*Plum Creek Timber Company*
*Native Fish Habitat Conservation Plan*

# Surface Erosion and Mass Wasting Assessment and Management Strategies for Plum Creek's Native Fish Habitat Conservation Plan

**Technical Report #3**

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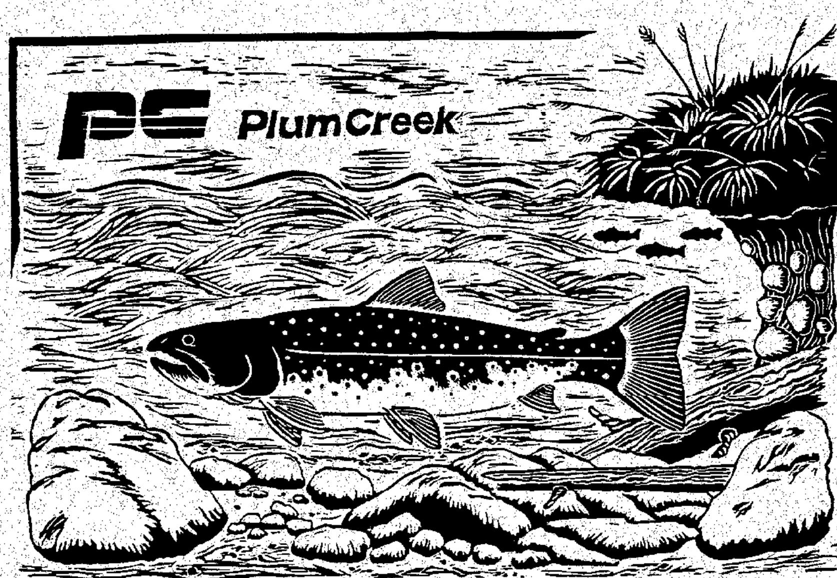


PlumCreek

# SURFACE EROSION AND MASS WASTING ASSESSMENT AND MANAGEMENT STRATEGIES FOR PLUM CREEK'S NATIVE FISH HABITAT CONSERVATION PLAN

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**Native Fish Habitat Conservation Plan**
**Technical Report #3**

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# 1.0 INTRODUCTION

Erosion is defined as the detachment and movement of soil or rock by water, wind, ice, or gravity (Buckman and Brady 1969). Geologically normal erosion is that rate of erosion which occurs naturally as geologic materials are broken down, decomposed, and subjected to further physical and organic processes to form soil, these materials then being subject to movement and detachment. Accelerated erosion is an enhanced rate of erosion caused by man-made disturbances such as grazing, logging, or cultivation (Dunne and Leopold 1978).

Two forms of erosion are of principal importance on forest hillslopes: surface erosion and mass wasting (Swanston 1991; Washington Forest Practices Board 1995a). Surface erosion in forested watersheds occurs principally through the action of water on the soil surface. Mass wasting occurs when the force of gravity exceeds the resistive forces which hold the soil on the hillslope, causing mass movement of the soil as a unit, and is usually the result of water accumulation on steep slopes.

Erosion is of concern for fisheries when excessive levels of fine or coarse sediment are deposited in streams. Levels of fine sediment in streambed gravels has been negatively correlated with salmonid embryo survival (Cederholm et al. 1981; Tappel and Bjornn 1983) and the quality of juvenile rearing habitat (Bjornn et al. 1977). Because of this well-documented sensitivity (see review by Chapman 1988), land managers should strive to minimize erosion and sediment delivery to streams (Chapman and McLeod 1987).

Since one of the important habitat elements for salmonids is the substrate in which they spawn and rear, the Native Fish Habitat Conservation Plan (NFHCP) must address erosion associated with Plum Creek's forest management activities. This report is intended to serve as a technical foundation upon which specific NFHCP strategies can be developed and their benefits evaluated. As the plan is under development, this paper does not provide specific commitments; it is intended to serve as a foundation upon which an intelligent plan can be based.

For various surface and mass erosion processes, this report will: 1) summarize the impacts of historical logging and road construction management practices; 2) discuss current regulations and the protection they provide; 3) evaluate the effectiveness of current state Best Management Practices (BMP's) in controlling erosion; and 4) present general strategies and opportunities for the NFHCP to better address erosion on Plum Creek Timber Company lands in the NFHCP area.

# 2.0 SURFACE EROSION

## 2.1 SURFACE EROSION PROCESSES

Surface erosion occurs when soils on sufficiently steep slopes are exposed to overland flow and/or the impact of rainfall. Raindrop splash, freeze/thaw, dry ravel, and processes such as windthrow and animal burrowing are natural causes of soil detachment. Gravity and overland flow of water are natural transport mechanisms for the detached soil particles. Surface erosion of hillslopes can be divided into raindrop, rill, and gully erosion (Schwab et al. 1981).[1] Raindrop erosion occurs when rainfall impacts directly on exposed soil particles and splashes them into the air. Rill erosion occurs as particles are detached by water from rivulets in the soil surface as overland flow develops and concentrates during intense rainfall. Gully erosion occurs as rills collect and concentrate into larger flows during heavy runoff, forming pronounced and persistent channels on hillslopes.

Undisturbed forest soils of the coastal and interior northwest are normally well protected by surface organic materials and a thick organic surface soil horizon, and as a result, raindrop splash and overland flow of water and associated surface erosion rarely occurs (Dunne and Leopold 1978).[2] However, overland flow and accelerated surface erosion can occur where soils are compacted or where mineral horizons are exposed through activities which remove the surface organic materials and expose underlying mineral soil horizons (Swanston 1991). Activities most likely to cause surface erosion include roads; harvest and site prep activities which involve poor yarding practices, high intensity broadcast burns, or mechanical scarification; and high intensity wildfire (McNabb and Swanson 1990; Washington Forest Practices Board 1995a).

The degree of compaction, soil exposure, slope length, and slope gradient of exposed surfaces are the main factors controlling the rate of accelerated erosion (Wischmeier and Smith 1965). During construction of forest roads, long continuous lengths of soils are purposefully excavated, exposed, and compacted, and to some degree these surfaces convey water directly to streams (Pearce, undated; Packer and Haupt 1965). In contrast, harvest activities result in surface soils which are typically less severely disturbed and exposed, are less compacted, tend to occur in discontinuous patches rather than in long continuous lengths, and rarely convey runoff directly to streams.[3] Furthermore, roads

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[1]Schwab et al. 1981, note that sheet erosion is an idealized concept which rarely occurs, because overland flow immediately concentrates to form microscopic rills. Megahan (1978) illustrates that in the Idaho Batholith, sheet erosion can occur in the form of dry creep, but is generally limited to coarser textured soils in very specific geographic locations, which are not representative of the area covered by this NFHCP.

[2]One example of note is documented by Clayton and Megahan (1977), where surface erosion did occur on undisturbed sites in the Idaho Batholith, but rates were much lower than they were for disturbed sites.

[3]Original conclusion of the authors based on their extensive observation of harvesting effects, watershed analysis results, and prohibition of stream-adjacent harvest-caused soil disturbance in state forest practices rules.

are generally subject to continued compaction and disturbance with traffic and maintenance activities, whereas areas disturbed during harvest begin to revegetate and recover immediately following harvest. These differences in erosion and sediment delivery characteristics of roads versus harvested areas result in rates of surface erosion from roads that are much greater (often by orders of magnitude) than those associated with harvesting (Gibbons and Salo 1973; Swanston 1971), and lead to a natural separation of road and harvest erosion and sediment delivery assessments (Idaho Department of Lands 1995; Washington Forest Practices Board 1995a; Burroughs et al. 1990; Megahan and Kidd 1972).

For road erosion assessments, accelerated erosion is assumed to occur; therefore, analyses focus on quantification of eroded and delivered volume. For harvest assessments, accelerated erosion is not assumed; analyses focus on identification of areas of soil disturbance, observation of any erosion occurring in these disturbed areas, and identification of travel paths, distances, and delivery of eroded materials to streams (Idaho Department of Lands 1995; Washington Forest Practices Board 1995a). In circumstances where accelerated surface erosion is observed to have occurred due to harvesting and related forestry activities, various methods for quantification of eroded and delivered volume may be employed, depending on the form and severity of the erosion features.

## 2.2 SURFACE EROSION ASSOCIATED WITH HARVESTING

### 2.2.1 Introduction

Soil disturbance associated with forest harvesting can result in erosion and subsequent delivery of eroded materials (sediment) to streams. However, erosion and sediment delivery caused by harvesting only occurs under specific circumstances where: 1) soils are disturbed and compacted, 2) disturbed soils are subject to overland flow and particle detachment (erosion), and 3) eroded soil particles (sediment) are transported to streams without deposition onto the forest floor (Washington Forest Practices Board 1995a; Bilby et al. 1989). Modern BMP's, such as current forest practices rules, are designed to prevent delivery of sediment to streams caused by forest harvesting. This section reviews the technical literature, recent watershed analysis results, and state forest practices rules effectiveness audits to investigate the effectiveness of modern BMP's.

### 2.2.2 Historical Forest Management Effects

Widespread logging began in the coastal areas of the Pacific Northwest in the mid 1800's and early 1900's. Logging in northern Idaho and western Montana also began in the mid 1800's for mining and railroad requirements (Sedell et al. 1991) and was widespread by the turn of the century, as major lumber mills were constructed and company land bases were acquired to provide them with logs (Bonner School 1976; McKay 1994; Miss 1994). Mining and smelting activities in interior areas depended on stream transport of logs, and railroad construction required large supplies of ties and construction timbers. These needs were met by logging watersheds adjacent to the railways and driving the logs down streams that intersected the lines (Brown 1936). Young et al. (1994), provides an example of how pervasive these practices were in local areas; in and around one national forest in Wyoming, 61 streams were used to supply railroad ties in this manner.

The earliest logging occurred in locations adjacent to the ocean, lakes, and rivers where logs could be felled, rolled, or dragged with horses or steam engines (steam donkeys) directly into the water (Sedell et al. 1991). As water-adjacent timber ran out, additional water-based horse and steam/cable logging systems were used. These systems relied upon chutes, flumes, and splash damming to move logs downhill and/or downstream. Horse skid roads, chutes, and many flumes were located in streams or on their banks and riparian zones. The effects of these early logging practices on stream and channel characteristics are well documented (Sedell and Luchesa 1982; Sedell et al. 1991). Effects on erosion and sediment delivery processes are less well documented. However, we know that logs were commonly dragged downhill directly to streams without erosion control practices, and large quantities of sediment were undoubtedly delivered to streams in watersheds logged with these early methods.

Splash damming depended on channel simplification and removal of large wood and boulder obstructions, as well as artificial and repeated flooding, followed by dewatering of channels. Channel beds and banks were scoured by log-laden flood waters. Use of these practices in some river systems continued as late as the 1950's and 1960's (Bisson et al. 1992; Sedell et al. 1991). These practices were widespread in interior areas, and several accounts record use of splash damming in tributaries of Flathead Lake in Montana, and tributaries of the St. Joe and Clearwater Rivers in northern Idaho - tributary watersheds that are included within this NFHCP area. The Blackfoot River in Montana and many of its tributaries were log driven and splash dammed between 1900 and 1925 to the mill at Bonner (Bonner School 1976). McKay (1994) documents that the Sommers Lumber Company, established in 1901, and other Flathead Valley mills of this era, transported logs down numerous tributary rivers, including the Swan, Flathead, Whitefish, and Stillwater rivers, and many streams tributary to them in western Montana. The remains of splash dams and flumes remain visible in many tributaries of rivers within the NFHCP area even today (examples include Marble Creek, Mica Creek, and Fishhook Creek on the St. Joe in northern Idaho; Beaver Creek, Flume Creek, Granddad Creek, and Benton Creek on the North Fork Clearwater River, also in northern Idaho). River transport of logs was also used around the turn of the century to supply logs to the mill at Libby, Montana, located on the Kootenai River.

Water-based logging systems were often coupled with railroad logging systems as they were developed (Robbins 1988). Although some rail routes were located on or near ridgetops, most were located up valley bottoms and often encroached on the streams, particularly in the narrower headwater canyons. Railroad logging practices of this era relied on cable logging systems, and ground-lead and downhill yarding systems were common.

Water and rail-based logging were slowly replaced by logging truck and logging road-based systems beginning in the 1930's and continuing into the 1940's, with the advent of more powerful equipment

(Robbins 1988). Both tractor and cable yarding systems were used to move logs to landings where they could be loaded onto trucks. Logging roads often occupied old railroad grades, but roadbeds had to be widened, and in contrast to railroads, truck traffic substantially increases rates of erosion from the travelway (Reid and Dunne 1984). In addition, sediment delivered to streams from ground-based logging systems of the era, which led downhill to stream-adjacent landings and used constructed (excavated and filled) skid trails, is estimated to have exceeded natural rates of erosion by two to three orders of magnitude (McGreer et al. 1996).

The authors of this paper have observed the pattern and extent of all of these practices on 1930's-era and later aerial photography, and from structural, erosional, and vegetative effects that remain visible on hillslopes and in channels to this day (McGreer et al. 1996; McGreer et al. 1997). In addition to direct stream impacts, the authors have observed locations where entire third, fourth, and even fifth order watersheds were accessed and logged in just a few years without buffer strips or other practices designed to lessen hydrologic effects. These practices were common at least into the 1950's, and in some locations may have continued into the 1960's.

Careful documentation and study of the effects of logging and roads on water quality, streamflow, and fish habitat began in the 1950's and 1960's. Prior to the development of forest practices acts and their implementing regulations in the Pacific northwest states, several studies were conducted which demonstrated that poor logging practices produced harmful effects on streams, including large increases in delivered sediment.

The Alsea watershed study in the Oregon coast range demonstrated that cable and tractor clearcut logging followed by broadcast burning of steep slopes in 1966, with no stream buffer strip, increased annual stream sediment load of a 175 acre watershed on the order of 100% to 400% compared to a control watershed during the four years following logging (Brown and Krygier 1971). This study and others helped lead to the passage of the Oregon Forest Practices Act in 1972, the first act in the northwest that addressed stream protection and hillslope erosion control practices (Brown 1978; Bisson et al. 1992).

In coastal British Columbia, Toews and Moore (1982) also documented the importance of buffer strips; logging without buffer strips in the 1970's increased streambank erosion by 250%. In the interior, an accounting of increased rates of surface erosion due to harvesting is provided by Megahan and Kidd (1972), who found on steep slopes (mean gradient = 70%) and highly erodible granitics of the Idaho Batholith, downhill high-lead logging in the 1960's increased the rate of surface erosion by a factor of 1.6 over rates in undisturbed areas.[4]

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[4]In both the Oregon and Idaho studies, increases in stream sedimentation due to surface and mass erosion of roads built on steep unstable slopes were orders of magnitude higher than increases due to harvesting.

In 1972, Congress passed the Federal Water Control Act Amendments (the "Clean Water Act"). Section 208 of the Act required the states to identify significant sources of nonpoint pollution and to develop pollution control programs for those sources. In response, in 1972, Oregon passed the first forest practices act, which included control of hillslope erosion and effects of forest management activities on streams as one of its major objectives (Brown 1978). Following Oregon's lead, Idaho and Washington passed similar Forest Practices Acts in 1974. The studies discussed above were relied upon to aid in implementation of forest practices rules under these Acts. In 1989, Montana adopted a comprehensive set of statewide Best Management Practices for forestry activities. For a detailed discussion of these and other forest practices regulations in the NFHCP area, see Sugden and Light (1998).

### 2.2.3 State Forest Practices Regulations

State forest practices regulations dealing with hillslope erosion and stream sedimentation control these processes by: 1) minimizing the areal extent and degree of soil disturbing activities, 2) minimizing erosion of disturbed areas (e.g., skid trails and fire lines) by providing adequate drainage and stabilization, and 3) minimizing sediment delivery to streams by maintaining buffer strips.

State regulations/BMP's control **soil disturbance** through rules that minimize the areal extent and degree of the disturbance (Idaho Department of Lands 1996; Montana Department of Natural Resources and Conservation 1997; Montana Department of State Lands 1994; Washington Forest Practices Board 1995b). These rules include:

- Selecting logging systems that are appropriate for the terrain, soils, and timber type
- Avoiding soil disturbance due to excavation and skidding with the blade lowered
- Suspending leading ends of logs during skidding
- Minimizing skid trail width and density
- Locating skid trails to avoid concentrating runoff
- Limiting the grade of constructed skid trails on geologically unstable, saturated, highly erosive, or easily compacted soils
- Avoiding site preparation techniques such as intense broadcast burning or ground scarification
- Avoiding tractor or wheel skidding on unstable, wet, or easily compacted soils and on steep slopes (40-45%)
- Restricting operations to appropriate times of the year

State regulations/BMP's control **soil erosion** by requiring adequate drainage and stabilization of skid trails. Requirements include:

- Water bars, cross draining, and outsloping
- Scarifying and seeding
- Covering disturbed areas with logging slash

- Requiring that each of these controls be applied concurrent with ongoing harvesting

State regulations control **delivery of sediment** by requiring vegetated buffer strips around streams. Idaho requires 75' and 30' buffers on fish-bearing and non-fish bearing streams, respectively. Equipment may be used within the buffer, but soil disturbance is prohibited (Idaho Department of Lands 1996). Montana requires 100' buffers for Class 1 and 2 streams where adjacent slopes exceed 35%, and 50' buffers for Class 1 and 2 streams where slopes are less steep, and for Class 3 streams. Equipment is prohibited within 50' of streams and can operate within 100' only if soils will not be rutted or moved (Montana Department of State Lands 1994). Washington requires 75' to 100' buffers around Type 1 and 2 streams, 50' buffers for Type 3 streams wider than 5', and 25' buffers for Type 3 streams less than 5' wide. Logging is allowed in Type 1, 2, and 3 buffers, but operation of equipment is allowed only as prescribed by the Washington Department of Natural Resources. Skidding across Type 4 streams requires temporary crossings and must be minimized, and integrity of streambanks and riparian undergrowth must be maintained. Operations near Type 5 waters are subject to the soil protection rules applicable to upland slopes (Washington Forest Practices Board 1995b).[5]

In addition to these basic state BMP's which control soil disturbance, erosion, and sediment delivery, Plum Creek implements additional practices which further reduce soil disturbance and erosion. Historically, most ground-based (tractor) harvests were done "conventionally," that is, a sawyer felled, limbed, and bucked a tree at appropriate lengths in the woods. These individual logs were then skidded to a landing where they were loaded on trucks. This approach required that skidders disturb more area, because they had to get reasonably close to each log to attach cables (chokers) to them. The conventional approach also resulted in heavy slash levels in the woods, which by law must be disposed of. Typical methods of disposing slash involved tractor piling with brush rakes and burning of the piles, or broadcast burning the entire harvest area. Both approaches to slash disposal often resulted in widespread soil disturbance.

In recent years, safety concerns and economics have promoted increased use of mechanical harvesters in logging activities. Today, Plum Creek uses mechanical harvesting on approximately 70% of the acres harvested with ground-based equipment in the NFHCP area. These harvesters cut and bunch several trees at one location, where skidders then retrieve and skid them to landings.[6] The result is that skidders make fewer trips, and on fewer skid trails, resulting in less soil disturbance. In addition, these skid trails are less disturbed, because the entire tree (limbs and top included) is skidded to a central landing where the log is limbed and cut to specified lengths. Because whole trees are skidded (instead of logs with sharp edges), ground disturbance is reduced. Furthermore, slash produced at landings is often transported back to the woods when skidders return for more logs. This slash is

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[5]For definitions of Montana stream Classes and Washington stream Types, see Sugden and Light (1998).

[6]Plum Creek Timber Company currently uses forwarders on less than 5% of the acres harvested with ground-based equipment in the NFHCP area. Although use of forwarders may increase, it is not anticipated that this method will be utilized for a significant portion of the ground-based harvest in the future.

placed on skid trails to reduce soil disturbance during subsequent passes and provides immediate surface erosion control during and following completion of harvesting (McGreer 1981). Lastly, by concentrating and burning excess slash at landings, machine piling of slash in the woods and broadcast burning are almost non-existent on Plum Creek's land in the NFHCP area today. This combination of activities is not explicitly represented in the BMP's, but is an example of practices which make sense economically and have significant environmental benefits.

## 2.2.4 Effects of Modern Era Practices

This section reviews the effects of modern era (post forest practices act) harvesting on erosion and sediment delivery processes. Three forms of information are available for review: 1) watershed research literature, 2) watershed analysis results, and 3) state forest practices audits.

### 2.2.4.1 Results from the watershed research literature

The effectiveness of modern streamside and soil management practices is demonstrated by many studies in the literature. In general, soil erosion from forest slopes results from soil disturbance and exposure of mineral soil (Megahan 1981; Packer 1967; Chamberlin et al. 1991). The importance of harvest operation planning and care for prevention of soil disturbance and erosion was first demonstrated by Reinhardt et al. (1963), who found that sediment production varied by more than three orders of magnitude, depending on the location and disturbance associated with skid trails. The *importance of avoiding soil disturbance was further demonstrated in north* central Idaho by McGreer (1981); where soils were deeply disturbed, first-year erosion was 72.6 tons per acre of steep skid trail, but on skid trails where surface soil litter was left intact, erosion rates were reduced by a factor of 280, to only 0.25 tons/acre.[7]

Continuous length of exposed soil is a key factor affecting erosion processes. Wischmeier and Smith (1965) found that eroded volume increases in proportion to the square root of continuous slope length. The effect of this slope factor is addressed through installation of water bars on skid trails. Where soils are exposed, Packer and Christensen (1964) demonstrated that skid trail erosion is effectively controlled through installation of water bars at recommended spacing which varies with soil type and slope.

Where soils are exposed and erosion occurs, sediment can be prevented from reaching streams by minimizing the distance that the sediment travels downslope. Ketcheson and Megahan (1996) and Brake et al. (1997) report that one of the most important variables affecting sediment transport

[7]Erosion rates were expressed in units of tons per acre to allow comparison to other rates of erosion reported in the literature. However, the areas of soil disturbance near streams reported in the literature and watershed analysis results are much smaller. The reader should note that 100 linear feet of trail 10 feet wide, a relatively large area of streamside disturbance, constitutes only 0.023 acres. For an erosion rate of 0.25 ton/acre, as observed by McGreer (1981), a disturbed area 10 feet by 100 feet would produce 0.006 tons of erosion, or 12 pounds.

distance is the volume of eroded material discharged from the eroding surface. Ketcheson and Megahan (1996) report that sediment from diffuse road drainage sources (e.g., road fills) in highly erodible granitics rarely moved downslope more than 47 feet, and Brake et al. (1997) found that travel distances of sediments generated from cross drain culverts on roads in finer textured soils in the Oregon Coast Range were even less. This finding suggests that transport distances for eroded materials originating from harvest-related soil disturbance would be much less than observed from roads, because for harvested surfaces, soils are normally less disturbed and less compacted, drainage is more dispersed, and rates of erosion are much lower than for roads (Megahan 1981).

Distance that sediment moves downslope from eroding surfaces is also affected by the density of limbs, tree stems, rocks, and other large obstructions on the forest floor (Haupt 1959a; Megahan and Ketcheson 1996; Brake et al. 1997). This finding illustrates the importance of discharging any sediment generated from disturbed soils onto undisturbed forest floor laden with obstructions - an important function of streamside management areas (Brown 1980). In a study applicable to eastside forest conditions, Hetherington (1976) found that clearcutting with buffer strips on highly erodible soils in the Okanogan Mountains of southern British Columbia resulted in no delivery of sediment to streams, but that sediment did enter streams where soils were disturbed adjacent to streams without buffers.

In summary, the literature demonstrates that vegetative buffer strips, coupled with practices which minimize soil disturbance and erosion, effectively prevent sediments from reaching streams from harvested areas.

### 2.2.4.2 Watershed analysis results

Watershed analyses conducted by Plum Creek and others have specifically evaluated effects of harvesting on surface erosion processes and the adequacy of standard forest practices rules (Dube 1996; Laird 1996; Laird 1995; McGreer et al. 1997; McGreer et al. 1996; McKinney 1997; Sugden et al. 1998; Sugden 1994; Vanderwal Dube 1997; Watson et al. 1997). We examined the Surface Erosion / Harvesting modules for 15 watershed analysis reports that have been completed for watersheds east of the Cascade crest in the past five years (see Figure 1 for the locations of these analyses). These analyses have been conducted in Montana (7 analyses), Washington (7 analyses), and Idaho (1 analysis) by Plum Creek, Boise Cascade, and the Washington Department of Natural Resources. In most cases, the analyses were conducted with formal participation and review by state agencies, additional landowners, and members of the interested public. All of the analyses relied upon the Washington State watershed assessment procedures (Washington Forest Practices Board 1995a). Using the Washington procedures, all areas harvested within 5 years prior to the analysis are identified and mapped. Harvested areas representative of the range of soil types, slopes, and logging methods which occur in the watershed are then carefully inspected. Inspections concentrate on slopes adjacent to streams where areas of soil disturbance and erosion are noted. Circumstances where sediments are delivered to streams are carefully recorded, and management prescriptions are subsequently developed o address these circumstances.

As summarized in Table 1 (Surface Erosion / Harvesting Findings Summary), the majority of the 15 analyses we examined report no delivery of sediment to streams from surface erosion sources attributable to recent harvesting activities. This was typically attributed to high compliance with BMP's which address disturbance and erosion control, as well as maintenance of vegetated buffer strips around streams in which equipment operation was restricted.

In 7 of the analyses, minor amounts of delivered sediment were reported to be associated with a limited number of locations where ground-based skidding either: 1) occurred on steep slopes near streams, 2) caused heavily disturbed skid trails near streams and/or landings, or 3) was conducted out of compliance with forest practices rules. Most of these instances were observed in Washington and often occurred adjacent to small, non fish-bearing streams. New rules are presently being promulgated in Washington to address these situations.

In summary, concluding remarks from the 15 analyses that we reviewed found without exception that application of BMP's and observance of stream management zone restrictions were effective at minimizing hillslope erosion and/or that harvest-related hillslope erosion contributes little or no sediment to streams.

### 2.2.4.3 State forest practices audits

As part of their state/EPA agreements, Idaho, Washington, and Montana have conducted formal forest practices water quality audits approximately every four years. These audits have assessed both rule compliance and effects on water quality. Idaho and Montana have found that hillslope erosion does not contribute sediment to streams except where disturbance has occurred adjacent to streams, which in most cases has occurred only where activities were found to have been out of compliance with the rules.[8]

In Idaho, the 1992 IDEQ 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 BMP's were not applied, pollutants, primarily sediment, were delivered to streams 75% of the time. The most frequent areas of non-compliance were related to operations in streams or stream protection zones; this was often due to failure to properly recognize a Class II stream.

Similarly, the 1996 IDEQ Water Quality 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." However, in contrast to the 1992 audit, the 1996 audit revealed that the *most frequent area of non-compliance was related to road construction and/or maintenance*; 69% of all cases of non-compliance were associated with road rules. In the 1996 audit, delivered sediment

[8]Washington only reports effects associated with rule violations.

"was primarily from roads with comparatively minor contributions from harvest systems." Road rules were cited as the issue 84% of the time in those cases where sediment delivery occurred.

In Montana, the state has conducted biennial audits of BMP implementation and effectiveness since 1990 (Schultz 1990; Schultz 1992; Frank 1994; Mathieus 1996). Over the course of these four audits, BMP compliance has continually improved, with statewide BMP application rates of 79%, 88%, 91%, and 92% in 1990, 1992, 1994, and 1996, respectively. This increase in compliance in Montana is thought to be the result of increased education of landowners, loggers, and forestry professionals (Patrick Heffernan, personal communication).

With this increasing level of BMP application over time, a commensurate decrease in water quality impacts per site has been observed (Schultz 1990; Schultz 1992; Frank 1994; Mathieus 1996). Figure 2 shows BMP compliance rate versus water quality impacts for statewide average data (1990-1996) and Plum Creek Timber Company (1994-1996) (Frank 1994; Mathieus 1996). The figure illustrates that compliance with the Montana BMP's has steadily improved over the years following their adoption, that water quality impacts are infrequent where BMP's are fully implemented, and that Plum Creek's rate of compliance is high relative to other ownerships.

Results from the most recent audit (Mathieus 1996) found that of the 10 BMP's most often not properly applied, nine dealt with road drainage and road erosion control. The only problem-BMP related to timber harvesting was #9: "Provide adequate drainage for temporary roads, skid trails, and fire lines." In addition, the study found that where hillslope erosion BMP's were properly applied, impacts to water quality were rarely observed.

In contrast to the Idaho and Montana forest practices audits, the Washington Forest Practices Compliance Report (TFW 1991), does not report any conclusions regarding the effectiveness of properly applied BMP's; it only reports instances of non-compliance and the number of cases in which such non-compliance was judged to result in damage to public resources. However, for comparison, the Washington report does lend insight into the relative impacts of timber harvest versus roads. The non-compliance rate for harvest related activities was lower than that for roads (62 instances of non-compliance for harvest activities vs. 95 for roads), and the number of cases in which damage to public resources occurred was also lower for harvest than it was for roads (10 instances of damage for harvest vs. 21 for roads).[9] Since 1991, there have been no forest practices audit reports completed for Washington.

[9]In the majority of cases, damage was judged to be "slight" for both harvest and roads.

### 2.2.5 Summary and Discussion of Hillslope Surface Erosion

Modern forest practices rules, developed at least in part in response to early research and observation of negative effects, have been demonstrated to be fully effective for control of disturbance, erosion, and sediment delivery processes. Little or no sediment delivery associated with harvesting activities is observed when today's standard BMP's are applied in concert with buffer strips along streams. In the 15 eastside analyses that we reviewed, excursions from standard BMP's were observed in some watersheds, but significant sediment delivery in relation to natural rates of watershed erosion was not observed.

While hillslope erosion has generally not been shown to be a significant process of concern in the planning area, surface erosion can be important in local areas. The landscape analysis process outlined by Watson et al. (1988) provides a means for identifying such local areas and provides a means for developing locally appropriate conservation practices.

## 2.3 SURFACE EROSION FROM ROADS

### 2.3.1 Introduction

Virtually all watershed studies in the northwest which allow comparison of road versus harvest rates of erosion have documented that roads produce the preponderance of erosion and sediment delivered to streams, with road sediment delivery exceeding harvest related delivery by as much as one or two orders of magnitude (Brown and Krygier 1971, Fredriksen 1970; Megahan and Kidd 1972).

Surface erosion occurs from nearly all roads. However, sediment delivery to channels due to surface erosion only occurs when ditches or culverts drain directly into streams, or where roads are located relatively close to streams such that the distance between the road and stream is insufficiently wide to absorb sediment-laden waters discharged from road surfaces and drainage structures (Ketcheson and Megahan 1996; Megahan and Ketcheson 1996; Washington Forest Practices Board 1995a). Erosion also occurs in association with culvert failures and diversions due to culvert blockages (Piehl et al. 1988; Furniss et al. 1991).[10] Road erosion rates are highest during the first one or two years following construction, and normally rates decrease to less than half as much in successive years (Megahan 1974; Washington Forest Practices Board 1995a). However, irrespective of road age, heavy traffic roads produce substantially more sediment from running surfaces than do low-use roads or roads closed to traffic (Reid and Dunne 1984; Bilby et al. 1989; Washington Forest Practices Board 1995a).

[10] Erosion associated with culverts is discussed in the Mass Wasting section of this paper.

## 2.3.2 Road Density Considerations

The scientific literature, reviewed in detail in following sections of this report, firmly establishes that forest roads can add significant quantities of sediment to streams. Roads can also cause a number of additional direct impacts to aquatic habitats. Prior to development of forest practices rules and modern operating restrictions, these impacts included construction of roads within and adjacent to channels, straightening of channels, permanent removal of shade, and loss of channel-adjacent large woody debris-producing vegetation and growing areas. Most of these impacts are associated with roads that were poorly located, poorly constructed, or improperly maintained in riparian areas or on steep and unstable slopes (Brown and Krygier 1971; Fredriksen 1970; Furniss et al. 1991; McGreer et al. 1997; Megahan and Kidd 1972; Packer 1967; Rice 1979; Swift 1986; Trimble and Sartz 1957).

Recently, the Columbia River Basin Ecosystem Management Project Assessment of Ecosystem Components in the Interior Columbia Basin (Quigley and Alberbide 1997) states in the executive summary that "increasing road densities (combined with the activities associated with roads) and their attendant effects are associated with declines in the status of four anadromous salmonid species." The Assessment also notes that activities associated with roads include fishing, recreation, timber harvest, livestock grazing, and agriculture, and that roads provide avenues for stocking of non-native fishes. The Assessment also states that, "Unfortunately, we do not have adequate broad-scale information on many of these attendant effects to accurately identify their component contributions. Thus we are forced to use roads as a catch-all indicator of human disturbance."

At the broad scales examined by the CRBEMP, it is not surprising that a positive correlation was found between road density, fish density, and habitat quality. Indeed, if impact from all road miles within any given basin are assumed to be equal. irrespective of road location and management practices, and if all other factors responsible for effects upon streams and fish within basins are ignored (the simplifying assumptions relied upon by the CRBEMP assessment), then road density, stream habitat, and fish declines will be correlated. However, for the purposes of establishing a cause and effect relationship between roads, stream habitat features, and fish populations, these are not valid assumptions. Management practices within basins not associated with road density may dominate effects on streams and cannot be ignored in a valid assessment of cause and effect relationships or identification of problems and solutions. Furthermore, the technical literature, as reviewed in the following sections of this report, demonstrates that impacts of roads on streams are predominantly dependent upon road location, design, construction, and maintenance practices. These are the factors that must be directly addressed.

Since our task in this NFHCP is to identify specific conservation actions, our approach moves beyond simple observation of correlations and uses proven methods to isolate specific cause and effect mechanisms. The focus of our approach to control adverse impacts on streams is to reduce the primary adverse effect of roads upon streams, which is sediment. We address the cause of the instream effect directly; for Plum Creek ownership within the area of this NFHCP, our analysis, as explained in detail in the following sections of this report, establishes that road surface erosion is the primary source of sediment delivered to streams, and we have identified a cause and effect relationship between road surface drainage characteristics and sediment delivery. We also establish that inclusion of additional drainage near stream crossings is a highly effective conservation measure for control of sediment delivery.

### 2.3.3 Road Drainage and Isolation of Segments Contributing Sediment

It is a well established principle that while all roads generate erosion, only a portion of the road system actually delivers sediment to streams (Brake et al. 1997; Ketcheson and Megahan 1996; Megahan and Ketcheson 1996; Washington Forest Practices Board 1995a). This principle is illustrated by recent sediment delivery analyses conducted according to the Washington Forest Practices Board (1995a) standard methods for watershed assessment of the LeClerc Creek watershed, located in northeast Washington (McGreer et al. 1997). Figures 3a, b, and c demonstrate that 80% of the road sediment delivered from these three subwatersheds originates from 4% to 14% of the road segment mileage. Furthermore, 70% to 80% of the road segment mileage contributes no sediment at all. In many cases, sediment delivery is limited to an even smaller portion of the total road system. Analysis of Goat and Piper Creek watersheds in the Swan River system reveals that less than five percent of the road mileage actually delivers sediment to streams (Watson et al. 1997).

Sediment is delivered to streams from forest road surface erosion processes in two ways: 1) "*directly*" *via road ditches which drain directly to streams, and* 2) "*indirectly*" either via drainage structures or from fillslopes where sediments are discharged onto forest slopes and where some portion of this sediment eventually reaches streams (Washington Forest Practices Board 1995a). In the case of direct delivery via road ditches, 100% of the eroded volume from the road cutslope, ditch, and portion of the road tread runoff contributing to the ditch is delivered to the stream system. In the case of indirect delivery, some or all of the sediments discharged from the road do not reach streams due to the filtering and sediment trapping effects of intervening buffer strips (Brake et al. 1997; Elliot et al. 1997; Haupt 1959a; Ketcheson and Megahan 1996; Megahan and Ketcheson 1996; Packer 1967; Swift 1986; Tennyson et al. 1981; Trimble and Sartz 1957; Washington Forest Practices Board 1995a).

### 2.3.4 Historic Effects of Roads

Many watershed studies have been conducted that document erosion and sediment delivery due to forest practices. However, only some of these studies were conducted in such a way as to allow separation of road effects from harvest and/or burning effects, or that separate surface erosion from mass wasting effects. We recount results from four studies that document effects of surface erosion from roads.

In the South Fork of Caspar Creek in northern California, Rice et al. (1979) found that in the four year period between road construction and timber cutting (1968-71), the watershed produced about 2.7 tons/acre excess sedimentation, or about 80% above the amount that would be predicted for an undisturbed condition. This increase was attributed primarily to the construction of approximately 3.7 miles of road within 200 feet of the channel.

In the Deep Creek drainage of the Idaho Batholith, Megahan and Kidd (1972) found that in the six year period (1962-67) following construction of 0.36 mile of road, sediment production due to surface erosion from roads increased by a factor of approximately 220 over that predicted for undisturbed conditions; furthermore, 84% of the total excess occurred in the first year after road construction. These roads were built on steep slopes averaging 70% gradient, on soils now recognized as exceptionally erodible, and without adequate drainage and erosion control practices. The 220-fold increase in sediment production due to roads compares with only a 1.6-fold increase attributed to ground-skid cable high-lead logging (Megahan et al. 1980).

In the Ditch Creek drainage of central Idaho, Megahan et al. (1983) found that "roadcut erosion represents the major long term source of sediment from road construction on granitic lands . . . over 1,000 times greater than the erosion on undisturbed forest slopes on the study watersheds."

At Castle Creek, California, where the primary influence was roads, Anderson and Wallis (1965) found average sediment concentrations and loads from a 4 square mile watershed increased five-fold in the first year.

These studies of the impacts of pre-forest practices act roads demonstrate the large increases in delivery of sediment to streams due to surface erosion that commonly occurred when roads were improperly located and constructed. These early results can be contrasted with sediment delivery rates observed in watersheds evaluated recently, as described in Section 2.3.7.2 and its appendix tables.

## 2.3.5 State Forest Practices Road Erosion Control and Drainage Requirements

Similar to the approach used to address hillslope erosion processes, Idaho, Montana and Washington each require control of road-related soil disturbance, erosion, and sediment delivery (Idaho Department of Lands 1996; Montana Department of Natural Resources and Conservation 1997; Montana Department of State Lands 1994; Washington Forest Practices Board 1995b). Soil disturbance is addressed through rules that regulate road width, disposal of cut and fill materials, and location and design considerations which include topography and logging system requirements. Soil erosion control is addressed by requiring revegetation of cut and fill surfaces; treatment with erosion control measures such as matting, rock surfacing, and/or similar measures; and by road drainage. Delivery of sediment is addressed through road location restrictions, buffer strip requirements, and design features that intercept and trap sediment, such as filter windrows and ditch-line sediment traps.

Road drainage is a key feature of each state's regulations, because appropriate drainage features control both the erosion and sediment delivery processes. Because road drainage is so important, we briefly note the key language from each state's requirements.

Idaho FPA Rule 040.02.e requires: " . . . plan drainage structures to achieve minimum direct discharge of sediment into streams." Idaho does not address minimum relief culvert spacing requirements (Idaho Department of Lands 1996).

Montana's forestry BMP III.C.6 requires: "Route road drainage through adequate filtration zones or other sediment-settling structures to ensure sediment doesn't reach surface water. Install road drainage features above stream crossings to route discharge into filtration zones before entering a stream." Montana does not address minimum relief culvert spacing requirements ( Montana Department of Natural Resources and Conservation 1997).

Washington FPA Rule 040.02.e requires: "Where roadside ditches slope towards a Type 1, 2, 3 Water . . . for more than 300 feet and otherwise would discharge into the stream . . ., divert the ditchwater onto the forest floor by relief culvert or other means at the first practical point." In addition, Washington provides minimum relief drain spacing requirements which are dependent on road gradient (Washington Forest Practices Board 1995b).

As previously described, the forest practices audits for Idaho, Montana, and Washington found that most instances of delivery of sediment to streams are associated with roads. Furthermore, one of the frequently reported causes for delivery is due to inadequate road drainage for the specific circumstances encountered. This finding from the audits is repeated in the findings from many of the watershed analyses that we examined; unacceptable quantities of road surface sediment were added to the stream systems of many watersheds, often due to inadequate road drainage. We conclude from these findings that whereas the states's road drainage BMP's are performance oriented, it appears that they do not always provide operators with sufficient guidance to ensure adequate control of erosion and sediment delivery. In addition, many roads, particularly in Montana, were constructed prior to the development of comprehensive state forestry BMP's in 1989. Our conclusion leads us to an in-depth analysis of the effectiveness of additional drainage practices for control of sediment delivery to streams and a recommendation for additional drainage based on this analysis as a major NFHCP conservation measure.

### 2.3.6 Sediment Delivery Control and Sediment Travel Distance

Sediment transport distance below roads is limited by sediment trapping effectiveness of the forest floor and by road erosion control features, such as road surfacing, density of vegetative ground cover on road cut and fill slopes, and road drainage features. Quantity of sediment reaching streams is minimized when erosion from roads is well controlled, drainage water is frequently dispersed, and the sediment trapping effectiveness of the forest floor is maintained (Brake et al. 1997; Ketcheson and

Megahan 1996; Megahan and Ketcheson 1996; Haupt 1959a; Haupt 1959b; Packer 1967; Swift 1986; Trimble and Sartz 1957).

Recent investigations report indirect road sediment transport distance as a function of both road erosion volume and characteristics of the area between the road and the stream below (Brake et al. 1997; Megahan and Ketcheson 1996; Ketcheson and Megahan 1996). This research makes it possible to combine erosion volume modeling procedures with sediment transport modeling relationships to determine required surface drainage spacing for rigorous control of sediment delivery to streams (Megahan and Ketcheson 1996; Elliott et al. 1997).

100% of the sediment carried by road ditches that discharge into streams at road/stream crossings is assumed to deliver to the streams (Washington Forest Practices Board 1995a). In contrast, less than 100% of the sediment discharged from relief drainage structures reaches streams where road drainage and vegetated buffer strip effectiveness is maintained. These principles reveal that the length of road ditch discharging sediment directly to streams should be limited to only short distances through location of relief drainage structures. However, as direct ditch length becomes shorter due to location of an intervening culvert (or surface drain), indirect delivery from the relief drain located closest to the crossing (the "first" drain) generally increases, because the length of slope between the drain outlet and the stream becomes shorter. Optimum placement of the first drain is where the combined total direct ditch and indirect first drain delivery are minimized (McGreer and Schult 1997).

### 2.3.7 Assessment of Rigorous Sediment Control Through Inclusion of Additional Road Drainage

This section discusses the methodology that we used to assess the benefits of applying current state-of-the-art road drainage BMP's across Plum Creek's ownership and the results of our analysis. Effects of additional drainage on road prism erosion and dependent sediment transport and delivery were modeled. Extensive analysis and sensitivity testing of drainage structure placement options were used to develop a generic spacing design that rigorously controls sediment delivery from roads.[11] In order to evaluate the effectiveness of the approach, the design was applied to the road systems inventoried within eleven Plum Creek Timber Company watersheds in Montana, Idaho, and Washington where detailed road erosion assessments were completed in the past few years. Figure 1 provides a map of these watershed locations.

[11]Drainage structure placement could be adjusted based on more detailed site-specific field assessment to potentially achieve even more rigorous sediment control, but these more site-specific circumstances could not be examined in this analysis at this time.

#### 2.3.7.1 Assessment methods

The first step in our assessment relied on the Washington State watershed assessment road erosion modeling procedures to predict direct sediment delivery to streams at road crossings (Washington Forest Practices Board 1995a; Megahan and Kidd 1972; Reid and Dunne 1984; Sullivan and Duncan 1980; Swift 1984).[12] We also used the Washington model to predict road erosion volume contributing to the first drain closest to the stream crossing, which we used as an input variable to the Megahan and Ketcheson (1996) sediment delivery equations for rock surface drains to solve for the quantity of indirect delivery:[13]

$$Y_c = E\, W_c\, L\, F_v / 43{,}560 \qquad (1)$$

$Y_c$ = sediment yield from cutslope (tons/year)
E = basic erosion rate (tons/acre/year)
$W_c$ = cut width (feet)
L = road segment length between relief drains (feet)
$F_v$ = cut vegetative factor (from Washington Board Manual)

$$Y_t = E\, F_g\, F_t\, F_s \qquad (2)$$

$Y_t$ = tread/traffic sediment yield rate (tons/acre/year)
$F_g$ = road gradient factor (derived from USLE)
$F_t$ = tread traffic factor (from Washington Board Manual)
$F_s$ = tread surface factor (from Washington Board Manual)

$$T_d = Y_t\, W_t\, L\, P / 43{,}560 \qquad (3)$$

$T_d$ = tread yield to ditch (tons/year)
$W_t$ = tread width (feet)
P = percent tread delivery to ditch (insloped or outsloped)

$$Y_d = Y_c + T_d \qquad (4)$$

$Y_d$ = total sediment yield to ditch (tons/year)

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[12]It should be noted that although predictions of actual volume of eroded materials may not be precise, the methodology employed here yields a valid comparison of the effects of different drainage treatment alternatives.

[13]Plum Creek intends to use "drivable dips" for the majority of its additional drainage structures, and energy and drain spacing characteristics of these structures more closely match those of Megahan and Ketcheson's (1996) rock drains than they do cross drain culverts; however, fillslopes below these drain dips must be protected from erosion for application of the rock drain relationship to remain valid.

For the case of direct delivery, this is the amount of sediment delivered to the stream at the road crossing. For indirect delivery, we routed this volume of sediment through the intervening buffer:

$$D_{max} = 111.5\ Y_d^{\ 0.589}\ B^{-0.361} \qquad (5)$$

$D_{max}$ = maximum sediment delivery distance (feet) (from Megahan & Ketcheson 1996)
B = obstruction density (m/30m) [mean value = 22.3]

$$K = 1.036\ \exp[-3.041\ D_l/D_{max}] - 0.0555 \qquad (6)$$

K = fraction of sediment yield delivered to stream (from Ketcheson & Megahan 1996)
$D_l$ = distance from drain to stream (feet)

$$K\ Y_d = \text{sediment delivery (tons/year)} \qquad (7)$$

This is the amount of sediment delivered to the stream indirectly via the first drain.

In order to best represent the generalized conditions affecting road erosion and sediment delivery within Plum Creek's ownership, our analysis was based on the following characteristics:

- Old, native surface, light traffic roads, 20 tons/ac/yr (low to moderate erosion hazard).[14]
- 14 ft. wide running surface.
- 80% of drainage structures will be rock drains.
- Two-thirds of all stream crossings are one-sided (road climbs continuously through crossing) and one-third of stream crossings are two-sided (road dips down into stream crossing from both sides).
- Average road gradient of 4%.
- Average hillslope gradient of 30%.

We considered various road drainage features as inputs to the modeling equations. We first assumed a distance of 400 feet between the first and second drains; this was a practical assumption to provide a starting place for the analysis. We then calculated the distance from the stream crossing to the first drain that resulted in the minimum total sediment delivery (direct and indirect combined). We found that the minimum total sediment delivery occurred when the first drain is located approximately 80 feet from the stream crossing. This location for the first drain puts the drain outlet approximately 50 feet slope distance from the stream (based on typical road crossing geometry, see Figure 4). We then calculated the total sediment delivery (both direct and indirect) to the stream for this average condition and found that if we reduced the distance between the first and second drains to 300 feet,

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[14]Tons/ac/yr for roads varies with surfacing and traffic considerations in the Washington procedure (Washington Forest Practices Board, 1995a).

we could virtually eliminate indirect delivery from the first drain. Therefore, in order to rigorously control sediment delivery, we arrived at the following features for inclusion of additional road drainage structures on Plum Creek's ownership:

- Installation of the first drainage structure approximately 80 feet, along the road centerline, from the ordinary high water mark of the stream.
- Installation of the second drainage structure 300 feet from the first structure.

For the typical conditions which we considered, this design results in virtually no indirect sediment delivery to streams; this is the approach to drain placement that we used to evaluate the effects of additional road drainage.

#### 2.3.7.2 Sediment delivery and drainage effectiveness evaluation

Eleven specific watersheds were selected to evaluate the benefits of applying these road drainage design BMP's. These watersheds were chosen because road sediment delivery had already been assessed in the course of watershed analyses conducted for these watersheds (McGreer et al. 1997; McKinney 1997; Sugden et al. 1998; Sugden 1994; Veldhuisen 1994; Watson et al. 1997).

Our approach for evaluating the effect of adding drainage structures was to substitute a new direct delivery distance for the field-measured distance recorded for each stream crossing in the eleven watersheds. Direct delivery distance, based on the spacing identified above, would be 80 feet. However, some crossings in the field are two-sided, with water flowing to the stream from both directions. Total distance of direct delivery is therefore greater than 80 feet. The watershed analyses identify total distance of direct delivery, but do not identify if they are one-sided or two-sided. From interviews with our field foresters, we estimated that one-third of all crossings are two-sided. Based on this assumption, 2/3 of all crossings have 80 foot direct delivery distances, and 1/3 of all crossings have 160 foot delivery distances; the representative "equivalent" direct ditch delivery distance is therefore 110 feet: (2/3 x 80' + 1/3 x 2 x 80' = 110'). Inclusion of additional road drainage designs were then incorporated in the sediment modeling in the following way:

- Any stream crossings with more than 110' of contributing length were reduced to 110' equivalent direct contributing length.
- Any stream crossings with less than 110' of contributing length were left unchanged.
- Any sediment contributed indirectly from stream-adjacent roads was left unchanged.
- All road parameters (e.g., surfacing, traffic level, seasonal use factors, etc.) remained the same as in the original watershed analysis.

The results of these simulations for the eleven watersheds are summarized in Table 2, and an example calculation for the Cedar Creek watershed is provided in Table 3. Additional road drainage structures near stream crossings eliminates 25 to 85 percent of road sediment delivered to streams in the eleven watersheds simulated. Sediment delivery was reduced by an average of 44%, from 7.2 tons/mile to

4.0 tons/mile. For the major geologic/geographic zones examined, the average road sediment reduction in belt geology, primarily in western Montana, is 64%; in granitics of northeastern Washington and northern Idaho, road sediment is reduced an average of 62%; the average reduction in road sediment in volcanics of the east Cascade slope is 37%.

#### 2.3.7.3 Discussion

This analysis demonstrates the substantial reductions in the quantity of sediment delivered to streams that can be achieved through installation of additional road drainage structures near stream crossings. Other potential alternatives for reducing road sediment delivery to streams include surfacing of the road tread near stream crossings or adding slash filter windrows below fillslopes. Although sufficient research has been done to allow modeling of sediment reduction due to these measures, we chose to evaluate addition of road drainage structures for the purposes of this NFHCP.

The Megahan and Ketcheson (1996) equations that we used in this analysis were developed for granitic soils in the Idaho Batholith, and although this may not be representative of Plum Creek's ownership, use of these relationships should result in a conservative approach. For example, Burroughs and King (1989) reported typical sediment travel distances from relief culverts in northern Idaho approximately half that found by Megahan and Ketcheson (1996). Brake et al. (1997) report average travel distance of sediments generated from cross drain culverts on roads in the Oregon Coast Range less than those reported by either Megahan and Ketcheson (1996) or Burroughs and King (1989). Furthermore, in our use of the rock drain equation, we used the average obstruction density reported by Megahan and Ketcheson (1996); however, we believe that obstruction densities will normally be higher on much of Plum Creek's land covered by this NFHCP, where precipitation and vegetation densities are naturally higher than in the Batholith of south central Idaho.

In addition to the sediment reduction benefits that will occur through installation of additional drainage structures, additional benefits can be achieved through treatment of more site-specific and less common sources of sediment which occur in association with roads that closely parallel streams and other "hot spot" problems of erosion and sediment delivery from roads and hillslopes. Both of these additional sources of sediment delivery will be addressed operationally as an action planned as a result of the NFHCP, and total percentage reduction of sediment delivery will therefore be greater than the percentage reductions discussed above resulting from addition of drainage structures alone. However, given the site-specific nature of these additional sources, we make no attempt to quantify these benefits in this paper.

# 3.0 MASS WASTING

## 3.1 INTRODUCTION

Mass wasting is a major erosion process in many forested watersheds of the northwest (Ice 1985; Swanston 1991). Slope gradient and ground water are the two factors that have the greatest effect on slope stability (Burroughs et al. 1976), although additional factors such as composition, depth, and degree of weathering of parent materials, and microtopographic features are also important (Swanston 1991). Three types of mass wasting contribute to stream habitat change: deep seated slumps and earthflows, shallow planar failures (debris avalanches), and debris flows down stream channels, sometimes referred to as debris torrents (Swanston 1991).

Slumps and earthflows are typically triggered by the build-up of pore water pressure in mechanically weak, and often clay-rich, parent materials (Burroughs et al. 1976; Swanston 1991). Earthflows are most commonly reported as significant processes in western Oregon, California, and Washington (Swanston 1991). Debris avalanches are more common than slumps and earthflows (Ice 1985; Swanston 1991; Megahan et al. 1978) and are primarily associated with two specific landforms: bedrock hollows (also referred to as swales or zero-order basins), and stream-adjacent inner gorges (Benda et al. 1997). Furthermore, few debris avalanches occur on slopes of less than 60 percent gradient, with the majority occurring on slopes exceeding 70 percent gradient (Benda et al. 1997). Debris avalanches and debris torrents are the forms most likely to be influenced by forest management activities (Ice 1985). Debris torrents are by far the most destructive form of mass wasting to stream habitat (Benda 1997; Swanston 1991).

Roads are the predominant cause of increased rates of mass wasting associated with forest management, with acceleration factors due to roads commonly found to be in the range of ten to one hundred times greater for roads than for harvesting (Swanston and Swanson 1976). Road fill failures, including fill failures associated with culvert blockages and diversions, are the predominant form of road-associated mass wasting (Ice 1985).

## 3.2 EFFECTS OF FOREST MANAGEMENT

Effects of forest management on mass wasting processes are well documented. Effects of harvesting on deep seated failure processes are negligible (Ice 1985), but roads can in some cases affect earthflow processes where road excavation removes lateral support from below potential failure masses, and where road drainage waters are concentrated and discharged onto areas susceptible to the earthflow process, which typically pre-exist the road (Benda et al. 1997; Burroughs et al. 1976). Several authors report highly accelerated rates of debris avalanche occurrence associated with forest roads, (Fiksdal. 1974; Gonsior and Gardner 1971; Gray and Megahan 1981; Ketcheson and Froehlich 1976; McClelland et al. 1997; Morrison 1975; Sidle et al. 1985). These same studies also demonstrate that most road failures are due to failure of road fills on slopes over 70 percent gradient or due to culvert failures.

Rates of debris avalanche occurrence associated with forest roads in westside studies conducted in the early to mid 1970's range from 25 to 344 times the rate in undisturbed forests (Benda et al. 1997; Sidle et al. 1985). For eastside areas, few rate studies are reported in the literature. Megahan and Kidd (1972) reported that roads built in small headwater basins in the 1950's and early 1960's in the central Idaho Batholith increased rates of mass wasting related erosion by a factor of over 400, but actual numbers of road failures in relation to natural were not reported.

As mentioned, most studies report that the majority of road failures are fill failures or failures associated with poor drainage practices, culvert failures, and/or obstructions and diversions. McClelland et al. (1997) recently observed for road related landslides in the area of the Clearwater National Forest in central Idaho that surface water was often diverted to road fills and that fills have invariably developed cracks and subsidence. Insufficient stream crossing culvert capacity, often compounded by debris obstruction, has also been noted as an important cause of culvert failure, resulting in overtopping or diversion from streambeds and onto unstable road fills, with associated mass wasting events (Furniss et al. 1991). Although the forest practices rules of Idaho, Montana, and Washington now call for stream culvert design capacity based on the 25 to 100 year flood event, many roads were built when the requirement and common practice was based on the 10 to 25 year event. This suggests that there may be a legacy of undersized culverts that remain potential site-specific mass wasting hazards on some roads.

Several authors also report that rates of debris avalanches on steep sites are accelerated during the first 6 to 15 years following clearcut harvest due to loss of apparent soil cohesion attributed to root decay (Benda et al. 1997; Burroughs and Thomas 1977; Gray and Megahan 1981; Swanston and Dyrness 1973). Rate of failure acceleration in clearcuts versus forest have been reported to range from 1.0 to 8.7 times. However, it should be noted that some of these studies inventoried failures only from aerial photographs, causing underestimation of the in-forest rate of failure (Benda 1997; Mills 1996). Ice (1985) reports that this overestimation factor for photo-based studies ranges from 10 to 30.

As has been noted, roads are the dominant source of accelerated rates of mass wasting. Many of the 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. As practices have improved, and as old roads eventually stabilize, this potential can be expected to decrease; as early as 1984, Ice (1984) noted evidence from westside studies that rates of road failure were decreasing. Recently conducted mass wasting evaluations within comprehensive watershed assessments provide the best evaluation of the significance of mass wasting in specific watersheds. Several of these assessments have been conducted in eastside watersheds within or applicable to the area of this NFHCP, and we review the key findings of these analyses in the Watershed Analysis Results section of this report.

## 3.3 STATE FOREST PRACTICES REGULATIONS

Montana, Idaho, and Washington forest practices rules address slope stability in sections which address timber harvest activities and road planning, location, design, construction, and maintenance. There is much similarity of language in the rules for each of these states. We excerpt from the December, 1997, Montana forestry BMP's to illustrate the nature of these rules.

**Road Planning and Location:**

- Review available information and consult with professionals as necessary to help identify erodible soils and unstable areas, and to locate appropriate road surface materials. (BMP I.A.2.)

- Locate roads on stable geology, including well-drained soils and rock formations that tend to dip into the slope. Avoid slumps and slide-prone areas characterized by steep slopes, highly weathered bedrock, clay beds, concave slopes, hummocky topography, and rock layers that dip parallel to the slope. Avoid wet areas, including moisture-laden or unstable toe slopes, swamps, wet meadows, and natural drainage channels. (BMP I.A.4.)

**Road Design:**

- Design roads to balance cuts and fills or use full bench construction (no fill slope) where stable fill construction is not possible. (BMP I.B.3.)

**Road Construction:**

- Keep slope stabilization, erosion and sediment control work current with road construction..... (BMP I.D.1.)

- Stabilize erodible, exposed soils by seeding, compacting, riprapping, benching, mulching, or other suitable means. (BMP (I.D.2)

- Minimize earth-moving activities when soils appear excessively wet. Do not disturb roadside vegetation more than necessary to maintain slope stability and to serve traffic needs. (BMP I.D.4.)

- Construct cut and fill slopes at stable angles to prevent sloughing and other subsequent erosion. (BMP I.D.5.)

- Avoid incorporating potentially unstable woody debris in the fill portion of the road prism. Where possible, leave existing rooted trees or shrubs at the toe of the fill slope to stabilize the fill. (BMP I.D.6.)

**Road Maintenance:**

- Avoid cutting the toe of cut slopes when grading roads or pulling ditches. (BMP I.E.3.)
- Haul all excess material removed by maintenance operations to safe disposal sites and stabilize these sites to prevent erosion. Avoid side-casting material into streams or locations where erosion will carry materials into a stream. (BMP I.E.5.)

**Timber Harvesting:**

- Locate skid trails to avoid concentrating runoff and provide breaks in grade. Locate skid trails and landings away from natural drainage systems and divert runoff to stable areas. Limit the grade of constructed skid trails on geologically unstable, saturated, highly erosive, or easily compacted soils to a maximum of 30%. Use mitigating measures, such as water bars and grass seeding, to reduce erosion on skid trails. (BMP II.A.5.)

In addition to these road and harvest rules, there are many additional rules that indirectly address management related slope stability concerns through rules that require drainage structures and water management on roads and skid trails.

In addition to this form of rule, in Washington, all forest practices activities applications are screened for the presence of high hazard mass wasting areas, and if any are found, they are classified as Class IV Special, whereupon an agency and landowner ID team is formed, and site-specific management practices are developed to address any hazards identified.

## 3.4 RECENT FINDINGS

### 3.4.1 Watershed Analysis Results

Watershed analyses conducted using the Washington State watershed assessment procedures (Washington Forest Practices Board 1995a) specifically evaluate effects of roads and harvesting on mass wasting processes and the adequacy of standard forest practices rules. We examined 23 mass wasting assessments which have been completed in the last few years and which are representative of the area covered by this NFHCP: the east slope of the Cascades in eastern Washington (11 analyses), northeastern Washington (6 analyses), and western Montana (6 analyses) (Dube 1996; Laird 1996; Laird 1995; McGreer et al. 1997; McGreer et al. 1996; McKinney 1997; Sugden et al. 1998; Sugden 1994; Vanderwal Dube 1997; Watson et al. 1997).

Mass wasting has been reported to be the dominant erosion process in many steep areas of the northwest, particularly for areas west of the Cascades and in the coast ranges of California and British Columbia. However, surface erosion processes tend to be dominant in more arid areas like the interior. In order to examine the relative importance of mass wasting in the interior versus the westside, we also examined the results from all western Washington assessments (9 analyses) that we were able to obtain from the Washington Department of Natural Resources. Table 4 summarizes the results for all of these analyses.

For each watershed listed, Table 4 recounts its watershed size, the total number of failures/mi$^2$, and the number of failures/mi$^2$ that were associated with land management activities. Because of their destructiveness to stream habitat features, Table 3 also displays the number of debris torrents/mi$^2$ that were observed.

Several relationships are revealed in Table 4. Westside rates of failure are far higher than are eastside rates. Westside rates are 3.3 times higher than found for the watersheds located just east of the Cascade crest, where precipitation remains high and slopes remain very steep for much of the area. For the more eastern areas - east Cascade slope east of the RMZ line,[15] northeast Washington, and western Montana - total number of failures/mi$^2$ decrease to 0.43, 0.25, and 0.13, respectively. Similar relationships are revealed for management related failures. Moving from the westside, rates decrease from 5.10 failures/mi$^2$ to 0.94 failures/mi$^2$ just east of the Cascade crest, and to 0.10 to 0.13 failures/mi$^2$ further east. For debris torrents, we see a similar relationship, with debris torrents/mi$^2$ decreasing in the east slope of the Cascades east of the RMZ line to only 0.10/mi$^2$ (7.5% of the Western Washington rate), down to 0.02 and 0.00 torrents/mi$^2$ for northeastern Washington and western Montana, respectively.

These results demonstrate that mass wasting is a more dominant process west of the Cascades than it is in the drier and generally less steep areas of the eastside. Furthermore, particularly for areas affected by continental glaciation, failures were confined to specific landforms. Most of the areas covered by the northeast Washington and western Montana assessments were affected by continental glaciation, and most of the failures observed in these areas occurred in inner gorge glacial terrace escarpment locations.[16] Nearly all remaining failures occurred on sites exceeding 70% slope, irrespective of geology.

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[15]The RMZ line is defined in the Washington Forest Practices Rules, Chapter 222-16 of the Washington Administrative Code (WAC), for the purposes of delineating eastern Washington from western Washington; however, this administrative boundary in fact lies east of the Cascade crest.

[16]Inner gorges are those areas where hillslopes steepen immediately adjacent to stream channels (Benda et al. 1997).

### 3.4.2 1995/1996 Floods and Landslides

Exceptionally heavy winter precipitation in Idaho resulted in severe flooding and high rates of mass wasting in Idaho in 1995 and 1996. The rates of landsliding, causes and associations, and instream effects in the area of the Clearwater National Forest were extensively studied by McClelland et al. (1997) and by Falter and Rabe (1997). Plum Creek owns lands near and/or included in these surveys in the Palouse, St. Joe, and Lochsa River watersheds.

McClelland et al. (1997) conducted a 100% survey of all failures greater than 25 cubic yards in volume in non-wilderness areas of the Clearwater. Associations with land use are of most interest:

| | Natural | Roads | Harvest |
|---|---|---|---|
| % of Total Number | 29 | 58 | 12 |
| % of Total Volume | 59 | 36 | 5 |
| % of Delivered Vol. | 71 | 25 | 4 |

Number of failures associated with roads was disproportionately high, however, volume relationships were less pronounced because natural failures tended to be larger than road failures.[17] Consistent with the literature, most road failures were fill failures on steep slopes and were generally associated with poor construction, maintenance, and drainage practices. Total sediment delivery from the 1995/96 landslides were reported to be approximately 10 times the natural background landslide rate, with approximately 2.5 times the natural rate attributable to roads. The authors also report that the rate of failure of roads built in the 1970's through the 1990's was approximately one-half the rate associated with roads built in the 1950's through the 1960's. Avoidance of hazardous locations and attention to road fills and drainage are noted as means of preventing failures for roads to be constructed in the future.

Regarding effects of harvest, McClelland et al. (1997) reports that 12% of the failures were found in harvested areas, versus 29% in areas never harvested. However, failures per unit area are not discussed in their report, so we are unable to conclude whether or not harvest affected the rate of mass wasting.

Regarding instream effects, McClelland et al. (1997) reports mixed results. Impacts to streams due to flooding and/or landslides in roaded areas were not more severe than those observed in unroaded areas of the Forest (Falter and Rabe 1997). Although not discussed by the authors, our familiarity

[17]This result (fewer but larger natural landslides) is typical of aerial photography-based landslide inventories, because many smaller natural landslides cannot be detected through the forest canopy on aerial photographs. However, McClelland et al. (1997) performed both aerial photo and ground-based inventories as part of their landslide survey.

with the Clearwater area causes us to hypothesize that the roadless areas of the Clearwater are generally steeper and more failure prone than are the more gentle and developed areas, perhaps helping to explain the high level of stream damage found in the roadless areas. In any event, landslide and flood damage to streams was found to be associated with landscape character, not with presence or absence of roads.

# 4.0 SUMMARY AND IMPLICATIONS TO THE HCP

Our review of the results from 15 watershed analyses found that hillslope erosion was rarely observed to deliver sediment to streams when BMP's were properly implemented and streamside vegetative buffers were maintained. These extensive field observations comport with findings of recent scientific literature and state audits which have examined the effectiveness of BMP's at controlling erosion and sediment delivery. While hillslope erosion has not been shown to be a substantial process of concern in the planning area generally, surface erosion can be important in local areas. The landscape analysis process outlined by Watson et al. (1988) provides a means for identifying these local areas and provides a means for developing locally appropriate conservation practices.

Roads were found to produce virtually all of the management-derived surface erosion sediment delivered to streams in the eleven areas studied through watershed analysis. By coupling indirect sediment delivery models with the direct road sediment delivery estimates, we were able to estimate the benefit of installing additional road drainage structures near stream crossings. These actions were predicted to reduce road-derived sediment delivery by 25% to 85%, with an average reduction of 44%.

Results of the road analysis could be used to estimate benefits of rigorously draining roads near stream crossings in watersheds throughout Plum Creek's NFHCP area. This could be done by normalizing the watershed analysis results on a "per road mile" basis, then extrapolating that rate to Plum Creek's transportation system.

The potential impact of new roads could be analyzed in a similar manner as existing roads. By assuming expected road prism dimensions and stream crossing geometries for new roads, average base erosion rates and road grades, and assuming various direct and indirect delivery distances, a "delivery per crossing" can be calculated. If the number of expected stream crossings per mile of new road is known, an expected "impact per mile of new road" could be estimated.

Mass wasting has been found to be the dominant form of erosion in many forested watersheds, and because of the potential destructiveness of individual mass wasting events, the process is of concern in nearly all watersheds. Although occurring at rates substantially lower than found in western Washington, mass wasting is a significant process immediately east of the Cascade crest. However, these areas are included in the existing Plum Creek Cascades HCP. Areas located further east and included within this current NFHCP experience far lower rates of mass wasting. While overall mass wasting rates are low in the NFHCP area, mass wasting is a locally important erosional process where higher hazard areas exist. Recent mass wasting assessments in the project area (e.g., Watson et al. 1997; Sugden et al. 1998), and other analyses using the approach outlined in Watson et al. (1998), could aid Plum Creek land managers in identifying and addressing these failure-prone areas.

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# 6.0 LIST OF TABLES AND FIGURES

Table 1. Surface Erosion / Harvesting Findings Summary

| Watershed | Effects of Old Practices | Impacts of Recent Practices | "Quantitative" Results | Conclusions |
|---|---|---|---|---|
| Ahtanum | Old logging practices were a significant contributor of sediment to streams | Standard forest practices adequate to prevent erosion and delivery; tractor logging resulted in minimal delivery, cable logging resulted in essentially no delivery | Management-related hillslope erosion negligible compared to natural background rates | Management-related hillslope erosion is not a significant contributor of sediment to streams |
| Beatrice | No comments | Recent harvest practices, both tractor and cable, have resulted in only minimal erosion and no delivery | None | Application of BMP's and observance of SMZ's has been highly effective at minimizing hillslope erosion |
| Belmont | Past ground-based practices of skidding logs down draws and very little erosion control caused high sediment delivery | Soil disturbance and sediment delivery due to recent ground and cable logging activities was minimal to none | Erosion due to harvest much less than either road erosion or natural background erosion | Hillslope erosion due to harvest activities appears to be negligible compared to natural background rates |
| Boiling Springs | No comments | Recent harvest practices, both tractor and cable, have resulted in only minimal erosion and no delivery | None | Application of BMP's and observance of SMZ's has been highly effective at minimizing hillslope erosion |
| Big Sheep Creek | No comments | Surface erosion and delivery at sites of (recent) harvest activities was not observed; skid trail erosion was not observed | None | Occurrence of erosion and delivery during or following harvest activities is minimal or non-existent |
| Goat Creek | No comments | Recent harvest practices, both tractor and cable, resulted in only localized ground disturbance, minimal erosion, and no delivery | None | When BMP's and SMZ's were appropriately applied, hillslope erosion was not observed |
| Gold Fork | No comments | Few locations noted where sediment eroded from (primarily ground-based) harvest units reached streams | Harvest-related sediment input 1% of natural background; road erosion 12x the erosion due to harvest | Recent practices have been successful in keeping most eroded sediment from reaching streams |

| Watershed | Effects of Old Practices | Impacts of Recent Practices | "Quantitative" Results | Conclusions |
|---|---|---|---|---|
| Huckleberry | No comments | Surface erosion limited to a few locations of recent ground-based harvest on steep slopes near streams | Sediment delivery to streams is concentrated at road stream crossings and roads paralleling streams | Ground disturbance due to ground-based harvest adjacent to streams delivered sediment during significant runoff events at some sites |
| LeClerc | Old practices of log flume construction, tramways, and rail lines along major tributaries has, and in some cases still does, contribute sediment to streams | Current logging practices have not contributed substantial amounts of delivered sediment; sediment was delivered only where activity was not in compliance with standard rules | Management-related hillslope erosion negligible compared to natural background rates | Hillslope erosion due to current standard harvest practices is not significant |
| Murr | No comments | Recent harvest practices, both tractor and cable, have resulted in only minimal erosion and no delivery | None | Application of BMP's and observance of SMZ's has been highly effective at minimizing hillslope erosion |
| Onion Creek | In the past, the mine, slurry flume, and tailings ponds were likely a source of sediment to streams | Evidence of erosion in tractor logged units was present, but little sediment reached streams | Greatest sources of delivered sediment: 1) heavy residential traffic roads, 2) gullies on native surface roads, 3) mines | Timber harvest was not observed to contribute substantial volume of sediment to streams |
| Panakanic | Soils deeply disturbed in skid trails, often adjacent to streams; impacts from past logging practices were severe | Delivery due to recent (ground-based) harvest limited to heavily disturbed skid trails and landings adjacent to streams | Harvest-related sediment delivery less than 10% of natural background | Recent logging practices have not delivered substantial amounts of sediment to streams |
| Piper Creek | No comments | Recent harvest practices, both tractor and cable, resulted in only localized ground disturbance, minimal erosion, and no delivery | None | When BMP's and SMZ's were appropriately applied, hillslope erosion was not observed |
| Teanaway | Past practices, including temporary roads and skid trails, tractor logging on steep slopes, logging during wet weather, and skidding across streams, disturbed soils significantly | Current forest practices (cable and ground) minimized soil disturbance, caused minor hillslope erosion, and did not deliver sediment to streams | Sediment delivery due to recent harvest activities is much less than natural background | Soil erosion and delivery from (current) harvest practices do not significantly impact resources |
| Thompson | No comments | No comments | None | Hillslope erosion is a minor contributor of sediment to public resources |

Table 2. - Plum Creek Road Sediment Summary

| Watershed | Area (acres) | Road mileage | Background fine sediment (tons) | Background fine sediment (tons/sq.mi.) | Sediment before treatment (tons) | Sediment before treatment (tons/mile) | Sediment before treatment (tons/sq.mi.) | Percent over background (before) | Sediment after treatment (tons) | Sediment after treatment (tons/mile) | Sediment after treatment (tons/sq.mi.) | Percent over background (after) | Percent reduction due to treatment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beatrice | 6,566 | 53 | 84 | 8.2 | 59 | 1.1 | 5.3 | 70% | 44 | 0.8 | 4.3 | 52% | 25% |
| Belmont | 18,630 | 135 | 40 | 1.4 | 198 | 1.5 | 6.3 | 495% | 40 | 0.3 | 1.4 | 100% | 80% |
| Boiling Springs | 5,490 | 49 | 28 | 3.2 | 27 | 0.5 | 3.1 | 98% | 14 | 0.3 | 1.6 | 51% | 48% |
| Cedar | 16,060 | 41 | 88 | 3.5 | 53 | 1.3 | 2.1 | 60% | 8 | 0.2 | 0.3 | 9% | 85% |
| Goat | 24,440 | 87 | 261 | 6.8 | 45 | 0.5 | 1.2 | 17% | 26 | 0.3 | 0.7 | 10% | 42% |
| Murr | 19,900 | 115 | 79 | 2.6 | 27 | 0.2 | 0.9 | 34% | 12 | 0.1 | 0.4 | 15% | 56% |
| Piper | 7,910 | 22 | 43 | 3.5 | 28 | 1.3 | 2.3 | 65% | 14 | 0.6 | 1.1 | 32% | 50% |
| LeClerc | 66,100 | 267 | 2,479 | 24.0 | 1,787 | 6.7 | 17.3 | 72% | 695 | 2.6 | 6.7 | 28% | 61% |
| Spruce | 15,810 | 39 | 173 | 7.0 | 257 | 6.6 | 10.4 | 149% | 87 | 2.2 | 3.5 | 50% | 66% |
| Ahtanum | 69,850 | 342 | 2,591 | 23.7 | 5,485 | 16.0 | 50.3 | 212% | 3,837 | 11.2 | 35.2 | 148% | 30% |
| Taneum | 29,410 | 78 | 610 | 13.3 | 930 | 11.9 | 20.2 | 152% | 179 | 2.3 | 3.9 | 29% | 81% |
| Total/Average | 280,166 | 1,229 | 6,477 | 14.8 | 8,896 | 7.2 | 20.3 | 137% | 4,956 | 4.0 | 11.3 | 77% | 44% |

Table 2. - Plum Creek Road Sediment Summary (continued)

Belt geology/western Montana

| Watershed | Area (acres) | Road mileage | Background fine sediment (tons) | Background fine sediment (tons/sq.mi.) | Sediment before treatment (tons) | Sediment before treatment (tons/mile) | Sediment before treatment (tons/sq.mi.) | Percent over background (before) | Sediment after treatment (tons) | Sediment after treatment (tons/mile) | Sediment after treatment (tons/sq.mi.) | Percent over background (after) | Percent reduction due to treatment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beatrice | 6,566 | 53 | 84 | 8.2 | 59 | 1.1 | 5.3 | 70% | 44 | 0.8 | 4.3 | 52% | 25% |
| Belmont | 18,630 | 135 | 40 | 1.4 | 198 | 1.5 | 6.3 | 495% | 40 | 0.3 | 1.4 | 100% | 80% |
| Boiling Springs | 5,490 | 49 | 28 | 3.2 | 27 | 0.5 | 3.1 | 98% | 14 | 0.3 | 1.6 | 51% | 48% |
| Cedar | 16,060 | 41 | 88 | 3.5 | 53 | 1.3 | 2.1 | 60% | 8 | 0.2 | 0.3 | 9% | 85% |
| Goat | 24,440 | 87 | 261 | 6.8 | 45 | 0.5 | 1.2 | 17% | 26 | 0.3 | 0.7 | 10% | 42% |
| Murr | 19,900 | 115 | 79 | 2.6 | 27 | 0.2 | 0.9 | 34% | 12 | 0.1 | 0.4 | 15% | 56% |
| Piper | 7,910 | 22 | 43 | 3.5 | 28 | 1.3 | 2.3 | 65% | 14 | 0.6 | 1.1 | 32% | 50% |
| Total/Average | 98,996 | 503 | 624 | 4.0 | 437 | 0.9 | 2.3 | 70% | 158 | 0.3 | 1.0 | 25% | 64% |

Glaciated granitics/NE WA/N ID

| Watershed | Area (acres) | Road mileage | Background fine sediment (tons) | Background fine sediment (tons/sq.mi.) | Sediment before treatment (tons) | Sediment before treatment (tons/mile) | Sediment before treatment (tons/sq.mi.) | Percent over background (before) | Sediment after treatment (tons) | Sediment after treatment (tons/mile) | Sediment after treatment (tons/sq.mi.) | Percent over background (after) | Percent reduction due to treatment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LeClerc | 66,100 | 267 | 2,479 | 24.0 | 1,787 | 6.7 | 17.3 | 72% | 695 | 2.6 | 6.7 | 28% | 61% |
| Spruce | 15,810 | 39 | 173 | 7.0 | 257 | 6.6 | 10.4 | 149% | 87 | 2.2 | 3.5 | 50% | 66% |
| Total/Average | 81,910 | 306 | 2,652 | 20.7 | 2,044 | 6.7 | 16.0 | 77% | 782 | 2.6 | 6.1 | 29% | 62% |

Volcanics/east Cascade slope

| Watershed | Area (acres) | Road mileage | Background fine sediment (tons) | Background fine sediment (tons/sq.mi.) | Sediment before treatment (tons) | Sediment before treatment (tons/mile) | Sediment before treatment (tons/sq.mi.) | Percent over background (before) | Sediment after treatment (tons) | Sediment after treatment (tons/mile) | Sediment after treatment (tons/sq.mi.) | Percent over background (after) | Percent reduction due to treatment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ahtanum | 69,850 | 342 | 2,591 | 23.7 | 5,485 | 16.0 | 50.3 | 212% | 3,837 | 11.2 | 35.2 | 148% | 30% |
| Taneum | 29,410 | 78 | 610 | 13.3 | 930 | 11.9 | 20.2 | 152% | 179 | 2.3 | 3.9 | 29% | 81% |
| Total/Average | 99,260 | 420 | 3,201 | 20.6 | 6,415 | 15.3 | 41.4 | 200% | 4,016 | 9.6 | 25.9 | 125% | 37% |

Table 3. Cedar Creek Sediment Budget

Before Treatment

| Stream Crossing # | Contrib. Road Length (ft) | Tread Width (ft) | Tread Area (acres) | Base Erosion (ton/ac/yr) | Surface Factor | Traffic Factor | Seasonal Use Factor | Tread Erosion (tons/yr) | Cutslope Width (ft) | Cutslope Area (acres) | Base Erosion (ton/ac/yr) | Cutslope Veg. Factor | Seasonal Use Factor | Cutslope Erosion (tons/yr) | Total Erosion (tons/yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C1 | 530 | 16 | 0.19 | 30 | 1 | 2 | 0.67 | 7.79 | 20 | 0.24 | 30 | 0.37 | 0.67 | 1.80 | 9.59 |
| C2 | 1,300 | 14 | 0.42 | 30 | 1 | 1 | 0.67 | 8.36 | 14 | 0.42 | 30 | 0.37 | 0.67 | 3.09 | 11.45 |
| C3 | 900 | 10 | 0.21 | 30 | 1 | 1 | 0.67 | 4.13 | 4 | 0.08 | 30 | 0.37 | 0.67 | 0.61 | 4.74 |
| C4 | 740 | 14 | 0.24 | 30 | 1 | 1 | 0.67 | 4.76 | 3 | 0.05 | 30 | 0.37 | 0.67 | 0.38 | 5.13 |
| C5 | 420 | 10 | 0.10 | 30 | 1 | 0.02 | 0.67 | 0.04 | 0 | 0.00 | 30 | 0.00 | 0.67 | 0.00 | 0.04 |
| C11 | 630 | 14 | 0.20 | 30 | 1 | 1 | 0.67 | 4.05 | 3 | 0.04 | 30 | 0.37 | 0.67 | 0.32 | 4.37 |
| C14 | 140 | 10 | 0.03 | 30 | 1 | 0.05 | 0.67 | 0.03 | 0 | 0.00 | 30 | 0.00 | 0.67 | 0.00 | 0.03 |
| C23 | 1,580 | 14 | 0.51 | 30 | 1 | 1 | 0.67 | 10.16 | 3 | 0.11 | 30 | 0.18 | 0.67 | 0.39 | 10.55 |
| C28 | 170 | 14 | 0.05 | 60 | 1 | 1 | 0.67 | 2.19 | 0 | 0.00 | 60 | 0.00 | 0.67 | 0.00 | 2.19 |
| C39 | 480 | 12 | 0.13 | 30 | 1 | 0.02 | 0.67 | 0.05 | 12 | 0.13 | 30 | 0.37 | 0.67 | 0.98 | 1.03 |
| C40 | 660 | 12 | 0.18 | 30 | 1 | 1 | 0.67 | 3.64 | 3 | 0.05 | 30 | 0.37 | 0.67 | 0.34 | 3.97 |
| Total | | | | | | | | 45.2 | | | | | | 7.9 | 53.1 |

After Treatment

| Stream Crossing # | Contrib. Road Length (ft) | Tread Width (ft) | Tread Area (acres) | Base Erosion (ton/ac/yr) | Surface Factor | Traffic Factor | Seasonal Use Factor | Tread Erosion (tons/yr) | Cutslope Width (ft) | Cutslope Area (acres) | Base Erosion (ton/ac/yr) | Cutslope Veg. Factor | Seasonal Use Factor | Cutslope Erosion (tons/yr) | Total Erosion (tons/yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C1 | 110 | 16 | 0.04 | 30 | 1 | 2 | 0.67 | 1.62 | 20 | 0.05 | 30 | 0.37 | 0.67 | 0.37 | 1.99 |
| C2 | 110 | 14 | 0.04 | 30 | 1 | 1 | 0.67 | 0.71 | 14 | 0.04 | 30 | 0.37 | 0.67 | 0.26 | 0.97 |
| C3 | 110 | 10 | 0.03 | 30 | 1 | 1 | 0.67 | 0.51 | 4 | 0.01 | 30 | 0.37 | 0.67 | 0.07 | 0.58 |
| C4 | 110 | 14 | 0.04 | 30 | 1 | 1 | 0.67 | 0.71 | 3 | 0.01 | 30 | 0.37 | 0.67 | 0.06 | 0.76 |
| C5 | 110 | 10 | 0.03 | 30 | 1 | 0.02 | 0.67 | 0.01 | 0 | 0.00 | 30 | 0.00 | 0.67 | 0.00 | 0.01 |
| C11 | 110 | 14 | 0.04 | 30 | 1 | 1 | 0.67 | 0.71 | 3 | 0.01 | 30 | 0.37 | 0.67 | 0.06 | 0.76 |
| C14 | 110 | 10 | 0.03 | 30 | 1 | 0.05 | 0.67 | 0.03 | 0 | 0.00 | 30 | 0.00 | 0.67 | 0.00 | 0.03 |
| C23 | 110 | 14 | 0.04 | 30 | 1 | 1 | 0.67 | 0.71 | 3 | 0.01 | 30 | 0.18 | 0.67 | 0.03 | 0.73 |
| C28 | 110 | 14 | 0.04 | 60 | 1 | 1 | 0.67 | 1.41 | 0 | 0.00 | 60 | 0.00 | 0.67 | 0.00 | 1.41 |
| C39 | 110 | 12 | 0.03 | 30 | 1 | 0.02 | 0.67 | 0.01 | 12 | 0.03 | 30 | 0.37 | 0.67 | 0.22 | 0.24 |
| C40 | 110 | 12 | 0.03 | 30 | 1 | 1 | 0.67 | 0.61 | 3 | 0.01 | 30 | 0.37 | 0.67 | 0.06 | 0.66 |
| Total | | | | | | | | 7.0 | | | | | | 1.1 | 8.1 |

Table 4.a. Western Montana Mass Wasting Rates

| Watershed | Watershed area (mi²) | Failures/mi² (†) | Mgmt.-related failures/mi² | Debris torrents/mi² |
|---|---|---|---|---|
| Belmont | 29 | 0.00 | 0.00 | 0.00 |
| Beatrice | 10 | 0.29 | 0.19 | 0.00 |
| Boiling Springs | 9 | 0.23 | 0.23 | 0.00 |
| Murr | 31 | 0.00 | 0.00 | 0.00 |
| Goat Creek | 38 | 0.10 | 0.08 | 0.00 |
| Piper Creek | 12 | 0.16 | 0.16 | 0.00 |
| Average | --- | 0.13 | 0.11 | 0.00 |

Table 4.b. Northeast Washington Mass Wasting Rates

| Watershed | Watershed area (mi²) | Failures/mi² (†) | Mgmt.-related failures/mi² | Debris torrents/mi² |
|---|---|---|---|---|
| LeClerc Creek | 103 | 0.39 | 0.35 | 0.01 |
| Onion Creek | 73 | 0.18 | 0.12 | 0.04 |
| Big Sheep Creek | 75 | 0.68 | 0.25 | 0.00 |
| West Branch | 100 | 0.01 | 0.01 | 0.00 |
| Thompson Creek | 29 | 0.03 | 0.03 | 0.00 |
| Huckleberry | 78 | 0.18 | 0.01 | 0.04 |
| Average | --- | 0.25 | 0.13 | 0.02 |

Table 4.c. Washington - East Cascade Slope (east of the RMZ line) Mass Wasting Rates

| Watershed | Watershed area (mi²) | Failures/mi² (†) | Mgmt.-related failures/mi² | Debris torrents/mi² |
|---|---|---|---|---|
| Panakanic | 59 | 0.37 | 0.14 | 0.14 |
| Teanaway | 46 | 0.96 | 0.26 | 0.00 |
| Naneum | 87 | 0.05 | 0.02 | 0.00 |
| Ahtanum | 109 | 0.37 | 0.05 | 0.38 |
| W. Fork Teanaway | 32 | 0.40 | 0.03 | 0.00 |
| Average | --- | 0.43 | 0.10 | 0.10 |

Table 4.d. Washington - East Cascade Slope (west of the RMZ line) Mass Wasting Rates

| Watershed | Watershed area (mi²) | Failures/mi² (†) | Mgmt.-related failures/mi² | Debris torrents/mi² |
|---|---|---|---|---|
| Taneum | 46 | 2.28 | 0.39 | 0.22 |
| Naches Pass | 64 | 0.58 | 0.02 | 0.16 |
| Keechelus | 83 | 2.79 | 1.53 | 0.48 |
| Alps | 60 | N/A | N/A | N/A |
| Big Creek | 43 | 0.74 | 0.53 | 0.12 |
| Cabin Creek | 30 | 2.80 | 2.23 | 0.90 |
| Average | --- | 1.84 | 0.94 | 0.38 |

Table 4.e. Western Washington Mass Wasting Rates

| Watershed | Watershed area (mi$^2$) | Failures/mi$^2$ (†) | Mgmt.-related failures/mi$^2$ | Debris torrents/mi$^2$ |
|---|---|---|---|---|
| Stillman Creek | 38 | 4.74 | 3.63 | 1.08 |
| Big Quilcene | 67 | 1.90 | 1.63 | 0.31 |
| Kosmos | 23 | 8.52 | 8.35 * | 3.35 |
| Jordan-Boulder | 42 | 3.71 | 2.52 * | 1.24 |
| Griffin-Tokul | 52 | 1.98 | 1.87 | 0.21 |
| Woods Creek | 54 | 1.48 | 1.48 | 0.04 |
| Kennedy Creek | 39 | 5.13 | 3.69 | 0.41 |
| Connelly Creek | 5 | 10.40 | 9.80 * | 5.00 |
| West Fork Satsop | 60 | 17.32 | 12.92 | 0.30 |
| Average | --- | 6.13 | 5.10 | 1.33 |

† - Excludes geologically ancient failures

* - Includes failures within "young forest" as management-related failures

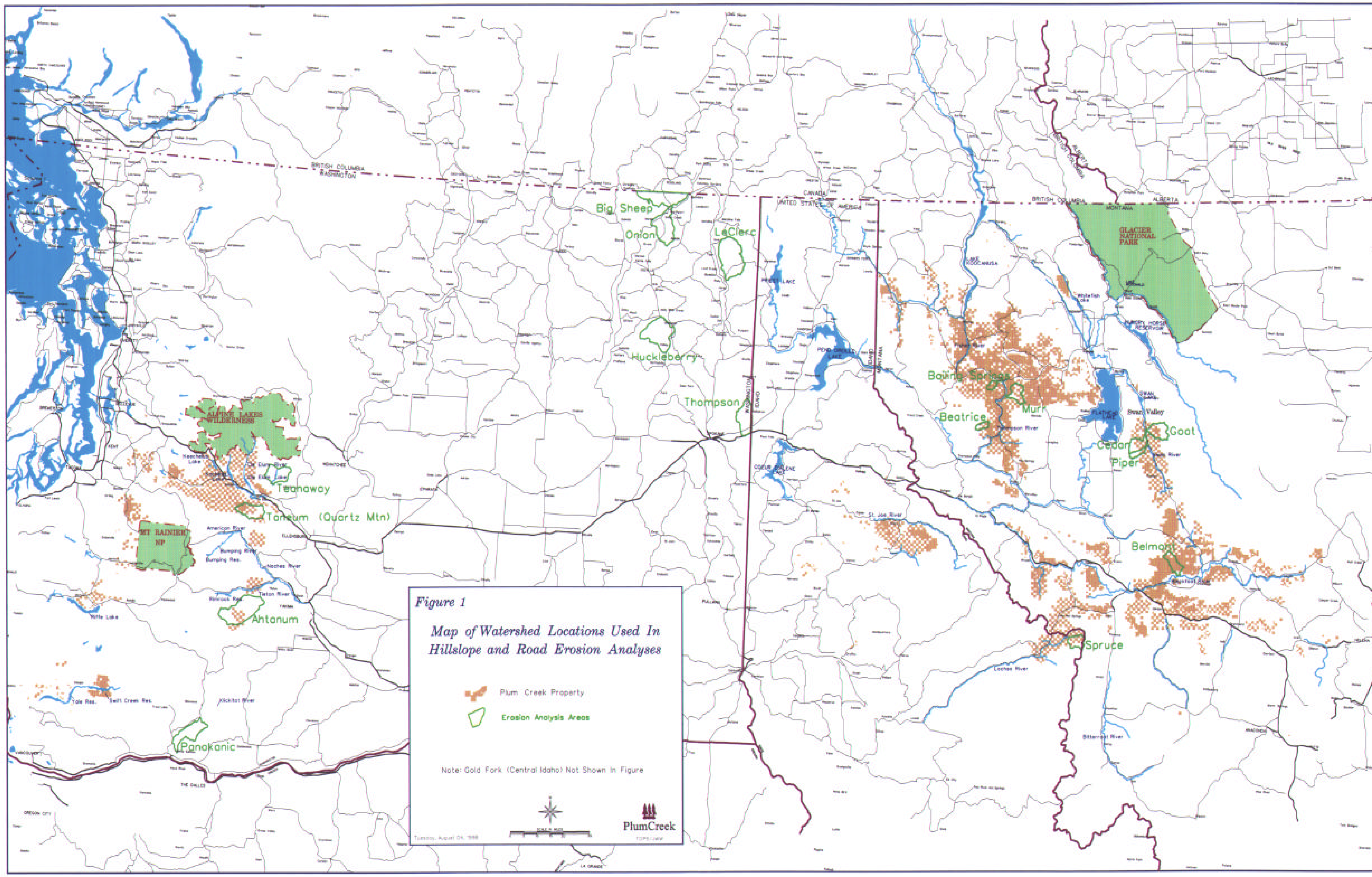
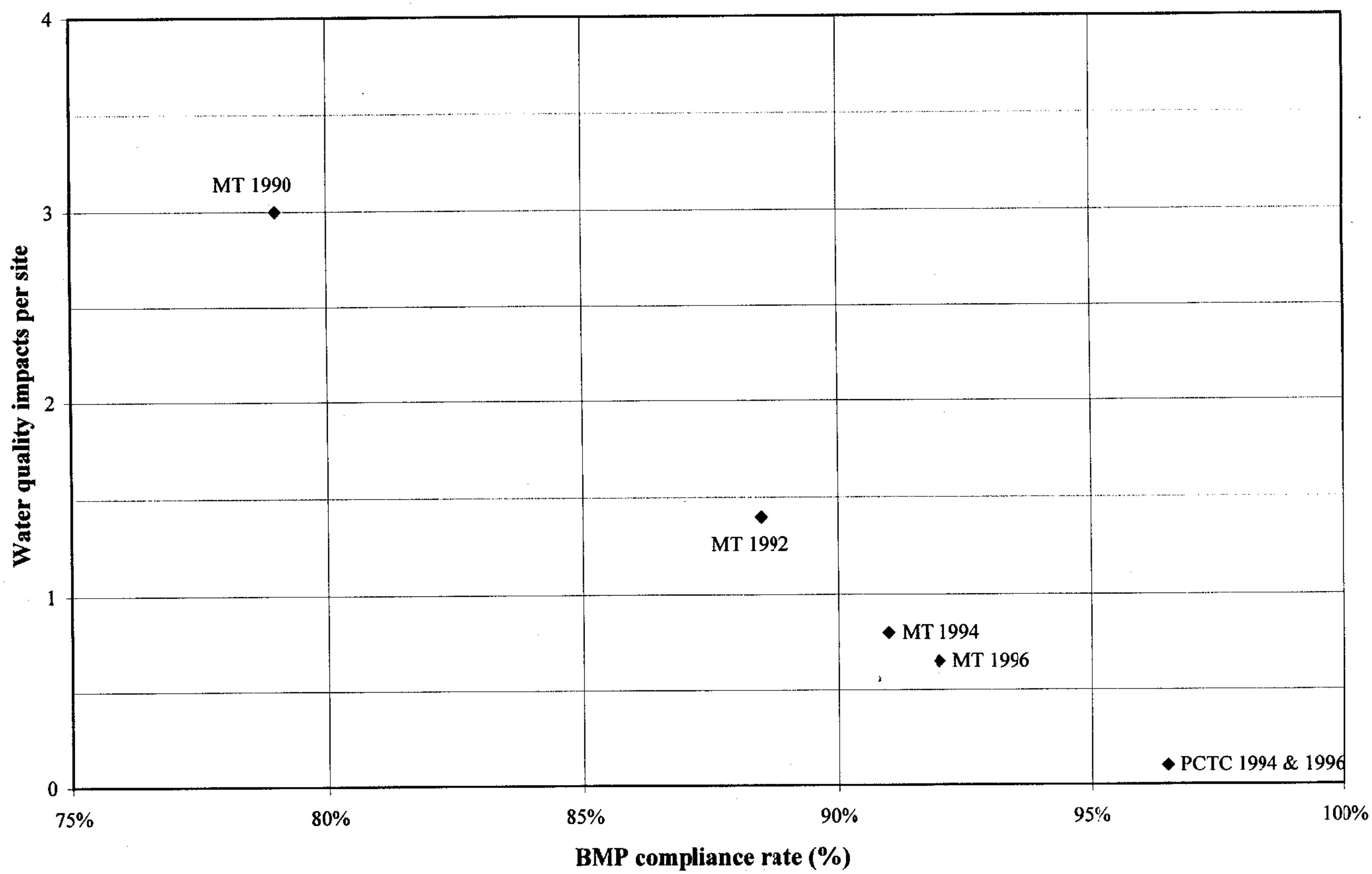



*Figure 1*

*Map of Watershed Locations Used In Hillslope and Road Erosion Analyses*

## Figure 2 - Montana Water Quality Audits



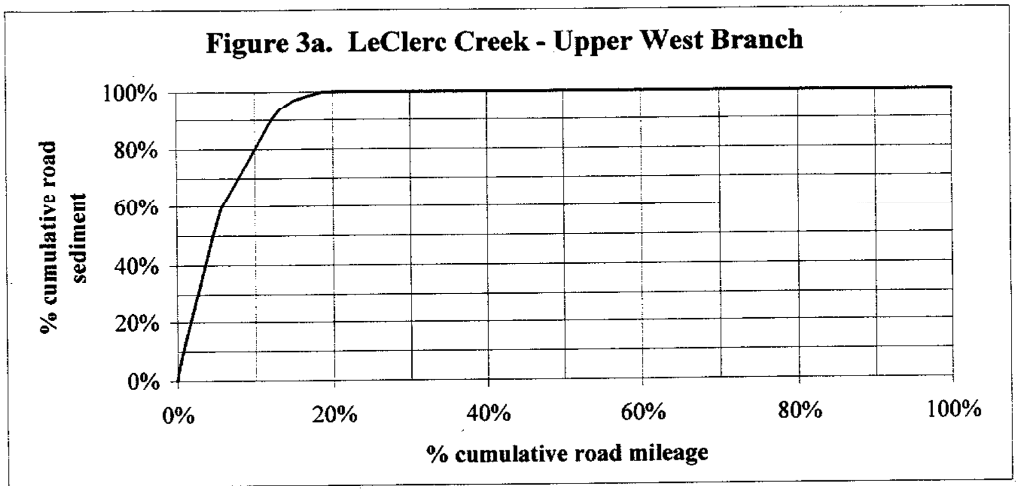


Figure 3a. LeClerc Creek - Upper West Branch
100%
80%
60%
40%
20%
0%
% cumulative road sediment
0%
20%
40%
60%
80%
100%
% cumulative road mileage

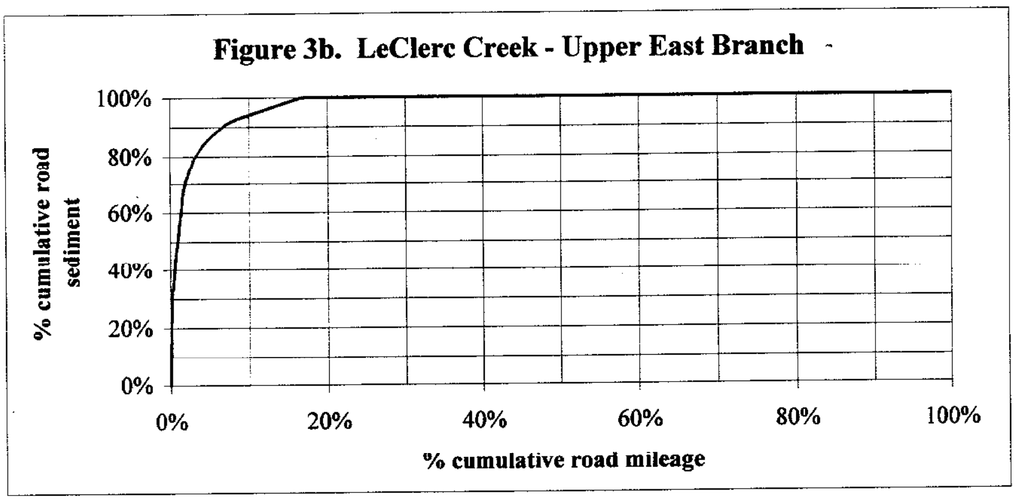



Figure 3b. LeClerc Creek - Upper East Branch
100%
80%
60%
40%
20%
0%
% cumulative road sediment
0%
20%
40%
60%
80%
100%
% cumulative road mileage

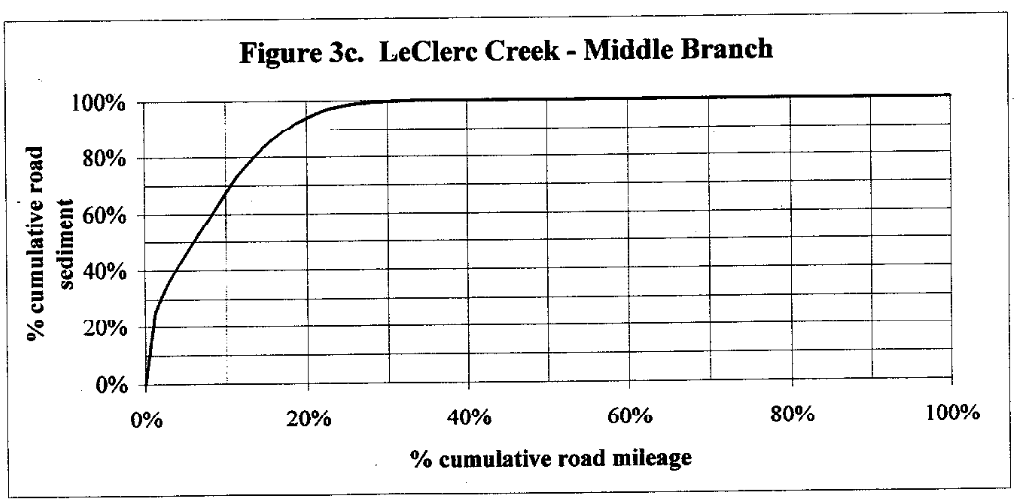
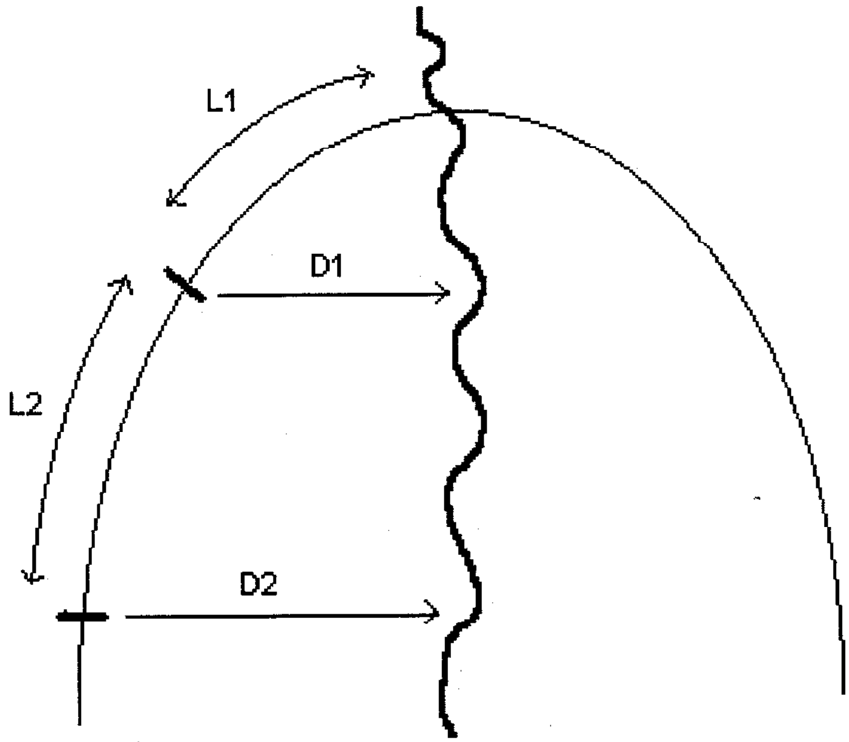



Figure 3c. LeClerc Creek - Middle Branch
100%
80%
60%
40%
20%
0%
% cumulative road sediment
0%
20%
40%
60%
80%
100%
% cumulative road mileage




$L_1$ = spacing between stream crossing and first drain

$L_2$ = spacing between first and second drains

$D_1$ = slope distance from outlet of first drain to stream

$D_2$ = slope distance from outlet of second drain to stream

**Figure 4. Typical Road Crossing Geometry**