA expects the state Regional Board to develop an implementation strategy that meets the requirements of 40 CFR 130.6.

More than 30 rivers where silviculture is a potential source of sedimentation and/or siltation are listed on California’s 2006 303(d) list. These include the following rivers:

<u>Navarro River</u> - Increased sediment and summer temperatures are detrimental to native cold water fish, such as coho salmon and steelhead trout. Both populations of these species are listed as threatened under the federal Endangered Species Act. Road-related sources dominate other anthropogenic sources, reflecting the dominant land uses in the watershed, specifically timber production and ranching, which use a vast network of roads.

<u>Garcia River</u> - Sedimentation has contributed to the reduction and loss of habitat necessary to support cold water fish such as these salmonids. An analysis of the road density indicates that road densities in the Garcia River watershed are well above the desired density to protect instream habitat, also indicating that erosion from roads is a probable source of concern.

Redwood Creek - Accelerated erosion and other causes of sedimentation are adversely affecting the migration, spawning, reproduction, and early development of coho salmon, chinook salmon, and steelhead trout. Specific in-stream problems in Redwood Creek include fine sediment in spawning gravels, channel aggradation, lack of suitable pools for rearing habitats, stream channel instability, and physical barriers to migration. Specific hillslope problems in the watershed include improperly designed or maintained roads, sediment from unstable areas, removal of riparian trees, and loss of large woody debris.

Noyo River - The primary beneficial use of concern in the Noyo River watershed is the salmonid fishery, particularly the coho salmon fishery. Several factors have contributed to the increased sediment delivery above natural rates throughout the watershed. They include: high rates of timber harvest, a strong reliance on ground-based yarding methods (particularly in the Headwaters and North Fork Noyo River Assessment Areas), and high road densities. These factors have led to an increase in the rates of sediment delivery due to landsliding, fluvial erosion, and surface erosion related to land management activities.

Elk River – The Elk River is listed by California as a high TMDL priority water body, and is classified as impaired for sediment under section 303(d). Less than 20 years ago, the Elk River supported domestic water uses and relatively healthy populations of chinook and coho salmon, steelhead, and cutthroat trout (EPIC, 2002). Approximately 5,000 forest acres the North Fork drainage were clearcut or similarly harvested between 1990 and 1997. Following logging, sediment pollution increased drastically in the North Fork of the Elk River. Native species declined significantly in number within the North Fork during this time frame, and domestic water uses were completely eliminated in downstream areas. There was extensive evidence that the large acreage and rapid rate of timber operations in the watershed on the North Fork Elk River have had major adverse effects on the beneficial uses of water. Although its conditions today are far from pristine, the South Fork Elk River contains some of the best habitat remaining in California for anadromous salmonid species and other native aquatic life. As summarized by the State Water Resources Control Board, the record establishes that the waters of the South Fork Elk River serve a large number of beneficial uses, several of which could be adversely impacted by increased sediment. In 2002, logging plans were pending that covered more than 1,400 acres in the South Fork. Combined with existing problems from past logging operations, this has put the South Fork at great risk of further degradation. The Regional Board found that logging in the “Hole in Headwaters” site would increase the amount of sediment delivery to the South Fork and adversely impact its important beneficial uses. Despite these warnings, the California Department of Forestry and Fire Protection (CAL FIRE) allowed logging to commence in the Hole in Headwaters and stood poised to approve six additional logging plans in the watershed. This would put more than half of the watershed under logging plans within a 10 year time period.

Bear Creek – The Bear Creek drainage was first intensively logged in the 1950s, when approximately 50% of the watershed was cut (EPIC, 2002). Subsequent to the logging, large landslides swept the creek, causing extensive damage to the stream channel. Restoration efforts followed in the 1990s at a cost of nearly $100,000. By the summer of 1996, Bear Creek once again supported coho salmon and steelhead. Simultaneous with these restoration efforts, however, logging in the watershed resumed at an unprecedented rate. Between 1987 and 1996, more than half of the land draining to Bear Creek was logged. In the winter of 1996-97, massive landslides again took place in Bear Creek, turning a confined channel with deep pools and high-quality salmon habitat to one that is wide, shallow and filled with sediment. All of the habitat structures that were put into place during restoration were either buried or eliminated by the landslides. The stream is now severely degraded by high temperatures, sediment pollution and sedimentation. Upon inspecting Bear Creek, CAL FIRE, Water Quality, the California Department of Fish and Game, and the California Department of Mines and Geology all declared that landslides in Bear Creek had resulted in significant adverse cumulative effects to the drainage. Reports from these inspections indicated that the drainage had been impacted “beyond reasonable limits” and would take years to recover.

Logging plans comprising over 900 acres have been approved since 1999 or are currently pending approval for Bear Creek, threatening to bring more than 15% of the watershed under the footprint of a logging plan in the span of less than 5 years. All of these plans include even-aged management prescriptions and winter operations, and many include extensive road construction. Staff of the Regional Board concluded that the current and projected rates of logging presented a clear threat to beneficial uses (D. Kuszmar, “Comments on Bear Creek Harvest Area Analysis” submitted by CAL FIRE on July 6, 2000).

It should also be recognized that not all impaired waters will be included on Section 303(d) lists. USEPA regulations recognize that alternative pollution control requirements may obviate the need for a TMDL. Specifically, segments are not required to be included on the Section 303(d) list if "other pollution control requirements (e.g., BMPs) required by local, State, or Federal authority" are stringent enough to implement applicable water quality standards within a reasonable period of time (40 C.F.R. section 130.7(b)(1)(iii)). These alternatives to TMDLs are commonly referred to as Category 4b waters. Over the past three listing cycles, USEPA has provided additional clarity and flexibility with respect to the use of Category 4b. As a result, use of Category 4b is increasing.

As of November 28, 2007, the TMDL Tracking System database[8] included data for 2,235 TMDLs, which is an incomplete list. As mentioned above, the source of the impairment to a water body is not identified in the current TMDL Tracking System database. However, the database can be searched by keyword and the results interpreted to infer the possible sources of water quality impairment for the included TMDLs. Table 2-1 summarizes the number of TMDLs matching search criteria for a number of forestry-related pollutants (sediment, turbidity siltation, habitat alteration), type of TMDL (point/nonpoint or nonpoint), and keywords (e.g., silviculture, forest, timber, forestry, roads). The search results in Table 2-1 are listed (in descending order) by the number of TMDLs matching each combination of search criteria. At the most, these results suggest that 6 to 7% of the TMDLs included in the Tracking System database may include silviculture as a potential source of impairment.

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[8] http://iaspub.epa.gov/waters/text_search.tmdl_search_form

3. DESCRIPTION, EFFECTIVENESS AND COSTS OF FOREST ROAD BMPS

BMPs are activities and practices to prevent or reduce pollution to waters of the U.S. They include treatment requirements, operating procedures, and practices to control runoff, spillage, or leaks. Silvicultural BMPs are intended to reduce nonpoint source pollution and maintain stream channel integrity so that state water quality standards are met (Prud'homme and Greis, 2002). Most forest practice regulations have been designed to address changes in temperature and fine sediment concentrations in water bodies, two parameters shown to have been increased by logging activities. By far the largest issue of concern for forest roads is controlling erosion and the resulting sedimentation. BMPs on private lands are almost exclusively prescriptions of practices to be employed in response to site conditions (Rice, 1992), and usually include a practice and some way of determining when and where the practice should be applied. The focus of regulatory activity on the development and implementation of BMPs reflects the failure of scientists and land managers to provide practical in-stream criteria for regulation of sedimentation from forestry activities (Corner et al., 1996). In the national forests, USFS BMPs are instead largely procedural, describing the steps to be taken in determining how a site will be managed (Rice, 1992).

There are many different BMPs for controlling water quality impairments due to forest roads, as will be presented in Section 3.1. However, these many practices are actually based on relatively few guiding principles (Megahan and King, 2004; Olzewski and Jackson, 2006) and are grounded in science or based on scientific principles. These include:

- Recognize and avoid high-erosion hazard areas;
- Minimize the total amount of landscape disturbed by roads, bare ground and soil compaction;
- Engineer stable road surfaces, drainage features and stream crossings to reduce erosion;
- Separate bare ground from surface waters and minimize delivery of road-derived sediments to streams;
- Provide a forested buffer around streams which exclude roads and minimize crossings;

- Design and install stream crossings to allow passage of fish, other aquatic biota, and large wood;
- Put BMPs in place to anticipate triggering events;
- Unless obliterated/removed, all forest roads, crossings and associated BMPs must be maintained.

Ideally, BMPs are selected and applied based upon site-specific needs. These include specific concerns and treatments for highly-erosive or landslide-prone locations, roads and crossings on steep slopes, or wetlands. Usually a collection of BMPs or BMP system will be used at a site, as this will be more effective and provide some redundancy in case of BMP failure. For example, combining BMPs for road construction and surface treatments significantly reduces the erosion and transport of soil away from forest roads (Swift and Burns, 1999). Relatively little information is available on the integrated effects of mitigation measures applied to separate components of the road prism (Burroughs and King, 1989). Selecting the individual BMPs to combine as a BMP system at a site is a combination of science, art, judgment and experience.

Disagreements about which BMP is “best” arise from a variety of factors. First and foremost, site conditions affect impacts and mitigation measures, and site conditions can vary tremendously. As discussed in Section 2.3.6, variations in site-specific and regional factors can result in highly variable erosion rates, risks of mass failure, etc. Depending on the proximity to and sensitivity of the receiving water, different degrees of erosion reduction and/or sediment delivery reduction efficiency may be required to prevent adverse impacts. Again, differences in effective BMP prescriptions depend on the nature and characteristics of the site. Different and evolving performance measures have also changed perceptions about BMP selection. As a result of findings in the Alsea watershed of Oregon and elsewhere, most western states enacted forest practices regulations by the early 1970s (Bisson et al., 1992) to address changes in temperature and fine sediment. New concerns about the effects of logging on peak flows and on the abundance of large woody debris in streams began to take shape in the 1970s and resulted in renewed research activity in the 1980s. More recently, there has been a research focus on the function of small headwater streams in storing and processing sediment and organic matter (Bisson et al, 1992). BMP regulations have changed greatly within a single decade (Bisson et al., 1992). Changes in logging systems, reforestation techniques, and environmental protection requirements have meant that the concepts of BMPs for forestry have always been evolving.

Most of the factors leading to increased surface erosion from roads are manageable by adjusting road design features, employing erosion control practices, and performing proper road maintenance (NCASI, 2001). However, these improvements are not accomplished easily or cheaply. Ultimately, forest managers and the regulatory agencies must determine how much change in existing road systems is sufficient to meet aquatic goals and how to achieve those changes most efficiently. This raises the issue of how environmental effectiveness is balanced with practicality, because BMPs are defined as what is practicable in view of “technological, economic, and institutional considerations” (CEQ, 1971).

The individual land manager’s value system will affect how they perceive both the benefits and the costs of operations. For example, the management practice of minimizing stream crossings is often ignored as “impractical”. This was also illustrated by the results of a small survey that was conducted to gain insight into the effect of a manager’s value system on clearcutting in steep inner gorges and the resulting landslide erosion (Rice, 1992). Statistical treatment of the survey results was not appropriate because the questionnaire respondents were self-selected (i.e., voluntary). Both public and private respondents gave high ratings to the management objectives of harvesting timber on stable land and mitigating high risk sites. Industrial foresters were more concerned about being able to harvest timber, while their Forest Service counterparts expressed about equal concern for timber harvest and landslide prevention. Private foresters’ appraisals of the loss from failing to cut timber on stable terrain was nearly twice that of Forest Service people, and they also attached a smaller penalty to causing a landslide. Rice concluded that if forest managers became accustomed to rigorously evaluating competing values and site conditions, improvements in erosion control could be obtained without reducing harvests.

Another example of the tradeoff between environmental protection and practicality that is implicit with BMPs is the prescription for the width of filter strips. Swift (1986) measured the distance that sediment traveled downslope below newly constructed forest roads in the southern Appalachian Mountains, and found they were less than previously reported. He concluded that filter strip standards currently applied to forest roads in that region specified greater widths than were necessary with prevailing construction practices. Swift noted that any guidelines for filter strip width should be based on extreme sediment flow distances rather than an average distance. However, a guideline that protects against all possible cases would require impractically wide filter strips. Swift also note that the distances he measured represent only the downslope extent of coarse particles of sediment (>0.05 mm), and that storm waters muddied by fine particles reached farther downslope. If the soil material exposed and eroded from a road contained a high percentage of silt and clay, then the transport of fine particles downslope could have an important impact beyond the distances used as guidelines.

Reductions in soil erosion losses achieved through runoff control and soil stabilization BMP techniques may not always be acceptable environmentally (e.g., areas that may contain sensitive terrestrial or aquatic species; Grace and Clinton, 2006). In those situations, sediment and storm water control practices are essential to reducing the quantity of sediment introduced into forest stands and available for transport directly to stream systems. Sediment control practices are installed in the path of sediment-laden storm runoff and are used to capture sediment as close to the source (e.g., the road prism) as possible.

3.1 What are the Types of BMPs and how are they Maintained?

There are a number of comprehensive sources of information regarding BMPs for forest roads (USEPA, 2005; Gallagher et al., 2000), and many references discussing specific BMPs. Table 3-1 is a comprehensive list of BMP control and mitigation measures for: road construction; operations and maintenance; closure, decommissioning and obliteration; wetland operations; and mitigation for fish habitat based on Gallagher et al. (2000). The table includes descriptions of each BMP, qualitative or quantitative measures of their effectiveness in terms of reducing erosion, and estimated costs when available. These BMPs are discussed below (Section 3.1) in the following categories: road planning and design; construction and reconstruction; management (maintenance, upgrading and closure); and decommissioning, obliteration and removal. Section 3.2 presents information on how well BMPs work, and Section 3.3 addresses the costs of BMP installation and maintenance.

3.1.1 Road Planning and Design

The planning and design of roads includes reconnaissance and route selection, determining road grade and terrain, the concentration of roads, future management, new road construction versus improvement of existing roads, and selection of construction methods. The road planning philosophy should be to fit the road to the landscape. Site conditions are often more important than management practices in determining the erosional consequences of logging or road construction (Rice and Lewis, 1992). The most important step in minimizing the impacts of roads on streams, including both surface and mass erosion, usually occurs during reconnaissance and route selection. This is the step where various measures to control potential adverse effects of roads on watershed processes are considered. Road design involves translation of field location survey and other data into specific plans to guide construction. Roads are now designed to minimize cut and fill volume by constructing roads no wider than necessary and by fitting them as closely as possible to the natural topography (Gardner et al., 1978). Many landslides can be avoided by identifying hazardous slopes and avoiding them, and much stream sedimentation can be prevented by constructing roads in locations where eroded sediment will not reach streams. For sediment from surface erosion, practices that regulate road runoff amount and distribution or that trap runoff prior to it reaching streams are particularly effective, in addition to practices that reduce the eroded volume. Fundamentally, this includes locating the road farther from the stream (Megahan and Ketcheson, 1996).

The mechanisms of mass failure point to design solutions to reduce the likelihood of landslides:

- Avoid slopes and locations with a landslide history.
- Avoid headwall and bedrock hollow locations.
- Avoid inner valley gorges (the oversteepened slopes adjacent to streams).

- Avoid large cuts and fills; minimize volume.
- Don’t incorporate woody debris in fills.

Any effort to apply BMPs should be governed by an estimate of the erosion hazard. The key to reducing adverse environmental effects lies in developing a way to identify high risk sites (Peters and Litwin, 1983). Unfortunately, past attempts at identifying high-risk sites, such as the erosion hazard rating that was made part of the FPRs for the Coast Forest Practice District in California, have been considered failures due to the lack of a sound scientific basis (Rice, 1992).

New roads tend to be located in mid-slope and ridgetop locations where channel encroachment, riparian impacts, and delivery of fine sediments are minimized (NCASI, 2001). Managers must identify inherently unstable slopes and either avoid these locations entirely, or construct roads using design and construction techniques that have been demonstrated to be effective at preventing landslides or the specific circumstances encountered (Miller et al., 2001).

A watershed analysis completed for the LeClerc Creek watershed in northeastern Washington provides an example of mass wasting assessment, development and implementation of mass wasting hazard management prescriptions, and adjustment (adaptive management) of prescriptions with improved information following major runoff events in 1998 and 1999 (NCASI, 2001b). Forty-six landslides were located and several moderate to high hazard mass wasting management units were identified and mapped in 1996 as part of the LeClerc Creek Watershed Assessment (McGreer et al., 1997). Subsequent detailed assessment of the area resulted in a new prescription that required total obliteration of all roads and no construction of new roads that lay within the area of particular hazard, as identified by geomorphic characteristics. No subsequent failures have occurred in the watershed.

Proper road design can also improve drainage issues. Roads can often be fit more closely to the topography, with rolling grades providing natural drainage, rather than the long uniform road grades used in the past. Roads should be purposefully designed to discharge water frequently, to minimize length of direct delivery, to discharge at locations chosen to minimize delivery of water and sediment to streams, and to minimize concentration of water that could contribute to slope gullying or landslides (NCASI, 2001). Drainage of existing road systems can also be redesigned to substantially reduce sediment delivery, often to only a fraction of the original amount, by increasing the frequency of relief drains or other techniques.

Another major improvement in road design and drainage involves the size and configuration of culverts placed in streams at road crossings. Today, the minimum design requirement of most state forest practices rules is 50 to 100 years (IDL, 2000a; ODF, 1994; WFPB, 2000).

3.1.2 Construction/Reconstruction

Many states have established BMPs to address construction practices to reduce surface erosion from the road prism, avoid landslides associated with roads, reduce sediment delivery to water bodies, construct stable stream crossings that do not block passage of fish and other materials, and special construction practices for roads in wetlands and bottomland sites. These BMP construction categories are discussed in the following sections; additional details for specific BMPs are provided in Table 3-1.

In addition to construction BMPs, methods of forest road construction have also changed. Hydraulic excavators, which can precisely excavate and place materials (Bechman, 1980), have almost universally replaced bulldozers for road construction on mountain slopes. Soil disturbances are usually addressed immediately following, or even during, construction activities. Important erosion control practices to consider during construction include (NCASI, 2001):

- Keep slope stabilization work as current as possible with road construction.
- Use at least a six to ten inch minimum depth of aggregate produced from sound igneous or metamorphic rock.
- Thoroughly clear and grub brush, timber, stumps, and other woody debris from roadbed and fill areas to prevent potentially serious surface and mass erosion problems.

- Spread cleared vegetation and woody materials over the soil surface below fills to enhance the sediment trapping and “buffer” characteristics of the slope below the road.

- Keep stream disturbance to an absolute minimum and avoid it altogether during high flows.

- Limit the work area during construction to small sections to limit exposure of disturbed area to erosion forces in the event of adverse weather, and keep installation of relief drains current with sub-grade construction.

The best planning and design is useless unless it is incorporated into the finished product (Megahan, 1977). Competent supervision of the construction phase is required (NCASI, 2001).

3.1.2.1 Surface Erosion Control

Practices are available for effective treatment of erosion hazards for all major road prism components: cutslopes, running surfaces, road ditches, fillslopes, and even the area downslope from roads (NCASI, 2001b). An excellent summary of road erosion control effectiveness is provided by Burroughs and King (1989), who calculated that erosion from the entire road prism could be reduced by over 90%. Table 3-1 includes descriptions for a variety of BMPs for surface erosion control, including slope stabilization practices, road surfacing and daylighting, and cutslope and fillslope stabilization. Table 3-2 includes data for the effectiveness of various surface erosion controls on different components of the road prism. The erosion reduction efficiency of these treatments vary widely. With increasing application rates and percent ground cover achieved, treatment of cut and fillslopes with straw, wood chips, rock, hydromulching, or erosion mats can reduce erosion by 80 to 100%, depending on the treatment applied. For instance, straw applied to fillslopes at a rate of 1 ton/acre reduces fillslope erosion by approximately 60%. In the southern Appalachian Mountains, Swift (1986) reported that overwinter mulch of straw and asphalt, at the rate applied, was a very poor substitute for grass. The majority of road construction sites relied on natural revegetation or dry grass seeding without mulching, and this was generally not effective in preventing chronic sediment delivery to streams.

Roadway surfacing can be a particularly important treatment, because tread erosion usually comprises 50% or more of total delivered road prism erosion, with increasing importance as road traffic increases. Development of wheel ruts in roads approximately doubles erosion; surfacing and/or traffic control prevents the formation of ruts (Foltz and Burroughs, 1990; Foltz et al., 2000). Treating road travel surfaces reduces tread erosion by 43 to 77% (Burroughs and King, 1985; Foltz and Truebe, 1995). Moreover, sediment reduction due to rock surfacing can vary by several-fold depending on hardness and quality of the rock (Foltz and Burroughs, 1990). Erosion from ditches can be eliminated with rock, and Burroughs and King (1989) summarize design principles and criteria.

Burroughs and King (1989) discussed the potential for erosion reduction by various treatments on each component of the road prism. Their research was based on sediment production experiments on 100 feet of roadway in northern Idaho at the Intermountain Research Station. They found that graveling the travelway reduced sediment production by an average 33%. Graveling both the travelway and roadside ditch was estimated to reduce sediment production by 57%. If graveling of the travelway and ditch were combined with cutslope protection, sediment production was reduced by an estimated 91%.

An Oregon wet season road use monitoring project made specific BMP recommendations for controlling road surface erosion under critical conditions, when conventional BMP prescriptions would not adequately control erosion (Mills et al., 2003):

- Use aggregate containing the minimum percentage of fines needed to bind and pack and seal the surfacing. Where there are excess fines; screen aggregate to reduce the percentage of fines in the rock and lower sediment delivery.

- Use at least a six to ten inch minimum depth of aggregate produced from sound igneous or metamorphic rock (use more where the subgrade is soft).

- Reduce the length of road segments that deliver to streams to less than 250 feet by adding cross drain culverts or other drainage structures.

- Prioritize inspection of wet weather active operations during the first moderate rainfalls (3 day total rainfall of 1.5- 3 inches) to determine if immediate repairs are needed or if ceasing road use is necessary.

Drainage control BMPs include road outsloping broad-based dips, waterbars, relief culverts, cross-drains, ditches and turnouts, and belt diverters (Table 3-1). Drivable broad-based dips divert runoff from the road tread onto the hillslope below the road, reducing overland flow distances and the resultant erosion (Logan, 2001). Drivable dips are popular because they are relatively inexpensive to install, and because they can be retrofitted to existing roads. However, these and other road BMPs such as ditch relief culverts, open top culverts, and belt diverters are only effective if they are located so that the sediment travel distance below the drainage outfall is less than the distance to the nearest stream (Woods et al., 2007). Research conducted at the Coweeta Hydrologic Laboratory demonstrated how a number of these drainage and erosion control BMPs (outsloped roads with no inside ditches; broad-based dips to divert road drainage; outside berms and brush barriers; gravel and/or grass cover; minimized road width and curve radius; and stream buffers) could be combined to construct low-cost, lower-standard forest roads that still reduced erosion and sediment generation. The Coweeta research is reflected in many state BMP programs, especially in the southeast region (Prud'homme and Greis, 2002).

Analyses of the effectiveness of erosion control BMPs suggests that they should be effective in controlling sedimentation at the watershed scale, if correctly and fully implemented. Watershed assessment conducted for the Plum Creek Timber Company Habitat Conservation Plan (HCP) indicated that construction of additional drainage structures near stream crossings would eliminate 25 to 85% of road sediment delivered to streams in the eleven watersheds that were evaluated (NCASI, 2001b). An extensive road system in the Spruce Creek watershed of northern Idaho was assessed using the Washington watershed assessment procedures (NCASI, 2001b). Analysis of site-specific conditions in this watershed revealed that the addition of drainage relief structures near streams would reduce sediment delivery from this existing road system from 257 tons to 108 tons (McGreer et al., 1998).

3.1.2.2 Landslide Avoidance

Aside from design precautions (Section 3.1.1), other BMPs that can significantly reduce likelihood of mass failure include minimizing sidecast, full-bench end-haul construction, and avoiding organic matter in fill (Table 3-1). In addition, the following guidance is offered for landslide avoidance (NCASI, 2001c):

- Carefully size culverts and install trash racks to prevent plugging, particularly where fill failure could lead to downstream debris flow.
- Drain water frequently to avoid concentration on or below fills and to help avoid further concentration in the event of cutslope failure.
- Outslope roads where practical, and consider reshaping insloped roads to outsloped prisms with surface drains when they become inactive.
- Eliminate sidecast on steep slopes (those over 50%).

3.1.2.3 Sediment Delivery Reduction

Table 3-1 also includes descriptions for a variety of BMPs to reduce sediment delivery to streams: removal of direct-entry culverts, control drain outlet erosion, and application of sedimentation basins and filter windrows. Reducing the length of road that drains directly to streams via ditches at road crossings can substantially reduce total road system sediment delivery (ODF, 2000; McGreer et al., 1998). Reducing the length of road segment contributing to a relief drain also reduces sediment delivery to streams, because the distance the water and sediment travel downslope before being trapped and infiltrated decreases due to decreasing source area for water supplied to the road segment in question (i.e., the volume of water and sediment discharged is smaller and is therefore trapped or infiltrated sooner; Megahan and Ketcheson, 1996; Packer, 1967; Elliot et al., 1997). BMPs should specify the maximum spacing of relief culverts for road segments within about 500 feet of any stream channel. Where relief culverts or water bars discharge within about 300 feet of any stream channel, adequately-sized sediment traps and energy dissipation and/or flow spreading measures should be applied to the discharge to prevent the road drainage from integrating with the natural stream network. Increasing obstructions (e.g., rocks, logs, stumps, slash, etc.) on the hillslope below a drain reduces sediment delivery because of increased opportunity for sediment deposition and reduced sediment travel distance (Brake et al., 1997; Megahan and Ketcheson, 1996). However, relying solely on slash berms or piles is not adequate to prevent channel development from concentrated discharges, such as relief culverts. Filter windrows constructed at the toe of fillslopes reduce sediment leaving the fillslope by approximately 85% (Burroughs and King, 1989).

3.1.2.4 Stream Crossings

The stream crossing is the most critical section of road influencing water quality (Taylor et al., 1999). The midwestern state forestry BMP manuals suggest that the best way to maintain water quality during forest management is to avoid crossing a stream (NCASI, 2007). Location, number, type and size of crossing structure, and timing and location of construction are all important factors. Table 3-1 includes BMPs for both temporary and permanent crossings. Portable bridges, log crossings, pole fords, and temporary culverts are examples of temporary crossings. Permanent crossing BMPs include fords (low water crossings), bridges, increased-capacity and arched culverts, and diversion proof (fail-safe or fail-soft) crossings.

Culverts are the most prevalent kind of stream crossing on forest roads, and usually cause the most problems in terms of blocking fish passage, plugging and subsequent failure, and chronic erosion and sediment delivery. Scouring at culvert outlets should be controlled with energy dissipaters. Although trash racks are prescribed to prevent culvert plugging by trees and other debris, their use may contribute to fish passage problems. Installation of round culverts should be avoided where fish passage is necessary; bridges and arch culverts are preferred for streams with migrating fish.

Washington State FPRs require that new and replacement culverts be installed to ensure free and unimpeded passage for fish, and that road maintenance and abandonment plans specifically address removing artificial barriers to passage of fish by adhering to specific culvert design guidelines (Cupp et al., 1999). For culvert fills at stream crossings, armoring (e.g., rock riprap) should be required on both the inflow and outflow side of the road (Rashin et al., 1999). Construction phase erosion control measures should be applied to all culvert tills at stream crossings. Special attention to armoring and revegetation is needed on tills greater than ten feet high. The extent to which stream crossing culverts become migration barriers to resident fish and other aquatic life, and the implications of such barriers to ecosystem integrity, should be fully evaluated. If subsequent evaluations determine that adverse ecosystem effects are occurring, measures to mitigate such effects should be developed. Alternatives to using culverts for crossings of steep streams, such as temporary or permanent bridges or other temporary crossings, should be promoted as a preventative measure.

3.1.2.5 Wetlands and Bottomlands

The CWA regulates road construction activities in wetland areas because of the potential for environmental impacts. If the road is constructed and maintained in accordance with 15 specific BMPs the USEPA provides an exemption to permitting requirements. The wetland BMPs are stated in performance language (i.e., required outcomes) rather than specific guidance, and provide no information on how to properly stabilize fill material in wetland road construction (Rummer, 1999). Most of the research studies on forest road construction and erosion control have been conducted in upland topography where erosion processes are significantly different from floodplain conditions. There is little scientific knowledge about the water quality effects of forest roads in bottomland stands.

The available research suggests that erosion with floodwater is a transport-limited process (Rummer, 1999). To minimize water quality impacts of forest roads in bottomland stands, BMPs should focus on reducing water velocity (i.e., brush barriers, vegetative stabilization) or appropriately anchoring soil in higher-velocity areas. Reducing the amount of exposed soil is not necessarily the best approach to avoiding water quality impacts, because water quality impacts in wetlands and bottomlands are transport-limited, not source-limited. Results of one long-term study (Rummer, 1999) suggest that forest roads in bottomland stands are unlikely to significantly impact the suspended sediment transport of passing floodwater. The key factor affecting sediment generation and transport in bottomlands is flow velocity and direction.

Table 3-1 includes several BMPs specifically for wetlands. These include runoff diversion, minimizing rutting, the use of temporary roads and fill removal, and berms.

3.1.3 Road Management

Road management includes inspection and maintenance activities, upgrading, temporary closure, putting to bed (decommissioning), and road obliteration (Table 3-1).

3.1.3.1 Maintenance

Maintenance is recognized as a critical component of both the transportation and environmental performances of roads. Road maintenance is critical in order to provide continued access and control environmental impacts (NCASI, 2001). Properly maintained roads have a stable surface and an operating drainage system that drains water from roads as quickly as possible onto the forest floor instead of directly to streams. Road maintenance BMPs executed to minimize surface erosion and mass wasting include: surface grading and maintenance of road gravel to prevent rutting; ditch cleaning to insure that water remains in ditches and does not erode the ditch or the running surface; monitoring, cleaning, and replacement of relief and stream crossing culverts; monitoring and grading of rolling dips; and treatment of cut and fillslopes to encourage and retain protective vegetation (NCASI, 2001). Roads should be inspected at regular intervals, especially during or following large rainfall or snowmelt events and can include an inventory of existing and potential erosion and slope failures on all roads.

Traffic access control through the use of gates is commonly practiced to minimize road surface damage during wet periods, to reduce erosion and sediment delivery. The results are often substantial; preventing ruts in road surfaces alone can reduce erosion by approximately 50% (Burroughs and King, 1989). Lowering the pressure of truck tires is another BMP that has been shown to be effective in preventing rutting and reducing erosion. Traffic control BMPs include road closure, access restriction, wet weather traffic restriction, and seasonal use roads.

Traffic and road maintenance are two interrelated components in road management that have the potential to influence sediment movement from forest roads (Grace and Clinton, 2006). Increased soil erosion has been attributed to traffic in previous research conducted on roads in mountainous regions (Bilby et al., 1989; Burroughs and King, 1989; Foltz, 1999; Reid and Dunne, 1984). Increased erosion losses can require increased maintenance to maintain drainage patterns and prevent (or minimize) the impact on downslope resources. However, in an investigation of the influence of traffic and road maintenance on sediment production from forest roads in the Oregon Coast Range (Luce and Black, 2001), ditch grading had a greater effect on increased soil erosion than traffic. Maintenance operations can increase soil erosion by removing armoring layers on the road surface and in the ditch that develop over time (Black and Luce, 1999). Road segments where vegetation was cleared from the cutslope and ditch produced seven times as much sediment as road segments where vegetation was retained, showing the potential reduction in erosion by revegetation following construction and potential impact of ditch cleaning during maintenance (Luce and Black, 1999).

In a study of road surfacing types on sediment yield in the Pacific Northwest, Reid and Dunne (1984) found that over a one year period, graveled road segments receiving heavy traffic produced 130 times more sediment than road segments receiving no traffic. In this study, traffic intensity greatly influenced (7.5 times the rate measured during periods of no traffic) soil loss and suspended sediment concentrations in runoff. It was hypothesized that soil loss from the road segments was influenced by the frequency of road maintenance and grading.

3.1.3.2 Upgrading

Upgrading activities are similar to maintenance, as they also involve ongoing inspection, assessment of problems, and control action to avoid or remedy the problems. With upgrading, old roads built to lower standards with lower sensitivity to environmental issues can be brought up to current standards as forest harvesting occurs in adjacent areas or where priority environmental concerns are identified (ODF, 2000; WFPB, 2000). In many cases, major reductions in environmental impacts are possible through relocation and improvement of old roads (NCASI, 2001). General recommendations are provided for improving ineffective and partially effective BMPs (Rashin et al., 1999). These recommendations are intended to attain a high confidence of achieving water quality standards by preventing or minimizing chronic sediment delivery from surface erosion and avoiding physical disturbances and habitat degradation in streams:

- For culvert fills at stream crossings, armoring (e.g., rock riprap) should be required on both the inflow and outflow side of the road.
- Alternatives to using culverts for crossings of steep streams, such as temporary or permanent bridges or other temporary crossings, should be promoted as a preventative measure.
- Road location practices should minimize new roads within about 500 feet of streams in order to minimize the integration of road drainage with the stream system.
- The maximum spacing of relief culverts should be reduced for road segments within about 500 feet of any stream channel.
- Where relief culverts or water bars discharge within about 300 feet of any stream channel, adequately-sized sediment traps and energy dissipation and/or flow spreading measures should be applied to the discharge to prevent the road drainage from integrating with the natural stream network.
- Relying solely on slash berms or piles is not adequate to prevent channel development from concentrated discharges, such as relief culverts.

Perhaps the most acceptable alternative to manage forest roads for soil and water protection is upgrading the most critical roads (Grace and Clinton, 2006). In many watersheds, specific road segments are responsible for a disproportionately high share of total road sediment delivery (NCASI, 2001). If the major stream impacts in a watershed are associated with sediment discharged from roads, the means of control is to identify and treat the specific roads that contribute the sediment, not merely to reduce road density. Where land managers recognize higher hazards for road erosion they can modify road design and maintenance practices to minimize impacts (Bourgeois, 1978).

3.1.3.3 Closure

Roads that will not be used again in the near future are often closed. This is a management BMP that temporarily removes the road from use and retains it for future use. This is an extremely cost-effective measure in cases where environmental concerns do not require obliteration (described below). With no traffic, closed roads can reduce soil loss and suspended sediment concentrations in runoff by an order of magnitude compared to roads with traffic (Reid and Dunne, 1984). At some time in the future, the road may be reconstructed with minimal disturbance. Roads that are closed may require periodic inspection and maintenance. A key to road closure is achieving self-maintaining drainage and, as part of the closing process, roads may be upgraded according to potential impact to riparian and aquatic resources.

3.1.4 Decommissioning/Putting-To-Bed and Obliteration/Removal

There is a continuum of BMPs for temporarily decommissioning roads (also known as “putting to bed”) to completely obliterating roads that can be used to decrease the costs and environmental impact of forest roads (Table 3-1). Decommissioning can involve closing access, reseeding the road surface, removing temporary stream crossings, and opening drainage structures that may fail. A decommissioned road is put into an erosion-resistant condition but can be re-opened at a later date when access again might be needed. Road obliteration, on the other hand, is the partial or complete removal of the road from the landscape. Obliteration goes farther than decommissioning in restoring hillslopes, natural drainageways, and vegetation. Obliteration is intended to eliminate future road maintenance. The road prism is obliterated and returned to a naturally functioning component of the landscape. Road removal involves the physical treatment of a roadbed to restore the form and integrity of associated hillslopes, channels, and flood plains and their related hydrologic, geomorphic and ecological processes and properties (Switalski et al., 2004).

Long-term road treatments such as decommissioning and obliteration are becoming more common. Road decommissioning can lead to improvements in fisheries habitat where sediment runoff from old forest roads enters streams (TetraTech, 1999). Reduction of sediment delivery to streams can be particularly significant where roads in highly erosive materials are located adjacent to streams. The practice was used in a watershed in northwest Washington as part of a watershed rehabilitation to improve fisheries habitats and water quality and to reduce flooding hazards. On unused, 30- to 40-year-old, largely impassable roads and landings, fills were stabilized, stream crossings were removed, slopes were recontoured, and drainage patterns were reestablished at an average cost of $5,600 per km (range: $2,100 to $10,600; TetraTech, 1999). Luce et al. (2001) outline fundamental principles for strategies to prioritize road closure and decommissioning. The most common priority is the ‘problem’ roads that yield substantial mass wasting or severe surface erosion. Such roads represent a small fraction of most road systems, and many such roads have already been decommissioned. In some cases, sediment modeling has been used to support prioritization for road closures and decommissioning. This is often in response to the goal of managing basin-wide sediment yields to be within prescribed limits (Luce et al., 2001).

Where there is significant landslide hazard, old roads may be obliterated. Full road recontouring has been used effectively to reduce landslides in northern California, western Washington, coastal Oregon, and northern Idaho (Switalski et al., 2004). In Redwood National Park, a 12-year storm produced very little sediment from treated roads. In Clearwater National Forest, a 50-year storm resulted in no landslides on treated roads. Although road removal treatments do not completely eliminate erosion associated with forest roads, they do substantially reduce sediment yields from abandoned logging roads (Madej, 2001). Removing abandoned forest roads and restoring the natural characteristics of slopes and stream channels in the Redwood National Park and State Parks in northern California have substantially reduced the delivery of sediment to salmon-bearing streams. However, it has also been noted that no form of road removal was able to prevent chronic erosion completely on steep lower slope roads (Switalski et al., 2004).

Methods to remove roads continue to evolve. Useful experience with this BMP has come from major federal road removal efforts as part of watershed rehabilitation in Redwood National Park, and other locations in Oregon, Washington and Montana (Gallagher et al., 2000). A critical issue in decisions about road decommissioning is whether disrupting the new environmental balance created by the presence and aging of the road is desirable (Gucinski et al., 2001). Road removal can cause accelerated erosion losses in the short-term (Switalski et al., 2004), and the risk of mass failure may still exist (Luce et al., 2001). Recontouring, the highest level of obliteration, involves removing embankments and replacing cuts, removing drainage structures, reestablishing soil permeability and subsurface flows, fixing gullies, reestablishing vegetations and controlling surface erosion (Moll et al., 1997). Hickenbottom (2000) reported that recently recontoured road segments produced significantly more sediment than roads recontoured 12 months previously. Although sediment yield was greatly reduced one year after recontouring, the recontoured roads were susceptible to erosion immediately after treatment. Given that there is little control or ability to maintain areas after recontouring or ripping, a well-designed, open, and maintained road may sometimes represent less risk for mass wasting (Luce et al., 2001).

The effectiveness of restoring natural stream and flood plain function by decommissioning and obliteration still needs to be addressed. No studies have examined influence of road removal on the recovery of aquatic, riparian and/or terrestrial ecosystems (Switalski et al., 2004).

3.2 How Well do Forest Road BMPs Work?

The key measure of nonpoint source pollution control success, laid out by USEPA guidance and the overall goals of the CWA, was whether the NPS control program could achieve desired water quality goals (Madej, 2001). It was assumed that BMP practices including forest road BMPs could successfully mitigate sedimentation impacts and BMP implementation would protect water quality from nonpoint source pollution. To some degree, it is unknown whether current forest practice rules have or will result in achieving PL 92-500’s specific water quality targets (Rice, 1992). The need to monitor and evaluate the relative efficacy of BMPs still exists. Although a substantial amount of research has been conducted on BMP performance at the site level, relatively little work has been undertaken to investigate the effect of forest road BMPs on erosion and water quality (Grace, 2002). There is a lack of info on how modern (post 1980s) road building technologies (including incorporation of BMPs) may reduce mass wasting and water quality impacts (USEPA, 2005). There is some evidence that modern road building practices are reducing the amount of sediment delivered to streams from forest roads. Binkley and MacDonald (1994), for example, cite many studies showing reduced impact of forestry practices with BMPs, although some degree of impact is usually detected. State agencies consistently report there is insufficient monitoring data to make sound assessments (Corner et al., 1996).

Studies of the effectiveness of silviculture BMPs in preventing water quality impairments have been undertaken at several different scales (Ice, 2000). For this report, effectiveness studies are categorized according to studies of individual sites (which also address smaller road networks and associated stream segments), and watershed scale studies. Although site-level research usually differentiates BMPs for forest roads from others (e.g., RMZs or harvest activities), the effectiveness of forestry BMPs are generally considered together at the watershed scale. Water quality impacts observed at this scale therefore reflect the integration of many individual sites and practices. However, these impacts are often related to roads and stream crossings, which are acknowledged to be predominant sources of sediment to forest streams.

Initial assessments of BMP effectiveness involved research plots, field evaluations, small paired watershed studies, and application of agricultural models like the Universal Soil Loss Equation (USLE) to forest conditions (Ice and Whittemore, 1998). These all provided valuable information, but they were also limited. Most were designed to provide only a local assessment of impacts, often to an individual operation. The assumption was that if impacts could be minimized at the site, they would be diluted downstream. However, concerns about cumulative effects caused forest managers to explore alternative assessment approaches. Early assumptions about downstream dilution, transport of impacts, and stream response were challenged. With maturation of CWE assessments, watershed specialists began to recognize both the dynamic nature of watersheds and streams, and the potential for and need to address operational fall-down of BMPs (Callaham and DeVries, 1987). This led to development of BMPs such as "diversion proof road designs" (Hagans and Weaver, 1987) and "debris torrent-resistant road crossings" designed to minimize impacts to watersheds during extreme events. In recent years, watershed-scale assessments were further stimulated by legal requirements to develop TMDLs and the growth of Geographic Information System (GIS) technology and landscape ecology methods capable of addressing spatially complex watershed problems.

3.2.1 Site Level Forest Road BMPs Effectiveness

Site level studies of forest road BMP effectiveness examine how well BMPs work in specific sections of roadway, crossings, and other features at a specific site or sites. The study methods include visual observations (e.g., eroded soil volumes, sediment plume travel distances), sediment traps, and monitoring of water quality parameters (TSS and/or turbidity) in runoff. Site level studies focus on how well BMPs control the sources of sedimentation (erosion, mass wasting and delivery), and are usually able to compare sites with BMPs to control sites lacking BMPs.

A number of methodologies have been developed for monitoring erosion and sediment production at sites based on upslope or on-site evaluations (Corner et al., 1992). Corner et al. (1996) compared the use of sediment traps, a relatively inexpensive upslope monitoring technique, with weekly instream monitoring of TSS. Upslope monitoring, using sediment traps above and below disturbed forest areas, has several advantages over instream monitoring. Instream monitoring is more time-consuming and expensive compared to the upslope approach. Careful observation of on-site processes, such as the formation of sediment trails, can document sedimentation processes unaccounted for by either instream or upslope monitoring procedures. Qualitative walk-in-the rain monitoring may help identify key problem areas and processes and considerably augment quantitative data (MacDonald and Smart, 1993).

Sediment traps were used by Sugden and Woods (2007) to measure rates of sediment production from forest roads in western Montana. They found that rates of road erosion in this region were relatively small and were limited by low erodibility of the dominant parent materials and low rainfall. The efficiency of five, 0.8 m^3 sediment traps in measuring road erosion ranged from 21 to 84%, with a mean of 56%, which compares favorably with those reported by other researchers. Sediment trap efficiency was inversely correlated with the fraction of clay in the roadbed. At the site where trap efficiency was 21%, the measured sediment yield had to be increased by a factor of 2.3. It is important to consider how the accuracy of erosion measurements made by different methods depend on factors such as the efficiency of sediment traps, as they can substantially affect the quality and comparability of erosion as well as sedimentation data. Likewise, methods based on dry-weather observation of sediment plumes are subject to possible bias.

BMP effectiveness studies, taken together, demonstrate that modern BMPs substantially mitigate nonpoint pollution from forestry activities at the site scale, although the BMPs are not 100% effective (Jackson et al., 2004). The exception to this generalization is unstable locations in key problem areas of the PNW (Idaho, northwest California, western Oregon and Washington, and southeast Alaska) where conventional BMPs for road construction may not be sufficient to prevent adverse effects on stream channels and fish habitat (Binkley and MacDonald, 1994). Table 3-2 is a compilation of numerous site level BMP effectiveness studies. Operations complying with BMPs led to stream sedimentation problems in fewer than 10% of 40 projects studied in Idaho (Harvey et al., 1988). Robinson et al. (1999) indicated that Oregon FPRs were likely reducing the size and number of road-associated landslides. Other site-level BMP effectiveness studies include the McGreer (1981) Potlatch skid trail erosion study, the North Carolina Flatwoods sites (Appelbloom et al., 1998), and the Megahan and Ketcheson (1996) study of sediment travel distances.

Swift (1984b) studied erosion on newly constructed timber sale access roads in the southern Appalachian Mountains. After seeding and grading the road surfaces with gravel, soil loss rates were greatly reduced, especially from the grass-covered cut and fill slopes. However, some erosion from the roadbed continued. Despite the reduced erosion rates after these mitigation measures, soil loss from the entire roadway was calculated to be about 20 times the normal rate for undisturbed forest. Improving roads for all-weather use by installation of adequate culverts and gravel surfaces can have short-term negative effects such as the generation of sediment.

A number of states have developed programs to monitor water quality and stream habitat condition in the proximity of sites (Ice et al., 1997). In the early 1990s, the North Carolina Division of Water Quality and the USFS examined the effectiveness of BMPs on a forest road in the Appalachians (North Carolina Division of Water Quality, 1994). A long-existing road, which closely paralleled Timbered Branch and its tributaries for about 2 miles and had been a chronic source of road sediments to the stream, was retrofitted with a number of measures designed to reduce sediment loading. They included ditch outlets, sediment traps, berms, weeps, outslopes, humps, and relief culverts. Sediment reduction was assessed qualitatively, and biological monitoring was conducted on the affected streams to determine effects on aquatic species. Improvements in taxa richness and diversity in the aquatic community were attributed to the sediment reduction practices (Prud’homme and Greis, 2002).

The South Carolina Forestry Commission, in cooperation with Clemson University and the South Carolina Department of Health and Environmental Control, evaluated the effectiveness of silviculture BMPs in protecting water quality in all physiographic regions in South Carolina (Adams et al., 1995). Twenty-seven harvested sites from the Coastal Plain to the mountains were selected. BMP compliance on the sites ranged from inadequate to excellent, thus bracketing the full range of potential effects. BMP effectiveness was determined by Stream Habitat Assessment (SHA) and benthic macroinvertebrate monitoring. Poor logging practices were linked to impaired benthic invertebrate condition and aquatic habitat (Dissmeyer, 1994). Ten sites that rated inadequate for BMP compliance experienced negative SHA impacts. On sites where BMP compliance was rated as adequate or excellent, SHA indicated that streams were not impacted. Sites that passed BMP compliance inspection scored well on the bioassessment. The authors concluded that BMP compliance inspections appeared to be a reliable and economical surrogate for monitoring BMP effectiveness in South Carolina (Prud’homme and Greis, 2002).

Seven and one-half miles of Three Forks Road were reconstructed in the Conasauga River Watershed in northern Georgia and southeastern Tennessee (Riedel and Vose, 2003). The gravel road was reconstructed to reduce slope and break up long grades; center crowns, ditches and culverts were removed; cut-and-fill slopes were vegetated; brush barriers were installed on fill slopes; settling areas were contained with hay bales, brush barriers and silt fences; and coarse run aggregate was added to roads to reduce surface erodibility (Swift and Burns, 1999; Swift, 1988). Sediment yields post-treatment were initially very high (though less than average pre-treatment) and rapidly declined to levels well below that of pre-treatment. Road reconstruction reduced sediment yield by 70% within 4 months, despite greater precipitation.

Woods et al. (2007) measured sediment travel distances below drivable drain dips along unpaved roads in the metasedimentary Belt Series and glacial till parent materials of western Montana. Drivable dips and other road BMPs such as ditch relief culverts, open top culverts, and flapper water bars are only effective if they are located so that the sediment travel distance below the drainage outfall is less than the distance to the nearest stream. The travel distances measured by Woods are lower than those measured in granitic parent material. Due to the limited sediment travel distances, most drainage outfalls in these parent materials do not contribute sediment to streams. However, the researchers note that dry weather determination of sediment travel distances are subject to error, and that fine sediment moves farther.

Studies of stream crossings and wetlands have been summarized by Rehder and Stednick (2006). Thompson et al. (1996) reported sediment production from fords, and sediment production from temporary culverts and bridges was investigated by Whitewater (1997) and the USFS (USFS, 1981). Thompson and Kyker-Snowman (1989) measured the short and long-term impacts of “mitigated” and unmitigated stream crossings. Wetland crossing studies reported generally minimal water quality impacts, but noted that sedimentation effects were most effectively controlled by keeping runoff on the roadway (as opposed to roads in upslope landscapes, where BMPs are applied to remove runoff from the road).

Although silviculture BMPs are grounded in science or are based on scientific principles, a lack of science to validate BMP effectiveness has been noted as a shortcoming of many BMPs related to forest roads (Grace, 2002). For example, routing runoff onto the forest floor is often presented as a trapping mechanism and means to reduce sediment delivery to streams. Through proper design, filtering of runoff from forest roads can be induced by directing flow onto the natural litter layer of the forest floor. However, in steep terrain, this filtering may not be sufficient to arrest sediment-laden flows. In addition, the filtering capacity of forest floor is limited and diminishes over time.

BMP performance is usually defined in terms of a constant pollution reduction efficiency, as presented in Table 3-2. In reality, the performance of BMPs and associated impacts vary considerably with geology, terrain, other watershed characteristics, site locations and weather. This, combined with various intensities of forestry practices and traffic levels, can lead to localized water quality problems that may not be fully controllable by BMPs, especially at the cumulative scale of watersheds.

The difficulty with rating BMP efficiency is that the same practice on different sites, in different watersheds, or even with different weather patterns can result in different impacts (Ice et al., 2004). In order to maximize the performance of BMPs at a site, the BMP prescription must be customized to the setting. Specific examples related to site conditions include the following (Olszewski and Jackson, 2006):

- Avoid sidecast road construction in steep, landslide prone regions;
- Diversion-proof or storm proof roads where gully formation is a significant risk (e.g., steep forest roads);
- Provide adequate rocking or use geotextile reinforcement where surface fines are generated by traffic;
- Remove runoff concentrated by interception of subsurface flow or precipitation from the road (using cross drain distance, outsloping, rolling dips, road runoff diversion structures) before concentration and excessive rutting occur;
- Avoid direct delivery of sediment from roads by limiting the road distance draining to stream crossings, by applying effective buffer distances and slash/debris/grass buffers;
- Use energy dissipaters where road runoff energy is high;
- Apply mitigation measures such as road decommissioning or removal, or upgrading with additional BMPs, to reduce risks in legacy watershed situations.

Customizing the BMPs for forest roads is a popular solution to “problem” roads and roads and crossings in highly erosive and high risk locations. However, customized BMPs require greater skill and effort on the part of the forest manager and knowledge of where the problems are located, both of which increase the difficulty for states to determine whether BMPs have been properly implemented. In this situation, performance standards that are realistically achievable should be used to set goals for the BMPs (Rashin et al., 1999).

Major storms are the design condition for many BMPs. Some BMPs will function in a 5-10 year storm; more on-slope BMPs will fail in a 25 year storm; and, all BMPs may fail in a greater than 25 year storm (Dissmeyer, 1994). At the level of rare events, natural impacts and processes may overwhelm management decisions, and their impacts may be obscured. Assessments of BMP effectiveness must therefore wait for “testing storms”, like the severe 1996 floods in Oregon and southern Maine.

3.2.2 Watershed Scale Forest Road BMPs Effectiveness

A number of large studies have focused on how forestry practices including BMP implementation has contributed to changes in sedimentation and other water quality impairments. Because such impairments are usually a cumulative response to many sediment sources and can occur considerably downstream, these studies are generally conducted at the watershed scale. These studies test the hypothesis that forestry practices, including the application of BMPs, will be effective at minimizing cumulative water quality impairments to maintain and restore beneficial uses. A number of these studies have examined how water quality impairments due to forest roads are mitigated by BMP implementation.

Watershed-scale research is much more complex, data-intensive and expensive than site studies. Interpreting the results of watershed studies can also be difficult and contentious. Large watershed-scale studies have a number of important advantages for monitoring effectiveness of BMPs (Ice and Whittemore, 1998). These include:

- Watershed-scale assessment allows for an integrated or cumulative measure of BMP and program effectiveness.
- It allows BMP effectiveness to be placed in the context of realistic variations in water quality throughout a watershed and over time;

- It allows for assessment of the conservative/non-conservative nature of water quality parameters;
- It connects upslope hazards with downslope aquatic resource risks; and
- It allows for assessment of unanticipated consequences that might not be identified at the site scale.

Several methods are used to compare the water quality response with BMPs to either undisturbed (i.e., no roads) or untreated (no BMPs) reference watersheds. The most common methods involve using paired watersheds or before/after comparisons of past and current measures of impacts from forest operations. Paired watershed studies may be superior in that they can be used to explain the important factor of weather variations (Loftis et al. 2001), although there are limits. In the Mica Creek Watershed Study a small thunderstorm cell perched nearly directly over one experimental watershed, causing significant runoff, while completely skipping a nearby paired watershed (Ice, 2000). Another method that is seeing more widespread use by states is trend monitoring of stream habitat conditions, such as the Aquatic Inventory Project in Oregon.

A possible measure of effectiveness is achieving state water quality standards or stream habitat goals (Ice, 2004). Under the CWA, states are required to establish water quality standards to protect beneficial uses of water. One trouble with water quality standards is that they have not adequately characterized what is achievable and even desirable. Furthermore, states have different standards for suspended sediment, turbidity and sedimentation. Turbidity standards capture suspended sediment, but not the degradation of stream substrates by fine sediment, and there are no criteria that measure hydrologic change (Scurlock, 2007). Efforts by USEPA to develop water quality criteria for suspended and bedded sediments (SABS) are noteworthy in this regard. SABS are defined by USEPA as particulate organic and inorganic matter that suspend in or are carried by the water, and/or accumulate in a loose, unconsolidated form on the bottom of natural water bodies (Swietlik, 2003). SABS are a unique water quality problem when compared to toxic chemicals, for example, because suspended solids and bedded sediments (including the organic fraction) occur naturally in water bodies in natural or background amounts and are essential to the ecological function of a water body. However, as documented in Section 2.2, SABS in excessive amounts constitute a major ecosystem stressor. Impairment of the movement of large wood in stream systems by road crossings is also poorly reflected by water quality criteria. Use of ecologically-based water quality criteria to designated impaired waters has been stopped by industry groups on legal grounds in several states: Oregon no longer lists streams under Section 303(d) on the basis of low instream flow or “habitat modification” because these are not “pollutants”.

In addition, traditional water quality monitoring has proven to be inadequate for detection of impairment caused by stormwater runoff (FDEP, 1997). Numerous studies have demonstrated that the biotic and chemical “noise” in larger streams renders the water quality effects of forestry activities using BMPs undetectable (Jackson et al., 2004). Accurate suspended sediment load estimation in small, rain-dominated watersheds like Caspar Creek depends upon frequent sampling when sediment transport is high. Sediment concentrations are highly variable and inconsistently or poorly correlated with water discharge. Errors of 50-100 percent are probably typical when sampling is based on convenience (Lewis, 1998).

Major watershed-scale studies that have investigated the effectiveness of forestry BMPs include the following:

- Caspar Creek, California
- Mica Creek, northern Idaho
- Hinkle Creek, southwest Oregon
- Alsea watershed, Oregon
- Six Rivers National Forest, California
- Alto watershed, east Texas
- Fernow Experimental Forest, West Virginia
- Coweeta Hydrologic Research Laboratory, Appalachian Mountains

These watershed studies are briefly introduced below. Since a number of the studies have been ongoing for as long as 50 years, there is no way to present or even summarize all of their findings. A number of books and research summaries have been published for the watershed-scale projects (Ice and Stednick, 2004; Ziemer, 1998).

The Caspar Creek Watershed Study is an important ongoing project to assess BMP effectiveness being conducted by the CAL FIRE and the USFS Pacific Southwest Research Station. This study provides research level data on how forest practice operations prior to and after the implementation of California's 1973 Z'Berg Nejedly Forest Practice Act (FPA) have affected water quality (Cafferata and Spittler, 1998; Lewis, 1998; Lewis et al., 2001; Ziemer, 1998; Ziemer, 2001). Streamflow and suspended sediment have been gauged continuously since 1962 at both the North and South Fork weirs of Caspar Creek in northwestern California since 1963, and at 13 tributary locations in the North Fork since 1986. The North Fork gauging station (NFC) was used as a control to evaluate the effects of logging in the South Fork on annual sediment loads in the 1970's. In summer 1967, a main-haul logging road and main spurs were built in the South Fork. The road right-of-way occupied 19 ha adjacent to the stream, from which 993 m3ha-1 of timber was removed. The first of three stages of logging began in the South Fork in 1971, during which 59% of the stand volume was selectively cut from 101 ha. In 1972, 69% of the stand volume was selectively cut and tractor yarded from an additional 128 ha. In 1973, 65% of the stand volume was selectively cut from the remaining 176 ha (Rice et al., 1979). Aerial photos of the South Fork Caspar taken in 1975 portray 66 recently active landslides (Keppeler et al., 2003). Of these, all but 3 were associated with roads, landings or skid trails. Of the 38 South Fork landslides documented between 1994 and 2003, 89% are road, landing, or skid trail related. An ageing system of logging roads and skid trails continues to deliver sediment to the stream channel. In the most conservative treatment of the data, suspended loads increased by 212 percent over the total predicted for a 6-yr period commencing with the onset of logging (Lewis, 1998). Sediment load increases were correlated with flow increases after logging. Field evidence suggested that the increased flows, accompanied by soil disruption and intense burning, accelerated erosion of unbuffered stream banks and channel headward expansion.

When the roles of the watersheds were reversed and the same analysis repeated to evaluate harvesting in the North Fork under California Forest Practice Rules in the 1990's, no significant increase was found at NFC in either annual suspended or bed load. Logging began in the main study portion of the North Fork in 1989 and ended in 1991. The timber volume removed from the North Fork was intended to approximate the volume cut from the South Fork in the early 1970's, but clearcutting with cable yarding was used in the North Fork rather than the selective harvest with tractor yarding that had been used earlier in the South Fork. Upstream of the North Fork gauging station, 48% of the area was clearcut and 4% of the streamside protection zone was selectively cut. The size of clearcut blocks in the North Fork ranged from 9 to 60 hectares (ha) and occupied 35% to 100% of individual tributaries. New roads, landings, and skid trails occupy from 2.1% to 7.0% of individual logged watersheds. Three tributaries in the North Fork were left in an untreated control condition. Post-logging measurements continue in the North Fork and South Fork watersheds to the present.

It is probable that the sampling methods in the 1960's and 1970's resulted in overestimation of sediment loads in the South Fork analysis by a factor of 2 or 3 (Lewis, 1998). Therefore, comparisons between relative increases are more appropriate. Excess suspended load was 212 to 331 % (depending on whether an adjustment is made for a North Fork landslide in 1974) after logging the South Fork, and 89 % after logging the North Fork, suggesting that the effect of logging on suspended sediment load was 2.4 to 3.7 times greater in the South Fork than in the North Fork. Flow increases accounted for only part of the variability in sediment production. Road systems would typically be expected to account for much of the sediment. However, in this case, roads were relatively unimportant as a sediment source because of their generally stable locations on upper hillslopes far from the stream channels.

The effectiveness of Idaho's forest practice rules is being tested by Potlatch Corporation and cooperators at Mica Creek in northern Idaho. In 1990, Potlatch Corporation initiated research at the Mica Creek Experimental Watershed to evaluate the cumulative effects of contemporary timber harvest practices on water flow, quality, and aquatic ecosystem health. The study consists of paired and nested experimental watersheds at three scales. Forest treatments include a 50% clearcut watershed and a 50% partial cut watershed (50% canopy removal). Watersheds were monitored for a pre-treatment calibration period of six years, a four year post-road period, and a five year post harvest + road phase to separate the effects of road construction from harvest practices. Monitoring includes basic hydrometeorological variables, streamflow, stream temperature, sediment, channel characteristics, aquatic macroinvertebrates, and fish. Results from Mica Creek are just beginning to be reported (Ice et al., 2004b). More recently, the Mica

Creek watershed has been transitioning into a working forest, with roads installed in 2006 and harvesting beginning in 2007.

The Alsea Watershed Study in Oregon began in 1957 as a cooperative effort between Oregon State University and federal and state agencies to address the effects of timber harvesting on the stream environment (Moring and Lantz, 1975; Ringler and Hall, 1975). The Alsea study also examined the response of salmon, trout, and other fish species to forest practices, often the most basic factor when the public considers the effectiveness of forestry BMPs. Coho salmon biomass and net productivity increased after logging, but cutthroat trout populations declined (Ringler and Hall, 1975; Moring and Lantz, 1975). This is not unexpected, because cutthroat trout are a stream-resident species that requires clean gravel for spawning. Coho salmon, on the other hand, are anadromous and can spawn in fine sediments. Although coho biomass and net productivity increased in the intensively clearcut watershed, some subtle measures of coho salmon performance were negatively affected (reduced condition factor of fingerlings and fry in streams at the time of logging, and fecundity of these coho when they returned to spawn). Macroinvertebrates may increase in abundance with some timber harvesting practices near streams, but the diversity may shift or light- and sediment-intolerant species may decline (Newbold et al., 1980). More recent studies in the clearcut watershed (Needlebranch Creek) show that coho are relatively unaffected by extreme harvesting practices, but cutthroat trout populations show persistent decreases in older age classes (Gregory et al., 2008). It has been hypothesized that the reason for the cutthroat response is that habitat quality (pool depth and complexity) was reduced during the initial harvest and has not recovered.

The forestry practices that took place during the Alsea study, extensive clearcutting and lack of stream protection, are no longer permitted under Oregon’s FPA, in large part because of the lessons learned in this watershed study. Results of the Alsea study were used to develop BMPs for timber harvesting in the temperate coniferous forests.

Since 1990, the Oregon Department of Fish and Wildlife (ODFW) has been working with forest landowners to collect information on stream habitat conditions as part of the Aquatic Inventory Project. This project has created a database representing 4,000 stream reaches throughout

Oregon. With resurveys of the stream reaches, it is possible to assess trends in stream habitat conditions. The information has been organized by Oregon State University scientists into a GIS database with nearly 100 variables describing stream and habitat attributes (Wing and Skaugset, 1998). One additional program of note is the Headwater Research Cooperative that is supporting research on mostly non-fish-bearing forest headwater streams to assess how they function and to determine what are appropriate management practices.

At the Fernow Experimental Forest in West Virginia, turbidity in runoff was compared between a watershed treated with BMPs, an unrestricted harvest watershed where road construction was not managed to control water pollution, and an undisturbed control watershed (Reinhart and Eschner, 1962). While the BMP watershed showed an increase in the maximum turbidity measured from 15 JTUs (Jackson Turbidity Units) for the control to 25 JTUs, the maximum turbidity measured for the runoff from the unrestricted harvest watershed was 56,000 JTUs (Ice, 2004).

Williams et al. (1999) evaluated BMP effectiveness in the South Carolina Piedmont, which they considered the most sensitive physiographic province in the state. The authors studied three harvest, site preparation, and regeneration alternatives (with BMPs) for changes in flow, sediment, and nutrients, and compared results to a control watershed. They observed statistically significant increases in observed parameters in all alternatives, but all waters met state water-quality standards. Further, they demonstrated that forestry BMPs reduced sediment yield to one-tenth of that occurring without BMPs (Prud’homme and Greis, 2002).

A number of watershed studies have compared past and current measures of impacts from forest operations. A before/after watershed study in the Six Rivers National Forest in California (Knopp et al., 1987) documented a 85% reduction in landslides associated with roads over a 10 year period, while fine material in stream bottoms was reduced from 22 to 15%. Ice (2004) compared the results of watershed studies in the South Carolina Piedmont by Williams et al. (1999) and Hewlett (1979). BMPs reduced sediment yield increases tenfold compared to yields observed prior to BMPs.

The majority of watershed scale studies reviewed for this report suggest that the use of BMPs at the site level to maintain water quality are effective at reducing cumulative effects with a basin, although more research is clearly needed. The paired watershed and before/after comparisons show that forest BMPs can reduce water quality impacts from 80 to >99% (Ice, 2004), although the continuing presence and use of unpaved roads typically precludes recovery to pre-disturbance levels (NCASI, 1994). Negative impacts of forest practices should be uncommon except in cases where: unstable areas and areas with highly erodible soils, when management activities coincide with extreme storm events, and possibly for cumulative effects in downstream deposition areas (Binkley and MacDonald, 1994). Extreme storm events can have unavoidable effects on both managed and unmanaged landscapes and streams. At level of rare events, natural impacts and processes may overwhelm management decisions, and impacts may be obscured (Dissmeyer, 1994). Assessments of BMP effectiveness must wait for "testing storms" like the 1996 floods in Oregon and southern Maine, or the December 2007 flood in Washington.

The effectiveness of BMPs in the California coastal region may be an exception to the findings summarized above. According to Harris et al. (2005), there are no quantitative data indicating that road BMPs have substantially improved instream water quality or salmonid habitat conditions in that region. These authors report that it is not known how site-level effects translate into benefits to water quality and stream habitat at the stream reach or watershed scales. Little is known about the temporal scale at which improvements may occur. Recent studies show that restoration of upper watershed locations or non-fish-bearing streams causes short-term impacts on local water quality due to post-construction adjustments (Klein, 2003).

3.3 What are the Costs of Installing and Maintaining These BMPs?

The costs of installing and maintaining BMPs is a major concern to the forestry industry, since BMPs increase the cost of timber harvesting and reduce harvesting revenues. Some cost information for forest practice implementation is based on the average increased cost of conducting a harvest when management measures, i.e., a suite of practices, are used versus when they are not used. The difficulty in separating the costs of implementing individual forest practices are emphasized when costs are provided in this way. This difficulty is due to incorporating the cost of using numerous BMPs into the accomplishment of a single harvesting or road construction activity, and spreading the cost for individual practices across the accomplishment of multiple activities. For example, the cost of adhering to a state regulation for stream crossings might be spread among the costs of planning a harvest to minimize the number of stream crossings, designing and constructing forest roads to accommodate the plan and minimize instream effect to water quality and fish, and the actual construction of the stream crossings. Furthermore, these costs differ with each harvest because the terrain, soils, location of harvest site relative to streams, and hydrology are different at each harvest site. Therefore, all costs presented here are best regarded as rough estimates. The BMP cost estimates presented here have all been updated to 2008 dollars, using the Bureau of Labor Statistics Consumer Price Index. Much of the summary of BMP costs presented below was taken from the USEPA report, *National Management Measures to Control Nonpoint Source Pollution from Forestry* (USEPA, 2005).

Estimates of the per acre cost of implementing BMPs for timber harvests were arrived at based on information obtained from published reports on regional studies of the cost of BMP implementation and cost estimates based on the regulatory structure of forestry practice programs. Studies have been conducted on the cost of implementing forestry practices for water quality and soil protection in the Southeast and some western states (Aust et al., 1996; Dissmeyer and Foster, 1987; Dubois et al., 1991; Henly, 1992; Lickwar, 1989; Olsen et al., 1987). Table 3-3 presents costs associated with complying with forest practices in states where their implementation is either voluntary or regulated, with differing numbers and types of requirements depending on the state (Ellefson et al., 1995).

The costs of implementing state forest practices arise from various activities including conducting timber surveys, preparing management plans, constructing roads, and implementing practices specifically designed to protect water quality. Many of these costs are borne whether or not a stream or other surface water is located on or near a harvest site, though additional costs (e.g., designing and flagging a Streamside Management Area (SMA), constructing stream crossings) are incurred where streams are present. Costs also take the form of lost revenue from trees that are not harvested to ensure compliance with forest practices. Revenue might be reduced if merchantable trees are left standing in SMAs or when selective cutting is called for rather than clear-cutting. An example of this is presented in a comparison of BMP cost estimates made by the Texas Institute for Applied Environmental Research (TIAER; Tanter, 2003). BMP cost estimates provided by Haney (1998) are much higher ($131 per acre) than cost estimates from other sources ($24 to $30 per acre); the difference was due to the greater value Haney attributed to timber in streamside management zones, which is not a cost ordinarily associated with forest road BMPs. Although the loss of revenue is a real “cost” to landowners, it is very market- and species-dependent and is generally not included in the cost estimates provided here. The overall costs of complying with regulatory forestry BMP programs might be borne by forest landowners alone or shared among landowners, timber operators, and others. Of course, BMP costs in this context ignore the very real benefits of protecting water quality.

Factors that typically affect the cost of implementing forest practices include the type of terrain on which a harvest occurs (with costs for harvesting on steeper terrain typically being higher than costs for harvesting on flatter terrain) and the regulatory structure of forest practice rules. Compliance in states that have numerous and stringent forest practice regulatory requirements generally costs more than compliance in states where regulatory requirements are fewer or less stringent, or are voluntary. Some states have single regulations that can add significantly to the cost of forest harvesting. An example is the requirement for a detailed forest harvest plan in California. This alone places compliance with forest practices in California in a category by itself.

Table 3-3 summarizes estimations of the overall per-harvest cost of complying with forest practice regulations in different regions and states. Table 3-4 provides cost estimates for implementation of individual management measures in the Southeast and Midwest. The costs have been verified with state and federal forest management agencies and have been found to be representative of actual expenditures. Although most of the cost information came from case studies in the southeastern United States, they are representative of costs incurred nationwide. Costs vary depending on the site-specific nature of the timber harvesting area. Table 3-5 provides estimates of costs for installing individual road construction and erosion control BMPs. Costs are provided by region, demonstrating that the costs for installing BMPs can vary considerably in different parts of the country. Specific factors that affect implementation costs are mentioned in the *Comments* column of the table.

Costs of installing BMPs are available from a variety of other sources (USEPA, 2005; Blinn et al., 1998; Gallagher et al., 2000; Kochenderfer and Helvey, 1987). Unfortunately, many of the available cost estimates are provided on different bases (cost by area, road length, individual treatment or site feature) making it difficult to compare costs for different BMPs as well as estimating the total cost of BMPs for a particular location and level of treatment. For implementation of standard BMPs, TIAER (2003) summarized four independent estimates of total costs that ranged from $24 to $131 per acre; for enhanced BMPs, total cost estimates range from $42 to $199 per acre. As previously noted, the BMP cost estimates provided by Haney (1998) were much higher than the other sources; this difference is due to the greater value Haney attributed to timber in streamside management zones, which is not a cost associated with forest road BMPs.

Road construction costs can vary widely on the National scale, depending on both the road standard and site conditions (NCASI, 2001). Road construction costs range from less than $12,800 per mile on gentle terrain remote from streams, to over $265,000 per mile on steep slopes where the design requires BMPs that prevent landslides and delivery of sediment to streams (Scherer, 2000; Clark et al., 2000). The costs of temporary roads currently being constructed range from $9,450 to $14,800 per mile in gentle to mountainous terrain (Coghlan and Sowa, 1998). Cost of constructing eight unsurfaced minimum standard roads in central West Virginia averaged $15,700 per mile (Kochenderfer and Helvey, 1987). Surfacing these roads with a 4 inch depth of limestone gravel would add about $19,400 per mile, more than doubling the road construction cost.

Where road BMPs are revised to better achieve water quality standards, it should be kept in mind that certain more costly erosion control practices are specifically needed in the vicinity of stream crossings and for road segments that drain to streams either directly via ditches or potentially via drainage relief discharges (Rashin et al., 1999). Therefore, the additional costs of such practices do not apply to the entire length of constructed roads, and such costs can be minimized through careful road location and drainage design.

Costs for road removal are provided in Switalski et al. (2004). Most common forms include roadbed “ripping” ($745-$2,264/mile), restoring stream crossings ($582-$175,000), and fully recontouring hillslopes ($5,660-$377,300/mile). The wide variation in the estimates for these costs is related to the complexity and variability of stream crossing restoration and full recontour. These factors make it easier to compare project costs on a per-cubic meter basis. The cost of excavating in Redwood National Park was reported to range from $1 to $3.50 per cubic meter (Bagley, 1998).

No costs estimates were found specifically for BMP maintenance. Broadly, appropriated annual maintenance for forest roads in the National Forests ranges from $405 to $810/mile for maintenance level 3-5 roads, $81 to $135/mile for maintenance level 2 roads, and $27 to $54/mile for maintenance level 1 roads (Coghlan and Sowa, 1998). For comparison, a survey conducted by the Illinois Institute for Rural Affairs in 1994 identified average annual costs of maintaining a mile of gravel or loose aggregate road at $11,853 for all counties, and $2,961 for all townships. Comparison of these expenditures indicates that roads in the National Forests receive much less maintenance than other roads.

3.4 What are the Recent Promising Innovations in Forest Road BMPs?

The forest road research literature points to stream crossings, including features such as bridges, fords, and culverts as causing the most significant sediment problems. Recent innovative technologies include portable bridges, mats, pipe bundles, and altered logging equipment (wider tires, low tire pressure, dual tires). Portable bridges have been gaining popularity because they can be installed with minimal site disturbance and water quality impacts, when compared to other types of crossings (Taylor et al., 1999). Studies have shown that these portable bridges are a cost effective way to reduce the environmental impacts of stream crossings. The Forest Service supports the use of portable bridges to temporarily cross streams. Several states have programs that loan these portable bridges to loggers such as the North Carolina Forest Service's Bridgemat Loan and Education Program, funded partially through USEPA's 319(h) grants.

An emerging focus of the post-flood studies in the Pacific Northwest is the importance of designing roads to accommodate disturbances, particularly in the area of road-stream crossings, which are implicated in most documented road failures (Gucinski et al., 2001). Road re-design that anticipates and accommodates movement of water, sediment, and debris during infrequent but major storms should substantially reduce road failures and minimize erosional consequences when failures occur.

Other innovations involve the development of methods to optimize BMPs. One example is customized cross drain placement based upon sediment flow analysis, which can reduce both sediment production and road construction cost in comparison to the prescriptive approach to cross drain placement. CulSed is a computer decision support tool developed by the Rural Technology Initiative for cross drain culvert design, that enables users with little technical training to find near optimal cross drain locations (Damian, 2003). CulSed is simple to use but requires accurate road geometry, stream and digital terrain data for a successful analysis.

Optimization strategies are also being applied for sediment reduction practices on roads in steep forested terrain (Madej et al., 2006). Applied optimization methods can be used to determine the most efficient way of minimizing sediment input to streams through road decommissioning. Roads can be decommissioned through a variety of techniques, each of which has its own cost and sediment savings. The optimization tool can formulate the most cost-efficient strategy for restoration across a watershed. Optimized restoration strategies have been shown to save more sediment under constrained budgets than the currently used approaches.

Some innovative BMPs might be effective, but the technology has not yet been developed to apply them (Ice, 2004). For example, a BMP for landslide-prone forest lands might be very effective if slope positions where the factor of safety for slope failure approaches 1.0 (i.e., no safety factor) during extreme precipitation and runoff events could be accurately defined. While general guidelines can be provided for these high risk sites, the technology to accurately map variations in soil depths and subsurface water transmissivity, as well as the spatial resolution needed for accurate prediction of critical slope angles, is not yet available (Robinson et al., 1999).

Another area of innovation related to forest road BMPs is the evolution of management systems, which address the question of how to tailor BMPs in watersheds to prevent cumulative impacts. One means of building on the reference stream approach is to couple stream indices with measures that index road system inputs (in this example, sediment) to the stream (NCASI, 2001). Such systems are being implemented by various states and companies. In these systems, instream measures of stream health (physical and/or biological) and evaluations of road sediment input are coupled in a management system that establishes levels or indices of sediment input that in turn indicate whether the input is acceptable or not. This is actually an evolution of implementation and effectiveness monitoring, in which the two resulting measures are compared and assessed to determine how much additional control is necessary. The target sediment input level must be decreased until the stream condition, as indicated by indices such as percent surface fines, channel stability, channel geomorphic type, or similar measures, is judged to be acceptable. The advantage of the target/index approach is that it is both adaptive and objective, providing feedback to the manager about the success of the BMPs in mitigating impairments. There are disadvantages as well. The approach essentially relies upon trial-and-error to obtain the desired water quality outcome and is highly reliant on the quality of the data for sediment input and instream measures; other scientific methods incorporating forecasting or modeling may be more efficient. The target/index approach can also delay remediation and recovery, because management action (e.g., improving BMP implementation or upgrading BMPs) to reduce sediment inputs will not necessarily occur faster than the response time of the water body to the sedimentation stressor. Finally, the approach assumes that the relationship between cause (sediment inputs) and effect (stream condition indices) can be discerned. This depends on factors such as natural variability and the magnitude of road-related sediment loading relative to other sources, which have already been discussed.

The promise of such management systems is that by understanding erosion and sedimentation processes as they apply to the specific circumstances of a watershed, as established by watershed assessment and road inventory procedures, managers can effectively reduce and control impacts to levels established as acceptable by current standards. Uncertainty exists regarding these standards and the targets and indices that reflect them, and future research will be needed to refine them through time (NCASI, 2001).

3.5 Why do Forest Road BMPs Fail to Protect Water Quality?

In general, the literature on forest road BMP effectiveness fails to address a seeming paradox: if BMPs are available to address erosion and sedimentation problems at most sites and rates of implementation are high, then why are there still water quality impairments from forest roads? Based upon state data for BMP implementation and effectiveness (Sections 4.2 and 4.3), BMPs appear to be highly effective: the BMP implementation rate is nearly 90% nationwide (Ice and Stuart, 2001). However, BMPs are apparently not effective enough to prevent documented impairments of sensitive aquatic resources. In discussing the results of an audit of forest practice rules for Idaho, Zaroban et al. (1997) reported, “On an individual rule basis, we found that when properly implemented and maintained, the practices described in the forest practice rules were effective 99% of the time”, but also stated, “We also found that half of the timber sales we audited had sediment being delivered to streams or stream channels as a result of forest practice activity”. Forest roads are commonly cited as problematic by western states. According to the 2002 USEPA National Assessment Database, California and Montana reported 9,713 forest road-related impaired miles of streams. Furthermore, California accounts for approximately 93% of all forest road related impaired miles of streams reported in the NAD (Beebe and Ice, 2007). Montana also reported forest road related impairments to waterbodies, but this number is considerably lower (439-mi, 707-km or 4%). These states demonstrate the same paradox regarding the effectiveness of BMPs, because both California and Montana report high rates of BMP implementation and compliance with state FPAs. In the most recent surveys, rates of compliance with forest road requirements in California and Montana averaged 95.8% and 89%, respectively.

In this regard, it should be acknowledged that the majority of studies documenting water quality impairments from forest roads were conducted prior to 2000. As previously mentioned, BMP programs for forestry in many states are dynamic. The extent to which conditions have changed since then is difficult to evaluate, but is an important source of uncertainty that should be addressed.

Based upon the information available for this report, there appear to be a number of reasons why BMPs fail to protect the water quality and other beneficial uses of aquatic resources. Most of these have already been discussed, and will only be summarized here.

3.5.1 Lack of Effective Implementation

In general, water quality problems may be due more to the failure to implement BMPs appropriately (Pardo, 1980; Whitman, 1989) than the ineffectiveness of the BMPs themselves (TetraTech, 1999). Rates of implementation for forestry BMPs are almost always less than 100%. This is especially true for road and crossing BMPs; state data consistently show the implementation rates for road and crossing BMPs to be among the lowest among all forest practice categories. Furthermore, just because BMPs have been implemented does not mean they are effective. Monitoring implementation can be straightforward, but BMP effectiveness is difficult to judge especially under dry weather conditions. Effective monitoring to detect sources of erosion, sediment delivery and obstacles to fish passage is a large and labor-intensive process, so may not be emphasized in many management systems. If problems are found and not corrected, they will continue and possibly grow worse.

3.5.2 Erosion Rates and Mass Failures can Exceed Capacity of BMPs to Prevent Generation, Transport and/or Delivery of Sediment to Water Bodies

BMPs, like any pollution control method, are effective up to a limit beyond which treatment effectiveness declines and may ultimately fail. In the case of BMPs for forest roads, the limits are related to the level of disturbance created by the road, the untreated rates of erosion, drainage connection and proximity to the surface water, and other regional and site-specific factors: unstable and/or highly erodible sites/locations, “Problem” roads, and excessive harvest rates and associated high road use. Erosion and sedimentation control may be ineffective because the BMPs in place are inadequate to control the runoff, erosion from the various components of the road prism, stability of cut and fillslopes, downslope sediment travel, plugging and washout of culverts, etc. In many cases, control of these problems is technically feasible if the BMPs are upgraded to a higher level of protection and performance or are enhanced by adding additional BMPs. In some cases, however, control of the problem may not be feasible: location "trumps" management practice. Downstream deposition areas involving cumulative effects are particularly vulnerable to the negative impacts of forest practices. Rare events are a special case (discussed below).

3.5.3 Legacy Roads and Crossings: Lack of Maintenance, Failure to Upgrade and/or Remove

How to address and remedy the legacy of past road-building, use and crossings is a serious problem. Old roads built with practices prevalent in the 1950's, 1960's, and early to mid-1970's are still significant sources of erosion (Cafferata and Spittler, 1998). Perched fill and poor watercourse crossings associated with old roads are often referred to as "loaded guns" waiting to fail with strong stressing storm events. It is imperative that forest managers develop long-term road management plans that inventory these source areas and quickly reduce their numbers with an organized schedule based on watershed sensitivity and vulnerability of downstream beneficial uses. In general, roads built under older standards are "grandfathered", or not required to be brought up to current design standards until either a segment needs to be reconstructed or the road shows immediate signs of failure that would damage waters of the state (Scurlock, 2007). Given that "old" roads and crossings make up most of the road network in many forested watersheds, it may take decades for the sediment delivery associated with these practices to be addressed. Lack of sufficient money for maintenance makes this problem worse. Large-scale road removal/obliteration is prohibitively expensive, so only the worst "problem" roads can be addressed.

3.5.4 Cumulative Impacts

Chronic erosion from many individual sites may impair a water body, even though relatively little sediment is delivered from each site. Fine grained sediment (usually the most significant pollutant from roads) is source limited, so once delivered to the water body it can be transported relatively far downstream to a deposition location. It is possible for many sites to deliver sediment to such a location. Cumulative impacts tend to be greater downstream of larger watersheds; watersheds with more forestry activity, higher road density and/or problem roads, crossings, etc.; watersheds with older road networks and a greater percentage of legacy roads; and watersheds where the rates of chronic sediment delivery and/or mass wasting are higher due to regional and site-specific factors.

3.5.5 Highly Sensitive Aquatic Resources

In several regions of the country forest streams and rivers downstream from forested watersheds, serve as habitat for aquatic species that are often highly sensitive to adverse effects of sedimentation. Endangered anadromous salmonids have very specific habitat requirements, which have become spatially limited in the Pacific Northwest due to anthropogenic activities not limited to silviculture. These include dam construction, fishing pressure, exotic species, resource extraction, increased water temperature resulting from climate change (see Poff et al., 2002), and loss of riparian vegetation. Substrate requirements for reproduction and other life stages are highly sensitive to sediment.

3.5.6 Rare events

Extreme storm events can have unavoidable effects on both managed and unmanaged forests, watersheds and streams (Binkley and MacDonald, 1994). The likelihood of failure of BMPs increases with the magnitude of rare events (Furniss et al., 1991). For example, a culvert sized to accommodate flow from a 50-year flood has a 33% chance of failure during it’s 20 year design life. In watersheds where culverts and other stream crossings are sized for a 5 or 10 year flood, essentially all the crossings may be subject to catastrophic “dambreak” failure in a 50 or 100 year storm. The likelihood of mass failures on roaded steep, unstable slopes likewise increase with the magnitude of rare events, although the probabilities of failure are less well understood. Robinson et al. (1999) indicated that Oregon’s FPRs are likely reducing the size of road-associated landslides as well as the number.

3.6 How Can Failing BMPs be Improved?

There are many possible ways to improve failing BMPs, depending on the specific circumstances. The descriptions of BMPs for forest roads (Table 3-1) include recommendations to address failing BMPs, including reconstruction and upgrading (Section 3.1.3.2). Adding components to BMP systems can help address BMP failure by increasing the overall treatment efficiency. Improving inspection and maintenance practices may also improve failing BMPs by anticipating and preventing failures. BMPs must be designed to anticipate and accommodate events (proactive) in order to be effective. For stream encroachment and culvert problems, removal of the road and offending culverts is effective (Luce et al., 2001). Regulatory and other management responses to BMP failure are addressed in Section 4.

In many cases, identifying the location of failures may be the greatest challenge. Although road inventories are usually based on dry weather observations, it would be much more effective to conduct them during wet weather. Qualitative walk-in-the rain monitoring may help identify key problem areas. In fact, public reporting of stream sedimentation, such as local observation of highly-turbid streams (Corner, 1992; Juul et al., 1990), is currently one of the most important means of learning of problems or potential violations (Irland and Connors, 1994).

One of the most important components of a comprehensive road management plan is the determination of which high-risk roads should be properly abandoned. Under the current California Forest Practice Rules, this means leaving a logging road in a condition that provides for long-term functioning of erosion controls with little or no continuing maintenance. Proper road abandonment usually involves removing watercourse crossing fills, removing unstable road and landing fills, and providing for erosion resistant drainage (Weaver and Hagans, 1996).

4. STATE FOREST ROAD BMP PROGRAMS

Nearly all BMP programs part of state forest practices, including state Forest Practices Acts, were initially developed in response to the requirements of Section 208 of the CWA. Each state's BMP program shares the basic objective of meeting the state's water quality standards and maintaining the beneficial uses. State forest practice rules and BMPs are generally considered to be minimum standards needed to protect public resources (NCASI, 2001). State BMPs are generally prescriptive (as opposed to procedural BMPs used in the NFS) because it is easier to assess BMP implementation than to measure compliance with water quality standards (Ice et al., 1997). Three considerations make the prescriptive approach to BMPs appropriate (Rice, 1992): (1) because most forestry-related pollutants are natural substances, their origin may be difficult to determine, (2) the practice that results in pollution may be difficult or impossible to correct once the pollution has occurred, and (3) the level of pollution is the result of the interaction of a practice and the subsequent weather.

When the 1972 legislation was enacted, only Oregon had passed a FPA that directly addressed water quality concerns. In 1974, the USEPA proposed that states adopt nonpoint source pollution control programs for forestry activities that were modeled after the FPAs of the Pacific Coast states (Rey, 1980). By 1982 most states had developed some type of NPS control program for silviculture. All states with significant timberlands now have NPS control programs, and several continue to evolve more refined BMPs and implementation elements. Measuring the success of BMP programs requires regular and credible surveying of BMP implementation (Prud'homme and Greis, 2002). Repeated assessments have shown that compliance with state BMPs and FPRs prevents major water quality impacts under most circumstances (Ethridge and Heffernan, 2000). There is some controversy about this conclusion, as will be discussed in Sections 4.3 and 4.5. State BMPs can also be inefficient (NCASI, 2001), because they are designed to protect resources under the general circumstances encountered in the area regulated. The result is that state BMPs over-protect in some cases (wasting resources that could be applied to higher priorities) and under-protect in others (allowing undesired impacts).

Although there are many similarities in FPRs and BMPs, there are also substantial differences between the state forest practice management systems designed to implement these rules. Some states have customized BMPs to regions within the state. States with diverse geographies and complex terrain, such as Washington, Oregon, and Idaho, have promoted various forms of watershed assessment to tailor BMPs more closely to the watershed and site conditions (NCASI, 2001). The Scientific Review Panel on California Forest Practice Rules and Salmonid Habitat also recommended a watershed analysis approach capable of assessing cumulative effects attributable to timber harvesting (Ligon et al., 1999). In some cases, management systems evolve around a specific issue or certain species of concern.

4.1 What are the State Programs that Address Forest Roads?

As of November 1999, thirty-six states have forest land management laws regulating all aspects of forest and timber resources and products derived from these resources (Defenders of Wildlife, 2000). Alabama, Alaska, California, Idaho, Minnesota, and New Jersey have the most laws, with five or more statutes on the books, whereas all other states have four or fewer laws. There are currently at least 105 state forest management laws which can be categorized into nine basic types of regulatory legislation: forest management laws, policy and purpose laws, powers and duties laws or administrative legislation, land acquisition laws, private landowner laws regulating privately owned forest areas, educational and forest research laws, timber laws regulating the cutting, harvesting and conservation of timber on state lands, prescribed burning and fire prevention laws, and disease and insect control laws. In many states there can be a complex legal framework of forestry regulations, and this framework varies considerably from one state to another.

For this report, the most relevant category of forestry laws is the forest management category. There are at least twenty of these types of laws dealing specifically with the need to manage state forest lands according to “multiple use” or sustainability principles (Defenders of Wildlife, 2000). There are relatively new scientific management methods designed to yield the most economic, recreational and social benefits from forest resources for generations of people.

Benefits from forest resources include soil and water quality, increased and diverse use of timber resources, and conservation of wildlife habitats.

The primary regulations applicable to the impacts of roads on freshwater ecosystems are the individual states' forest practices policies, which generally establish standards for the design of forest roads and also serve as the BMPs called for under Section 208 of the CWA. These programs vary in their substantive level of protection, their specificity and their enforceability. The programs generally fall into four categories: regulatory, nonregulatory without enforcement, nonregulatory with enforcement, and combination programs. Though BMP implementation is not mandatory under the CWA, states have the option of developing and implementing regulatory approaches for that purpose. Regulatory programs exist mostly in western and northeastern states such as California and Massachusetts or mountainous states with large timber industries such as Kentucky and North Carolina. BMPs are mandatory under regulatory forest practice programs. Nonregulatory BMP program without enforcement include states without a large timber industry or steep terrain such as Illinois, Oklahoma and Utah. Eighteen states have nonregulatory programs with enforcement, where use of BMPs are not mandatory but enforcement action can be taken against polluters or landowners who refuse to implement proper BMPs (e.g., Montana, Arkansas, and Michigan). Eight states have combination programs that mix aspects of regulatory and nonregulatory programs; Georgia is an example of a state having a mixed regulatory/nonregulatory program.

Regional trends in forestry BMP programs are also evident (NCASI, 2007). BMP implementation is largely voluntary in southern states (Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia), but three states (Florida, North Carolina, and Virginia) have linked BMP implementation to other state regulatory programs, making them quasi-regulatory in some circumstances, and BMP implementation became mandatory in Kentucky in July 2000.

While forestry BMPs have become the foundation of NPS water protection programs in the south, forest management programs in the west are overwhelmingly regulatory. Furthermore, most states in the western region have developed extensive guidelines for implementation of forest practices rules (FPRs) related to water quality as well as protocols to monitor compliance and effectiveness. These regulatory programs fall under either a FPA (Alaska, California, Idaho, New Mexico, Nevada, Oregon, Washington) or a streamside management act (Montana). Conversely, the states of Arizona, Colorado, Utah, and Wyoming do not have established forest practices acts. Even though Utah relies on voluntary BMP implementation, the Utah Forest Practice Act of 2001 requires registration of forest operators and notification of intent to conduct forest practices.

In the northeastern states (Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Vermont, and West Virginia) all states have developed forestry BMP recommendations. However, in general, many states have not put strong, consistent efforts into monitoring programs (except Maine and West Virginia). While the use of BMPs may be voluntary for some of the northeast states, there still exist legal requirements for forest management. Because of these various requirements, characterizing the use of forestry BMPs in this region as voluntary or required under law is difficult. In the northeast there is a strong focus by states and the forest products industry on education and training, strong ‘regulatory’ or legal programs, and, when compared to other regions (i.e., south and west) considerably lower levels of harvesting.

In the Midwest, only Minnesota has enacted a FPA. All states in this region (Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, North Dakota, South Dakota, and Wisconsin) have developed recommendations for implementing major BMP elements which generally cover the areas of timber harvesting, riparian forest management, stream crossings, and forest roads.

Summaries of the state programs for forest road management are provided in Tables 4-1 and 4-2. The 35 states in which BMPs for forest roads are voluntary are presented in Table 4-1, while Table 4-2 summarizes the programs in the 15 states in which BMPs for forest roads are mandatory. These tables are updated and expanded from ones reported by TetraTech[9] (2004).

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[9] TetraTech noted a number of limitations associated with the tables upon which Tables 4-1 and 4-2 were based. The tabulated information did not necessarily constitute a complete picture of all of the regulatory mechanisms available for protecting water quality from the impacts of forest roads. The tables presented only readily available information

The tables identify which of ten BMP categories are addressed in each state's forest practice rules, and whether the state engages in training and technical assistance, implementation/effectiveness monitoring, and/or compliance and enforcement activities in conjunction with the BMP programs. Implementation/effectiveness monitoring in each state is covered in Section 4.3. The most recent revision date of each state's BMPs is identified (dates ranging from 1993 to 2003 were found), and other relevant state BMP information (e.g., the statutory or administrative rule citation for the forest roads program and the state agency(s) administering the forest roads program) is included in the tables. Compliance and enforcement mechanisms are identified, which normally occur through referral to state environmental protection agency and water pollution control laws. The tables include information on formal agreements between state agencies for handling suspected incidents of water pollution from forestry operations.

Based on Tables 4-1 and 4-2, 44 states had some form of BMPs which addressed road construction; 40 had BMPs for crossings and road maintenance; 24 had BMPs for road closure; and 23 states provided training and technical assistance as part of their forest roads program. Many states do not address some of the most critical aspects of reducing water quality impacts from roads. A review of state BMPs found that 40% of state BMPs do not address maintenance of roads, 80% do not address use of roads in wet weather, and 72% do not address road closure (TetraTech, 2004). There are some discrepancies between different sources of information regarding state forest practices, and some BMP categories may be under-represented due to limited data. Table 4-3 provides a more detailed review of forest practices in five western states and selected Habitat Conservation Plan (HCP) provisions for roads (Scurlock, 2007). Only Washington addresses "orphan" roads and has a timeline to bring old roads up to current standards. Not all of the states use 100-year storms for crossing design, or allow passage of fish, bedload and debris. There are only limited applications of tools such as watershed analysis or cumulative watershed effects (CWE) evaluations.

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regarding the extent of state BMP programs. Some of the information was obtained from state forestry Web sites which provide an overview of each state's activities, but the full extent of their efforts might not be presented.

In the documents reviewed for this report, we found no examples of states where water quality agency review, concurrence, or approval of BMPs was required. We also found little information about the existence of state program for addressing water quality problems related to forest roads including legacy issues. In many states, roads built under older standards are “grandfathered”, or not required to be brought up to current design standards until either a segment needs to be reconstructed or the road shows immediate signs of failure that would damage waters of the state (Scurlock, 2007). In his commentary on the Northwest Forest Plan, Scurlock (2007) points to other weaknesses in roads policy on non-federal lands. Common limitations on the effectiveness of state forest practices rules to address road-related issues include the following:

- Although new roads are uniformly discouraged, and are subject to improved design and standards, they are not prohibited, even on steep, unstable or otherwise sensitive sites.
- There is limited enforcement and enforceability of rules/guidance relevant to direct road discharges to channels, cross-drain spacing, road surfacing, tire pressure, wet season operation, revegetation of exposed surfaces and roadside vegetation remediation.
- Decommissioning is deemphasized.
- Most rules have no requirement that roads be brought up to standards on any set timeline, and improvements are conducted according to operations convenience (except Washington).
- Lack of general performance standards for road design, rehabilitation and maintenance limits effectiveness of implementation (as on federal lands).
- FPRs do not recognize ecological importance of maintaining low road density where it exists, and reducing road density in high density watersheds is not a rational resource prioritization.

When problem areas in state BMP programs are identified, the overwhelming response by the various regulatory agencies is to strengthen education and training programs in the specific area identified (NCASI, 2007). Many state agencies have developed programs in cooperation with university extension programs to improve education and training of loggers. States in the northeast region rely heavily on BMP implementation as well as logger education and training programs to control NPS pollution during forest management. Increasing education opportunities, particularly for loggers and non-industrial private forest landowners, should increase rates of BMP implementation and compliance across the southeast and other regions. Implementation of effective BMPs, once designed, requires continuous education of an ever-changing population of forestry practitioners and landowners (Prud'homme and Greis, 2002).

The voluntary nature of the majority of state BMP programs precludes establishing permit conditions. Lacking this mechanism, states have employed logger, forester, forest practice purveyor, and landowner education as the primary tool to achieve BMP implementation. Training has traditionally been conducted in cooperation with forest industries, forestry associations, and state agencies.

States that report high rates of BMP implementation often attribute this to outreach and education programs (NCASI, 2007). On industrial forestlands, the high rates of BMP implementation can also be attributed to industrial involvement in sustainable forestry certification programs. The Sustainable Forestry Initiative (SFI) of the American Forest and Paper Association requires that member companies adhere to BMPs on company land. Member companies of the American Forest and Paper Association are required by the SFI guidelines to meet or exceed State BMPs on company-owned forest land (Prud'homme and Greis, 2002). In addition, some forest products companies impose sanctions on timber producers who fail to implement BMPs when logging on other ownerships. Forestry operations that utilize experienced and informed land managers generally have high rates of BMP implementation. Thus, many states recommend that landowners utilize forestry professionals (e.g., private consultants, certified Master Loggers) when planning any forest management operations. Kentucky requires that a certified forestry professional be on-site for the entire harvest operation.

Educating an ever-changing population of small forest landowners is a continual challenge for state BMP programs. A survey of state foresters found that landowner knowledge of BMPs and landowner attitude towards complying with BMPs was a top barrier to BMP implementation and effectiveness. These same state foresters noted that the top two keys to future progress of the BMP program are landowner and logger awareness and providing pre-harvest assistance while the top funding priorities in their respective programs are education, training, and monitoring.

Compliance and enforcement of BMP programs vary among states, along with whether the state water quality agency is involved. Florida, for example, relies on primarily voluntary compliance with state approved forestry BMPs. However, BMPs can be enforced when implementation is found to be deficient. When incidence of noncompliance is found at the practice level, a further evaluation is made to determine if a significant risk to water quality existed (NCASI, 2007). The Florida DOF defines significant risk as, "a situation or set of conditions where non-compliance with BMPs has resulted, or may result, in the measurable and significant degradation of physical, chemical, or biological integrity of water quality, to the extent that it presents an imminent and substantial danger to the designated beneficial use." When a significant risk has been identified, the BMP Forester advises the landowner on how to implement corrective measures. Afterward, a follow-up site evaluation is made to reassess compliance. Landowner non-compliance with recommendations made by the BMP Forester will result in a referral to the appropriate regulatory agency for enforcement action. Under the State's water quality laws, the Florida Department of Environmental Protection can enforce BMPs while the Florida Water Management Districts regulate forest roads, stream crossings, and several other forestry related activities.

The Kentucky DOF has a four-step enforcement process and is empowered to issue fines and designate noncooperators as 'bad actors'. Where noncompliance with BMPs is observed, a written warning is issued describing which requirement is not in compliance. Upon receiving a written warning an operator has an opportunity to meet with the district forester and the inspector to discuss how to remedy the infraction. This technical assistance meeting is referred to as an informal conference. A logger failing to effectively address an infraction (i.e., written warning) can receive a notice of violation. In some instances non-compliance can result in a special order being issued that allows the DOF to shut down a portion of the operation until compliance is achieved. Where violations pose significant threats to water quality, an emergency order can be issued which will shut down the entire operation. The DOF can initiate administrative hearings, levy fines, or bring court actions for all violations deemed to have impacts or potential impacts on water quality.

The Alaska DOF, with input from the Department of Environmental Conservation (DEC), instructs the forest landowner, timber owner, operator, or forest manager to, "…conduct routine or comprehensive water quality monitoring for the purpose of assessing the impacts of operations on water quality and protected water uses, and for the purpose of demonstrating the effectiveness of best management practices in meeting water quality standards". Routine monitoring includes, at a minimum, visual inspection of streams to assess turbidity levels and can also include temperature measurements during harvesting operations. If routine monitoring is deemed necessary by DOF during harvesting operations, the guidelines are as follows: (1) make water quality observations at one or more locations at regular intervals; (2) use simple, qualitative assessment techniques; and (3) report data findings and any measures implemented to correct water quality problems to DOF and DEC.

Publicly owned forests are managed in ways that differ in some ways from forests under private ownership. On a national scale, 29 percent of timberland is publicly owned (Smith et al., 2001). In the Rocky Mountains and Pacific Coast regions, the majority of timberland is in National forests (USEPA, 2005). States with greater than 60% of their forests in public land include Arizona, California, Oregon, New Mexico and Washington; Idaho, Utah and Wyoming each have more than 80% of their forests in public land. Federally managed forests must meet state requirements, but also requirements of the USFS (Rice, 1992). The USFS manages more than 193 million acres in the NFS. Although most forested watersheds are in satisfactory condition, some waterbodies on NFS lands do not meet state water quality standards. Year 2005 data show that over 4,300 water quality impairments (in 2,600 waterbodies on NFS lands) are included on the Section 303(d) lists in 41 states, representing about 8 % of all water quality impairments nationally. Leading causes of the impairments on NFS lands include elevated temperature, excess sediment, and habitat modification.

Significant policy-level progress has been made to recognize the ecological impacts of roads on federally managed lands over the last decade. Policy changes can generally be linked directly to Endangered Species Act (ESA) listings for salmon, trout and other native fish, and CWA compliance concerns. Under the ESA, guidance has been developed in association with federal lands consultation with the National Marine Fisheries Service (NMFS) and the US Fish and

Wildlife Service. For example, current NMFS guidance recognizes a series of indicators that relate directly to the impacts of roads on salmonids (road density and location, substrate character and embeddedness, physical barriers, and suspended sediment/intergravel dissolved oxygen/turbidity). In many National Forests, watershed restoration is synonymous with removal of excess roads (Elliot, 2000).

On September 28, 2007 the USFS and the USEPA signed a Memorandum of Agreement (MOA) on “Fostering Collaboration and Efficiencies to Address Water Quality Impairments on National Forest System Lands”. The purpose of the MOA is to establish greater coordination and collaboration between the USFS and the USEPA’s Office of Water to foster efficient strategies to address water quality impairments by maintaining and restoring NFS watersheds. The USFS has already coordinated and collaborated with states and USEPA on many activities to maintain and restore water quality in the National Forest System. For example, the USFS has supported states and USEPA in development of more than 300 TMDLs in more than 30 National Forests. For several National Forests, the USFS has also assisted states’ efforts to develop a record that supports placement of waters in Category 4b.

In addition to these activities, the USFS uses a variety of watershed management techniques to address water resource impairments. The USFS Watershed Management Program includes guidance to inventory and assess watershed conditions, identify and prioritize improvement needs, restore ecosystem components and functions, apply BMPs, implement pollution prevention design strategies, monitor project success, and adapt management measures. For example, the USFS is in the process of updating national BMP guidance for administering its nonpoint pollution control strategy on NFS lands. This new USFS National BMP Program is intended to meet or exceed all state BMP objectives as well as simplify and standardize water quality protection measures and monitoring on NFS lands.

4.2 State BMP Implementation and Effectiveness Monitoring

Measuring the success of BMP programs requires regular and credible surveying of BMP implementation (Prud’homme and Greis, 2002). However, implementation (or compliance) monitoring of nonregulatory BMPs is unique to forestry nonpoint source management. While other nonpoint-source sectors, such as agriculture, are generally unregulated, the degree of compliance with BMPs for agricultural activities is not systematically measured or reported. Many states have been monitoring forestry BMP implementation for a major portion of the 25 years of the nonpoint source program existence. During that time, state forestry agencies have approached implementation monitoring in different ways, degrees of detail, precision, and statistical strength.

Under CWA Section 319, states must monitor forestry BMP implementation, to assess whether BMPs are being applied, whether they are being applied appropriately (based on the state guidelines or rules) and, in some states, whether the BMPs are effective. Data obtained from the monitoring surveys has provided valuable information which states have used to improve implementation rates and identify problem areas where corrections are warranted (NCASI, 2007). Summaries of the state forest road BMP implementation surveys are presented in Tables 4-4 and 4-5. Table 4-4 presents implementation data for states in which BMPs for forest roads are voluntary, and implementation data for states with mandatory BMPs are given in Table 4-5. These tables show which states are monitoring BMP implementation, and the general nature of the results of the most recent surveys. Tables 4-4 and 4-5 include the number of surveys that have been conducted, the date of the most recent survey, the survey site sampling design and methodology, and who conducts the survey. Results presented in these tables include the percent implementation (for all BMPs and specific categories related to roads and crossings), specific problematic BMPs, and whether the risk to water quality due to failure to implement BMPs was evaluated. The tables also indicate whether the implementation data is maintained and tracked and if it accessible to agencies and the public; implementation results from 7 states where BMPs for forest roads are voluntary or mandatory are not published. States in which there are formal agreements between agencies for handling suspected incidents of water pollution from forestry operations are noted in the tables as well. Finally, Tables 4-4 and 4-5 indicate whether the surveys evaluate implementation separately for different categories of land owners, and what those categories are. In general, BMP implementation has been reported to be highest on public land, followed in descending order by forest industry land, corporate non-industrial land, and private non-industrial land (Prud'homme and Greis, 2002). BMP implementation data from several states are presented in more detail in Sections 4.4 and 4.5.

A National Association of State Foresters survey of state silviculture nonpoint source control programs (Ice and Stuart, 2001) found that the BPM implementation rate is nearly 90% nationwide. Overall, rates of BMP implementation or compliance for western states are high, exceeding 80%. From recent survey data, the breakdown of statewide (i.e., data averaged across land ownership groups and performance measures) implementation was as follows: Alaska (89%); California (94%); Idaho (96%); Montana (96%); Oregon (96%); Utah (81%); Washington (80%); and Wyoming (97%). Ice et al. (2004) reported that over a 10-year period, audit reports show that BMP implementation has increased from 78 to 96% and water quality issues have decreased. Implementation rates in other regions are generally comparable, although there are also some states reporting lower rates of implementation.

Careful review of the tabulated summaries also demonstrate the difficulty of discerning actual rates of implementation with forest road BMPs. The overall BMP implementation rates can be misleading, because while 31 states regularly conduct compliance (or implementation) monitoring, only 21 states specifically monitored road BMPs and only 19 monitored stream crossings. Where they are monitored, implementation rates for road and crossing BMPs tend to be considerably lower than the overall implementation rates.

Due to differences in methods for measuring BMP implementation, comparisons of rates among states cannot generally be made. Past differences in survey design and statistical strength, rigor of inspections, and metrics chosen for evaluation within and among states also preclude precise reporting of state or regional progress over time. Results range from statistically valid to informative but of unknown statistical strength. The numbers of inspected sites and practices can vary widely between states and even among different surveys within a state. For similar reasons the degrees of implementation achieved by regulatory versus nonregulatory programs are difficult to assess (Prud'homme and Greis, 2002).

Another area of inconsistency with the implementation surveys is how states quantify rates of BMP compliance and/or implementation. The state BMP manuals and monitoring reports often do not clearly define compliance and implementation. As a result, some states use these words interchangeably and readers may interpret them differently. Measures of BMP compliance indicate that a forest management action or practice abides by a requirement or recommendation. Conversely, implementation rates indicate whether or not a BMP prescription was utilized or installed. For these reasons, implementation monitoring is only partially effective in producing effective BMP implementation.

Another major difference among states for BMP implementation/compliance reporting involves whether states identify or quantify ‘significant risks to water quality’ when BMPs are not implemented or are implemented incorrectly. Tables 4-4 and 4-5 indicate whether the rates of implementation were evaluated in terms of threats to water quality. Though this measure can often be subjective, this additional piece of information is useful when trying to understand the implications of compliance or non-compliance rates. When states report that a specific BMP was not implemented or was not implemented correctly, this provides no information regarding the impact to water quality. Improperly installed BMPs often do not result in significant risks to water quality, and this measure provides some insight when assessing rates of implementation or compliance.

Several regional groups have made efforts to promote consistency among state implementation monitoring programs. These include the Southern Group of State Foresters (SGSF), which developed voluntary BMP implementation monitoring procedures in 1997, and the Northeastern Area Association of State Foresters (NAASF) and the USFS-Northern Region Program for State and Private Forestry, which jointly developed a protocol for monitoring the implementation and effectiveness of forestry BMPs (Welsch et al., 2007).

4.3 Are Compliance and Effectiveness Monitoring of BMP Programs Actually Capturing the Success of These Programs in Addressing Forest Road Runoff?

It is questionable whether high rates of BMP implementation and compliance truly reflect the effectiveness of programs to address forest roads and protect water quality. As stated by Ice et al.

(2004), there is unlimited skepticism about the effectiveness of forest nonpoint source control programs and limited assessment resources. Compliance rates per se may not be the best indicator of program effectiveness (Ellefson et al., 1995). For example, if a state has out-dated or inadequate BMPs, compliance with these ineffective practices does not show true water quality protection. The majority of compliance monitoring efforts are usually completed on recently harvested land. These evaluations may not investigate road maintenance or obliteration practices. On-the-ground determinations of BMP implementation are qualitative and judgmental by design, adding to the difficulty of comparing or reproducing results. Implementation audits usually occur during summer, when conditions are dry and vegetation is leafed out; under these conditions it would be unusual to actually observe runoff, erosion, or sediment transport. It is also noteworthy that most state surveys are conducted after on-the-ground activities have ceased. Thus, it is possible that water-quality impacts could occur but stabilize prior to the site being evaluated.

Moreover, effectiveness is different than implementation and can be much more difficult to accurately measure. Although implementation of BMPs is commonly over 90%, this does not correctly identify the effectiveness of the practice (Rehder and Stednick, 2006). Effectiveness is how well a BMP system meets its goal, usually a water quality standard. In a monitoring strategy document for Washington, Schuett-Hames et al. (1996) noted that monitoring of aquatic resource trends was important because protection and restoration of aquatic habitat and species are the fundamental management objectives (Ice et al., 2004). In 2000, seventeen states were conducting effectiveness monitoring of their BMPs (Ice and Stuart, 2001). No national-level analysis of the results of these BMP effectiveness studies has been undertaken. Effectiveness studies may not truly measure the effects of roads under the conditions that cause the most significant damage, such as during wet weather or under heavy usage. For example, an effectiveness study may not necessarily have monitored how road drainage features handle stormwater during wet weather events and directly after—they may have only monitored their effects during dry weather when stormwater erosion was not taking place.

Of all the state monitoring implementation, only Texas has prepared an approved Quality Assurance Project Plan (QAPP) for collecting monitoring data. To fully address the quality of the information produced by implementation monitoring requires an evaluation of the sampling design, methods and conduct of inspections, and analysis of the results. Are sampling programs based on random, representative site selections? Are a sufficient number of practices and BMPs inspected to yield precise, accurate and representative results? Are the inspections objective, reproducible and complete? Durgin et al. (1988) observed that compliance with regulations tended to diminish with distance from the point of entry to the harvest area, so this should be considered when selecting practices for evaluation. If monitoring results are used to assess trends in BMP implementation, are the inspection survey results comparable through time? Many states have found it necessary to revise their implementation monitoring programs over time, because it is difficult to foresee all of the potential site conditions that will be encountered during inspections; protocols require modification and revised protocols must be field tested. An example of this refinement is the Interagency Mitigation Monitoring Program (IMMP) pilot project implemented in California in 2006. The first phase of the IMMP pilot project (2006) revealed that monitoring protocols required modification and revised protocols are being field tested in the second phase of the IMMP pilot project in 2007 (NCASI, 2007).

The success of forestry BMP programs can be largely assessed by two measures: are BMPs being used, and when BMPs are applied do they reduce impacts so that desired water quality goals are achieved? The implementation monitoring discussed above and in Section 4.3 largely deals with the first of these questions. A number of states have developed active monitoring programs, using water and biological sampling, bioassessment and habitat research, to address the second question.

4.4 BMP Implementation Data: Examples from States

In the following sections, BMP implementation and effectiveness data are presented (alphabetically) for eleven states: California, Colorado, Florida, Georgia, Idaho, Maine, North Carolina, Minnesota, Oregon, Virginia and Washington. This list includes states from each of the forestry regions in the United States.

4.4.1 California

California's forest management rules and sediment control measures for forestry are arguably the strictest in the nation. For example, the requirement for a detailed forest harvest plan alone places compliance with forest practices in California in a category by itself. California's rules are also extensive: the 2007 FPRs are 212 pages long (NCASI, 2007). This state also has a rich legacy of compliance monitoring (NCASI, 2007). These include the following programs:

- Hillslope Monitoring Program (HMP) pilot project, evaluating FPR implementation and effectiveness, conducted in 1993-95 by the CAL FIRE and the California State Board of Forestry and Fire Protection (CSBOF);
- HMP annual statewide evaluations conducted by independent contractors from 1996-2002;
- Modified Compliance Report (MCR) monitoring to assess water quality related FPRs, conducted from 2001-04 by CAL FIRE and CSBOF;
- Forest Practice Rule Implementation and Effectiveness Monitoring (FORPRIEM), a second phase of the MCR program, focused on high risk (non-random) watercourse crossings and road segments that drain to crossings, is being implemented in 2007; and
- The Interagency Mitigation Monitoring Program (IMMP) pilot project was begun in 2005 to provide information about forest practices at high-risk sites where measures have been specially designed to protect water quality.

The main conclusions from all the monitoring completed to date are that California's water quality-related rule implementation rate is among the highest of any of the western United States, and that when properly implemented, the FPRs are effective in protecting water quality. Monitoring results have also shown, however, that improvements are needed in watercourse crossing design, construction, maintenance and for road drainage, particularly near stream crossings. To improve practices on roads and at stream crossings, there have been several efforts over the past five years, including the development of a guidebook on how to properly design crossings for 100-year flood flows and the passage of wood and sediment.

IMMP data collection has focused on high risk (non-random) watercourse crossings and road segments that drain to the crossings, since past monitoring work has shown that these are particularly high risk sites for sediment delivery to stream channels. The first phase of the IMMP pilot project (2006) revealed that monitoring protocols required modification and revised protocols are being field tested in the second phase of the IMMP pilot project in 2007. Pilot project work completed in 2006 showed that improper installation of high risk crossings and drainage structures near crossings is often the major cause of water quality problems. Preliminary conclusions from the pilot work are that improved implementation of practices can be accomplished with additional timber operator education and more frequent multi-agency crossing inspections, both during logging operations and immediately following completion of harvesting.

From 2001 to 2004, the MCR monitored 244 randomly selected 1,000-ft (305-m) road segments (i.e., 46 forest road miles). Of the 1,991 road features rated for implementation, only 83 departures from the FPR requirements were observed, a 95.8% implementation rate. The MCR report also indicated that these departures from the FPRs tended to be clustered, with 33 departures found within five road segments. Departures from FPRs were found for 4% of road segments. The most frequent problems (lack of compliance with the FPRs) were found to be related to road drainage. Evidence of sediment movement to waterbodies was found for nine road related features out of 1,147 features rated for effectiveness (~1%). Approximately 8% of the features with evidence of erosion (e.g., rills, gullies, mass failures,) delivered sediment to stream channels. Of the nine instances of sediment delivery to channels from roads, five were found to be non-compliant with the FPRs. Two involved sediment movement onto “erodible materials or failure to discharge into cover” and three were found to have “an inadequate number of drainage structures or inadequate spacing.”

The earlier Hillslope Monitoring Program found overall FRP implementation ratings greater than 90 percent for landings and for road, skid trail, and watercourse protection zone transects (Cafferata and Munn, 2002). Implementation of applicable BMPs at problem points was nearly always found to be less than that required by the FPRs. HMP monitoring suggested that the forest practice rules were generally found to be sufficient to prevent erosion, and 97% of the 727 erosion problem points identified were associated with departures from rule requirements (CBOF, 1999). Watercourse crossings had the lowest overall implementation ratings at 86 percent. BMPs for crossings were noted as a problem, and a larger proportion of the crossing rule implementation ratings were for major departures (significant outlet scour, 35%; some degree of plugging, 22%). Watercourse crossing problems were caused by a number of factors, including inherent uncertainties in determining and implementing site specific construction and abandonment needs, improper maintenance, the finite expected life of culverts, and high risk locations for sediment delivery when stream discharge exceeded the design conditions. The majority of the evaluated crossings were existing structures that were in place prior to the development of the FPRs. Common problems included culvert plugging, stream diversion potential, fill slope erosion, scour at the outlet, and ineffective road surface cutoff waterbreaks. A need for greater attention focused on improvement of crossing design, construction and maintenance was also noted (MSG, 1999).

Rules related to roads had greater than 90% compliance, and most road rule departures were related to drainage and maintenance. The other main problem area identified by the HMP program was erosion from roads caused by improper design, construction, and maintenance of drainage structures. Nearly half the road transects had one or more rills present and approximately 25% had at least one gully. Evidence of sediment transport to at least the high flow channel of a watercourse was found on 12.6 and 24.5% of the rill and gully features, respectively, with high percentages of delivery to Class III watercourses. These erosion features were usually caused by a drainage feature deficiency, and the BMPs at these problem sites were nearly always found to be out of compliance. Most of the identified road problems were related to inadequate size, number, and location of drainage structures.

Two of the major conclusions of the HMP monitoring was that “roads and their associated crossings were found to have the greatest potential for delivery of sediment to watercourses,” and that “where roads are built will remain critical for reducing the likelihood of producing significant sediment input to channels.” Recommendations therefore included greater attention to and better implementation of rules related to drainage, crossing design, and maintenance. Erosion problem points were almost always associated with improperly implemented FPRs.

Standard BMPs generally appeared to provide adequate water quality protection when they were properly implemented, and poor implementation was most common cause of observed water quality impacts (MSG, 1999).

There are several cooperative in-stream monitoring projects in watersheds throughout California, including: Caspar Creek in Mendocino County, where data has been collected since 1962, Garcia River in Mendocino County, South Fork Wages Creek in Mendocino County (CAL FIRE and Campbell Timberland Management), Judd Creek in Tehama County (CAL FIRE and Sierra Pacific c Industries), and Little Creek in Santa Cruz County (CAL FIRE and Cal Poly-San Luis Obispo). These instream projects are an important component of our overall water quality monitoring program. They are measuring sediment concentrations in water samples and recording the turbidity, or clarity of the water, at automated monitoring stations. This data helps provide connections between stream channel conditions and management practices occurring on hillslopes in the watershed.

Watershed-scale monitoring conducted in California has produced mixed results for the effectiveness of road BMPs on water quality. Review of 40 years of research in Caspar Creek found that while California’s sediment control measures for forestry mitigate some of the problems with runoff from roads, these impacts are not eliminated. There are no quantitative data for the California coast indicating that road BMPs have substantially improved instream water quality or salmonid habitat conditions (Harris et al., 2005). It is not known how site-level effects translate into benefits to water quality and stream habitat at the stream reach or watershed scales. Little is known about the temporal scale at which improvements may occur. Recent studies show that restoration of upper watershed locations or non-fish-bearing streams causes short-term impacts on local water quality due to post-construction adjustments (Klein, 2003).

In the North Coast region, more than 85% of the rivers are listed as impaired under the Clean Water Act because of excessive amounts of sediment in stream channels, and all native salmon species are listed as threatened with extinction under the Endangered Species Act. In listing these streams and fish during the 1990's, the USEPA and the NMFS both identified logging operations approved under the FPRs as being the primary reason for such listings becoming necessary (EPIC, 2002).

There are few regulatory regimes whose adverse impacts to water quality have been more comprehensively documented than the California FPRs. The same fundamental problems have been noted by a variety of agencies, blue-ribbon panels, scientists, and courts throughout the last two decades (EPIC, 2002). Various federal and state agencies, including National Oceanic and Atmospheric Administration (NOAA), USEPA, the California Department of Forestry, and the California Department of Fish and Game have been critical of the effectiveness of the California FPRs (EPIC, 2000). As noted by Leslie Ried of the USFS Redwood Sciences Laboratory, the rules have not prevented the cumulative watershed impacts that led to the recent listing of multiple northern California streams as impaired by sediment under section 303(d) of the Clean Water Act (Reid, 1999). Modern FPRs were unable to prevent nearly a 10-fold increase in landsliding rate in the Bear Creek watershed that occurred when Pacific Lumber Company increased the rate of logging (PWA, 1998a; Reid, 1998; Reid, 1999b). Results from nearby watersheds show similar landslide increases by factors of 3 to 13 (PWA, 1998b; Michlin, 1998; PWA, 1999). Even in the absence of major landsliding, the implementation of current forest practice rules could be associated with increased turbidity levels in streams. According to Reid (1999), the Forest Practice rules were not adequate to prevent forestry-related changes to the production and transport of sediment, water, and woody debris in watersheds. Changes in these "watershed products" are the most common causes for downstream cumulative impacts. The rules were not sufficient to restrict excess sediment production from logging-related activities to levels that will not accelerate reservoir sedimentation, increase flooding by channel sedimentation, and degrade water quality (Reid, 1999).

According to an analysis prepared by Reid (1999), standard FPRs were not protective enough to avert cumulative impacts. Cumulative impact evaluations submitted with Timber Harvest Plans (THPs) and Sustained Yield Plans (SYPs) prepared by Pacific Lumber Company she examined did not adequately evaluate the potential cumulative impacts of the plans. The expertise available in state and federal agencies did not appear to be appropriately employed during the review process. Contributing factors to the failure of FPRs to protect water quality in these cases included excessive harvesting rates, even in previously-degraded watersheds, and the political control of the CAL FIRE.

In the case of both sediment production and hydrologic change, some impact from forest land use is inevitable. Effective management for cumulative impact prevention, according to Reid (1999), would require that the intensity of land use in a watershed be maintained below the level at which the resulting impacts are no longer acceptable. Such an approach would require that the FPRs include provisions that allow regulation of the rate of logging and the density of roads in a watershed. Without such provisions, standard rules and BMPs would need to be excessively protective to ensure that incremental additions are not damaging. Such an approach would also require improvement of cumulative impact assessment methods, including a provision for a preliminary watershed assessment to be done by interagency staff. This assessment would identify issues of concern, the impacts affecting them, and the causes of those impacts. The watershed assessment would provide the background information needed to analyze cumulative impacts of future projects anywhere in the watershed and would provide guidance for carrying out such analyses. Additionally, Reid (1999) recommended giving authority to staff of relevant departments (i.e., Water Quality Control Board, Department of Fish and Game, etc.) for decisions falling within the purview of those departments' areas of expertise.

4.4.2 Colorado

Roughly 14.5 million acres of forest are located on public lands in Colorado (NCASI, 2007). Forest inventory data show substantial timber volumes in the state; however, growth and harvest rates are very low (USFS 2000). In 1998, Colorado developed forestry BMPs, referred to as forest stewardship guidelines (FSG), to protect water quality. This is a non-regulatory approach to forestry BMP implementation. The recommendations included in the Colorado forest stewardship guidelines to protect water quality were approved by the Colorado State Forest Service in partnership with the Colorado Timber Industry Association (CTIA). The foundation of Colorado’s recommendations is based, in large part, on recommendations developed by Montana (CO FS, 1998).

Colorado, along with Arizona, appear to be the only western states that have not conducted audits to evaluate rates of BMP implementation and effectiveness. Colorado has been active in education outreach, largely through the Central Rockies Sustainable Forestry Education Program, which includes a 30 hour course on forest BMPs. Instead of conducting field surveys of BMP implementation, Colorado has used anecdotal feedback on BMP implementation rates through these workshops (Ice et al., 2004). According to NCASI (2007), the Colorado State Forest Service and the Colorado Timber Industry Association hope to initiate a statewide audit of BMP implementation at some time in the future.

4.4.3 Florida

Commercial forest land covers 47% of the land area in Florida (FDEP, 1997). Since 1981, the Florida Division of Forestry (DOF) has monitored forestry operations for BMP implementation by conducting biennial surveys. Through 2005, the DOF has evaluated over 4,400 individual forestry operations and recorded statewide implementation ranging from 84% in 1985 to 99% in the most recent survey (FL DOF, 2006). Averaged over the years, the FL DOF reports a cumulative statewide average of 93.4% for overall forestry BMP implementation.

Sites for the 2005 survey were selected using criteria that provided the FL DOF with a list of sites where "…the greatest potential for forestry-related nonpoint source (NPS) pollution exists, and where any such impacts are still discernible and measurable at the time of the survey" (NCASI, 2007). DOF BMP Foresters evaluated and scored implementation at three levels on each site: (1) individual practice(s), (2) categories of practices, and (3) overall. For individual practices, implementation was recorded as yes, no, or not applicable. For categories of practices, as well as the overall score, implementation was expressed as a percent of all applicable BMPs. Each incidence of non-compliance at the practice level was further evaluated to determine if a "significant risk to water quality" existed. The FL DOF defines significant risk as, "A situation or set of conditions where non-compliance with BMPs has resulted, or may result, in the measurable and significant degradation of physical, chemical, or biological integrity of water quality, to the extent that it presents an imminent and substantial danger to the designated beneficial use." When a significant risk has been identified, the BMP Forester advises the landowner on how to implement corrective measures. Afterward, a follow-up site evaluation is made to reassess compliance. Landowner non-compliance with recommendations made by the BMP Forester will result in a referral to the appropriate regulatory agency for enforcement action.

In 2005, the FL DOF BMP implementation survey examined 4,477 practices on 190 sites in 39 counties. There were fourteen categories monitored for BMP compliance such as special management zones; wetland forestry operations; roads and stream crossings; timber harvesting, site preparation and planting; fireline construction; and waste disposal. The landownership breakdown was as follows: 24% on non-industrial private forest landowners (46 sites), 62% on industrial lands (119 sites), and 13% on public forestlands (25 sites). Overall, 87% of sites visited, regardless of ownership, showed complete implementation of all applicable BMPs (FL DOF, 2006). The statewide BMP implementation rate average was 99.1%, and rates of implementation ranged between 85-100% across the state for individual sites. Most important, the 2005 survey reported no instances of non-compliance that would result in a significant risk to water quality (FL DOF 2006). For forested wetland harvesting operations, 94% (560 practices on 70 monitored sites) were found to be in full compliance with recommended forestry BMPs. Forest road and stream crossing BMP compliance averaged 98.1% and 100%, respectively. The most commonly cited incidence of non-compliance for roads was a failure to “stabilize critical road segments” and install drainage structures (FL DOF, 2006).

In 1996, the Florida Division of Forestry and Department of Environmental Protection conducted a biological assessment of four commercially harvested sites before and after harvest (Vowell, 2001). Four sites were selected on forest industry land; the methods for selecting the study sites were unknown. The sites were scheduled for harvest as part of normal ongoing company operations, and the state’s silviculture BMPs were strictly adhered to during all operations. Forestry activities took place in 0.05 to 24% of the site watersheds. Forest roads were not discussed in the study report, although all sites had roads and 2 sites had stream crossings. Upstream and downstream habitat and biological assessments were conducted before and immediately after activities were performed, and were continued for 2 years. The investigators found no statistically significant differences in parameters measured between the reference and treated sites. From this limited study, the authors concluded that Florida's silviculture BMPs were effective in protecting water quality, aquatic habitat, and overall stream ecosystem health (Prud'homme and Greis, 2002).

4.4.4 Georgia

The Georgia Forestry Commission (GFC) is responsible for the development, implementation, and monitoring of forestry BMPs in Georgia. BMP implementation and compliance surveys were conducted in 1991, 1992, 1998 and 2002. For the 2002 survey, the number of sites evaluated in Georgia was based on the amount of timber harvested in each county as determined by the USDA Forest Service's Forest Statistics for Georgia, 1997 report (GA FC 2005). This methodology resulted in a pool of 421 potential survey sites with at least one site in each of Georgia's 159 counties. The sample was also targeted to reflect the range in forest ownerships using the USFS Forest Statistics report. The ownership classes are categorized into non-industrial private forestland, forest industry lands, and public lands. Of the 421 potential survey sites identified by the GFC, 283 sites (69%) were on non-industrial private forest land, 107 sites (26%) were on forest industry lands, and 22 sites (5%) were on public lands.

Survey sites were evaluated using 108 specific, yes/no questions directly related to BMPs recommended in the manual. Rates of implementation and scoring occurred at three levels: (1) individual BMP, (2) category of BMP practices, and (3) overall site BMP implementation. The SGSF BMP monitoring framework was utilized. For categories of BMP practices and overall site BMP implementation, the score was expressed as a percent of all applicable BMPs implemented against all applicable BMPs in the category of practice and overall site (NCASI, 2007). Therefore, each category of practice and overall site could score between 0% and 100%. Included in the 13 categories of BMP practices evaluated by the GFC were stream crossings and main haul roads.

In addition to evaluating rates of BMP implementation, BMP performance was also evaluated in terms of 'water quality risk assessments' and levels of BMP compliance. The GFC defined a risk to water quality as, "a situation or set of conditions that has resulted, or may result, in erosion or other pollutants entering a water body, an increase in stream temperature, or the physical degradation or obstruction of water bodies observed at each BMP question." Rates of BMP compliance are used by the GFC to track temporal changes among sample surveys for specific BMPs.

Overall, BMP implementation and compliance rates were 89.8% and 99.4%, respectively, for the 2004 GFC BMP survey (GA FC, 2005). Rates of BMP implementation and compliance, respectively, were 80.6 and 44.1% for stream crossings, and 88.1 and 93.4% for main haul roads, and 95.9% compliance in terms of stream miles. These results suggest that stream crossings are the priority area to focus attention regarding water quality (NCASI, 2007). The GFC 2004 survey more specifically notes that, "The biggest concern and area for the greatest improvement is eliminating the skidder fords and debris and dirt type crossings (GA FC, 2005)." Stream crossings were problematic in that 115 out of 349 stream crossings were, "…associated with skidder fords or debris type crossings. These automatically count as noncompliant since the [State] BMPs do not recommend their use. Just eliminating these type crossings offers the greatest potential to increase compliance". The GFC differentiated existing roads and stream crossings from 'newly' constructed forest roads and crossings. Overall compliance of pre-existing roads and stream crossings averaged 94.7% and 62.0%, respectively. Conversely, newly constructed road compliance averaged 83.7%. New stream crossings scored only 31.9%. Skidder fords made up 52% of the non-compliance observations for new stream crossings. Removing skidder fords from the analyses would have raised 'newly' constructed stream crossing compliance to 66.7%. Still, the compliance rate for stream crossings was well below the overall BMP implementation and compliance rates.

The previous BMP implementation survey was conducted from fall 1997 through summer 1998 on 386 sites selected from across Georgia in a stratified random sample, and was the first that conforms to the BMP monitoring protocol endorsed by the SGSF in 1997. All sites experienced some kind of silvicultural treatment in the preceding 2 years, and represented all land ownership categories in all geographic and physiographic provinces (Prud'homme and Greis, 2002). By ownership, 72 % of the sites were non-industrial private, 26 % were forest industry, and 2 % were public. By physiographic province, about 6.5 percent were in the mountains, 34.5 % were in the Piedmont, 19 % were in the upper Coastal Plain, and 40 % were in the lower Coastal Plain. A judgment was made for each BMP not properly implemented, or found to have failed, as to whether a significant risk to water quality resulted. Results were also expressed in acres, miles of road and streams, and number of stream crossings in full compliance for each BMP category, for the site as a whole, and for the State overall.

A total of 6,690 individual BMPs were evaluated over about 43,118 acres. Statewide BMP implementation compliance was estimated at 78.7 % for all BMP categories in all land ownerships and all physiographic regions. By land ownership, BMP compliance was 75.4 % on private non-industrial, 86.3 % on forest industry land, and 84 percent on all public land, respectively. Compliance rates for stream crossing BMPs were 58.8 % and 76.6 % for main haul roads. Stream crossings were of particular concern to the GFC. However, it was also noted that many of the out-of-compliance stream crossings existed before silvicultural treatments were conducted and were not specifically related to forestry operations. operations.

4.4.5 Idaho

Assessments of forestry BMPs in Idaho suggest that hillslope erosion does not contribute sediment to streams except where disturbances have occurred adjacent to streams, which in most cases has occurred only where activities were found to have been out of compliance with the rules (NCASI, 2001). In 2001, Idaho published the results of the state's fifth statewide Forest Practices Water Quality (FPWQ) audit (Hoelscher et al., 2001). That survey was conducted during the summer of 2000 on 40 timber sales that were harvested between 1996 and 1999 (NCASI, 2007). The purpose of the audit was to assess the implementation and effectiveness of Idaho's forest practices described in the 1998 FPA. To evaluate rates of compliance with Idaho's FPRs, the FPWQ audit team was split into two groups. One group evaluated road segments and skid trails, road construction, and maintenance. The other group evaluated a Class I stream segment to assess compliance with the timber harvest rule.

On nine sales (23%) the audit team found violations with site-specific riparian prescriptions, specifically all roads paralleling the stream in the Stream Protection Zone. Thirty Class I stream crossings were also evaluated within the 40 timber sales. Eighteen were culverts (existing or new), of which five were found to be compliant (27.7%) with Idaho's FPRs. Reasons for culverts being non-compliant fell into two groups, culverts that exceeded requirements for fish passage and culvert with excessive drop. The remaining crossing structures (bridges, fords, and temporary crossings) were all found to be compliant. Ten out of 12 new stream crossing structures provided adequate fish passage within Class I streams and, again, the problematic crossings were culverts. Adequate culvert installation has historically been problematic in Idaho, with 11 of 18 culverts not meeting the minimum requirements (Hoelscher et al., 2001). To improve culvert compliance rates, the audit team recommended that the FPRs specify water velocity or drop requirements so that culverts would ensure adequate fish passage.

The 1992 Idaho Department of Environmental Quality Water Quality Audit (Hoelscher et al., 1993) concluded that "BMP's ... were judged to effectively prevent pollutant delivery to streams 99% of the time," but that when BMPs were not applied, pollutants, primarily sediment, were delivered to streams 75% of the time. Similarly, the 1996 audit (Zaroban et al., 1997) concluded that "when properly applied and maintained, the management practices described in the Idaho forest practices rules are effective 99% of the time." The most frequent area of non-compliance with BMPs was related to road construction and/or maintenance; 69% of all cases of non-compliance were associated with road rules. Sediment was found to be delivered primarily from roads, with comparatively minor contributions from harvest systems. Road rules were cited in 84% of those cases where sediment delivery occurred. Non-industrial private forest (NIPF) landowners, who own twice as much forestland as industrial timber companies in Idaho, do not have a good BMP implementation record (TetraTech, 2004).

4.4.6 Maine

A review of silvicultural NPS pollution control programs for Maine and eleven other northeastern states (Connecticut, Delaware, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and West Virginia) produced four principal findings related to BMP implementation and water quality monitoring (NCASI, 2007). First, while recognizing data limitations, states generally rank silvicultural sources of NPS pollution as insignificant. Second, state agencies in the Northeast generally devote few resources to enforcement and monitoring. Third, states in the region rely heavily on BMP implementation as well as logger education and training programs to control NPS pollution during forest management. Forth, only a handful of surveys evaluating BMP implementation have been conducted by states in this region. Since only a handful of state agencies have conducted BMP implementation surveys, the Northeastern Area Association of State Foresters (NAASF) and the USFS-Northern Region Program for State and Private Forestry jointly developed a protocol for monitoring the implementation and effectiveness of forestry BMPs (Welsch et al., 2007).

The state of Maine has been actively involved in the NAASF and USFS-NR BMP Monitoring Protocol, and has collected field data to assist in the protocol's testing and validation (NCASI, 2007). Additionally, the state has conducted three BMP implementation and effectiveness surveys. The results of the first study were published by Briggs et al. (1998) and two subsequent surveys have been conducted by the Maine Forest Service in 2001 and 2005. The study by Briggs and colleagues concluded that Maine's BMPs were highly effective when implemented properly. However, implementation of individual BMPs was highly variable across the state (Briggs et al., 1998). The Maine Department of Environmental Protection (1994, as cited in Stafford et al., 1996) found that 30% of timber harvests reviewed for potential nonpoint source pollution exhibited serious potential for erosion and had not followed BMP procedures.

In 1999, the Maine Forest Service (MFS) developed and tested a new field monitoring methodology. The state evaluates BMP implementation on specific principles or prescriptions within a harvest area, and evaluates BMP effectiveness by evaluating the impact of harvest activities on water quality and is rated in terms of soil movement and delivery to waterbodies. In the second round of this survey (based on data collected from June 2001 to November 2003; ME DOC, 2005), overall BMP use was either 'appropriate' or a 'good attempt, but needs improvement' on 75% of the sites evaluated. These findings represent a 12% increase over the previous round of monitoring by the MFS published in 2001. The MFS 2005 publication also reported a 'minimal attempt' to implement BMPs on 16% of the monitoring sites; 8% of the sites did not attempt to implement BMPs. No evidence of major soil transport or deposition within waterbodies was observed on the 150 sites where BMPs were implemented properly. BMPs were highly effective in preventing soil transport to waterbodies on 82% of the sample sites. This represented a 22% improvement over the 2001 MFS report.

BMP implementation for logging filter strips were used appropriately or with a ‘good attempt, but needs improvement’ on 89% of the sites evaluated. Implementation rates for skid trails averaged 86%. Implementation rates for temporary stream crossings were much lower, however, and only used appropriately on 54% of the harvest sites evaluated. Minimal attempts and failure to implement stream crossing BMPs totaled 30%. Incidences of sediment delivery to streams were also high for temporary crossings (23%). Categories of correct application and good attempt, but needs improvement for haul road stream crossings were somewhat low scoring at 78% implementation, and only slightly higher than implementation levels for haul road filter strips and drainage systems (74%).

Implementation of forestry BMPs was also evaluated based on forestland ownership. In the ME DOC 2005 Report, 88% of the survey sites were selected from the non-industrial private forest and industrial forestland categories. Implementation rates (sum of the appropriate use and good attempt, but needs improvement categories) varied among these categories from a low of 65% on investor forestlands to a high of 88% on public forestlands. The implementation rates of forest industry lands scored 81% while non-industrial private forests had an implementation rate of 70%. The 2005 report also indicated that nearly one-third of the investor forestland sites (~9 sites) had visible evidence of soil transport to surface waters.

Some ten years earlier, the Maine Department of Environmental Protection (1994, as cited in Stafford et al., 1996) found that 30% of timber harvests reviewed for potential nonpoint source pollution exhibited serious potential for erosion and had not followed BMP procedures. Historic information suggests that watershed disturbance in Maine related to agricultural practices has decreased dramatically and that much of the land formerly in active farms has reverted to forests (Irland, 2000). However, it is unclear whether this change in land use has affected surface water quality.

4.4.7 North Carolina

North Carolina has linked BMP implementation to other State regulatory programs, making it quasi-regulatory in some circumstances. The North Carolina Division of Forest Resources (NC DFR) established forestry BMPs to ensure that the state's nine Forest Practice Guidelines (FPGs) related to water quality were met by forest management operations in the State (White, 1992). Mandatory FPGs are required for exemption of forestry operations from the 1973 North Carolina Sediment Pollution Control Act. The FPGs are performance standards that are mandatory and, therefore, must be complied with. The state-recommended forestry BMPs are the more specific 'on-the-ground methods' that, when applied correctly, should result in maintaining compliance with the FPGs.

The NC DFR conducted forestry BMP surveys in 1995, 1996, and 2000. The most recent BMP implementation survey, conducted by the DFR, was published in 2005 (NCASI, 2007). In that survey, rates of BMP implementation for the state averaged 82% (NC DFR, 2005). The survey was conducted in all three of North Carolina's physiographic regions and included measurements in all 100 counties. Forestry BMP implementation rates in the Coastal Plain and Piedmont (85 and 87%, respectively) exceeded those in the Mountains (69%). Specific BMPs examined in the survey were: SMZs, stream temperature, debris entering streams, waste entering streams, permanent forest roads, skid trails, stream crossings, access road entrances, and project site rehabilitation (NC DFR, 2005). The implemented BMPs scoring consistently highest (>85%) for the state as a whole were those related to SMZs, stream temperature management, debris entering streams, waste entering streams, and access roads. Conversely, implementation rates for stream crossings, skid trails, and site rehabilitation BMPs were consistently lower (65%, 72%, and 41%, respectively) across all physiographic regions. FPGs related to water quality maintenance for the surveyed sites had an 82% statewide compliance rate.

NC DFR also assessed the overall threat or risk to water quality posed by a forest management practice, as a surrogate measure of BMP effectiveness (NCASI, 2007). The 2005 survey results indicated that forestry practices posed a small threat to water quality, averaging only 8%, when BMPs were implemented (NC DFR, 2005). This indicates that either the BMP was implemented incorrectly, and water quality impairments occurred as a result, or the recommended forestry BMP was inadequate for a specific situation. Mountain region sites had the highest occurrence of water quality risks (~15%). Water quality risks due to BMP non-implementation were approximately 42% (NC DFR, 2005). The 2005 North Carolina monitoring survey also indicated that the North Carolina Forestry Association's ProLogger Program, "…can do more in the future by focusing training on areas identified in this report that need improvement, such as stream crossings, debris entering streams, skid trials and streamside management zones. Also, additional training will be needed to improve performance in the mountains and foothills."

NC DFR conducted earlier forestry BMP surveys in 1995 and 1996 (Hensen, 1996). In the 1996 survey, overall statewide BMP implementation was rated at 95 percent as either good or excellent. Implementation on public land was rated at 100 percent, industry land at 90 percent, and non-industrial land at 76 percent. There was no discernable BMP implementation pattern based on slope.

In the early 1990s the North Carolina Division of Water Quality and the USFS examined the effectiveness of BMPs on a forest road in the Appalachians (North Carolina Division of Water Quality, 1994). A long-existing road, which closely paralleled Timbered Branch and its tributaries for about 2 miles and had been a chronic source of road sediments to the stream, was retrofitted with a number of measures designed to reduce sediment loading. They included ditch outlets, sediment traps, berms, weeps, outslopes, humps, and relief culverts. Sediment reduction was assessed qualitatively, and biological monitoring was conducted on the affected streams to determine effects on aquatic species. Improvements in taxa richness and diversity in the aquatic community were attributed to the sediment reduction practices.

4.4.8 Minnesota

In 1995, the Minnesota Legislature adopted the Sustainable Forest Resources Act (SFRA), the only forest practices act in the midwest region. The act established policies and programs to ensure sustainable use and management of the states forest resources. The SFRA presents a broad strategy for achieving forest sustainability in two areas: site-based timber harvesting/forest management guidelines and landscape-level forest resource planning and coordination. Supporting programs involve BMP monitoring, research, and education. While the other states in this region do not have forest practices acts, many do require permits or notification of management activities (NCASI, 2007). This is generally required when constructing or repairing stream crossings.

The SFRA statute requires the Minnesota Department of Natural Resources (DNR) to develop and administer the implementation monitoring program, with oversight provided by the Minnesota Forest Resources Council MFRC. In 2004, the DNR published a report summarizing three years of monitoring sites harvested prior to the publication of the States integrated timber harvesting and forest management (TH/FM) guidelines (Dahlman and Phillips, 2004). The information contained in that report was intended to be used as baseline data for comparison with future BMP implementation assessments. Site selection procedures varied among years, due to concerns over sample bias. Implementation of TH/FM guidelines was monitored in the following forestland ownership categories: state, county, public, forest industry, NIPF, and other (tribal, other public and non-forest industrial). The categories of BMPs examined in this report include: use of filter strips and riparian management zones, protection of water quality and wetlands (waterbody crossings and approaches), and protection of forest soil resources (landings, roads, and skid trails).

During the three survey years, a total of 1,262 filter strips were identified for wetlands and open water bodies associated with monitored timber harvest sites (NCASI, 2007). Effective filter strip BMP applications were found for 73% of the site evaluations (Dahlman and Phillips, 2004). Only 31% of the SMZs for waterbodies within the harvest area met the guidelines for SMZ width and basal area, compared to 64% of the riparian management zones (RMZs) for water bodies adjacent to the harvest area. Rates of BMP implementation for waterbody SMZs appear low in this report. However, the results in this report reflect management practices for sites that were harvested prior to the publication of the current TH/FM guidebook (Dahlman and Phillips, 2004).

The DNR also reported monitoring results for 548 road and skid trail crossings (NCASI, 2007). There were also 1,033 stream crossing approaches and 80 wetland approaches found. A majority of the crossings and approaches (68%) were reported to be ‘winter-only operations.’ Furthermore, the majority of crossings for wetlands and open waterbodies were assumed to have taken place when the ground was frozen, thereby, limiting impacts to soils and water quality (Dahlman and Phillips, 2004). Data collected in the 2002 survey indicated that a majority of approaches to waterbodies were in good condition with only 6% showing signs of erosion and rutting and only 3.4% having sediment reaching a wetland or waterbody. The implementation of BMPs to protect soil resources generally scored well. The TH/FM guidelines recommend that forest roads and landings occupy no more than 3% of the harvest area. The statewide averages were similar all three years and averaged 3.0% for all ownerships. The TH/FM guidelines for forest roads recommend using an appropriate combination of erosion control and water diversion practices on all road segments, especially those road segments with grades exceeding 2%. A total of 311 road segments with a grade less than 2% were identified during the three years of monitoring. More than 85% of the segments had a grade less than 10%, as is recommended in the TH/FM guidelines. Monitoring in 2002, however, found that only 41% of these sampled road segments were stable. Furthermore, 12% of the sample road segments had sediment that reached a wetland or waterbody. As indicated in the 2004 monitoring report, the limited use of erosion control structures and water diversion practices, “…is a cause for concern that has been and will continue to be addressed in future training programs.” A majority of the monitoring sites (57%) were found to have minimal, randomly distributed, and lightly trafficked skid trails across the harvest sites.

Minnesota’s 2004 survey did not calculate a statewide BMP implementation average. The data from this report was to be used as a baseline measure for future implementation assessments (NCASI, 2007). Activities scoring poorly included use of water diversion techniques and approaches to stream crossings. Minnesota reported that common departures or non-implementation of BMPs was observed for water diversion structures on roads and skid trails. Implementation was highest on both public lands and industrial forestlands and lowest on non-industrial forestlands.

Implementing BMPs for stream crossings were generally not reported as problematic by states in this region. The reasons for this trend are many and include reasons such as: monitoring sites not containing waterbodies or managers conducting harvests in a manner where crossing a stream was not necessary. Another reason stated in the Minnesota report was that wetland and stream crossings were "assumed to be frozen" during harvesting (Dahlman and Phillips, 2004).

4.4.9 Oregon

In Oregon, BMP compliance rates from 1987 to 1996 have averaged between 96 and 98% (Dent and Robben, 1999). As in many states, the most frequent areas of non-compliance found in the 1998 Oregon Department of Forestry (ODF) monitoring were in road construction and/or maintenance (Dent and Robben, 1999). Of 20 road-related practices out of compliance with BMPs, 9 resulted in sediment delivery to streams. Non-compliant practices having the greatest impacts on streams were related to road drainage or temporary crossings. Of 22 sediment sources identified in the 1998 inspections, 19 were associated with roads. Six of the 22 sediment sources were estimated to be "incidental" (less than 1 cubic yard of sediment), 10 were "moderate" (1 to 10 cubic yards), and 6 were judged to be "significant" (more than 10 cubic yards).

Additional monitoring by ODF indicated that 31% of the surveyed road length potentially delivered sediment to streams, and that two-thirds of that potential delivery length occurred immediately upslope of live stream crossings (Skaugset and Allen, 1998). However, less than half (40%) of that potential delivery length occurred where surface drain spacing exceeded recommended criteria, suggesting that drainage spacing is not sufficient by itself to adequately control sediment delivery from roads. For the portions of the road network where sediment delivery is occurring, three major issues were identified (Mills et al., 2003):

- There is a general lack of filtering of drainage waters near streams. A number of cases were observed where cross drainage structures were not in place to filter road runoff before the runoff reached stream crossings.
- Steep-gradient roads tend to have cross drainage structures at wider spacing than lower gradient roads. Under the current rules, road design and maintenance practices should

- There are inconsistencies in drainage practices between georegions, with special concerns in the Siskiyou georegion.

Most forest roads in Oregon were constructed prior to state rules that marginally improved construction standards (Mills et al., 2001). A significant amount of road networks in most watersheds remain hydraulically connected to streams (Rhodes and Huntington, 2000; Wemple et al., 1996). Although Oregon forest practice regulations since 1978 have required operators to locate stormwater management BMPs so that runoff is filtered before entering streams, a report prepared on the Kilchis watershed in the Tillamook State Forest found that roads in western Oregon generally do not comply with this rule (ODF, 1997).

ODF monitoring in 1996 showed that about 1/3 of active and inactive roads can (rated as “certain” or “possible”) deliver sediment to streams by ditches (FPAC, 2001). That report noted the potential for significant amounts of sediment to be delivered from these sources during haul operations, especially during wet season. One problem area not directly addressed by FPRs was erosion and sediment delivery associated with the use of roads during rainy or thawing periods. Current road maintenance rules directed operators to stop hauling when high levels of turbidity were observed entering streams. However, there were no rules that addressed the specific level of turbidity considered acceptable during wet season hauling.

4.4.10 Virginia

The Virginia Department of Forestry (VA DOF) conducts quarterly BMP monitoring assessments (VA DOF, 2007). The VA DOF implementation and effectiveness field audits serve four functions (NCASI, 2007). First, to quantify levels of effort in attempting to use BMPs and whether BMPs utilized meet technical specifications. The second function is to identify current levels of BMP implementation as compared to the technical BMP standards. Implementation is a measure of the attempt to implement BMPs to the technical specifications described in the BMP manual. The third function of the assessments is to identify levels of potential sedimentation. Finally, the assessments are also seeking to identify levels of active sedimentation.

Virginia state law requires landowners or managers to notify the VA DOF at least 3 days prior to conducting a timber harvest; therefore, a pool of potential survey sites is readily available. For each semiannual survey, the VA DOF randomly selects and visits at least 30 timber harvests from their database for field audits. Monitoring is conducted in nine categories: stream crossings, water control structures, seeded areas, SMZs, skid trails/road grade, rutting, gravel/mats, oil spill/trash, and other.

The most recent BMP monitoring data (annual data) is available for 2006 (VA DOF, 2007). Rates of full BMP implementation expressed as a percentage of the total ranged from 1% (rutting) to a high of 100% (other category) (VA DOF, 2007). Effort, expressed as a percentage of the total needed, ranged from 2% to 119% in 2006. Effort to implement water control structures was found to average 59% in 2006. By contrast, effort was high for stream crossings (119%), road/trail grade (94%), SMZs (86%), gravel/mats (100%), and oil spills and trash (84%). The reason for the high stream crossing effort level can be explained as follows. VA DOF personnel determined that 149 'total efforts' were needed for stream crossings and total effort for logging sites totaled 178 (VA DOF, 2007). Full implementation scored somewhat low for use of water control structures (35%). While strong efforts were made for stream crossing BMPs, full implementation was found to only be 68%. While the aforementioned levels of BMP implementation appear low, the impacts to water quality were not dramatic. For example, the percentage of sampled sites that received a positive evaluation (yes) in the potential and active sedimentation categories for 2006 were 9% and 6%, respectively (VA DOF, 2007). This finding indicates that while BMP prescriptions were not precisely meeting the VA DOF BMP technical specifications, the levels of effort 'on-the-ground' were having positive effects on water resources during forest management (NCASI, 2007).

Earlier BMP monitoring in Virginia produced very low rates of compliance (Prud'homme and Greis, 2002). For example, BMP compliance rates between 1991 and 1999 ranged from only 7 to 16%. However, this was largely a consequence of the scoring methodology. To be in full compliance, 100 % of applicable BMPs at the audit site had to be 100 % implemented and meet 100 % of the technical specifications of the BMP manual. Effort to implement BMPs was noted on 90 percent of the sites visited. The field evaluator indicated that 90 % of the sites were experiencing no related water-quality impacts, but 38 % exhibited potential for impact.

4.4.11 Washington

The State of Washington has a reputation for intensively monitored watersheds and a strong emphasis on biological monitoring to measure BMP effectiveness (Harris et al., 2005). However, Washington has no regular program to monitor BMP implementation, aside from a number of detailed but sporadic studies of rule implementation (Ice et al., 2004). New road construction and haul road maintenance BMPs were comprehensively evaluated from 1992-95 in Washington to determine their effectiveness (Rashin et al., 1999). The evaluation focused on determining whether these BMPs were effective at achieving state water quality standards pertaining to sediment-related water quality impacts. Field investigations were conducted to assess surface and stream channel erosion processes during the first one to three years following the forest practice operations. A number of qualitative and quantitative survey techniques were employed in a case study approach to assess surface erosion and chronic sediment delivery to streams, physical disturbance of stream channels, and the condition of aquatic habitats and biological communities. Practices for installing stream crossings for new road construction were generally found to be ineffective or only partially effective at preventing chronic sediment delivery to streams. Road drainage BMPs, specifically practices for installing relief culverts, were found to be effective at over half of the new road sites evaluated. Practices for construction and stabilization of cutslopes on road segments draining to streams were generally found to be ineffective or only partially effective at preventing chronic sediment delivery to streams, while fillslope construction BMPs (beyond the immediate area of stream crossing fills) were generally found to be effective.

Design BMPs for road drainage, specifically practices for locating and installing relief culverts, were found to be effective at six of the new roads (55%), partially effective at four roads (36%), and ineffective at one road (9%). Eighteen percent of the 49 individual relief culverts evaluated at 5 of the 11 roads referred to above were found to deliver sediment and road drainage to streams via channel development or overland flow. Sediment transport distances below these relief culverts ranged from 36 to 330 feet. Sixty-seven percent of all relief culverts monitored had channel development or distinct overland flow sediment plumes developed below their outfalls during the first one to three years following road construction. BMPs for construction and stabilization of cutslopes on road segments draining to streams were rated ineffective at five of the new roads (46%) partially effective at four roads (36%), and effective at two roads (18%). The effectiveness of road construction practices was influenced by steps taken to control construction phase erosion and promote the establishment of vegetation on cut and till slopes, and to control ditch erosion. The majority of road construction sites relied on natural revegetation or dry grass seeding without mulching, and this was generally not effective in preventing chronic sediment delivery to streams. Fillslope stabilization and active haul road maintenance appeared to be effective.

4.4.12 Summary

As the cases above illustrate, there are wide variations in state efforts to monitor BMP implementation rates and effectiveness. Collectively, these state reports demonstrate that while compliance with forestry BMPs is high, most excursions are associated with roads, and that when road BMPs are not properly applied, sediment delivery to streams is likely (NCASI, 2001b). However, even when BMP implementation rates exceed 90% or higher, sediment delivery from roads can still occur. The questions then become: “How much sediment is delivered?” and “Will this much sediment impair aquatic resources?” Unfortunately, these questions are still difficult to answer. Whether current forest practice rules and BMPs will achieve the specific water quality targets of the Clean Water Act remains unknown (Rice, 1992).

4.5 Are Voluntary or Regulatory BMP Programs Effective?

Either type of BMP program (voluntary or regulatory) can be effective. Several factors have been used to compare and contrast regulatory and nonregulatory approaches to preventing nonpoint pollution from forest management sources (Prud’homme and Greis, 2002). These include level of compliance, degrees of water-quality protection, costs to landowners, and program costs to the state. The evolution of “blended” BMP programs, which seek to capitalize on the strengths of each approach, provide an indication that one kind of program may not necessarily be better than the other. States with regulatory programs like Oregon are seeking incentives for voluntary stewardship, while states that based their programs on nonregulatory approaches now backing up these efforts with "bad actor" regulations or developing fully regulatory BMPs (Ice et al., 1997).

Different measures of implementation among states, reliability of these data, and other differences and inconsistencies preclude objective comparisons between the effectiveness of voluntary and regulatory BMP program. One reason for the high rates of BMP implementation or FPR compliance reported for the western states has to do with the regulatory framework under which foresters must operate. Oversight or approval of a management or harvest plan or, in some cases, an approved HCP is required prior to any management activities taking place. For example, California requires approval of a THP before operations may begin. Washington requires application and notification regarding forest management activities; the degree of detail or applicability of the state's FPRs depends on which class of forest practices fall under which activity. Oregon's notification protocols require the landowner or land manager to supply basic information on the type of operation, its location, and the parties involved. Information provided in the notification is used to determine whether or not a site inspection or technical assistance visit is necessary to avoid potential water quality problems. However, there is also some evidence that continually changing, detailed, and complex rules can also reduce compliance in some cases. Results from the 2006 BMP compliance survey in Washington appear to demonstrate this, as this state has some of the most complex guidelines for forest management. Compliance with BMPs is higher in other western states (California, Montana and Oregon), where management requirements in the states' FPRs are less complex and have been in place longer. Mandatory programs also on average report lower rates of compliance with BMPs guidelines, due in part to their complexity and strictness.

In the southeast region, mandatory programs report on average lower rates of compliance with BMPs guidelines (NCASI, 2007). Rates of BMP compliance reported in Kentucky and Virginia, regulatory and quasi-regulatory states, are typically at the low end for the region. It is clear, however, that regulatory programs with mandatory BMPs often have larger monitoring and enforcement programs and, therefore, tend to have higher operating costs (Ellefson et al., 2006).

Hawks et al. (1993) compared Maryland's regulatory with Virginia's nonregulatory program. Neither approach was found to be clearly superior to the other in achieving BMP compliance or protecting water quality. Both states were reasonably effective in obtaining BMP implementation, but Maryland's regulatory approach was more costly to landowners and to the state.

Another evaluation by NCASI (1994) compared and modeled economic and non-economic costs and benefits of existing and hypothetical regulatory scenarios in Virginia and Washington. The modeled regulatory program and the most aggressive nonregulatory program scenario were predicted to result in nearly equal water quality benefits. The projected costs of the regulatory program estimated to be nearly double those of the nonregulatory program.

Regulatory frameworks used by states to ensure mandatory implementation of BMPs and other FPRs can require substantial financial resources. These include tasks such as rule-making (e.g., California, Oregon, and Washington have forestry boards and staffs that assess and update state FPRs), permit approval, onsite inspections, and enforcement programs. Costs to operate these programs can be quite high on non-federal forestlands. For example, in 2003, states in the western region spent between $220,000 (Utah) and $13.8 million (California) regulating forest practices programs; these states had 337 full-time equivalent regulatory staff, of which 35% were used by forest resource management agencies and 26% by air and water pollution control agencies (Ellefson et al., 2006; NCASI, 2007).

4.6 How Often do States Revise Their BMPs?

There is considerable variation in how often states revise their BMPs. The most recent revision date of each state's BMPs is identified in Tables 4-2 and 4-3; dates ranging from 1993 to 2003 were found. Some states like California, Washington and Oregon continuously revise their

BMPs and several states are currently revising their BMPs or have done so in the past 5 years. On the other hand, a few states are still operating under BMPs that are more than a decade old.

In California, implementation and effectiveness monitoring data have been used to revise BMPs. Determining which rules have the poorest implementation and effectiveness and the highest frequency of violations both provides input to the California State Board of Forestry (CSBOF) on needed rule changes and identifies training needs for CAL FIREs Forest Practice Inspectors, Registered Professional Foresters submitting THPs and Licensed Timber Operators (Ice et al., 2004). As an example of how the monitoring data have been used, the CSBOF adopted rule language in 2000 requiring FPR supervision of active timber operations based on information provided by the HMP (Ligon et al. 1999). Workshops on proper watercourse crossing design, construction, and maintenance were held in 2003 to provide training needs identified by monitoring.

Washington State FPRs were established in 1975 and have been revised 13 times (Holter, 2001). The most significant improvements for BMPs relating to fish habitat and water quality protection occurred in 1987 (the Timber, Fish and Wildlife Agreement), 1992 (cumulative effects assessment/Watershed Analysis), and 2001 (Watershed Analysis/ Endangered Species Act; Ice et al., 2004). For the past 15 years, an important feature of Washington’s forest management system has been the use of the adaptive management approach to guide BMP development. Adaptive management requires the collection of information for feedback on system performance, and adaptive management approaches are designed to utilize ongoing management as a test from which to learn (Ice and Whittemore, 1998). Probably the two most useful examples of adaptive management monitoring at the watershed scale are source searches and watershed analysis. Watershed analysis is defined as a structured approach to develop a forest practice plan based on a biological and physical inventory" (WFPB, 1993).

In Oregon, Department of Forestry administrative rules continually evolve in response to scientific knowledge. Major revisions to the 1973 FPRs were made in 1978, 1983 and 1994 (FPAC, 2001).

In Montana, rule improvements recommended by the Montana Environmental Quality Council (EQC, 1988) have precipitated several changes in nonpoint source management program for forestry, including formation of a Technical Committee to guide development of a set of statewide forestry BMPs. This committee included industrial and nonindustrial landowners, logging contractors, Montana Water Quality Bureau staff, representatives of the USFS, and was led by the Montana Department of Natural Resources and Conservation (Ice et al., 2004).

In Idaho, the rules of the Forest Practices Act require a “default” level of BMPs applicable across the state (NCASI, 2001b.). Every four years, the Department of Environmental Quality and the Department of Lands conducts an audit of the BMPs to determine if they were effective in maintaining water quality. Rule changes are developed to address instances where practices have been found to be inadequate.

Florida first established BMPs in the mid 1970s. In 1992 a BMP technical advisory committee was formed and a BMP manual was published in 1993. The manual was revised in 1995 (FDA, 2004). Some forest road and stream crossing BMPs in the Florida manual appear to be outdated, at least in comparison to the western states. However, this can be a difficult judgment to make, given the differences in the nature of forestry-related impacts between the west and the southeast.

4.7 Do Existing BMPs Include the Most Technologically Up-to-Date and Useful Practices Available?

BMPs are not uniform from one state to another, and in some states BMPs are based on older (pre 1980s) technology. In some cases, BMPs have not yet incorporated new research findings and/or lack long-term effectiveness studies (Ice et al., 1997). The low-cost, low-maintenance intermittent-use roads pioneered by Coweeta Hydrologic Laboratory in the 1960s is widely accepted and adapted to local conditions by government and industry land managers, and strongly recommended by state agencies with the aim of reducing sediment (Swift, 1988). The Coweeta research demonstrated outsloped roads and other BMPs (Section 3.1.2.1) that are reflected in state BMP programs. However, some of these BMPs may not be suitable for all regions, locations or sites. Haupt et al. (1963) documented a case involving mountain haul roads on granitic soils in Idaho in which severe rainstorms caused more damage to outsloped roads than insloped/ditched roads. Based on observed slope failures, Hartsog and Gonsior (1973) recommended outsloping only where surfaces were relatively nonerodible. In some unstable areas and regions, especially in the Pacific Northwest, conventional BMPs for road construction may not be sufficient to prevent adverse effects on stream channels and fish habitat.

Designing and/or reconstructing stream crossings to avoid diversion potential, to accommodate natural disturbances, and to allow unrestricted passage of fish, sediment bed load and large wood, are examples of modern BMPs that have not been incorporated by many states. Several states still consider log crossings to be acceptable BMPs (Grace, 2002), although they are not generally recommended (Taylor et al., 1999). Fords are also generally perceived to have greater impacts on water quality than other crossings (Taylor et al., 1999), yet are considered to be acceptable BMPs in many states. Fords introduce sediment into streams during construction and vehicle crossings, and provide more opportunity for runoff to flow down road approaches into streams.

4.8 What Processes are Used to Address and Correct Failing BMPs?

The response of state forestry agencies to BMP violations or complaints varies widely. Some follow established, formal interagency agreements that can include referral to enforcement agencies. Other states have no formal process for follow-up or referral, but do refer some cases to other agencies. Information on the methods and mechanisms used by state forestry agencies to address water quality problems related to BMP are noted under the “other information” heading in Tables 4-2 and 4-3. It should be reiterated that when problem areas in state BMP programs are identified, the overwhelming response by the various regulatory agencies is to strengthen education and training programs in the specific area identified. All state forestry agencies attempt to work with landowners to correct deficiencies prior to referral to enforcement agencies (Prud’homme and Greis, 2002). Persistent noncompliance can result in a variety of enforcement actions, which range from mandatory installation of BMP, fines, and orders to cease forestry activities.

States also use different mechanisms to identify and locate failing BMPs. Examples include public reporting of stream sedimentation. Local observation of highly-turbid streams has been reported to be one of the most important means of learning of problems or potential violations (Corner, 1992; Irland and Connors, 1994; Juul et al., 1990). A number of states acknowledge the role of citizen complaints (Corner et al., 1996) in identifying, locating and addressing nonpoint source pollution problems.

4.9 Is Concurrence or Approval by the State Agency Administering the Clean Water Act Required For: (a) Forest Road Bmps? (b) Forest Practice Rules Related to Roads and Water Quality? (c) Forest Operations or Plans Involving Road Construction and Maintenance?

In several states, agencies administering the CWA are notified of forest operations or plans involving road construction and maintenance. Oregon and Idaho have forest practice notification programs that are designed to alert state agencies to proposed operations (NCASI, 2001b.). Notification allows for pre-harvest inspections where there are priority risks and where special protection may be needed. In Oregon, where there are special risks associated with activities in areas with a high risk of landslide or near fish-bearing streams and wetlands, written plans are required. The Oregon and Idaho FPRs also allow for special protection rules in watersheds that are water quality limited.

In California, it has been suggested that lead-agency responsibility for approval of THPs and SYPs lies with the wrong agency (Reid, 1999), and should be shifted from the Department of Forestry to the California Resources Agency. Staff of the relevant state departments (i.e., Water Quality Control Board, Department of Fish and Game, etc.) should be given authority for decisions falling within the purview of those departments' areas of expertise. Reid noted that some Department of Forestry staff members perceive their primary mission to be to facilitate production of maximum sustained yield of high-quality forest products, Water Quality Control Board staff perceive their mission to be protection of water quality, and Department of Fish and Game staff perceive their mission to be maintenance of fish and wildlife populations. Some of these goals conflict with one another. Decision-making for THPs and SYPs is the responsibility of the Department of Forestry, yet the most generally valued and utilized "commodity" produced by California's forest lands is clean water.

4.10 What are the Circumstances Producing Effective BMP Implementation? Case Studies of Successful State BMP Programs: Washington, Oregon and Idaho

Forestry BMP programs in the Pacific Northwest are quite advanced in relationship to other states. Forestry BMPs vary from state to state on the Pacific coast, and their detail and rigor seem to be related to the degree of urbanization and the economic importance of the forest products industry in each state (Rice, 1992). While some of the details may differ slightly for other regions, the fundamental issues and principles that apply to the West remain applicable across the country. Building on state FPR BMP-based systems, western states including Washington, Oregon and Idaho have developed watershed analysis systems that address watershed conditions on a site-specific basis. Much of the material in this section was taken from NCASI (2001), which provides comprehensive descriptions of the FPRs in western states. Although aspects of these state programs and their implementation have been criticized (see Section 4.5), each of the programs described below has developed analysis and management systems which address site-specific forest road impacts which vary widely within each state.

4.10.1 Washington Watershed Assessment Process

Writing watershed-specific rules has reached its most detailed level in Washington, where watershed analysis is used (Ice et al., 1997). Washington’s watershed analysis approach to watershed management is based on biological and physical inventories of watershed conditions. It is a collaborative process involving resource scientists and managers representing landowners, agencies, tribes, and other interested citizens. Both the assessment and the management process based on assessment findings are highly structured and defined within the Forest Practices Act and its implementing rules, and are designed to be repeated and adaptive (NCASI, 2001).

In Washington’s system for management of road erosion and sediment delivery impacts, roads are field inventoried and the data are used with simple spreadsheet based models that quantify erosion and sediment delivery in comparison to estimates of natural background watershed sediment delivery. When delivery is considered to be too high, an adverse condition exists that must be addressed with management prescriptions designed to alleviate the condition. These prescriptions are developed by local land managers and agencies, must address the specific areas of hazard and resource concern identified by the scientific assessments, and are subject to public review and appeal prior to final acceptance of the plan.

4.10.2 Idaho Cumulative Watershed Effects Process

The objective of Idaho's CWE assessment and forest practices management process is to lead landowners to conduct future forest practices according to three "staged" criteria (IDL, 2000b):

1. In watersheds where beneficial uses are not supported as a result of forest practices and are not improving, mitigation and rehabilitation activities must be conducted in conjunction with current forest practice activities so that, in balance, a generally improving trend is maintained until adverse conditions no longer exist.
2. In watersheds where beneficial uses are not supported as a result of forest practices but conditions are improving, activities must be conducted in a way that does not interrupt this improving trend.
3. In watersheds where beneficial uses are supported, forest practices will be designed to prevent loss of this support.

The Idaho assessment procedures are designed to detect the presence of adverse watershed or stream conditions, to identify causes for the conditions, and to identify actions that will correct and prevent existing and potential future problems. The result of implementation of the CWE process in a watershed is the development of mandatory special rules for the watershed, called Cumulative Watershed Effects Management Practices, that are authorized by the state's Forest Practices Act and are enforced by the Idaho Department of Lands. As in Washington, roads in Idaho watersheds are inventoried, and although based on a qualitative rating of erosion and delivery of sediment to streams, road conditions leading to adverse instream conditions must be corrected until the qualitative rating score is reduced to within the range considered to be acceptable.

4.10.3 Oregon Watershed Assessment Process

The Oregon watershed assessment process is designed to identify how natural processes and human activities affect fish habitat and water quality, and to evaluate the cumulative effects of land management practices over time. Although the process does not include development of site specific watershed management prescriptions, it provides the information necessary for development of action plans and monitoring strategies for protecting and improving fish habitat and water quality. The assessment provides broad-scale screening and is developed by local citizens with some assistance from technical experts using the assessment manual's "cookbook" procedures for compilation and evaluation of information about watersheds. The procedure concludes with development of a Watershed Condition Evaluation and Monitoring Plan. A standard list of Critical Questions is addressed for each of six watershed characterization modules.

Road erosion and sediment delivery are evaluated as a component of a broad sediment source assessment that identifies where human caused sediment increases are most severe, as well as priority restoration opportunities. The assessment manual provides highly structured and organized procedures for evaluation of landslide hazards, road surface erosion, and stream culvert capacity and condition.

The Oregon Department of Forestry (ODF) also conducts watershed analysis projects in basins containing State Forest land. These projects evaluate the interactions between ODF management and a watershed's physical and biological processes. The ODF watershed analyses are performed in several steps:

- The analyst compiles available information to describe current watershed condition.
- Based on this description, factors limiting important watershed functions are identified and assessed.
- The analysts and ODF resource specialists determine whether riparian and aquatic strategies are addressing the appropriate concerns regarding process and function within the watershed.

Information provided by watershed analysis can be used to refine district implementation plans and, as necessary, contribute to a comprehensive review of forest management plan goals and strategies. In 2008, analyses were finalized for 5 watersheds: Elliot State Forest, Trask Watershed, Miami Watershed, Upper Nehalem and Wilson Watershed. As one component of these analyses, state-developed Rapid Watershed Risk and Current Condition Surveys were used to evaluate the current effects forest roads have on aquatic resources within a particular watershed, and capture attributes associated with roads and their potential environmental risks (Duck Creek Associates, 2008).

4.10.4 Special Issue Management Systems

In some cases, management systems have evolved around a specific issue or certain species of concern. Examples of this include Habitat Conservation Plans (HCPs), the Oregon Plan for Salmon and Watersheds, and Washington State's Forest and Fish Agreement.

4.10.4.1 Habitat Conservation Plans

The ESA notes that it is unlawful to "take" endangered species, with the definition of "take" including, "…harass, harm, pursue, hunt, shoot, wound, kill, trap, capture or collect…" Regulations under Section 4 of the Act clarify that "harm" in the definition of "take" includes "significant habitat modification" that aresults in injury or death to the animal (50 C.F.R. section 17.3). In one of the few amendments to the 1973 ESA, Congress modified Section 10 in 1982 to permit "take" for listed species incidental to such otherwise lawful activities as grazing, farming, or logging (16 U.S.C. section 1539 (a)(a)(B)). Each application for such an incidental take permit must be accompanied by a HCP (16 U.S.C. section 1539 (a)(2)(A)). The process is intended to be proactive and creative, with the landowner taking the initiative to obtain the HCP and suggest the habitat conservation measures designed to avoid take. The legal assurances provided by an HCP are not without cost – both in terms of the cash outlay necessary for the completion of the agreement and the delays and modifications to land uses that might be required in exchange for the HCP. The HCP for native fish species developed by Plum Creek Timber Company (NCASI, 2001) is one example of an HCP that addresses existing and potential future road impacts through comprehensive assessment and inventory followed by implementation of forceful (and expensive) road maintenance and construction requirements.

4.10.4.2 Oregon Plan for Salmon and Watersheds

Several "Evolutionarily Significant Units" of salmon and steelhead have been listed in recent years under the ESA in numerous rivers of coastal and interior Oregon. Under sponsorship of the state's Governor, Oregon has developed its Plan for Salmon and Watersheds. The key elements of the Oregon Plan are:

- An ecosystem approach that requires systematic consideration of the full range of attributes of aquatic health;
- A focus on reversing factors for decline and meeting objectives that address those factors;
- Use of adaptive management and a comprehensive monitoring strategy; and
- Building citizens and constituent groups into the restoration process.

Several forest land initiatives have been implemented, including development of the watershed assessment process (OWEB, 1999), development of standard road inventory and assessment procedures, and development of training materials for landowners, including the Forest Road Management Handbook (ODF, 2000). These procedures emphasize design and construction of culverts to ensure fish passage, along with road maintenance and repairs to prevent surface erosion, washouts, and road failure associated landslides.

Several watershed assessments using the Oregon procedures have been completed and many more are in progress. Many members of the Oregon Forest Industry Council and smaller forest landowners have voluntarily completed the required inventories and have initiated rehabilitation of road systems to address existing adverse circumstances (ODF, 2000).

4.10.4.3 Washington Forest and Fish Agreement

In 1986, the timber industry, tribes, the state, and the environmental community agreed to resolve contentious forest practice problems through negotiations, resulting in Washington's watershed assessment process and several stream and landscape research efforts. As a result of research findings and common findings within many of the completed watershed analyses, the Timber/Fish/Wildlife (TFW) program parties, expanded to include federal and local governments, began working together again to address ESA listings, 660 streams included on the 303(d) list of water quality limited water bodies, and the cost and uncertainty attendant upon timber acquisitions and harvest activities. Agreement was reached and recommended to the Forest Practices Board and the Governor's Salmon Recovery Office in February 1999. The recommendations were subsequently adopted as Emergency Forest Practices Rules. These rules substantially modified the then-existing FPRs in such important areas as stream classification, riparian management requirements, management of unstable slopes, and road management.

Under the agreement and the subsequent Emergency Rules, the road management policy is to maintain or provide passage for fish in all life stages, provide for the passage of some woody debris, meet water quality standards, control sediment delivery, protect streambank stability, and divert most road runoff to the forest floor. Perhaps the most comprehensive of these new rules is that all landowners are now required to develop and submit for public review, and Washington Department of Natural Resources approval formal road maintenance and abandonment plans for their entire ownership and road system within specified time frames. Requirements to inventory all stream crossing culverts and to replace or correct those with fish passage problems are included. Culverts not passing the now-required 100 year flood flow must be replaced at the end of their useful life. The new rules also contain comprehensive location, design, maintenance, and abandonment requirements for prevention of both mass and surface erosion.

5. SUMMARY AND CONCLUSIONS

In 2007, Great Lakes Environmental Center (GLEC) conducted a literature review and evaluated data to provide recent examples of water quality impacts from forest roads and to survey the effectiveness of forest road BMPs to prevent these impacts. This report summarizes these findings, focusing on three areas of interest to USEPA:

Section 2: Impacts of forest roads on water quality and aquatic resources.
Section 3: BMPs for forest roads (descriptions, effectiveness, shortcomings and costs).
Section 4: State BMP programs for forest roads.

This research builds on previous studies conducted by USEPA, USFS, NCASI, the states, forestry and water quality scientists, and other interest groups. Although much has been studied and written about forest roads, their relationship to water quality impacts, and the role of BMPs in mitigating these impacts, a number of conclusions have emerged from the process of reviewing and summarizing this literature. These are listed below:

- Potential effects of roads on water quality include increased loading of sediment due to erosion and mass wasting (landslides), increased suspended solids and turbidity, increased sediment deposition and bed load, siltation of coarse streambed substrates, physical barriers to migration and downstream transport, and altered streamflow and pollution from other chemicals associated with road use.

- Adverse impacts of forest roads on aquatic ecosystems, especially anadromous salmonids, are well documented. These impacts arise from a number of factors: erosion and sediment delivery to streams, fine sediment accumulation, and obstructions to passage of fish and large debris. The greatest impacts occur along the Pacific Coast and Northwest.

- National level assessments of water quality are based on state lists of impaired waters, the so-called 305(b) and 303(d) lists. These assessments represent the only available National data on the extent and causes of impairment to rivers and streams, lakes, wetlands, and other waterbodies. The 2002 National Water Quality Inventory lists silviculture as the 12th leading source, responsible for impairment of 19,071 river miles; this represents 5% of impaired river miles.

- Although the information in the National Assessment Database provides a picture of state assessment results, these data cannot be used to compare water quality conditions between states or to identify trends in statewide or national water quality.

- Roads can have very different effects on water resources depending on road size, design, location, construction, access, usage and maintenance techniques. Although most roads will have some effect on their watersheds, a small percentage of road area (or length) is often responsible for most of the erosion. A key to understanding this variation is the placement of roads in relationship to the erosion and sediment delivery potential of various points in the forest landscape.

- The commonly-cited 80/20 rule (80% of the problems come from 20% of the roads) suggests that relatively few forest roads cause most of the problems.

- Soil losses and erosion occurring closer to a stream have greater potential to deliver sediment and lead to water quality impairment. In this regard, stream crossings have the greatest potential to adversely impact water quality on the forest landscape.

- Adverse environmental effects from forest roads change over time and vary with season of construction and use, age, weather, kinds and intensity of maintenance, traffic level, and other location factors such as geology, geomorphic location, soils and terrain.

There are a number of guiding principles for forest road BMPs, including:

- Recognize and avoid high-erosion hazard areas.

- Minimize the total amount of landscape disturbed by roads, bare ground and soil compaction.

- Engineer stable road surfaces, drainage features and stream crossings to reduce erosion.

- Separate bare ground from surface waters and minimize delivery of road-derived sediments to streams.

- Provide a forested buffer around streams which exclude roads and minimize crossings.

- Design and install stream crossings to allow passage of fish, other aquatic biota, and large wood.

- Put BMPs in place to anticipate triggering events.

- Unless obliterated/removed, all forest roads, crossings and associated BMPs must be maintained.

- Although silviculture BMPs are grounded in science or are based on scientific principles, a lack of science to validate BMP effectiveness is a shortcoming of many BMPs related to forest roads.

- Rating BMP efficiency is difficult because the performance of BMPs and their associated impacts vary considerably with geology, terrain, watershed characteristics, site locations and weather.

- The difficulty with rating BMP efficiency is that the same practice on different sites, in different watersheds or even with different weather patterns, can result in different impacts.

- To maximize the performance of BMPs at a site, the BMP prescription must be customized to the setting, but customized BMPs require greater skill and effort on the part of the forest manager and knowledge of where the problems are located. Both increase the difficulty for states to determine whether BMPs have been properly implemented. In this situation, performance standards that are realistically achievable should be used to set goals for the BMPs.

There are a number of recent promising innovations in forest road BMPs, including:

- Portable bridges, mats, pipe bundles, and altered logging equipment (e.g., wider tires, low tire pressure, dual tires).
- Development of methods to optimize BMPs.
- Management systems.

BMPs for forest roads fail to protect water quality for a variety of reasons, including:

- Lack of effective implementation.
- Erosion rates and mass failures can exceed capability of BMPs to prevent generation, transport and/or delivery of sediment to water bodies.
- Legacy roads and crossings (i.e., lack of maintenance, failure to upgrade and/or remove).
- Cumulative Impacts.
- Highly sensitive aquatic resources.
- Extreme storm events.

There are a number of ways to address failing forest road BMPs, including:

- Improving inspection and maintenance practices.

- Identifying the location of failures.

- Determining which high-risk roads should be properly abandoned.

- Road reconstruction and upgrading to current standards.

- Adding components to BMP systems.

- 15 states (Alaska, California, Connecticut, Idaho, Kentucky, Maryland, Montana, Nevada, New Hampshire, New Mexico, Oregon, Pennsylvania, Vermont, Washington, and West Virginia) have developed regulatory programs that require permits or mandatory BMPs. Forest management programs in the western states are overwhelmingly regulatory.

- BMP implementation is largely voluntary in the other 35 states. This includes the southern states (Alabama, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas and Virginia) although 3 states (Florida, North Carolina, and Virginia) have linked BMP implementation to other state regulatory programs, making them quasi-regulatory in some circumstances, and BMP implementation became mandatory in Kentucky in July 2000.

- 9 states have a nonregulatory BMP program without enforcement. These states typically use incentive and education programs to ensure pollution control and include states without a large timber industry or steep terrain such as Illinois, Oklahoma, and Utah.

- 18 states have nonregulatory programs with enforcement where use of BMPs are not mandatory but enforcement action can be taken against polluters or landowners who refuse to implement proper BMPs.

- 8 states have combination programs that mix aspects of regulatory and nonregulatory programs.

- As the preceding summaries of state programs demonstrate, not all state BMPs are the same.

For example:

- 20% of state BMPs do not address maintenance of roads.
- 80% do not address use of roads in wet weather.
- 48% do not address road closure.
- 30 states have conducted implementation and effectiveness monitoring of their BMPs since 2000.

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TABLES

Table 2-1. Results of Keyword Searches in the TMDL Tracking System Database

Keyword(s) searched	Type of TMDL	Impairment (pollutant)	Number of TMDLs
silviculture	Point/nonpoint	(Any)	155
silviculture, forest, timber, forestry	Point/nonpoint	sediment	127
(none)	Nonpoint	Sediment	91
silviculture, forest, timber, forestry	Point/nonpoint	turbidity	82
silviculture, forest, timber, forestry	Point/nonpoint	siltation	70
road, roads, timber	Point/nonpoint	sediment	70
road, roads	Point/nonpoint	sediment	70
forest road	Point/nonpoint	(Any)	52
road, roads, timber	Point/nonpoint	sediment	46
road, roads	Nonpoint	sediment	45
road, roads, timber	nonpoint	turbidity	36
forest roads	nonpoint	sediment	8
road, roads, timber	nonpoint	habitat alteration	1
road, roads, timber	Point/nonpoint	habitat alteration	2

Table 3-1. Best Management Practices for Forest Roads: Descriptions, Measures of Effectiveness, and Costs. (source: Gallagher et al., 2000)

Best Management Practice	Description of Practice	Measures of Effectiveness	Costs
Control And Mitigation Measures For Road Construction			
Temporary Stream Crossings	Stream crossings can be designed and installed for temporary use and then removed after use. In some cases, portable and re-useable crossings are used. The streambed is restored following removal of the crossing.		
Portable Bridges	Portable bridges made of wood, steel, and concrete can be used on haul roads and skid trails where permanent structures are not needed. Bridges can be installed and removed with minimal disturbance to the streambank, channel, and adjacent RMA.	Portable and temporary bridges make suitable lower cost alternatives to permanent bridges, and they can reduce the environmental impacts associated with culvert crossings, stream fords, and roads constructed to detour around crossings.	Hinged steel bridge (8 m long): $14,205 Concrete bridge (10.6 m long) : $11,500 Glued-laminated bridge (9.1 m long): $16,100 Stress-laminated timber bridge (9.7 m long): $14,000 Taylor (1994) estimated the hauling and installation costs of the glued-laminated bridge to be $1000 per crossing. Using the bridge ten times yields a cost per crossing that is equivalent to installing culverts.
Log crossings and pole fords	Log crossings and pole fords are temporary stream crossings that are created by placing logs in shallow channels. The surface of log crossings may be improved with decking or with log mats. Log crossings are removed immediately after use or before the upstream end becomes clogged with sediment.		
Temporary culverts	Temporary placement of culverts reduces the chance of culvert failure, and subsequent stream crossing failure and erosion, compared to permanently placed culverts.	There may be considerable sedimentation from a culvert crossing from the time of installation until removal. Culvert installation can increase sediment loads (King 1981). Sediment loads 100 to 1000 times higher than normal have been reported following culvert installations.	
Use of Cofferdams or Stream Diversions Around Construction Sites	Flowing water is diverted around the construction site of stream crossings and excavations are not made in flowing water. Instream flows are maintained. Excavation and equipment operation is kept out of streams to reduce sediment yield which could cause turbidity and excess fines that may clog stream gravels and fill pools		

Table 3-1. Best Management Practices for Forest Roads: Descriptions, Measures of Effectiveness, and Costs. (source: Gallagher et al., 2000)

Best Management Practice	**Description of Practice**	**Measures of Effectiveness**	**Costs**
Timing Construction Activities Near Streams to Avoid Critical Periods for Aquatic Organisms	Construction activities near a stream can be timed to avoid disturbances that create increased sediment loads during periods when sensitive aquatic species are present or are more susceptible to increased turbidity or suspended sediment.		
Pioneer Roads	Pioneer roads are temporary access ways for construction equipment during construction of permanent roads. They are used to reduce the amount of area disturbed during road construction and to ensure the stability of the roadway. Pioneer roads are confined to the surveyed permanent roadway and are fitted with drainage structures.		
Mulching, Seeding, and Stabilizing Disturbed Areas	Areas of disturbed and bare soil, including ditches, cut- and fillslopes, roads, landings, skid trails, fire lines, stream crossings, and slides, are seeded and treated with erosion control practices. These can include includes planting trees, seeding, and applying mulch, hydromulch, erosion blankets, straw bales, filter fabric fences, and riprap.		
Mulching	Mulches protect the soil surface from rain impact and help prevent surface seal formation until vegetation is established. Mulch improves soil conditions for seed germination by maintaining infiltration capacity, preventing crust formation, shading the soil, and reducing evaporation.	Research has shown that seeding and mulching effectively control erosion on road cutslopes and fillslopes. Effectiveness of each cover type increases as the percentage of groundcover increases (52 to 95% erosion reduction)	Megahan et al. (1992) reported costs of $7,400 to $31,000 per acre.
Vegetation Establishment	Establishment of vegetation on disturbed areas provides a living mulch which effectively reduces erosion and has advantages over a dead or synthetic mulch. However, it takes time for vegetation to become established and seeding is more effective when mulch is applied.	Dense grass can be used in erosion control of previously bare soils; 86 to 100% sediment reductions with grass. Planting grass reduces erosion on light traffic roads. Grassed roads had 45% lower sediment yield than bare soil roads.	
Erosion Barriers	Erosion barriers such as straw bales, erosion filter fabric fence, rock dams, and geotextile barriers slow flowing water and cause sediment deposition.	The best performing slope-protection products reduced sediment 84 to 93% compared to control (seeding without any additional erosion control treatment).	
Channel and Ditch Protection	Channels and road ditches can be protected with channel liners, rock blanket, or riprap. Check dams can be constructed in gullies and channels to prevent scour. Flexible channel liners are made of jute, coir (coconut fiber), straw, excelsior, plastic, nylon, and other synthetics.	The best performing flexible channel liners significantly reduced sediment yield 82 to 88% compared to control (seed alone).	
Fords (low water crossings)	Fords can be used in place of conventional culverts and bridges	Low-water crossings minimize the need for fill, reduce or eliminate	Costs vary with structure type, stream characteristics, and labor rates.

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Best Management Practice	**Description of Practice**	**Measures of Effectiveness**	**Costs**
	where the streambed is firm, banks are low, and the water is shallow. Simple fords are made of crushed rock, rock-filled gabions, or concrete structures.	culvert and bridge costs, and have low maintenance requirements	Milauskas (1988) provided the following cost estimates of materials: Natural fords, using concrete barriers cost $130 to $160 per meter; Paved fords (Cast-in-place concrete) would cost $260 per meter.
Trash Racks (Debris Control Structures)	Trash racks are used to trap woody debris and trash before they can plug a culvert. Designs vary with materials available.	Trash racks are located upstream of culverts, to reduce the risk and likelihood of culvert plugging and failure by woody debris and sediment transported down a stream channel. May prevent fish passage.	
Increasing Capacity at Constructed Crossings	The flow capacity of bridges and culverts is increased to reduce the probability of road washouts in areas where there is a problem of plugging from large wood, debris and sediment.	Increasing the clearance under bridges and using larger culvert sizes allow debris to pass that might otherwise result in a crossing failure and road washout. Oversizing the culvert increases the expected life of the crossing. Increasing culvert size may reduce low-flow fish passage in certain situations.	There are added costs of design upgrading and additional materials. However, these costs may be offset over time if they result in reduced road washouts and maintenance costs.
Diversion-Proof Crossings	Stream-diversion potential at crossings is eliminated by constructing crossings at right angles to the stream and by designing both approaches to grade into the stream. By grading the road toward the crossing, failure of the culvert by blockage or overflow does not divert downslope but flows with the channel, potentially removing only the road prism.	If the stream channel is diverted into the road, ditch, or skid trail during a storm flow, the diverted channel may cut gullies into roads and hillslopes. This may lead to debris torrents and delivery of large sediment loads to streams. Failure dips in the road can be constructed at stream crossings to prevent crossing failure and stream diversion.	Costs to develop diversion-proof crossings include design and planning as well as extra construction costs for grading toward the stream. Reconstruction costs following failures and diversions can often exceed the original construction costs.
Benched Slopes (Terraced Slopes)	Level benches or terraces are constructed to reduce the amount of soil leaving the cutslope. Eroded soil is deposited on the level part of the bench instead of being transported off the slopes.	Terraced cutslopes reduced sediment production by 86 to 94%.	Costs can be estimated from the cost of operating the equipment to build benches.
Minimizing Sidecast Material	Sidecasting of road cut material is kept to a minimum to reduce the	Sidecasting road construction methods are not suitable on steep or	

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Best Management Practice	Description of Practice	Measures of Effectiveness	Costs
	amount of bare soil that is exposed and to reduce the volume of uncompacted fill material on unstable landscapes where mass erosion is a problem. This practice is intended to reduce sediment sources from roads.	moderate slopes near stream channels where loose material could saturate during wet weather and slide further downslope. Summaries of landslide inventories suggest that new road construction methods, including the use of full-bench roads as opposed to sidecast road construction, had resulted in fewer road-related failures.	
Full-Bench/End-Haul Construction	Full-bench and end-haul construction methods involve cutting the full width of the roadbed into the hill slope. Cut material is hauled to a suitable disposal area. These methods are used where there is a high probability of fillslope failure and sediment delivery to fish-bearing waters if sidecast methods were used. End-hauling is also used to prevent sidecast entering floodplains, wetlands, and other sensitive sites.	Many landslides in steep areas originate in roadfill. Full-bench construction eliminates fillslopes and can reduce slope failures originating from roads. Road stability is improved by full-bench construction on slopes in excess of 55%. This method reduced the area of bare slopes prone to erosion.	There is an additional cost of end-hauling and providing stable waste placement since a larger amount of hillslope is removed in full-bench construction.
Avoiding Incorporation of Large Organic Material in Road Fill/Base	Incorporation of slash, logs, and other large organic material in landings and roads can create an increased risk of landslides Decomposition of the organic matter can result in loose fill which is subject to liquefaction and failure.		
Road Surfacing (Gravel, Crushed Rock, Lignosulfonates, Asphalt)	Forest roads are surfaced with gravel, rock, asphalt, or other suitable materials to provide bearing strength, and to reduce deterioration and erosion of the traveled way. Covering roads with asphalt or gravel can effectively reduce the amount of sediment produced.	Swift (1984b) demonstrated that covering roads with a 15 cm layer of crushed rock reduced sediment losses by 78%. Kochenderfer and Helvey (1987) showed an 87% reduction in sediment yield from roads covered with a 15 cm thick layer of “3 in. clean limestone rock,” compared to bare soil roads. The authors noted that rock type affected performance. Less information is available for	Costs vary with availability of material and distance of transport. Swift (1984b) estimated that surfacing roads in the southern Appalachian Mountains with 15 cm of crushed rock would cost $6,000 per km. Kochenderfer and Helvey (1987) estimated the cost for construction of unsurfaced road in West Virginia to be $13,000 per km; surfacing with 15 cm of crushed rock

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Best Management Practice	**Description of Practice**	**Measures of Effectiveness**	**Costs**
		sediment reductions for other road surface treatments. Burroughs and King (1989) report that dust oil reduced sediment yield by 85.3% and bituminous surface reduced sediment yield 96.6%, compared to bare soil roads.	would cost an additional $16,000 per km.
Daylighting Roads	Trees and vegetation that shade the road are removed in order to “daylight” roads where there are sections of road that are slow to dry. Removing tree canopy near streams may violate SMZ.	Wet roads are subject to rutting, which concentrates runoff and leads to increased sediment yields.	Costs of daylighting roads are associated with the removal of trees and vegetation.
Maintaining or Planting Trees and Woody Species on Disturbed or Steep Areas	Native woody species are planted on disturbed areas and steep slopes, including cut- and fillslopes, closed roads, landings, skid trails, fire lines, stream crossings, and slides. Mulch, hydromulch, erosion blankets, straw bales, filter fabric fences, and riprap may be used to provide soil protection until trees are established. A buffer strip of trees can be left above the cutslope and below the fillslope to help stabilize slopes.	Trees, shrubs, and grasses provide two functions for disturbed areas. In certain landscapes, tree roots can markedly increase slope stability. In other cases, plant foliage and litter provide cover and resistance to surface erosion.	Weaver et al. (1987) provided the following cost estimates from watershed rehabilitation work done at Redwood National Park: Hand-planted trees: $0.10 each seedling; Hand-planted Shrubs: $0.12 - 0.35 each shrub. Seed, fertilizer, etc. is an additional cost.
Outsloping Roads	Outsloped road sections can be used to shed water on moderate slopes and low-volume roads, on closed and decommissioned roads, landings, and skid trails. Outsloping is an alternative to insloping with inboard ditches and frequent cross drains.	Outsloped roads are less likely than ditched roads to have catastrophic failure, because the entire road system is designed to drain, assuming there is adequate maintenance to keep the road tread rut free. Outsloping is becoming an increasingly attractive option in locations where minimal maintenance can be expected. Severe rainstorms caused more damage to outsloped roads than to insloped roads on mountain haul roads in granitic soils in Idaho.	Weaver et al. (1987) estimated costs for outsloped roads and landings during watershed rehabilitation in Redwood National Park. A bulldozer and a dragline crane outsloped two landings at a total cost of $16,400. Outsloping during road obliteration cost $5665 per km.
Road Dips (Broad-Based Dips, Rolling Dips)	Broad-based dips and rolling dips drain water from the road by creating	Megahan and Ketcheson (1996) found shorter downslope sediment	

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Best Management Practice	Description of Practice	Measures of Effectiveness	Costs
	a reverse grade and an outsloped dip. Dips are used in place of ditch relief culverts. Broad-based dips are constructed by scooping out a shallow dip on the upslope side and building up a short reverse grade (about 3%) on the downslope side of the dip, with a berm crossing the ditch. Rolling dips are usually used on steeper gradient roads (up to 15%, although difficult when >10%) and are constructed by creating a short 3 to 8% reverse grade and a dip that is shorter and deeper than a broad-based dip. Rolling dips are usually used during road construction and in road closure after hauling and not when the road is actively being used for hauling.	travel distances for "rock drains" versus relief culverts.	
Water Bars (Log Bars, Earthen Drains, Turnout Ditches)	Waterbars are supplemental drainage structures not used during active log hauling. A water bar consists of a combination of berm and trough constructed to divert runoff from a road or trail onto vegetated areas or other stabilized outflow.	Water bars function as cross drains and are very effective at removing water from roads and trails. Diagonal water bars and ditches are more effective in reducing soil erosion on skid trails than are slash dams and slash mulches. Water bars and cross ditches are effective because they divert water off the trail and reduce slope length.	Lickwar, Hickman, and Cubbage (1992) estimated that water bars were most expensive of the six evaluated BMPs that are used in the South. Based on an aggregate sample of 22 timber harvests with an average of one water bar per 5.4 acres, the authors found that water bars cost an estimated $20 per water bar (1987 dollars).
Stabilizing Cutslopes and Fillslopes	Several construction methods are used to overcome the instability of slopes, to repair slides, and to correct incipient slide conditions. Failure of road fill sections and road cutslopes can deliver sediment to streams or deposit loose sediment in ditches and block culverts which can lead to road failure. Small rock buttresses can be constructed at the foot of a cutslope to stabilize the	Reinforced soil walls and fills have been successfully constructed from treated timber and geogrids; straw-, soil-, manure- and seed-faced reinforced fill; and fiberglass-reinforced fill (Burke 1988). McNemar (1989) determined that a geogrid retaining wall was the most cost-effective method to repair a steep fill slide. Porior (1991) used logs to face one	McNemar (1989) reported that geogrid material to repair a slide 14 m long and 2.4 m high cost $700. Other costs were not specified but included backhoe work, dump truck hauling, stone, seed and mulch, and netting. Porior (1991) constructed a 15 m long and 2.4 m high log-faced chain-link retaining wall for $3500. A 9.1 m long and 2.4 m high hay-bale-faced chain-link retaining wall was

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Best Management Practice	Description of Practice	Measures of Effectiveness	Costs
	slope from sliding and undercutting. Geotextile filter fabric and chain-link fencing are used to construct earthen retaining walls. These walls are faced with a variety of materials including logs, hay bales, and used tires. Bioengineering techniques are used that incorporate live and dead materials in slope-stabilizing methods.	chain-link retaining wall and used hay bales to face another in road fill failures. Keller and Cummins (1990) demonstrated that tire retaining walls can be used to provide quick, easy, and inexpensive repairs to failed slopes.	constructed for $1300. Keller and Cummins (1990) constructed a tire-faced geotextile-reinforced wall for $183 per square meter. Burke (1988) estimated the construction cost of treated-timber-faced walls at $151 per square meter of facial area.
Relief Culverts, Cross Drains, Ditches	Road ditches and cross drains are installed to control surface and subsurface runoff from trails and roads. Road drainage structures include cross drains and water diversion structures. Cross drains carry water from one side of the road to the other. Commonly used cross drains include pipe culverts, open top culverts, broad-based dips, rolling dips, water bars and flexible belt diverters. Where necessary, drain-outflow water is spread and directed onto stable vegetation, rock riprap, or other outlet structure.	Proper cross drain sizing and spacing help to minimize surface erosion, saturation of road fills and the distance of sediment transport below drains. Proper drainage helps keep the road surface dry and structurally sound. The closer the spacing between cross drains the lower the rill erosion (50 to 97% control reported) of the road surface. Effective spacing distance decreases with steeper road gradients and with lower topographic position (Packer, 1967). Decreasing the drainage structure spacing from 15 to 8 m resulted in a 62% decrease in erosion on skid trails with 20 to 30% slopes (Kidd, 1963). The installation of frequent culvert cross drains can reduce the number of landslides, the volume of material lost in mass erosion, and sediment delivery to streams from road-associated landslides originating in road fills (Megahan, Day, and Bliss, 1978). Culverts will either plug or corrode with time. Such failures can result in debris torrents and stream diversions and severe damage to hillslopes and stream channels. Therefore, it is necessary to regularly	Costs include machine time for excavation and construction as well as extra maintenance expenses. Material costs include culverts, rock, downspouts, outlet structures, trash racks, and other necessary material.

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Best Management Practice	Description of Practice	Measures of Effectiveness	Costs
		clean and eventually replace or remove culverts to prevent failures.	
Belt Diverters and Other Surface Water Deflectors	Surface water deflectors constructed of rubber belt (or PVC belt) are used to divert water from forest roads on steeper grades where dips are less effective. Strips of conveyor belt imbedded in the road surface stand up to intercept water flowing down the road and carry it to a stabilized outfall. The belt is flexible so that it will flatten to allow tires to pass and then rebound to upright.	Surface water deflectors effectively reduce erosion on roadways and are especially suited for medium- to low-volume roads with steeper grades (Rossman 1991). Effectiveness depends on spacing between structures, as described in Section 4.21 on relief culverts and ditches.	Rossman (1991) provided the following costs for structures: Two-ply conveyor belt: $11.50 per meter; Rubber skirting: $8.22 per meter. Typical installation costs $250. Contractor low bid prices for three contracts were $16, $30, and $66 per meter.
Removing Direct Entry Culverts	Direct entry culverts deliver sediment and water directly to streams where they can be routed downstream. This minimizes opportunities for spreading and settling of sediment and redistribution and infiltration of runoff. Furniss, Flanagan, and McFadin (2000) concluded that direct entry culverts are an important source of sediment to streams.	While there are no watershed-scale tests of the effectiveness of direct entry culvert removals, NCASI (1986) estimated that effectiveness (reduction in suspended sediment delivery from road drainages) is approximately equivalent to the reduction in area contributing to direct entry.	Costs involve placement and reconstruction of alternative drainage structures to divert runoff from direct entry culverts. The cost of reconstructing culverts can often be several times the cost of installing them at the time of initial road construction.
Controlling Erosion from Drain Outlets	Outfall protection is installed below drains including riprap, rock-filled pipe, rock gabion, and log-rubble spreader (WDNR, 1997). Rock and other coarse materials are used to absorb energy of flowing drainage water. Synthetic erosion blankets are used as channel liners.		
Sedimentation Basin (Settling Basin)	Sedimentation basins are impoundments that are designed to receive runoff and remove suspended sediment before the water is discharged to an outlet. Sedimentation basins may be used to treat sediment-laden runoff from road	While the opportunities for using sedimentation basins in normal forestry operations may be limited, this practice is effective in retaining sediments and thus preventing their entrance into aquatic ecosystems. Fennessey and Jarrett (1994)	

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Best Management Practice	**Description of Practice**	**Measures of Effectiveness**	**Costs**
	and landings, gullies, quarries, pits, mines, and other high erosion sites.	reviewed the literature on effectiveness of sedimentation basins and cite a range of 75 to 95% effectiveness for urban and construction sites. They emphasize that this is "highly dependent on the influent particle size distribution."	
Filter Windrow (Brush Barrier, Slash Windrow)	Filter windrows are constructed of slash (from road clearing or logging) placed at the toe of newly constructed or otherwise eroding fillslopes. Slash, consisting of tops, limbs and brush that have been cleared from rights-of-way, is conserved and stockpiled at appropriate sites. Large logs are anchored against stumps, rocks, or trees at the toe of the fillslope. Slash is placed either by machine (backhoe) or by hand on the bottom of the fillslope toe, upslope of the anchor log, to form a neatly compacted windrow. Filter windrows are also used at outlets of culverts, diversion ditches, water bars and dips. Slash is placed at outlets to slow runoff and trap sediment diverted and drained off roads.	Much of the sediment transported in runoff from roads and road fill can be trapped in a filter windrow. The practice decreases runoff velocity and reduces sediment delivery to water bodies. Effectiveness is measured as trapping efficiency and distance traveled of the definable sediment plume. Average sediment removal efficiency is about 50%, but wide variations are reported. Filter windrows reduce the distance of sediment flows below fillslopes; effectiveness of treatments with filter windrows increased as slope percent increased compared to treatments with no filter windrows	
Control And Mitigation Practices For Road Operation And Maintenance			
Controlling Traffic (Closing Roads, Restricting Access, Wet Weather Traffic, Seasonal Roads)	Traffic is restricted on certain forest roads by one or more practices in order to prevent road deterioration and to prevent erosion and sedimentation. The traffic control practices and road upgrading practices used depend on local conditions and road management goals. Access may be blocked using gates, guard rails, concrete barriers, pole fences, pipes, natural onsite materials (logs and rocks, water bars), or vegetative plantings. When a road is no longer necessary or desired, it can be obliterated.		

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Best Management Practice	Description of Practice	Measures of Effectiveness	Costs
Closing Roads	"Closed" roads are temporarily removed from use and are retained for future use, but are not obliterated. They may require periodic inspection and maintenance. As part of the closing process, roads may be upgraded according to potential impact to riparian and aquatic resources. Upgrading can include improving stream crossings for fish passage and stormflow, outsloping, stabilizing fills, and installing water bars and cross drains. Roads may be seeded and mulched.	"No traffic" control roads had an order-of-magnitude lower sediment concentration than roads with traffic.	Moll (1996) provides the following costs for access control: Closure using onsite materials (Rocks, logs, water bars, slash piles, etc.): $50 – 500; Vegetative Plantings (Trees, shrubs, mulches, grasses): $100 -$1000. Imported Material (fences, gates, guardrails, concrete barriers): $200 - $2000; Pole Fences (poles with protective metal strips): $500 - $5000. Closure Devices (telescopic tubing, pipe and well casing): $500 - $5000; Road Obliteration (recon tour road junction or entire road): $2000 - $5000 km of road.
Restricting Access	Access is controlled to restrict unsuitable and nonessential traffic.	Restricting access limits erosion and sedimentation because sediment yield from the road surface increases with traffic volume. Sediment yield can be reduced by 75% (light vs. heavy traffic).	
Wet Weather Traffic	Wet weather traffic may be restricted to prevent rutting and sedimentation.	Accelerated erosion increases in proportion to traffic. Sediment yield increases one to two times when a road becomes rutted	
Seasonal Roads	In cold climates, certain roads may have traffic restricted to times when soils are frozen.	Temporary road closures are particularly important for roads designed for seasonal use only. For example, unsurfaced roads in the California Sierra Nevada Mountains can be used during the summer when precipitation is low and soils are dry. Extensive rutting and erosion would occur if these same roads were used in the winter (absent frozen soil or snow cover), especially if used for purposes other than log hauling and when maintenance is absent.	

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Best Management Practice	**Description of Practice**	**Measures of Effectiveness**	**Costs**
Lowered-Pressure Truck Tires (Central Tire Inflation)	Trucks can be equipped with lowered-pressure tires and central tire inflation to reduce ground pressure on logging haul roads, thereby reducing rutting, sediment yield, and road maintenance. Central tire inflation (CTI) allows the operator to change tire pressure between lowered-pressure on haul roads and higher-pressure on paved roads.	Lowered-pressure tires effectively reduce sediment losses from roads (Foltz 1994). Using lowered-pressure tires on rock-haul trucks in southeast Alaska reduced rutting depth by 78% and reduced road grading by 85% compared to use of high-pressure tires (Brunnette and Newlun, 1988).	Brunnette and Newlun (1988) reported that the cost of changing to lowered-pressure off-highway tires for four rock haul trucks was $49,000, or $12,250 per truck, and included tires, tubes, and wheels. Cost savings occurred in reducing the number of road grading operations from daily to weekly.
Road Maintenance (Grading)	Road grading removes rills and ruts that can speed the deterioration of the road surface and grading conserves the road surface by returning materials from the side of the road back onto the traveled way. This restores the road surface for good vehicle travel, helps maintain truck productivity, and minimizes maintenance costs. Grading schedules and spot grading can improve efficiency since excessive road grading is costly and can be detrimental to the road prism stability.	There is conflicting information in the literature on the effectiveness of road grading in conserving the road prism and in preventing erosion and sediment yield. Megahan (1988) reported that long-term road erosion was inversely proportional to road maintenance. Regular grading can remove rills and ruts that degrade roads. However, grading can initiate an episode of surface erosion by loosening an armored surface. Effectiveness and efficiency can be improved by moving from an automatic (e.g., everyday) grading schedule to one that is based on frequent inspections and that uses spot grading and a flexible schedule	Most of the cost of grading is associated with operator and machine costs. Provencher and Me'thot (1994) demonstrated that machine hours could be reduced by more than 30% by switching from an automatic or systematic grading program to one that uses spot grading and flexible scheduling based on variables such as slope, shape of road segments, and traffic.

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Best Management Practice	Description of Practice	Measures of Effectiveness	Costs
Inspecting Roads (Road Survey, Erosion and Landslide Inventories)	Roads are inspected at regular intervals, especially during or following large rainfall or snow melt events. Road inspections can include an inventory of existing and potential erosion and slope failures on all roads. Inspections can be used to provide information about potential sediment sources from roads for planning watershed restoration projects. Skid trails, landings, and obliterated roads are also given thorough inspections. Culverts need to be located and their condition checked for proper sizing, corrosion, separations, bends, and breaks. Culvert inlets and outlets should be checked for plugging, upslope debris, shotgun outlets, and barriers to fish passage. Crossing fills are inspected for diversion potential, condition, and volume. Road inspection may also include a survey of mass erosion potential including failure indicators in the cutslope and road surface, location of tension cracks, and the potential for delivery of sediment from incipient failures.	Piehl, Pyles, and Beschta (1988) demonstrated the effectiveness of road inspections in a random survey of stream-crossing culverts in the Oregon Coast Range. Harr and Nichols (1993) documented a road condition survey in Canyon Creek Watershed, Washington that effectively identified road upgrade needs including ditch relief, larger culverts at crossings, ditch cleaning, improved culvert gradients and alignments, and installment of flexible downspouts on culverts. The survey also identified roads that subsequently were chosen for closure and decommissioning.	Costs include labor cost of personnel for inspections.
Control And Mitigation Measures For Temporarily Putting-To-Bed, Decommissioning, And Obliterating Roads			
Temporarily Putting-to-Bed, Decommissioning, and Obliterating Roads	There is a continuum of practices for temporarily putting roads to bed or completely decommissioning and obliterating roads that can be used to decrease the costs and environmental impact of forest roads. These procedures are used to reduce road maintenance costs, to rehabilitate watersheds and associated wildlife and fish habitat, and to enhance aesthetics of forested landscapes		

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Best Management Practice	Description of Practice	Measures of Effectiveness	Costs
Putting-to-Bed/Decommissioning	Putting a road to bed can involve closing access, reseeding the road surface, removing temporary stream crossings, and opening drainage structures that may fail. The road is put into an erosion-resistant condition but can be re-opened at a later date when access again might be needed	Harr and Nichols (1993) documented the practices used and the overall effectiveness of decommissioning forest roads as part of a watershed rehabilitation project in northwestern Washington aimed at improving fish habitat and reducing flood hazards. The road decommissioning work stabilized fills, removed stream crossings, recontoured slopes, and reestablished drainage patterns. During a 50 yr rain-on-snow event, the decommissioned road sections were largely undamaged compared to untreated sections and to nearby mainline haul roads that were severely damaged.	Harr and Nichols (1993) provided the following cost estimates for several levels of road decommissioning work: Insloped, water bars rebuilt, dips at draws, sidecast pullback: $1615/km; Extensive alder clearing, extensive sidecast pullback, recontoured landings: $4154/km; Clearing of trees and brush, sidecast pullback, built water bars: $3798/km.
Obliterating	Road obliteration is the removal of the road from the landscape. Obliteration goes farther than decommissioning in restoring hillslopes, natural drainageways, and vegetation. Obliteration is intended to eliminate future road maintenance. The road prism is obliterated and returned to a naturally functioning component of the landscape. Vegetation is restored by site preparation, seeding, planting woody plants, fertilizing, mulching, and encouraging natural regeneration.	There has been a large effort at Redwood National Park to restore watersheds that had been logged and that had poorly constructed roads, triggering landslides and severe gullying. Several creeks had received enormous sediment loads and floods, and sediment threatened some of the largest trees in the park. Weaver et al. (1987) documented the wide variety of labor-intensive practices and heavy equipment used to obliterate roads, restore watershed hydrology and vegetation, and to repair erosion damage.	Weaver et al. (1987) provide extensive cost information for road obliteration work in Redwood National Park. Average obliteration costs ranged from $21,627 to $74,580/km of road (1979 dollars).
Control And Mitigation Measures For Wetland Operations			

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Best Management Practice	Description of Practice	Measures of Effectiveness	Costs
Maintaining Flow through Roads	Maintain flows using porous fills, culverts, and bridges and construct roads at ground level. Wetland roads and crossings are kept to a minimum and are constructed at natural ground level where possible. Where fill is necessary, roads are built on porous fills in order to maintain natural subsurface flow regimes. Fill segments have culverts and bridges that allow cross drainage. Culverts and bridges are installed so they do not interfere with duration, direction, or magnitude of flows.	Only qualitative reports are available on the effectiveness of maintaining flow through roads.	Cost information is not currently available but would include the following: culverts, bridges, and fords; fill gravel and crushed rock; road relocation costs; and, removal of fills and crossings.
Diverting Runoff from Crossing Approaches	Road approaches to wetlands are designed so that sediment delivery from the road is diverted before entering the wetland. Water bars, dips, turnouts, and other cross drainage structures are used to guide runoff to a stable outfall. Eroding ditches can be treated with rock check-dams, rock blanket, or suitable flexible channel liner. Design and construct ditches that are wide, shallow, U-shaped or flat bottomed, and well vegetated		
Minimizing Rutting on Wetland Roads	Operations are ceased on forest roads when rutting becomes excessive. Roads are closed with gates or other barricades.	The presence of wheel tracks on roads can increase rill erosion by concentrating runoff instead of shedding it (Foltz and Burroughs, 1990; Elliot, Foltz, and Remboldt, 1994). However, research in some studies has found little connection between rutting depth and soil movement.	

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Best Management Practice	Description of Practice	Measures of Effectiveness	Costs
Using Temporary Roads and Removing Fills	Use temporary roads and crossings. Remove temporary fills and structures to restore wetland flow patterns. End-haul fills to nonwetland sites.		
Berms on Wetland Roads	The creation of a continuous filter berm along flat wetland roads allows for infiltration of surface runoff through the berm and keeps sediment from being transported to nearby wetlands or streams.	Appelboom et al. (1998) tested several control options to reduce delivery of road sediments from a wetland road to adjacent wetlands and streams. They found that a graveled road surface reduced sediment loss by 61%. A grass strip along the side of the road reduced sediment loss from the road by 56%. However, a continuous berm filtered sediment from the road and reduced sediment loss by 99%.	
Water Level Management	In wetlands where drainage channels are present, riser boards can be used at ditch outlets to provide some control over the water levels in the wetland. Careful operation of these outlets can create soil moisture storage and can reduce stormflows and material losses from the site.	As early as 1980, Hollis, Fisher, and Beers suggested that drained forest wetlands might actually moderate runoff and sediment loss from sites by creating soil moisture storage. This, along with rapid revegetation and careful application of BMPs, could avoid serious sediment losses.	
Suspending Operations When Rutting Becomes Excessive	Harvesting operations are halted when soil rutting becomes excessive. Depending on the climate and soil character, skidding can be done when soil compaction potential is low, such as when soils are dry or snow covered and frozen.	Wetland surface and subsurface flows that can decrease site productivity or cause sediment delivery to water. Aust, Lea, and Gregory (1991) report that "bogging down" and excessive rutting due to skidding on wet sites in the Southeastern Coastal Plain can be minimized by one-pass skid trails. Welch et al. (1995) recommend scheduling harvest during the drier seasons of the year or when soils are frozen in order to avoid rutting.	

Table 3-1. Best Management Practices for Forest Roads: Descriptions, Measures of Effectiveness, and Costs. (source: Gallagher et al., 2000)

Best Management Practice	Description of Practice	Measures of Effectiveness	Costs
Operating Equipment on Frozen Roads	Log hauling is restricted to periods when roads are frozen in order to reduce rutting and sedimentation.	Operating on frozen roads helps to prevent rutting. Sediment yield increases one-to-two times when a road becomes rutted.	
Mitigation And Enhancement Measures For Fish Habitat			
Fish Passage	Stream-crossing culverts, bridges, and fords are designed and maintained to allow fish migration, and to pass a minimum peak flow.	Robison (1997) discusses advantages and disadvantages of alternatives for facilitating fish passage through culverts. Improvement of fish passage is the most poorly documented and evaluated of all stream habitat improvement techniques (Hall and Baker, 1982).	Relative costs for fish passage improvement options are presented in Robison (1997) and Murphy and Pyles (1989).

Table 3-2. Effectiveness of Surface Erosion Control on Forest Roads (Source: US EPA, 2005, Adapted from Megahan, 1980, 1987)

Stabilization Measure	Portion of Road Treated	Percent Decrease in Erosion[a]
Hydro-mulch, straw mulch, and dry seeding[b]	Fill slope	24 to 58
Tree planting	Fill slope	50
Wood chip mulch	Fill slope	61
Straw mulch	Fill slope	72
Excelsior mulch	Fill slope	92
Paper netting	Fill slope	93
Asphalt-straw mulch	Fill slope	97
Straw mulch, netting, and planted trees	Fill slope	98
Straw mulch and netting	Fill slope	99
Straw mulch	Cut slope	32 to 47
Terracing	Cut slope	86
Straw mulch	Cut slope	97
Wood chip mulch	Road fills	61
Straw mulch	Road fills	72
Grass and legume seeding	Road cuts	71
Gravel surface	Surface	70
Dust oil	Surface	85
Bituminous surfacing	Surface	99

[a] Percent decrease in erosion compared to similar, untreated sites.

[b] No difference in erosion reduction between these three treatments.

[c] Intermountain Forest and Range Experiment Station, Forestry Sciences Laboratory, Boise, ID, nd.

Table 3-3. Estimations of Overall Cost of Compliance with State Forestry BMP Programs by Program Type (source: US EPA, 2005)

Applicability	Cost Estimation	Reference
Virginia and southeastern states (applicable to central and northern states)	Voluntary-to-mandatory implementation ($) Coastal plain region: =$15.79 per acre Piedmont region: =$41.02 per acre Mountain region: =$60.05 per acre Stringent/Enforceable implementation ($) Coastal plain region: =$28.88 per acre Piedmont region: =$51.28 per acre Mountain region: =$66.26 per acre	Aust et al., 1996
California	Average cost =$337.37 per acre Inland areas =$109.31-558.68 per acre Coastal areas =$620.76 per acre	Henly, 1992
Oregon, Washington, Alaska	Average cost =$236.16-503.35 per acre Noncoastal areas =$236.16 per acre Coastal areas =$503.35 per acre	Ellefson et al., 1995 (Division between coastal and noncoastal based on California model)
Nevada, New Mexico, Idaho	Other Western states with forest practice regulation. Cost per acre is estimated as the average of costs in western states without forest practice regulation and the low-end cost given for Oregon noncoastal forests: $202.42 per acre	
Arizona, Colorado, Montana, Utah, Wyoming, Hawaii	Western states without forest practice regulation. Cost per acre is estimated as one-half of California’s noncoastal cost: $168.68 per acre	

Note: All costs in 2008 dollars.

Table 3-4. Estimations of Implementation Costs by Management Measure in the Southeast and Midwest (source: US EPA, 2005)

Practice	Average Cost	Cost Range	Comments
Planning			Savings were associated with avoiding problem soils, wet areas, and unstable slopes. Maintenance savings resulted from revegetating cut and fill slopes, which reduced erosion. Southern states.
Savings from road design/location	($520/mil)		
Savings in maintenance	($312/mil)		
SMA	$5,392		Costs for average tract size of 1,361 ac; include marking and foregone timber value. Southern states.
Road Construction		$7,154/mi-$57,208	Lower end for no gravel and few culverts; upper end for complete graveling and more culverts. West Virginia.
		$19,974-$57,208	Lower end for 1,832-ac forest with slopes <3%; upper end for 1,148-ac forest with slopes > 9%. Southern states.
		$309/mi-$15,659	Lower end for grass surfacing; upper end for large stone surfacing. Appalachia.
Construction Phase (as percent of total cost)		10%	Equipment and Material
		20-25%	Clearing, grubbing, and slash disposal
		20-25%	Excavation
		10%	Culvert installation
		30-40%	Rock surfacing
Road Maintenance	$2,976-$5,318		Lower end for roads constructed without BMPs; upper end for roads constructed with BMPs. Costs over 20 years discounted at 4%.
Mechanical Site Preparation	$189/ac	$104/ac-$379/ac	Lower end for disking only; upper end for shear-rake-pile-disk. Southern states.
		$101/ac-$243/ac	Lower end for light preparation, including hand; upper end for chemical-mechanical site preparation.
Regeneration		$113/ac-$479/ac	Lower end for direct seeding; upper end for tree planting with purchased planting stock.
	$67/ac	$65/ac-$81/ac	Lower end for machine planting; upper end for hand planting. Southern states.
Revegetation	$30,688		Cost for average sized tract of 1,361 ac; includes seed, fertilizer, mulch. Southern states.
		$178/ac-$323/ac	Lower end for introduced grasses; upper end for native grasses. Includes seedbed preparation, fertilizer, chemical application, seed, seedlings.
Prescribed burning	$18/ac	$13/ac-$26/ac	Lower end for windrow burning; upper end for burning after chemical site preparation. Southern states.
Pesticide application	$138/ac	$76/ac-$186/ac	Lower end for ground application; upper end for aerial application. Southern states.
Fertilizer application	$85/ac	$58/ac-$99/ac	Lower end for ground application; upper end for aerial application. Southern states.

Note: All costs in 2008 dollars.

Table 3-5. Estimations of Construction and Implementation Costs for Individual Road Construction and Erosion Control BMPs, by Region (2008 dollars; source: US EPA, 2005)

BMP	Approximate Construction and Implementation Costs per BMP installed, by Region							Comments
	Northeast	Southeast	Midwest	Rocky Mountains	Northwest	Southwest	Alaska	
Broad-based dip		$54	$54-$121	$67-$81	$34-$47	$135-$175	$40-$54	Depends on the cost of labor, equipment, and terrain (Northwest costs include profit and overhead).
Waterbar		$27 (not including labor)	$81-$101 (on skid trails)	n/a	$135	$61-$81	$34-$47	Cost varies with size and construction material.
Mulch		$96	$27-$108 (ton)	n/a	$2,024 (ac) (hydro-mulch)	$540-$675 (ac)	$108-$121 (ton)	Cost varies with regional market price and haul distance.
Seed	$1,349 (ac) (hydro-seed)	$1-$8 (lb)	$1-$13 (lb)	$8 (lb)	$540-$607 (ac)	$270-$540 (ac)	$9-$13 (lb)	Cost varies with species of seed, regional market price, and terrain.
Riprap		n/a	\$7-\$13 (yd^{3})	\$28 (yd^{3})	\$20-\$40 (yd^{3})	n/a	\$26-\$50 (yd^{3})	Price varies with size of rock used.
Gravel		$8-$13 (ton)		$47,232 $53,979 (mile, 14’ W x 4”)	\$22-\$35 (yd^{3})	\$40 (yd^{3})	\$24-\$30 (yd^{3})	Cost varies with the size of rock and haul distance.
Culvert		$567	$675-$2,699	$26 (ft, 18” pipe)	$35 (ft, 24” pipe) $135 (ft, 72” pipe)	$32 (ft, 18” pipe)	$31 (ft, 18” pipe)	Cost varies with size and length of culvert. Costs provided reflect base cost for installation.
Straw Matting		$76 (roll, 7.5’ x 120’)		n/a	\$3(yd^{2})	\$1-\$4 (yd^{2})	\$3.40 (yd^{2})	Cost varies with size of matting.
Geotextiles		\$510 (700 yd^{2})	$3-$8 (ft)	$11-$16 (ft)	$1-$3 (ft)	n/a	$19 (ft)	Woven geotextiles are the only geotextile recommended for road-stream crossings.
Hardwood Mats (pallets)	$162-$270	$162-$270	$229 (10’ x 12’)	$162-$270	$162-$270	$162-$270	$209 (10’ x 12’)	Cost varies with size.
Turn-outs	$54-$67	$67-$94	$67-94	$67	$67	$54-$67	$96	Cost varies with equipment and labor costs.
Silt Fence		$32 (24” H x 100’ L)	not commonly used	not commonly used	\$2 (yd^{2})	$5.40 (ft)	\$2.70 (yd^{2})	Cost varies with regional prices and length.
Dust Control	$1,349 (mile, using calcium chloride)				$1,349-$4,048 (mile, annually)	$256 (ton)		Varies widely with traffic level.
Temporary Bridge		$675-$26,989	$675-$20,242	$270-$33,737	$1,349-2,699 (ft)	n/a	$1,687-$3,374 (ft)	Cost varies widely with quality of materials used, width and span.
Barge (Alaska)	--	--	--	--	--	--	$1,349 (hr)	Barge transport in southeastern Alaska (Tongass Natl. Forest) is the most common means to deliver material to a site.

Note: All costs are per unit provided (ac = acre; ft = linear foot; hr = hour; lb = pound; yd^{2} = square yard; yd^{3} = cubic yard; D = depth; H = height; L = length; W = width).
Where units are not provided, cost is per BMP installed.

Table 4-1. Summary of State Programs for Forest Road Management: States in which BMPs for Forest Roads are Voluntary (adapted from TetraTech, 2004)

	Types of BMPs Specified														
State	Construction	Drainage	Location/Spacing	Maintenance	Road Closure	Stabilization/Soils/Slope	Stream Crossings	SMZs/Bank Stabilization/ Buffer Strips	Wet Weather Use	Winter Operations	Training/ Technical Assistance	Implementation/ Effectiveness Monitoring	Compliance/Enforcement	Year of Latest BMP Revision	**Other Information**
AL	✓	✓		✓		✓					✓	✓	✓	1993	• Licensing requirement for foresters • Through cooperative agreement, Alabama Division of Environment refers suspected water-quality complaints due to forestry to the forestry commission. • Rely on the Water Pollution Control Act for enforcement
AZ	✓														• Arizona state law does not contain silvicultural requirements related to NPS pollution from forestry activities or established BMPs .
AR	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓		• Division of Environmental Quality (DEQ) has regulatory water pollution control authority, and a formal memorandum of understanding exists between the forestry commission and DEQ to address complaints or violations of water quality suspected to be due to forestry.
CO	✓	✓		✓	✓	✓	✓	✓						1998	
DE	✓	✓		✓			✓	✓			✓		✓	1996	• Voluntary BMPs plus enforcement • Forestry administrator is responsible for preventing pollution to waterways and will perform BMP inspections on informal field visits • Streamside Management Zone not required as long as BMPs are implemented
FL	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	1993	• "Combination" BMP program containing regulatory and nonregulatory elements • State permits are required for forest roads, stream and wetland crossings • Florida Department of Environmental Protection can enforce BMPs
GA	✓			✓			✓	✓			✓	✓	✓	1999	• "Combination" BMP program containing regulatory and nonregulatory elements • BMPs mandatory for stream crossings • Persistent forestry-related water pollution

Table 4-1. Summary of State Programs for Forest Road Management: States in which BMPs for Forest Roads are Voluntary (adapted from TetraTech, 2004)

	Types of BMPs Specified														
State	Construction	Drainage	Location/Spacing	Maintenance	Road Closure	Stabilization/Soils/Slope	Stream Crossings	SMZs/Bank Stabilization/ Buffer Strips	Wet Weather Use	Winter Operations	Training/ Technical Assistance	Implementation/ Effectiveness Monitoring	Compliance/Enforcement	Year of Latest BMP Revision	**Other Information**
															violations are referred to the Georgia Environmental Protection Division for enforcement action • Registration of professional foresters
HI	✓	✓	✓	✓		✓	✓	✓							• "Combination" BMP program containing regulatory and nonregulatory elements
IL	✓	✓	✓	✓	✓	✓	✓	✓		✓					
IN	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		• Voluntary BMPs plus enforcement • State provides logger BMP training
IA	✓	✓	✓	✓	✓	✓	✓								
KS							✓	✓							
LA	✓	✓		✓						✓	✓	✓	✓	1998	• Voluntary BMPs plus enforcement • No formal departmental process exists for dealing with specific forestry operations suspected of causing water pollution
ME	✓	✓	✓	✓		✓	✓	✓			✓	✓			• "Combination" BMP program containing regulatory and nonregulatory elements • Land Use Regulation Commission • Shoreland Zoning Act • Natural Resource Protection Act • Marine Forest Practices Act • General Permitting process for stream crossing • State provides training for Certified Logging Professionals and Certified Master Loggers and workshops for landowners are held throughout the state.
MA	✓	✓	✓	✓	✓	✓	✓	✓		✓					• Massachusetts Forest Cutting Practices Act
MI	✓	✓	✓		✓	✓		✓					✓		• Voluntary BMPs plus enforcement
MN	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓		• Sustainable Forest Resources Act • Voluntary BMPs plus enforcement • State provides logger BMP training

Table 4-1. Summary of State Programs for Forest Road Management: States in which BMPs for Forest Roads are Voluntary (adapted from TetraTech, 2004)

	Types of BMPs Specified														
State	Construction	Drainage	Location/Spacing	Maintenance	Road Closure	Stabilization/Soils/Slope	Stream Crossings	SMZs/Bank Stabilization/ Buffer Strips	Wet Weather Use	Winter Operations	Training/ Technical Assistance	Implementation/ Effectiveness Monitoring	Compliance/Enforcement	Year of Latest BMP Revision	**Other Information**
MS	✓	✓	✓	✓		✓	✓	✓				✓	✓	2000	• Voluntary BMPs plus enforcement
MO	✓	✓	✓	✓				✓	✓			✓			
NE	✓	✓	✓	✓	✓		✓	✓							• Erosion and sediment control program • Written plans encouraged
NJ							✓								• No formal legal requirements focused on forestry. • Permanent steam crossings are regulated and require a Stream Encroachment Permit. • BMP manual can be purchased for $5
NY	✓		✓	✓	✓	✓	✓	✓				✓			• "Combination" BMP program containing regulatory and nonregulatory elements • Permit required for stream crossings
NC	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	1994	• Adoption of Forest Practice Guidelines (performance standards) mandatory, but BMPs for forestry are "recommended" • Cases of noncompliance are referred to department of land resources, division of water quality, or division of forest resources law enforcement • Registration for professional foresters is mandatory • North Carolina Forestry Association (NCFA) ProLogger program
ND	✓	✓	✓	✓			✓	✓							
OH	✓	✓	✓	✓			✓	✓				✓	✓		• Ohio Agricultural and Silvicultural Abatement Act • Silvicultural Nonpoint Source Pollution Plan required • Voluntary BMPs plus enforcement
OK	✓	✓	✓	✓			✓				✓	✓	✓	1994	• Forestry-related water-quality violations are referred to the DEQ for necessary enforcement action
RI															• "Combination" BMP program containing regulatory and nonregulatory elements

Table 4-1. Summary of State Programs for Forest Road Management: States in which BMPs for Forest Roads are Voluntary (adapted from TetraTech, 2004)

	Types of BMPs Specified														
State	Construction	Drainage	Location/Spacing	Maintenance	Road Closure	Stabilization/Soils/Slope	Stream Crossings	SMZs/Bank Stabilization/ Buffer Strips	Wet Weather Use	Winter Operations	Training/ Technical Assistance	Implementation/ Effectiveness Monitoring	Compliance/Enforcement	Year of Latest BMP Revision	**Other Information**
															• BMP manual can be purchased for $5
SC	✓		✓	✓		✓	✓	✓			✓	✓	✓	1994	• Voluntary BMPs plus enforcement • State Forestry Commission must develop an erosion, sediment, and stormwater management plan • Department of Health and Environmental Control may initiate enforcement action based on referral • Memorandum of understanding between the Forestry Commission and Department of Health and Environmental Control (DHEC) defines the role of each agency in preventing or correcting water-quality impacts from forestry operations. • Courtesy Exam Program, a proactive means to encourage proper BMP implementation, is unique in the southern States
SD	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			• South Dakota Nonpoint Source Pollution Management Plan
TN	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	1996	• Voluntary BMPs plus enforcement • Department of Environment and Conservation may take appropriate enforcement action for water pollution due to forestry.
TX		✓				✓	✓	✓			✓	✓		2001	• “Combination” BMP program containing regulatory and nonregulatory elements • No formal State interagency agreement by which BMP noncompliance is addressed. • State coordinating committee consisting of all regulatory agencies and the forestry community provides advice for recommended BMPs and seeks cooperation of the logger and/or landowner in cases of reported or discovered BMP noncompliance.
UT	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓			• Utah Forest Practice Act

Table 4-1. Summary of State Programs for Forest Road Management: States in which BMPs for Forest Roads are Voluntary (adapted from TetraTech, 2004)

State	Types of BMPs Specified													Year of Latest BMP Revision	Other Information
	Construction	Drainage	Location/Spacing	Maintenance	Road Closure	Stabilization/Soils/Slope	Stream Crossings	SMZs/Bank Stabilization/ Buffer Strips	Wet Weather Use	Winter Operations	Training/ Technical Assistance	Implementation/ Effectiveness Monitoring	Compliance/Enforcement		
VA	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	1994	• Voluntary BMPs plus enforcement • Must notify Virginia Department of Forestry before start of logging operations. • Silvicultural Water Quality Law authorizes the Department of Forestry to require corrective measures for silvicultural operations causing, or with potential to cause, sedimentation of State waters. • The Department inspects harvesting operations for water quality degradation
WI	✓	✓	✓	✓		✓	✓	✓				✓			• Voluntary BMPs plus enforcement
WY	✓	✓	✓		✓	✓	✓				✓	✓			• Voluntary BMPs plus enforcement • Wyoming Nonpoint Source Management Plan • State provides training in water quality protection measures • Wyoming retains authority to take enforcement actions for violations of water quality standards

Table 4-2. Summary of State Programs for Forest Road Management: States in which BMPs for Forest Roads are Mandatory (adapted from TetraTech, 2004)

	Types of BMPs Specified														
State	Construction	Drainage	Location/Spacing	Maintenance	Road Closure	Stabilization/Soils/Slope	Stream Crossings	SMZs/Bank Stabilization/ Buffer Strips	Wet Weather Use	Winter Operations	Training/ Technical Assistance	Implementation/ Effectiveness Monitoring	Compliance/Enforcement	Year of Latest BMP Revision	**Other Information**
AK	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		• Forest Resources and Practices Act • For private, municipal, or non-state owned land, a “detailed plan of operations” must be submitted to the state forester that heads the Division of Forestry • For state forests, the Commissioner must submit a forest management plan
CA	✓	✓	✓	✓			✓	✓		✓	✓	✓	✓		• California (Z’Berg-Nejedly) Forest Practice Act • Must have a timber harvesting plan prepared by a Registered Professional Forester • Non-industrial forests must have a timber management plan that addresses erosion • The California Coastal Act regulates alterations to rivers and streams • The Fish and Game Code mandates stream alteration permits for nonpoint source pollution that results in diversion or obstruction of the natural flow of any river, stream, or lake
CT													✓	2007	• Connecticut Forest Practices Act • BMP manual can be purchased for $90 • Commercial foresters must obtain a state certificate • Soil Erosion and Sedimentation Control Act
ID	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	2003	• Idaho Forest Practices Act • Must post a notice of intent to engage in forestry practices • Must implement site-specific BMPs for stream segments of concern
KY	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	1996	• Kentucky Forest Conservation Act • Master Logger training provided by Department of Forestry

Table 4-2. Summary of State Programs for Forest Road Management: States in which BMPs for Forest Roads are Mandatory (adapted from TetraTech, 2004)

	Types of BMPs Specified														
State	Construction	Drainage	Location/Spacing	Maintenance	Road Closure	Stabilization/Soils/Slope	Stream Crossings	SMZs/Bank Stabilization/ Buffer Strips	Wet Weather Use	Winter Operations	Training/ Technical Assistance	Implementation/ Effectiveness Monitoring	Compliance/Enforcement	Year of Latest BMP Revision	**Other Information**
MD	✓	✓	✓	✓		✓	✓	✓				✓	✓		• Maryland Erosion and Sediment Control Standards and Specifications for Forest Harvest Operations • Professional foresters must be licensed • Forest conservation practices • Compliance Agreement for the Standard Erosion and Sediment Control Plan for Forest Harvest Operations must be obtained when disturbing more than 5,000 square feet of land
MT	✓	✓	✓	✓	✓			✓				✓	✓	1997	• Montana Streamside Management Zone Act • 50-foot wide streamside management zones for forest streams • Mandatory notice before engaging in forest practices • Inspects SMZs/BMPs on Federal, State, and Private Land • Refers water quality violations to Department of Health and Environmental Services
NV													✓	1994	• Nevada Forest Practices Act • Requires a permit from the State forester for logging or cutting operations, which may be denied if significant soil erosion and siltation will be caused • BMP handbook can be purchased for $25 • Forestry statute prohibits skidding, rigging, or construction of roads within 200 feet of a waterbody
NH	✓	✓	✓	✓	✓	✓	✓	✓					✓		• Timber Tax Law or Notice of Intent to Cut • New Hampshire Wetlands Law, Basal Area Law • Slash Law • BMP program contains voluntary elements

Table 4-2. Summary of State Programs for Forest Road Management: States in which BMPs for Forest Roads are Mandatory (adapted from TetraTech, 2004)

State	**Types of BMPs Specified**													Year of Latest BMP Revision	**Other Information**
	Construction	Drainage	Location/Spacing	Maintenance	Road Closure	Stabilization/Soils/Slope	Stream Crossings	SMZs/Bank Stabilization/ Buffer Strips	Wet Weather Use	Winter Operations	Training/ Technical Assistance	Implementation/ Effectiveness Monitoring	Compliance/Enforcement		
NM	✓	✓	✓	✓	✓	✓	✓	✓					✓	2002	• New Mexico Forest Conservation Act • “Combination” BMP program containing regulatory and nonregulatory elements
OR	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	1995	• Oregon Forest Practices Act and Forest Practice Administrative Rules
PA	✓	✓	✓	✓		✓	✓		✓		✓		✓		• Pennsylvania Department of Environmental Protection Chapter 102 Rules and Regulations, the Clean Streams Act • Chapter 102 regulations govern stream crossings • Erosion and sediment pollution control plan required for timber harvesting operations • Road maintenance activity involving 25 acres of earth disturbance or more requires an Erosion and Sediment Control Permit • Adding or closing a state forest road requires permission from State Forester • State provides BMP classroom training and on-site assistance provided by Service foresters located throughout the state
VT	✓	✓	✓	✓			✓					✓			• No formal Forest Practices Act • 1986 amendments to Vermont Water Quality Protection Statutes require Acceptable management Practices (similar to BMPs) • Alteration of Streams Law.
WA	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	2001	• Washington Forest Practices Rules and Timber, Fish, and Wildlife Agreement. • Small forest landowners must submit a checklist and road maintenance and abandonment plan with application for forest practice • Forest practice standards mandatory

Table 4-2. Summary of State Programs for Forest Road Management: States in which BMPs for Forest Roads are Mandatory (adapted from TetraTech, 2004)

State	Types of BMPs Specified														Other Information
	Construction	Drainage	Location/Spacing	Maintenance	Road Closure	Stabilization/Soils/Slope	Stream Crossings	SMZs/Bank Stabilization/ Buffer Strips	Wet Weather Use	Winter Operations	Training/ Technical Assistance	Implementation/ Effectiveness Monitoring	Compliance/Enforcement	Year of Latest BMP Revision	
WV	✓	✓	✓					✓			✓	✓	✓		• Logging and Sediment Control Act • State certification in logger training including BMPs.

Table 4-3. Detailed Review of State Forest Practices and Selected Habitat Conservation Plan (HCP) Provisions for Roads (from Scurlock, 2007)

	State or Corporation						
State Forest Practices and Selected HCP Provisions	CA	OR	WA	ID	MT	Palco	Plum Creek
Enforceable Road Design Standards?	Yes	Yes	Yes	Yes	No		Yes
Steep/Unstable Slope Prohibition?	No	No	No	No	No	Yes	No
Steep Slope Building special process?	Yes	Yes	Yes	No	No	-	Yes
Timeline for Old Roads up to Standards?	No	No	2016 for large landowners	No	No	500 mi/year	2015; 2010 for high priority watersheds
100 year flood passage at new crossings?	Yes	No 50y	Yes	No 50y	No 25y	Yes	No 50y
Bedload/debris passage?	Yes?	No	Some	No	No		No
Upstream and downstream passage required? (Juveniles and adults)	Yes	Yes	Yes	Only for new crossings	No		Yes
Seasonal/wet weather hauling restrictions?	Yes	Some	No	Yes	No	Some (visible turbidity)	
Orphan Roads addressed?	No	No	Yes	No	No		
Adequately?	n/a	n/a	No	n/a	n/a		
Watershed analysis/CWE process?	No	No (yes on state lands)	No	Yes	No	?	

Table 4-4. Summary of State Forest Road BMP Implementation Surveys for States in which BMPs for Forest Roads are Voluntary. Information and data compiled from Dissmeyer (1994), Grace (2002), Ice et al. (2004), Jones (2005), NCASI(2001), Prud'homme and Greis (2002), Simpson et al. (2005), Vowell (2004)

State	Number of BMP implementation surveys	Year of most recent survey	Sampling design	Number of sites	Type of survey	Latest reported BMP implementation rate (%)						Formal inter-agency State agreemints	Ownership classes reported	Identified BMP implementation needs	Comments
						Overall forestry	SMZs	Permanent roads	Temp. road/Skid	Crossings	Wetlands				
AL	>6	2006	Random (sites less than 1 year old)	50 (SW); 64 (NW & NE)	Aerial survey	94 (SW) 95 (NW& NE)						yes			• Alabama Forestry Commission monitors BMP compliance rates. • BMP implementation surveys are conducted annually for select portions of state. • Data are not published in reports.
AZ	0														• Arizona has not conducted a review of forestry BMP implementation.
AR	3	2005	random	249		88	84	84				yes	F, FI, S, NIPF	Roads (close out), temporary stream crossings, harvesting and SMZ	• Arkansas Forestry Commission monitors BMP compliance rates. • Southern BMP monitoring recommendations incorporated. • BMP implementation lowest on sites owned by non-industrial, private landowners and highest by those who had BMP training • Implementation rates improving for FI landowners (roads and harvesting BMPs)
CO															
DE															
FL	>10	2006	Randomly selected by aerial observation	190	Forester on site; 139 y/n question survey	99	99	98		100	94	no	PU, FI, NIPF	Stabilize critical road segments & drainage structures	• Florida Division of Forestry monitors BMP implementation. • Biennial surveys. • Risk to water quality is evaluated. • Southern BMP monitoring recommendations incorporated. • Overall implementation has increased from 84% (1985) to 99% (2006).

Table 4-4. Summary of State Forest Road BMP Implementation Surveys for States in which BMPs for Forest Roads are Voluntary. Information and data compiled from Dissmeyer (1994), Grace (2002), Ice et al. (2004), Jones (2005), NCASI(2001), Prud'homme and Greis (2002), Simpson et al. (2005), Vowell (2004)

State	Number of BMP implementation surveys	Year of most recent survey	Sampling design	Number of sites	Type of survey	Latest reported BMP implementation rate (%)						Formal inter-agency State agree-mints	Owner-ship classes reported	Identified BMP implementation needs	Comments
						Overall forestry	SMZs	Permanent roads	Temp. road/Skid	Crossings	Wetlands				
GA	>3	2005	Targeted random	412	Forester on site; 108 y/n question survey	90	91	88		81		yes	FI, PU, NIPF	Skidder fords, Debris and dirt type crossings	• Georgia Forestry Commission monitors BMP implementation. • Risk to water quality is evaluated. • Southern BMP monitoring recommendations incorporated. • Newly constructed road compliance 84%; new stream crossings 32%.
HI															
IL	0														• Illinois has not conducted a review of forestry BMP implementation
IN	1	2004		154	Inter-disciplinary team	88	81	93	77	79			S, NIPF, P+NIPF	Placement and construction of water diversion, crossing structure design, skidding in stream channels	• Indiana Department of Natural Resources, Division of Forestry and Woodland Steward Institute monitor BMP implementation. • Implementation based on combining 4 rounds of monitoring (1996-2000)
IA	0														• Iowa has not conducted a review of forestry BMP implementation
KS															
LA	>4	2005	Scattered	145	Survey-or on site	96	>34[10]	62-95	70	35		no	FI, CNIF, PU, NIPF	Permanent roads (seeding and	• Louisiana Department of Agriculture and Forestry, Office of Forestry monitors BMP compliance rates. • BMP implementation increased

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[10] Rate of BMP implementation is underestimated since many sites were rated as having no action required or no assessment was available.

Table 4-4. Summary of State Forest Road BMP Implementation Surveys for States in which BMPs for Forest Roads are Voluntary. Information and data compiled from Dissmeyer (1994), Grace (2002), Ice et al. (2004), Jones (2005), NCASI(2001), Prud'homme and Greis (2002), Simpson et al. (2005), Vowell (2004)

State	Number of BMP implementation surveys	Year of most recent survey	Sampling design	Number of sites	Type of survey	Latest reported BMP implementation rate (%)						Formal inter-agency State agree-mints	Owner-ship classes reported	Identified BMP implementation needs	Comments
						Overall forestry	SMZs	Permanent roads	Temp. road/Skid	Crossings	Wetlands				
														mulching)	with technical assistance from professional forester.
ME	3	2005	Random	288		75	89[2]	74	86	78			NIPF, FI, PU, IF	Temporary stream crossings, haul road BMPs	• Maine Forest Service monitors BMP implementation. • Involved in NAASF and USFS-NR BMP Monitoring Protocol[11].
MA															• Massachusetts has not conducted a review of forestry BMP implementation.
MI	0														• Michigan has not conducted a review of forestry BMP implementation.
MN	1	2004	Varies by year	315			31-64, 73[12]	41-85	57				PU, FI, NI	Erosion control structures, water diversion, crossing approaches	• Minnesota Forest Resources Council monitors BMP implementation. • Implementation based on 3 years of monitoring (2000-2002). • Majority of logging operations occur only in winter.
MS	>1	2006	Randomly selected from sites identified by aerial recon-naissance	203	Water quality team on site; 73 question survey	90		88	77	88	93	no		Roads, SMZs, temporary roads and skid trails, crossings	• Mississippi Forestry Commission monitors BMP implementation. • Risk to water quality is evaluated.

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[11] Northeastern Area Association of State Foresters (NAASF) and the USFS-Northern Region Program for State and Private Forestry Protocol.

[12] Filter strips.

Table 4-4. Summary of State Forest Road BMP Implementation Surveys for States in which BMPs for Forest Roads are Voluntary. Information and data compiled from Dissmeyer (1994), Grace (2002), Ice et al. (2004), Jones (2005), NCASI(2001), Prud'homme and Greis (2002), Simpson et al. (2005), Vowell (2004)

State	Number of BMP implementation surveys	Year of most recent survey	Sampling design	Number of sites	Type of survey	Latest reported BMP implementation rate (%)						Formal inter-agency State agree-mints	Owner-ship classes reported	Identified BMP implementation needs	Comments
						Overall forestry	SMZs	Permanent roads	Temp. road/Skid	Crossings	Wetlands				
MO		2007	Random	5 sites/year	Logger trainer evaluation on site										• State of Missouri and Missouri Forest Products Association monitor BMP implementation. • Small sample size precludes calculating implementation. • Data are not published in reports.
NE															
NJ															• New Jersey has not conducted a review of forestry BMP implementation.
NY	2	2000		53			73	78	59				FI, S, NI	Road drainage, stream crossings	• State University of New York, New York Department of Environmental Conservation, New York City Department of Environmental Protection, and New York City Watershed Forestry Program monitor BMP implementation. • 2000 survey of Adirondack and Catskill regions. • Involved in NAASF and USFS-NR BMP Monitoring Protocol.
NC	4	2005	Sites only selected if water body present			82	85	85	72	65		yes	P, FI, NIPF	Permanent roads, water bars on temporary roads and skid trails, and SMZ encroach-mint	• North Carolina Division of Forest Resources monitors BMP implementation. • As professional assistance increased, BMP implementation increased. • Southern BMP monitoring recommendations incorporated.
ND	0														• New monitoring report under

Table 4-4. Summary of State Forest Road BMP Implementation Surveys for States in which BMPs for Forest Roads are Voluntary. Information and data compiled from Dissmeyer (1994), Grace (2002), Ice et al. (2004), Jones (2005), NCASI(2001), Prud'homme and Greis (2002), Simpson et al. (2005), Vowell (2004)

State	Number of BMP implementation surveys	Year of most recent survey	Sampling design	Number of sites	Type of survey	Latest reported BMP implementation rate (%)						Formal inter-agency State agree-mints	Owner-ship classes reported	Identified BMP implementation needs	Comments
						Overall forestry	SMZs	Permanent roads	Temp. road/Skid	Crossings	Wetlands				
															development.
OH	1	1999												Failure to implement streamside management zones and skid trail BMPs	• Ohio Division of Forestry monitors BMP implementation. • Data are not published in reports. • Lack of BMP-trained loggers
OK	3	2006	random	100	Surveyor on site; Texas BMP monitoring checklist	92	97	90	77	91	100	no	FI, PU, NIPF	Road drainage and stabilization, temporary crossings, SMZs	• Oklahoma Department of Agriculture, Food, and Forestry monitors BMP implementation. • Risk to water quality is evaluated. • Southern BMP monitoring recommendations incorporated. • Data are not published in reports.
RI															
SC	7	2005	Random selection from sites identified by aerial survey	200	Trained forester on site	94	87	92		78		yes	P, FI, NIPF	Harvesting systems, SMZs, stream crossings, road stabilization and poor design	• South Carolina Forestry Commission monitors BMP implementation. • Risk to water quality is evaluated. • Courtesy exam believed effective. • monthly summary report of completed courtesy BMP exams is provided to the state water quality agency and to timber buyers.
SD		2004	Targeted			92								Road design and water diversion, drainage features near stream	• Black Hills Forest Resource Association, South Dakota Department of Environment and Natural Resources and Department of Agriculture-Division of Resource Conservation and Forestry monitor BMP

Table 4-4. Summary of State Forest Road BMP Implementation Surveys for States in which BMPs for Forest Roads are Voluntary. Information and data compiled from Dissmeyer (1994), Grace (2002), Ice et al. (2004), Jones (2005), NCASI(2001), Prud'homme and Greis (2002), Simpson et al. (2005), Vowell (2004)

State	Number of BMP implementation surveys	Year of most recent survey	Sampling design	Number of sites	Type of survey	Latest reported BMP implementation rate (%)						Formal inter-agency State agree-mints	Owner-ship classes reported	Identified BMP implementation needs	Comments
						Overall forestry	SMZs	Permanent roads	Temp. road/Skid	Crossings	Wetlands				
														crossings	implementation. • Site selection and implementation rating based on Montana procedures.
TN	3	2005	Random selection from a spatial grid	215		82				45		yes		Stream crossings	• Latest BMP implementation survey conducted by University of Tennessee, Department of Forestry, Wildlife & Fisheries, and Tennessee Department of Agriculture, Division of Forestry. • Risk to water quality is evaluated. • Southern BMP monitoring recommendations incorporated. • Data are not published in reports.
TX	6	2005	Random selection from sites identified by aerial survey and forest service knowledge	156	1 or 2 trained foresters on site	92	91	93	90	31-81		no	PU, FI, CNIF, NIPF	Roads (reshaping and stabilization), stabilizing temporary stream crossings	• Texas Forest Service monitors BMP implementation. • Monitoring data collected in accordance with QAPP approved by Texas State Soil and Water Conservation Board and EPA. • Risk to water quality is evaluated. • Southern BMP monitoring recommendations incorporated. • Implementation was higher when loggers had BMP training and when landowners were members of forest organization; lower when the site was owned by non-industrial private forest owner, mainly due to improper stream crossings.
UT	1	2006		40	Audit team		92	64-81	77	86				Road drainage,	• Utah Division of Forestry, Fire, and State Lands monitors BMP

Table 4-4. Summary of State Forest Road BMP Implementation Surveys for States in which BMPs for Forest Roads are Voluntary. Information and data compiled from Dissmeyer (1994), Grace (2002), Ice et al. (2004), Jones (2005), NCASI(2001), Prud'homme and Greis (2002), Simpson et al. (2005), Vowell (2004)

State	Number of BMP implementation surveys	Year of most recent survey	Sampling design	Number of sites	Type of survey	Latest reported BMP implementation rate (%)						Formal inter-agency State agree-mints	Owner-ship classes reported	Identified BMP implementation needs	Comments
						Overall forestry	SMZs	Permanent roads	Temp. road/Skid	Crossings	Wetlands				
														diversion and wet period use	implementation.
VA	>10	2007			Survey- or on site		83			68		no		Rutting and seeding, water control structures, stream crossings	• Virginia Department of Forestry monitors BMP implementation. • Risk to water quality is evaluated.
WI	3	2004	Random	60	Inter-disciplinary monitoring teams	90 (S) 93(C) 95(IF)[13]		71(S) 96(C)	78 (S) 69 (C)				S, C	Diversion devices, road shaping and grading, maintenance, culvert sizing	• Wisconsin Department of Natural Resources, Division of Forestry monitors BMP implementation.
WY	1	2005		6	Audit team	97									• Wyoming Timber Industry Association, Department of Environmental Quality, and State Forestry Division monitor BMP implementation.

Ownership codes and definition: F= Federal, FI= Forest industry, S= State, C= County, PU= Public, P=Private, CNIF= Corporate non-industrial, IF=Investor forestlands, NIPF= Nonindustrial private forest owners, NI= Nonindustrial forest, SM=Small landowners.

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[13] Overall BMP implementation on industrial forest surveyed in 2002.

Table 4-5. Summary of State Forest Road BMP Implementation Surveys for States in which BMPs for Forest Roads are Mandatory. Information and data compiled from Dissmeyer (1994), Grace (2002), Ice et al. (2004), Jones (2005), NCASI(2001), Prud'homme and Greis (2002), Simpson et al. (2005), Vowell (2004)

State	Number of BMP implementation surveys	Year of most recent survey	Sampling design	Number of sites	Type of survey	Latest reported BMP implementation rate (%)						Formal inter-agency State agreemints	Ownership classes reported	Identified BMP implementation needs	Comments
						Overall forestry	SMZs	Permanent roads	Temp. roads/Skid	Crossings	Wetlands				
AK		2005		93 (C) 74 (N)	Evaluator on site; score sheet	94(C) 84(N)								Roads (retiremint) and stream crossing (landslides, blocked and washed out culverts)	• Alaska Department of Forestry monitors BMP implementation. • Implementation surveys conducted for coastal (C) and northern (N) regions. • Site evaluators are owner, operator or manager. • Department of Forestry provides on-site assistance during field inspections.
CA	3	2006	Random	187 (WLPZ) 244 (roads) 357 (crossings)	Forest practice inspectors on site;	95[14]	69-84	96		83				Drainage, culverts	• California Department of Forestry and Fire Protection and State Board of Forestry and Fire Protection monitor BMP compliance rates. • Hillslope Monitoring Program (HMR): 1996-2002. • Modified Completion Report monitoring program: 2001-2004. • Forest Practice Rule Implementation and Effectiveness Monitoring: 2007.
CT															
ID	5	2001	Randomly selected from targeted "pool" of sites	40	Multi-agency audit teams		95			57				Culverts (fish passage)	• Idaho Department of Lands, Department of Fish and Game, Intermountain Forest Association, Idaho Forest Owners Association, USDA-FS and Idaho Department of Environmental Quality monitor

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[14] Overall implementation rate for FPRs related to water quality determined in earlier HMR.

Table 4-5. Summary of State Forest Road BMP Implementation Surveys for States in which BMPs for Forest Roads are Mandatory. Information and data compiled from Dissmeyer (1994), Grace (2002), Ice et al. (2004), Jones (2005), NCASI(2001), Prud'homme and Greis (2002), Simpson et al. (2005), Vowell (2004)

State	Number of BMP implementation surveys	Year of most recent survey	Sampling design	Number of sites	Type of survey	Latest reported BMP implementation rate (%)						Formal inter-agency State agree-mints	Owner-ship classes reported	Identified BMP implementation needs	Comments
						Overall forestry	SMZs	Permanent roads	Temp. roads/Skid	Crossings	Wetlands				
															BMP implementation. • Risk to water quality is evaluated. • Data have not been published in reports.
KY	>1	2006	Randomly selected by aerial observation	116	Forester on site; 38 y/n question survey	56	69	56			35	no	PU, FI, NIPF	Roads (spacing and proper implementation of drainage structures) and SMZs	• Kentucky Department of Forestry monitors BMP implementation • Risk to water quality is evaluated. • Data have not been published in reports.
MD	1	2007		99		82	83	82		75					• Maryland Department of Natural Resources-Forestry Service monitors BMP compliance rates. • Involved in NAASF and USFS-NR BMP Monitoring Protocol. • Data are not published in reports.
MT	>7	2007	Stratified and prioritized site selection	44	Inter-disciplinary team; 58 potential practices rated on 5-pt. scale	93-96	98						F, FI, NIPF		• Montana Department of Natural Resources and Conservation monitors BMP implementation.
NV	0														• Nevada has not conducted a review of forestry BMP implementation.

Table 4-5. Summary of State Forest Road BMP Implementation Surveys for States in which BMPs for Forest Roads are Mandatory. Information and data compiled from Dissmeyer (1994), Grace (2002), Ice et al. (2004), Jones (2005), NCASI(2001), Prud'homme and Greis (2002), Simpson et al. (2005), Vowell (2004)

State	Number of BMP implementation surveys	Year of most recent survey	Sampling design	Number of sites	Type of survey	Latest reported BMP implementation rate (%)						Formal inter-agency State agree-mints	Owner-ship classes reported	Identified BMP implementation needs	Comments
						Overall forestry	SMZs	Permanent roads	Temp. roads/Skid	Crossings	Wetlands				
NH															• New Hampshire has not conducted a review of forestry BMP implementation. • Participates in NAASF and USFS-NR BMP Monitoring Protocol.
NM	0														• New Mexico has not conducted a review of forestry BMP implementation. • NCASI (2007) estimated 75% implementation based on timber harvest plan inspection reports.
OR	>3	2002	Stratified random	189 94 (fish passage)	Forest practice forester & 2-person field survey team	96		87-100	48[15]	71-95	70-88			Fish passage, Crossing fill stability, road surface drainage and maintenance	• Oregon Department of Forestry monitors BMP compliance rates. • Sampling stratification intentionally biased to capture high number of fish-bearing streams. • 2 cases of sediment delivery >100 cubic yards.
PA	0														• Pennsylvania has not conducted a review of forestry BMP implementation. • Participated in development of NAASF and USFS-NR BMP Monitoring Protocol.

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[15] Removal of temporary crossings.

Table 4-5. Summary of State Forest Road BMP Implementation Surveys for States in which BMPs for Forest Roads are Mandatory. Information and data compiled from Dissmeyer (1994), Grace (2002), Ice et al. (2004), Jones (2005), NCASI(2001), Prud'homme and Greis (2002), Simpson et al. (2005), Vowell (2004)

State	Number of BMP implementation surveys	Year of most recent survey	Sampling design	Number of sites	Type of survey	Latest reported BMP implementation rate (%)						Formal inter-agency State agreemints	Ownership classes reported	Identified BMP implementation needs	Comments
						Overall forestry	SMZs	Permanent roads	Temp. roads/Skid	Crossings	Wetlands				
VT	2	1996		17	Surveyors on site									Implementation of drainage structures on forest roads and skid trails	• Vermont Forest Resources Advisory Committee Assessment Working Group monitors BMP implementation. • 1996 report was not a statistically valid study. • Participated in development of NAASF and USFS-NR BMP Monitoring Protocol. • Increased fine sediment deposition downstream at 8 of 17 crossings.
WA	2	2007	Stratified random	97	Field teams	80		86		78			FI, SM		• Washington Department of Natural Resources, Department of Ecology, and Department of Fish and Wildlife monitor BMP compliance rates. • 2006 survey focused on road and riparian rule implementation. • Low sample size for crossings. • Previous Forest Practices Compliance Report published in 1991.
WV	4	2007		116		85	80	84	86					Drainage structures, spacing btwn. trails and water bodies, haul roads in SMZs	• West Virginia Department of Forestry monitors BMP implementation.

Ownership codes and definition: F= Federal, FI= Forest industry, S= State, C=County, PU= Public, P=Private, CNIF= Corporate non-industrial, IF=Investor forestlands, NIPF= Nonindustrial private forest owners, NI= Nonindustrial forest, SM=Small landowners.

FIGURES

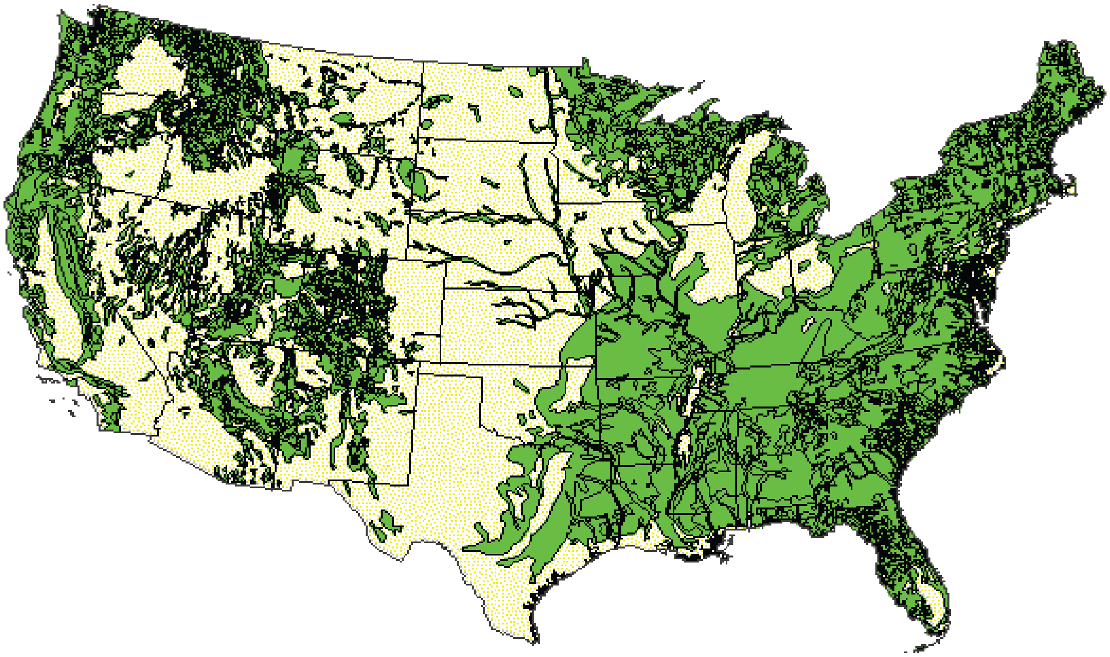

Figure 2-1. Distribution of Forest Land in the Continental United States (from USEPA, 2005)

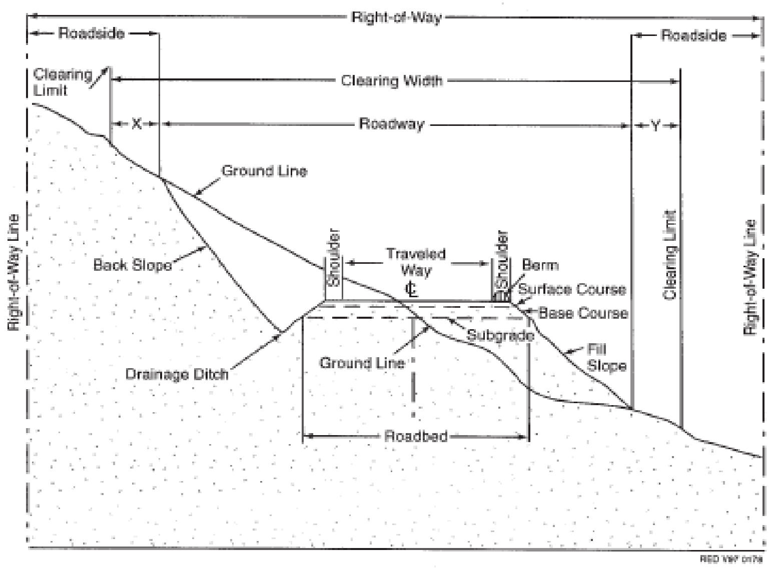

Figure 2-2. Cross-Sectional Diagram of the Forest Road Prism and Components (from Moll et al., 1987)

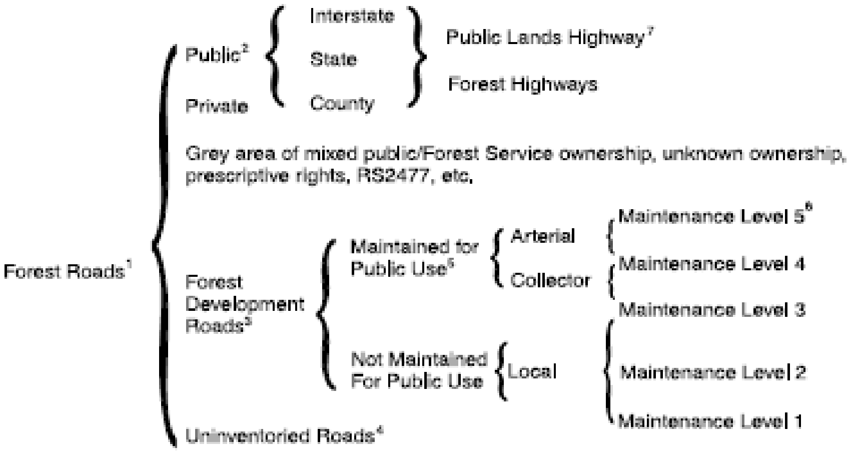

Figure 2-3. Legal Basis and Definitions for Roads in the National Forests (from Coughlan and Sowa, 1998)

Notes:

1. **Forest Roads:** Roads wholly or partially within, or adjacent to, and serving the National Forest System and necessary to the protection, administration, and use of the National Forest System and the use and development of its resource (23 USC 101).
2. **Public Roads:** Roads under the jurisdiction of, and maintained by, a public authority that are open to public travel. (23 USC 101(a)).
3. **Forest Development Roads (FDR):** Forest roads under the jurisdiction of the Forest Service (23 USC 101).
4. **Uninventoried Roads:** Short term roads associated with fire suppression, oil, gas or mineral exploration or development, or timber harvest not intended to be a part of the forest development transportation system and not necessary for resource management. Regulations (36 CFR 223.37) require revegetation within 10 years.
5. **Maintained for Public Use:** An MOU with FHWA defines FDR's managed as open to the public as those roads open to unrestricted use by the general public in standard passenger cars, including those closed on a seasonal basis or for emergencies.
6. **Maintenance Level 5:** Roads that provide a high degree of user comfort and convenience. Normally double lane, paved facilities, or aggregate surface with dust abatement. This is the highest standard of maintenance.
   Maintenance Level 4: Roads that provide a moderate degree of user comfort and convenience at moderate speeds. Most are double lane, and aggregate surfaced. Some may be single lane. Some may be dust abated.
   Maintenance Level 3: Roads open and maintained for travel by a prudent driver in a standard passenger car. User comfort and convenience are not considered priorities. Typically low speed, single lane with turnouts and native or aggregate surfacing.
   Maintenance Level 2: Roads open for use by high-clearance vehicles. Passenger car traffic is discouraged. Traffic is minor administrative, permitted or dispersed recreation. Non traffic generated maintenance is minimal.
   Maintenance Level 1: These roads are closed. Some intermittent use may be authorized. When closed, they must be physically closed with barricades, berms, gates, or other closure devices. Closures must exceed one year. When open, it may be maintained at any other level. When closed to vehicular traffic, they may be suitable and used for nonmotorized uses, with custodial maintenance.
7. **Public Lands Highways, Forest Highways:** A coordinated Federal Lands Highway Program includes Forest Highways, Public Lands Highways, Park Roads, Parkways and Indian Reservation Roads. These are roads under the jurisdiction of and maintained by a public road authority other than the Forest Service and open to public travel (23 USC 101).

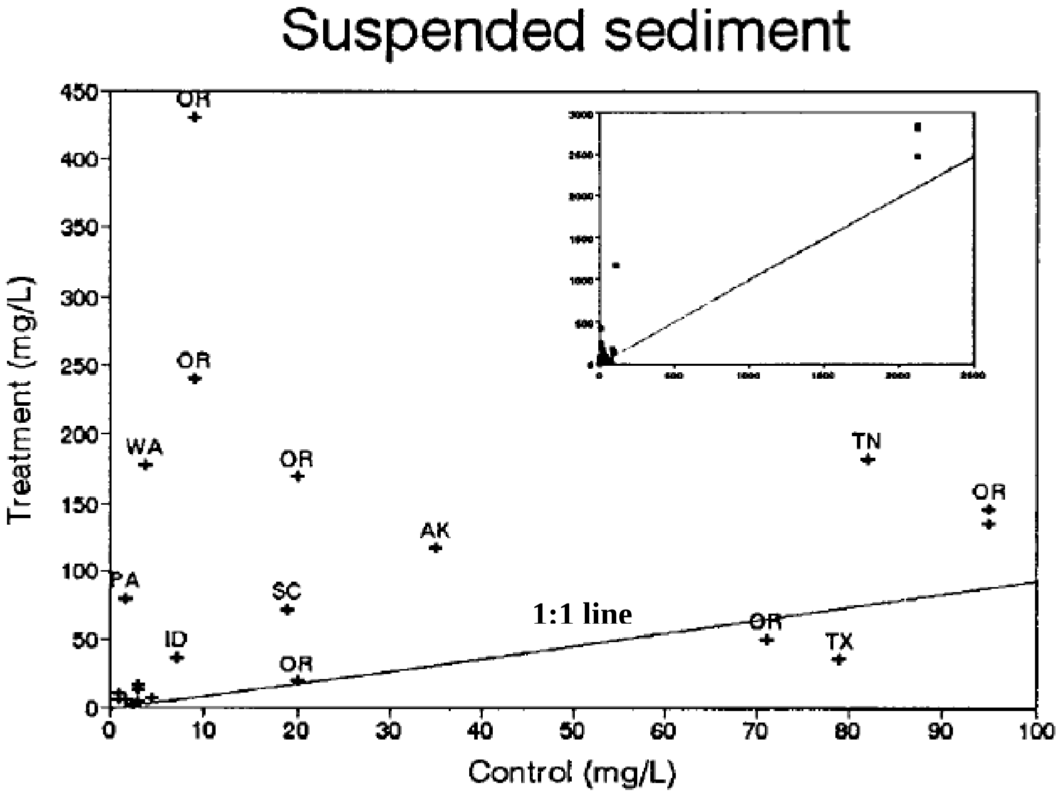

Figure 2-4. Response of Suspended Sediment Concentrations to Forest Harvesting at Experimental Watersheds (from Binkley and Brown, 1993)

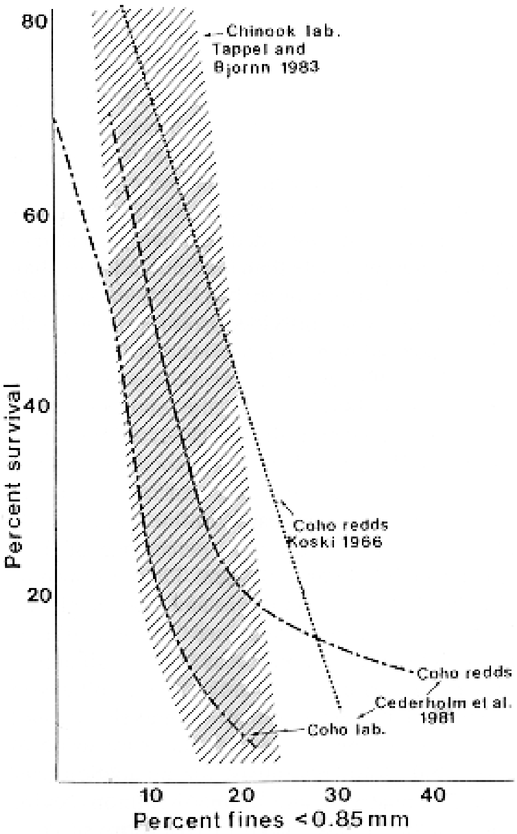

FIGURE 5.—Survival of salmonid embryos to emergence in relation to fines smaller than 0.85 mm in diameter. Data provide comparisons of coho salmon survivals in laboratory (lab.) and field (Cederholm et al. 1981), of coho salmon in two different streams (Koski 1966; Cederholm et al. 1981), and of chinook salmon in gravels with a range of percentages of particles less than 9.5 mm in diameter (shaded area; Tappel and Bjornn 1983).

Figure 2-5. Figure 5 from Chapman (1988). Graph of percent survival of salmonid embryos to emergence in relation to percent fines smaller than 0.85 mm. Data provide comparisons of coho salmon survivals in the laboratory (lab.) and field (Cederholm et al., 1981), of coho salmon in two different streams (Koski, 1966; Cederholm et al., 1981), and of chinook salmon in gravels with a range of percentages of particles smaller than 9.5 mm (shaded area; Tappel and Bjornn, 1983).

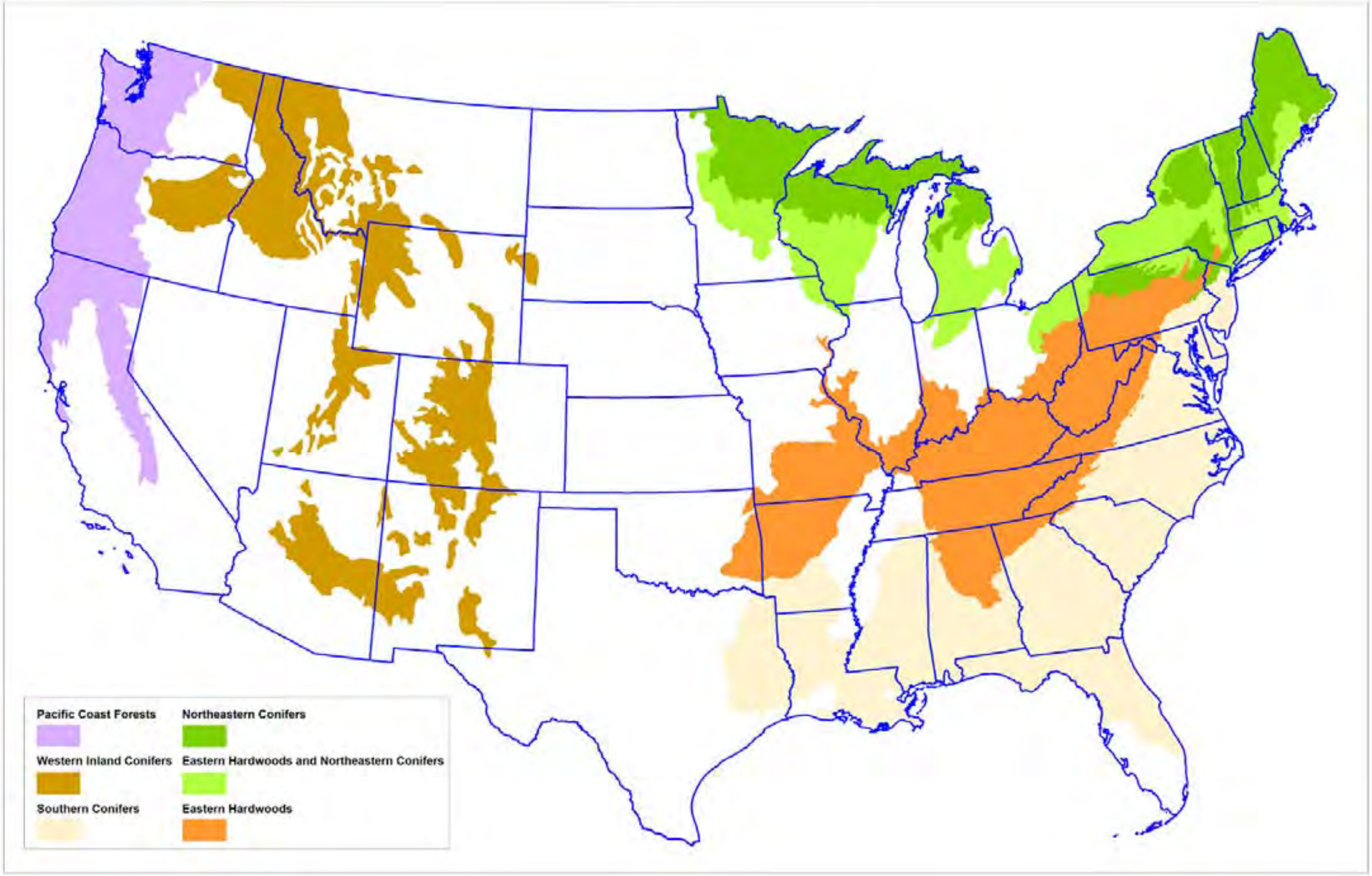

Figure 2-6. Distribution of major forest types in the continental United States.
Sources and References: Swank et al., 1989. Forest Cover Types map compiled by the U. S. Geological Survey and the U.S. Department of Agriculture Forest Service Forest Inventory Analysis Program for the National Atlas of the United States. Landsat Thematic Mapper imagery with 25 forest categories, 1991 growing season. U.S. Environmental Protection Agency. 1997. Level III Ecoregions of the Continental United States, Map M-1 (revision of Omernik, 1987). NHEERL, Corvallis, Oregon. Ecological Regions of North America, Commission for Environmental Cooperation, 1997.