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A Comparative Analysis of Surface Erosion and Water Runoff from Existing and Recontoured Forest Roads: O'Brien Creek Watershed, Lolo National Forest, Montana

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In recent years more efforts have been made to return unneeded roads to natural states through obliteration or total recontouring methods. Yet, few data exist to support the road obliteration process. The purpose of this study was to assess some of the relative physical impacts of road obliteration for the O'Brien Creek (Montana) watershed. Three road treatments were chosen: recontoured road at 0 months, recontoured road at 12 months, and existing roads broken down into four segments (cutslope, fillslope, road center and road tread). Two types of geologic formations were sampled (Bonner and Mount Shields) along with two slope categories (<45% (low) and >45% (high)). Each combination of factors was sampled 5 times for a total of 100 samples. Simulated rainfall was applied to each plot in order to assess erosion potential as sediment yield and runoff. Site characterization measurements, such as bulk density, sieve analysis, and organic matter content, were also taken. One-way analysis of variance was used to compare treatment means for the Bonner geologic formation while two-sampled T-tests were used to compare treatment means for Mount Shield samples. Recontoured roads (0 months) consistently had higher runoff and made more sediment available for erosion than any other treatment for both geologic formations. Statistics also showed that in the Bonner there was no significant difference in the recontoured road (12 months) and the natural slopes in the < 45% category for both runoff and erosion. The high slopes for Bonner were split, with no significant difference in the runoff, but significant difference in the erosion. For the Mount Shields there was no significant difference in the recontoured road (12 months) and the natural slopes in the > 45% category for both runoff and erosion. The low slopes were split, with no significant difference in the sediment, but significant differences in the runoff. In all cases it was found that recontoured roads (0 months) produced sediment and runoff comparable or higher than the road segments. But, after allowing for 1-year of revegetation, the volume of runoff and erosion greatly decreased to near natural slope conditions.

PREFACE

I would like to express my most sincere appreciation to Tom DeLuca and Tara Barrett for serving as my co-chairs and co-advisors, and for giving so generously of their time, patience, and guidance over the course of my graduate program at the University of Montana. I would also like to thank my committee members, Marc Hendrix and Len Broberg for their assistance, advice, and encouragement.

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CHAPTER 1: INTRODUCTION

In the words of Forest Service Chief Mike Dombeck,

> "There are few more irreparable marks we can leave on the land than to build a road...Our overriding objective is to work with local people to provide a forest road system that best serves the management objectives and public uses of national forests and grasslands while protecting the health of our watershed" (USDA Forest Service 1998).

Few natural resource issues in recent years have attracted as much public scrutiny as the management of the forest road system.

The United States Forest Service road network consists of 383,000 miles of road (Foltz 1996, USDA 1998). The Lolo National Forest alone is currently managing about 6,500 miles of road (USDA 1993). Many studies in the United States have shown that low-volume forest roads are one of the primary causes of water quality degradation (Elliot et al. 1999). Research by forest land managers and technical specialists nation wide indicate that forest roads are the greatest single source of sediment delivered to streams (Burroughs 1991). In a hydrologically stable environment, a small percentage of roads in a watershed can significantly alter the hydrologic response and sediment yield (Elliot et al. 1996). These impacts include (USDA 1998):

1) Increased frequency of flooding and landslides
2) Increased stream sedimentation and associated reductions in fish habitat productivity
3) Increased habitat fragmentation and degradation which reduces travel corridors for wildlife, such as elk and grizzly bear
4) Increased frequency of person caused fires as a result of access
5) Invasion of exotic species that displace native species

The Chief of the Forest Service recently declared a moratorium on the construction of future roads on National Forest Land until the Forest Service can resolve how to maintain and improve the roads that currently exist. The interim moratorium is considered necessary to safeguard the significant ecological values of unroaded areas from the potentially adverse effects associated with road construction until a new, permanent road policy is in place (USDA Forest Service 1998). Many of the most productive forests in the Pacific Northwest grow on marginally stable slopes where road construction increases the likelihood of erosion (Amaranthus et al. 1985). The moratorium on roads will help the Forest Service make decisions in a more informed manner. New knowledge and concepts in the areas of landscape ecology, managing for healthy ecosystems, habitat fragmentation, etc., give us cause to reevaluate the road paradigm (Lolo National Forest 1991).

Many studies were found to support the belief of road induced forest productivity degradation. In a 6-year study, Packer (1967) found that roads generated 8,443.5 cubic feet of erosion, averaging about 220 times greater than the rates for undisturbed land. In the mountains of the Western United States, forest roads were found to contribute an estimated 85 to 90 percent of the sediment reaching streams in disturbed forest lands (Burroughs 1990). Greater awareness of these problems has moved the Forest Service road system in the direction of road decommissioning.

The Forest Service's National Resource Agenda advocates the decommissioning of 250+ miles of Forest Service roads in the next 3-5 years. There are several different options for road decommissioning: gating, physical barriers, debris on the road prism, partial recontouring, total recontouring, or area closure. The decision to maintain or decommission a road should be based on the maintenance required, transportation system needs, and potential environmental risks. More and more specialists are choosing to remove or "obliterate" unneeded roads, after concluding that road abandonment (closing a road) was not rectifying erosion hazards. Road obliteration is the removal of a road by recontouring it to the "approximate original contour" (AOC) of the natural slope (Bell et al. 1989). It is part of the road decommissioning process and is also called road removal, total recontouring, obliteration, or road restoration. The off-site impacts of altered hydrographs and increased sedimentation have led to the partial or complete removal of roads as a frequent practice in the USDA Forest Service watershed restoration program (Elliot et al. 1999, Harper and Lider 1998). Recently, more and more efforts have been made to return unneeded roads to natural states. Yet, there are insufficient data to support the road obliteration process and decisions (Elliot et al. 1996).

Many Forest Service districts are creating road obliteration programs. Yet, there is a lack of quantitative information available to justify or guide their management decisions. These forests, such as the Clearwater National Forest, Idaho Panhandle National Forest, and Lolo National Forest, are some of the leading contributors to the obliteration process. Their work in the past few years is helping to "pave" the way for more solid and adequate design techniques, with data to help support it. The need for quantitative data is necessary to support current trends in road decommissioning actions.

As the question of erosional problems due to forest roads increases, the Forest Service began to use prediction models, such as WATSED, as a means of extrapolating the use of data. Many have used WATSED generated data to support the use of road obliteration, while others have used the data to refute the method of road obliteration. The use of models has been highly scrutinized due to lack of site-specific information. This lack of site-specific information also affects the choices and results of road decommissioning actions. Surface erosion models are seen by many as too inconclusive to make any solid statements regarding the effects of road related erosion. Current techniques for evaluating the effectiveness of road obliteration/recontouring are based on empirical studies and basic soil erosion properties that are then extrapolated to the forest environment. This has led to administrative and legal challenges to NEPA documents containing road obliteration elements[1]. The Forest Service is unable to quantitatively demonstrate to regulatory agencies the progress it is making toward improving water quality and fish habitat impacted by sediment from existing and recontoured roads.

Based on their location and condition, current unclassified roads will either be tracked as a non-road feature (already closed and revegetating), will be removed/obliterated (need some stabilization), or will be put on the forest system if they are needed for long-term access (Clearwater National Forest 2000). Thus, the greater need for more quantitative data on which to base these decisions.

The purpose of this project is to contribute quantitative information on the effects of a particular road decommissioning practice (road recontouring), relating it to specific site characteristics (geologic type and slope type) of the Lolo National Forest.

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[1] Skip Hegman, Personal Communication, 2000

An ongoing road restoration project in the O'Brien Creek Watershed offered a unique opportunity to monitor and compare the effects of recontoured roads on surface erosion. Total road obliteration was chosen for this study because that was the only method of closure being conducted on this watershed area. Many miles of roads have already been obliterated in the O'Brien Creek Watershed. Here are the some of the visual results obtained thus far, which had lead many to believe that road obliteration succeeds in removing sedimentation problems from the land.

Figure 1.1. Total obliteration road segment (series of 4 months)

(a) Existing road

(b) Newly recontoured road (with path)

(c) One month after seeding

(d) Two months after seeding

(e) Three months after seeding

These roads have been closed to motorized public for many years, and were not going to be reopened. In order to reestablish elk habitat and aesthetic quality, etc. all excess roads are going to be removed by total obliteration techniques as shown in Figure 1.1. This project was going to go forward without any sediment erosion or runoff data, except for predicted measurements from the WATSED model. Thus, it was of great importance to gather this data, in order to determine what potential effects this road decommissioning treatment will have on the area.

CHAPTER 2: LITERATURE REVIEW: EROSION AND LAND MANAGEMENT

2.1. SOIL EROSION PROPERTIES

Soil erodibility is defined as "the measure of a soils' susceptibility to particle detachment and transport by the agents of erosion" (Hudson 1995, Lal 1994). The effects of soil erosion are enormous. Each year, 75 billion metric tons of soils are removed from the land by wind and water erosion with most coming from agricultural land (Pimentel et al. 1995). The normal rate of erosion is inseparably related to the natural mantle of vegetation as it existed prior to disturbance from outside factors, such as man. Erosion rates beyond the normal rates have been termed "accelerated erosion" (Lowdermilk 1930, Hudson 1995). Accelerated erosion reduces the depth of the soil profile on sloping lands and thereby reduces the capacity of the soil to absorb rainwater. Accelerated erosion caused by human activity is detrimental in terms of environmental impacts such as non-point source pollution, creating turbid water, harming stream channels, and silting of reservoirs (Andre and Anderson 1961, Bajracharya 1992). A common index of accelerated erosion is increased silt or suspended soil carried in the streams of run-off water (Hudson 1995).

Moderately eroded soils absorb from 10 to 300 mm less water per hectare per year then uneroded soils, or between 7 to 44% of total rainfall (Mutchler et al. 1994, Pimentel et al. 1995). This leads to a large amount of soil loss every year. The loss of 17 tons of soil per hectare by rainfall can remove nearly 2 tons of organic matter per hectare, greatly decreasing the productivity of the soil (Young 1979).

There are several forms of soil erosion due to water. These are listed in terms of increasing magnitude (Hudson 1995, Lal 1994, Moll 1996):

Groundwater Erosion: Movement of fine material underground due to subsurface flow.

Raindrop Erosion: Occurs as the force of the falling drop dislodges soil particles, making them available for transport. Splash moves some particles to plug pores in the soil surface, increasing surface layer density and decreasing porosity and infiltration, thus further increasing runoff and erosion potential—referred to as "surface sealing". Raindrop impact erosion is greatly increased as vegetation is removed, forest floor organics are disturbed, and mineral soils exposed. Is often seen as the first true phase of erosion.

Sheet Erosion: A direct result of raindrop impact erosion and is relatively uniform over a smooth surface. Sheet flow rarely occurs on undisturbed forest soils due to protective cover, the presence of organics, and interconnected pore space within the upper soil strata.

Rill Erosion: Results when sheet erosion begins to cut into the surface; flow attains sufficient force to detach particles for transport in suspension or by rolling.

Gully Erosion: A continuance of rill erosion and is greatly intensified by water concentration. The capture, storage, and release of moisture is paramount in preventing gully erosion.

Fluvial Erosion: The continuance of gully erosion and is characterized by down cutting in certain areas and sedimentation in others, as eroded material from highlands becomes deposition in lower areas. Sediment delivery contributes to aggraded and widened channels, reduced pools, braided streams, and shallower flows. Fish habitat and water quality suffer as channel erosion and sedimentation are elevated.

Sediment yield is the primary variable of interest in many erosion studies. It is an accepted means of quantifying relative soil erodibility and can be measured when soil particles are suspended and transported (Lal 1994, Lal and Stewart 1995, Middleton 1930, Hudson 1995). Erodibility is a function of soil characteristics, while erosivity is defined as the force driving the soil detachment and transport process (Hudson 1995, Lal 1994). Water erosivity is the influence of raindrop impact, which is a measure of the volume of rain over some duration of time. The detachment and transport characteristics of the soil are a function of raindrop size, velocity, and intensity.

For many years, scientists have attempted to develop an index for relative soil erodibility using soil properties, with varying degrees of success (André and Anderson 1961, Middleton 1930, Wischmeier and Mannering 1969). Many years ago, Middleton (1930) proposed his now famous "dispersion ratio" and "erosion ratio". He defined them as:

Dispersion Ratio = suspension percent/ultimate silt plus clay
Erosion Ratio = dispersion ratio/ratio of colloid percent to moisture equivalent

Erosible Soils = dispersion ratios greater than 10; erosion ratios greater than 15
Non-Erosible Soils = dispersion ratios less than 10; erosion ratios less than 15

By comparing these ratios with the filed reports of erosibility, Middleton noticed association between them, which permitted separation of soils into erosible and nonerosible categories. Middleton (1930) found that the dispersion ratio decreased as the resistance to erosion increased and believed that it was the most valuable single criterion in distinguishing between erosible and non-erosible soils

Many of the basic soil parameters that contribute significantly to soil loss have been studied. These studies have improved the understanding of the complex nature of soil erosion characteristics (Barnett and Rogers 1966, Bubenzer and Jones 1971, Middleton 1930, Wischmeier and Mannering 1969). The influential characteristics are:

- Depth of the A horizon
- Gradient and length of slope
- Soil moisture content
- Carbon content and organic matter content
- Soil pH
- Bulk density
- Percent clays
- Percent silt
- Percent sands
- Soil structure
- Aggregation
- Soil texture
- Iron and Na content

There are three broad groups of factors that influence soil erodibility (Hudson 1995):

1) Physical features of the soil including the chemical and physical composition
2) Topographic features, such as the slope of the land
3) Management of the land i.e. how it is used

The mechanics of soil erosion involves three distinct processes: detachment, transportation, and deposition (Ekern 1950). Soils vary in these mechanics and in their susceptibility to erosion (Middleton 1930, Andre and Anderson 1961, Bajracharya et al. 1992). Clays, particularly those that are tightly bound into large aggregates, tend to be difficult to detach. However, once detached, clays are easily transported and can be suspended and carried in overland flow for great distance (Meeuwig 1970, Gilliam and Bubenzer 1987). Sands are less cohesive and are easily detached, but because of larger size, are less easily transported and are not carried as far by overland flow unless it is rapid and turbulent (Meeuwig 1970). Because of this, the amount of soil transported from each soil type may follow a different order from that detached, since the latter depends mainly on the cohesive forces binding the particles.

Most researchers agree that soil erodibility decreases in the following order of coarse fragments (Bryan 1969):

silt > silt loam > sandy loam > loamy sand > sandy clay loam > loam > clay loam

Generally speaking, soils that are high in silt, low in clay and low in organic matter are the most erodible (Wischmeier and Mannering 1969, Barnett and Rogers 1966).

It was also concluded that one of the principal differences between erosible and nonerosibile soils is the degree of aggregation of the finer mechanical separates into large, stable granules. André and Anderson (1961) found that eroded particles were aggregates rather than mechanical separates. Because of their physical mass, gravel and very coarse sand particles may be very resistant to detachment. Coarse and medium-size particles detach quite readily under raindrop impact. From coarse sand sizes through the silt sizes, resistance to detachment increases, possibly due to the effects of particle cohesion (Farmer 1973).

The soils' resistance to detachment is controlled by shear strength. Shear strength is defined as the maximum resistance a soil can offer under certain stress conditions before particles start to slide over each other (Al-Durrah and Bradford 1981). Convectional rainstorms usually cause overland flow and thus sheet erosion where the soil particles overcome the soil shear strength (Meeuwig 1970). Transport capacity increases with greater amounts of overland flow and is largely determined by rainfall intensity and infiltration rates that are a function of surface roughness, surface sealing, steepness, and length of slope (Lal 1994).

It is from studies such as these that the complex interactions of the soil properties are determined. For example, it was found that for a high-silt soil, increased pH increases erodibility if the structure is very fine or fine granular. If the structure is medium, or coarse granular, subangular, or angular, erodibility decreases with increased pH (Gilliam and Bubenzer 1987). As surface soil is removed by erosion, it appeared that the texture changed, resulting in an increase in the clay content with increasing soil erosion (Lowery et al. 1995). Furthermore, it was concluded that soil structure stability decreases with erosion (Burroughs et al. 1992). This was thought to result from the loss of organic matter.

In addition to reductions in the organic matter, it was discovered that bulk density increased as erosion class increased for most of the 14 soils studied by Lowery and colleagues (1995). Since there was a linear relationship between bulk density and porosity, the porosity decreased with increasing erosion. Because the porosity decreased, the hydraulic conductivity of the saturated soil decreased. Meeuwig (1987) also found that bulk density influences erosion because aggregation and porosity are inversely related to bulk density. He found that well-aggregated soils tended to have low bulk density and greater resistance to erosion. Meeuwig also found that soil of high porosity had good infiltration characteristics and, consequently, produced less overland flow and erosion.

Water also plays an important role in affecting soil erosion properties. (Wischmeier and Mannering 1969; Wischmeier and Smith 1965) Soil properties that influence susceptibility of a soil to water erosion may be grouped into two types:

1) Those properties that affect the infiltration rate and permeability
2) Those properties that resist the dispersion, splashing, abrasion, and transporting forces of the rainfall and runoff.

Meeuwig (1971) conducted a study on the infiltration and water repellency in granitic soils. He found that within the geographical area covered by his study, water repellency was the major limiting factor in the capacity of granitic soils to absorb high-intensity summer rainfall. Other limiting factors discovered were: inadequate moisture storage capacity due to thin soil, surface sealing caused by raindrop impact on soil surfaces unprotected by litter and vegetative cover, and low porosity due to compaction caused mainly by human activity. If the subsurface repellent layer is continuous and unbroken, infiltration is limited to the storage capacity of the wettable surface layer and severe runoff and erosion will occur during high-intensity storms (Meeuwig 1971).

Two factors responsible for a decrease in the infiltration rate with time during a rainstorm are: 1) the decrease in the vertical hydraulic gradient with wetting of the soil profile (the decrease takes place whether the soil is wetted by rain or by flooding) 2) surface sealing, which is of great importance only when the energy of the water drops is involved. Topography plays an important role in soil erosion, as well. Steep land is more vulnerable to water erosion than flat land for the obvious reason that the erosive forces, splash, scour, and transport all have a greater effect on steep slopes (Rose 1962, Ellison 1952, Moldenhauer and Long 1964.)

One of the most highly studied aspects of soil erosion studies is the vegetative cover factor. Percent ground cover by forest litter, duff, and organic material is the principal variable of the forest environment for protecting the soil and reducing surface runoff (Burroughs 1990, Elliot et al. 1996a). Wischmeier and Smith (1965) cite vegetal cover as the greatest deterrent to soil erosion. Packer (1967) concluded that adequate control of summer storm runoff and erosion on wheatgrass range requires at least 70 percent ground cover of plants and litter and that bare openings should be no larger than 4 inches. In Farmer and Van Haveren's study (1971), they found that all three of the soils tested exhibited little resistance to erosive forces when stripped of vegetation. Therefore, they concluded that high-intensity rainstorms over areas of sparse vegetal cover could be expected to produce tremendous quantities of sediment.

Middleton (1930) found that the cover-density variable had a highly significant influence on erosion. His equations indicated that erosion varied inversely as the square of the cover density in the range of cover encountered. Lowdermilk (1930), too, concluded that forest litter greatly reduced surficial runoff, particularly in the finer textured soils; and this influence continued long after the consequent exposure of the soil greatly increased the amount of eroded material and reduced the absorption rate of the soil. He also concluded that the capacity of forest litter to absorb rainfall was significant in comparison with its ability to maintain the maximum infiltration capacity of soil profiles.

Meeuwig (1972) and Hudson (1995) found that soil erosion was more closely correlated with the proportion of soil surface protected from direct raindrop impact by plant, litter, and stone than any other measured variable. The organic matter content of the mineral soil is an important component of vegetation and cover. Soil organic matter facilitates the formation of soil aggregates, increases soil porosity, and thereby improves soil structure, water infiltration, and ultimately overall productivity. Removal of the surface litter layer of the forest floor promotes surface sealing, and crusting that decreases infiltration capacity and increases erosion (Childs et al. 1989). In addition, organic matter facilitates cation exchange, enhances root growth, and stimulates the proliferation of important soil biota (Pimentel et al. 1995, Elliot et al. 1996a). Bryan (1968) and André and Anderson (1961) established a vegetation sequence of erodibility: grass cover is associated with the least erodible soils, forest cover with the intermediate erodible soils, and brush cover with the most erodible soils.

It is well known that the thickness of topsoil decreases with soil erosion; therefore, soil productivity may be reduced. Lowery et al. (1995) suggested a decrease in the available water-holding capacity of the upper soil, the most direct impact on productivity. Lowery et al (1995) also found that as erosion became more severe, the composition of lower horizons increasingly determined the physical properties of the resulting surface layer. Surface erosion proceeds downward from the surface soil horizon. Because the highest concentrations of nutrients and biota and the maximum water-holding capacity are in the uppermost horizons, incremental removal of soil nearer the surface is more damaging than subsoil losses (Elliot et al. 1996b). Productivity may inevitably decline on most shallow forest soils as erosion causes root-restricting layers to be nearer the surface and as organic matter is washed away (Pimentel et al. 1995).

Compaction of surface soil leads to increased erosion potential of the soil. Compaction reduces soil porosity, reduces root growth, plantheight, and in particular reduces the amount of macro-pore volume, which in turn reduces infiltration rates (Meeuwig 1971, Elliot et al. 1996b). Reduced infiltration increases overland flow and kinetic energy available to enhance sediment transport. A soil's resistance to compaction is determined by particle size distribution, texture, and organic matter content. In general, however, the environmental degradation observed in the field results from both compaction and removal of surface organic horizons (Childs et al. 1989).

It was discovered that the soil erodibility index is significantly related to soil-geologic rock type and that the surface-aggregation ratio is also related to geographic zone (André and Anderson 1951). Studies in Oregon (Anderson 1951) showed that soil characteristics associated with geologic rock types and surface aggregation were related to measured discharge from watersheds.

For a given soil, erodibility is a function of its chemical and physical properties. Identifying the most important properties and how they affect soil erodibility, either directly or indirectly through their influence on aggregate stability, structure, or infiltration, has been the topic of many of these studies (Trott and Singer 1983, Middleton 1930). The most extensive of the soil erodibility studies was undertaken by Wischmeier and Mannering (1969). Correlating an array of soil properties with erodibility for 55 cornbelt soils, they found that soil texture, organic matter, structure and pH were among the most important soil properties affecting erodibility.

Middleton (1930) evaluated soils from diverse geographical areas and reported that soil dispersion provided a good indication of a soil's tendency to erode. Anderson (1951), using his surface aggregation ratio (S/A) and Middleton's dispersion ratio (DR), found both erodibility indices significantly related to measured erosion from watersheds. André and Anderson (1961) related these two erodibility parameters to soil forming factors for 168 low-elevation soils in California. Parent rock type, vegetation type, elevation, and geographical zone, were found to be highly significant in influencing soil erodibility.

Correlating watershed studies with soil studies can often be difficult. The indices of relative erosibility may be used to determine the average soil erosibility for a watershed, when the areal extent of the various soil geologic-types is known. The indices may be used together with equations relating erosion to watershed discharge, channel characteristics, and cover characteristics in making quantitative estimates of erosion from watersheds (Anderson 1951). It may be much too difficult otherwise to study these watersheds. Deviations in soil-forming factors from the standard conditions may be expressed as watershed characteristics and evaluated as they affect erosion directly (Middleton 1930). However, soils respond differently to land treatments and conditions based on the soil physical characteristics, and therefore, study results may vary with soil type.

2.2. The Affects of Forest Roads on Sediment Production

As previously stated, the United States Forest Service road network consists of 383,000 miles—approximately 75 percent are unsurfaced, 20 percent are aggregate surfaced, and 5 percent are paved (Foltz 1996, USDA 1998). And the Lolo National Forest is currently managing about 6,500 miles of these roads (USDA 1993). Roads are one of the four basic components of the Forest Service National Resource Agenda (USDA 1998). Almost all visitors to the National Forests use forest roads. They not only make our Nation's wildlands accessible, but they also shape the wildland experience for most forest visitors by determining where they will go and what they will see.

Much of the forest access was built over the last 50 years for timber harvest and log removal (USDA 1998). In the decades after World War II, logging traffic tripled, peaking in 1990. But when timber harvests on the national forests declined in the 1990's, logging traffic plunged to 1950 levels (USDA 1998). Logging now accounts for only one-half of 1 percent of all forest road use (USDA 1993). By contrast, recreational forest road use has soared to 13 times its 1950 rate, dwarfing logging traffic. While keeping this in mind, we need to consider the detrimental effects that recreational use has on the rest of the environmental system.

The Forest Service has a number of definitions for roads that occur on National Forest lands. The definitions are not always agreed upon within the agency, but they do represent most of the terms regarding roads:

Forest Road: Any road that accesses forest resources, regardless of ownership. County, state and private roads that go through national forest land.

Forest Development Road: Any road that is on the transportation system of the US Forest Service. Alternately, any road that exists on national forest land, which remains open and driveable to the public and that is not on any other private/agency/public system.

Historical Road: A road that was formerly a forest development road, which still exists on the ground, is no longer used, but is not closed.

System Road: Any road that is under the jurisdiction of the Forest Service.

Non-System Road: Roads that exist on National Forest land but are not under the jurisdiction of the Forest Service.

Specified Road: Roads that are authorized for a specific resource need.

Specified Short-Term Road: Temporary roads that are constructed by a timber contractor and that are subject to specific design constraints to protect sensitive resource values, and obliterated after use.

Specified Long-Term Road: A road constructed for a timber sale or other resource extraction that is part of the long-term transportation plan. All specified long-term roads are forest development roads, though the opposite is not always true.

Temporary Road: Roads that are constructed for specific resource needs, but are not intended to be part of the permanent transportation system. They are required to be revegetated within 10 years of the completion of their use. They are not tracked by the Forest Service and there are no design standards for temporary roads other than locations and clearing width and state best management practices, unless the road is classified as a specified short-term road.

Intermittent Long-Term Road: A road constructed for resource extraction that will only be used on an intermittent basis. The road prism will be "stored" so the road causes minimal damage to watershed/ecosystem health while leaving it available for future access to resources.

The construction and use of a road is one of the most permanent marks the Forest Service can leave on the landscape. Scientific information continues to increase understanding of the ecological and social impacts of existing roads and associated management activities. Examples of these road-related impacts include (USDA 1998, Moll 1996):

- Increased frequency of flooding and landslides when water concentration potential is built into a road by insloping and/or leaving a berm on the down-hill shoulder.
- Increased stream sedimentation and associated reductions in fish habitat productivity when stumps supporting side cast fills on steep slopes begin to rot, initiating mass wasting of fills and contributing to debris torrents flowing directly into streams.
- Increased habitat fragmentation and degradation which reduces the secure travel corridors needed by species requiring large home ranges
- Increased frequency of person caused fires as a result of access
- Invasion of exotic species that displace native species
- Fines are alternatively generated by passing wheel loads and washed off the road into the stream by storm events.
- A cascade of over-topped pipes and/or a fill washout down the road due to a single cross drain that fails to pass a flow.
- Heavy sedimentation downstream due to a stream diversion initiated by a plugged drainage structure. A uniform road grade rather than a sag vertical curve over the pipe provides an alternative flowpath. A new channel is cut along the road ditch line and results in heavy sedimentation downstream.

Soil erosion in an undisturbed forest is extremely low, generally under 1 Mg/ha/yr^{-} (0.5 ton/acre/year). Disturbances, however, can dramatically increase soil erosion to levels exceeding 100 Mg/ha/yr (50 tons/acre/year) (Elliot et al. 1996a). In most forest watersheds, eroded sediment comes from roads that have no vegetative protection and low hydraulic conductivities, leading to runoff and erosion rates that are greater than in the surrounding forests (Elliot et al. 1994). In a recent study in the Western Cascades in Oregon, Wemple (1994) found that roads could have a significant effect on the surface hydrologic response of small watersheds. Swift (1988) attributed the entire sediment yield from a forest watershed to new road construction. Roads can have major adverse impacts on both surface and subsurface hydrology. The construction-generated and traffic-induced sediment from a road severely disturbs both the surface and subsurface soil, increasing runoff rates, reducing subsurface flows, and altering shallow ground water equilibrium (Elliot et al. 1996a, Swift 1988, Bilby et al. 1989). Roads increase the potential for erosion due to removal of vegetative cover, destruction of natural soil structure, cut and fill slopes which necessarily exceed the original slope gradient, decreased infiltration rates, and interruption of subsurface flow (Megahan and Kidd 1972).

In addition to erosion, roads reduce forest productivity by the lands that they occupy. A kilometer (0.6 miles) of road in 1 km^2 (250 acres) of forest represents a 0.5 percent loss in area and removal from productivity (Elliot et al. 1996a). Forest roads can occupy up to 10 percent of the forest area if there is a history of intensive logging. It is believed by some that the primary source of sediment from logging activities is the roads themselves, used to access forest stands rather than the timber management activities (Megahan and Ketcheson 1996).

Many studies in the United States have shown that low-volume (low-traffic, closed roads (i.e. gated)) forest roads are one of the primary sources of sediment in many watersheds and a major cause of water quality degradation (Elliot et al. 1999). Erosion of road surfaces is of particular concern both because a high proportion of the eroded sediment is introduced directly to streams, and because most sediment from this source is finer than 2 mm. This fine-grained material is the size most harmful to fish and water quality (Reid and Dunne 1984). The probability of sediment depositing on the streambed is positively correlated with its particle size (Bilby et al 1989). The particle size is greatly affected by the disturbance of the soil caused by construction and use of the road.

In an undisturbed condition there is little evidence of any surface erosion and stream sediment is predominantly derived from channel sources (Frye et al. 1982, Pierce et al. 1983). However there is a high potential for surface runoff erosion following disturbance of the forest floor (King and Gonsior 1981). Many of the most productive forests in the Pacific Northwest grow on marginally stable slopes where road construction increases the likelihood of erosion (Amaranthus et al. 1985). The sediment production rate attributed to erosion within the area disturbed by road construction averaged 770 times greater than that for similar, undisturbed land in the vicinity (Megahan and Kidd 1972). In a 6-year study by Packer (1967) the roads he studied generated 8,443.5 cubic feet of sediment, averaging about 220 times greater than the rates for undisturbed land.

Research data shows that traffic on an unsurfaced traveled road can increase sediment production by a factor of 1.90 (Burroughs and King 1989) and erosion is greater for the heavily used roads than for the lightly used roads (Trimble and Weitzman 1953, Reid and Dunne 1984). The increase in erosion with increased use is a result of two factors:

1) Mechanical, as each logging truck passes, part of the soil is carried down the hill and part is compacted.
2) subsoil characteristics

Each succeeding logging truck continues to disturb the soil to a greater depth. The lower part of the soil profile is more susceptible to erosion because infiltration is slower and there is less organic matter at greater depths (Trimble and Weitzman 1953). Heavily used road sections by logging trucks produced sediment at 2 to 25 times as much as lightly used road sections. These values are 1/5 to 1/10 of that reported by one study (Reid and Dunne 1984) and equivalent to another study (Bilby et al. 1989) in similar climates. Trimble and Weitzman (1953) also found that post-logging erosion on the heavily used roads was greater than on the lightly used roads. This, too, is a result of the exposure of the more easily eroded subsoil material through more intensive use (Megahan and Ketcheson 1996, Trimble and Weitzman 1953).

Roads contribute sediment to streams by two primary pathways (Bilby et al. 1989): 1) mass failures of cuts and fill slopes, 2) surface erosion of the road prism, followed by transport of this material to the channel. The two major factors determining the amount of sediment washed from a road surface are: transport capacity of the water flowing off the roads, and availability of eroded material (Bilby et al. 1989).

Transport capacity is a function of rainfall intensity and characteristics of the road segment (Reid and Dunne 1984). Precipitation intensity and amount determine the sediment transport capacity of road surface runoff and, along with characteristics of the road segment, determine the ditch-flow (Bilby et al 1989). Both road gradient and surface area were found to influence the timing and volume of runoff for a given storm (Bilby et al. 1989).

Trimble and Weitzman (1953) found that skid roads on which erosion had apparently ceased for a period of several months show considerable erosion after intense rainfall. The amount of transportable sediment available is largely a function of traffic (Reid and Dunne 1984, Elliot et al. 1999), but is influenced by type of construction of the road (Swift 1984, Elliot et al. 1999), surfacing material (Swift 1984, Kochenderfer and Helvey 1987), and maintenance activity (Swift 1984, Elliot et al. 1999).

The three dominant effects of roads on the environment are: 1) surface erosion, 2) alteration of watershed runoff characteristics, and 3) mass failures (Elliot et al. 1999). Increased mass failures reduce site productivity and water quality, cause loss of fish habitat, and damage roads and bridges (Amaranthus et al. 1985). In Amaranthus' 20-year inventory study (1985), he found that 1.5 million yd^3 of debris slide erosion had occurred. He found the slide frequency to be about one slide every 4.3 years on each 1,000 acres and the erosion rate was about ½ yd^3 per acre per year. Roads occupied only 2 percent of the area inventoried, yet contained over half of the slides and 60 percent of the slide volume. The rest of the study area, which was in natural condition, produced only 22 percent of the slide volume. Amaranthus and colleagues (1985) also found that debris slide frequency and erosion were strongly associated with slope. Terrain with slopes greater than 50 percent accounted for 98.5% of the debris slide erosion, but comprised only 32 percent of the study area.

Road construction practices and their relationship to mass failure were also studied by McClelland and his colleagues (1999). The practices observed varied from sidecast construction, prone to fill failures, to roads that had been located by geotechnical personnel to avoid landslide hazards and were adequately designed and constructed. Fifty eight percent of the 907 landslides on the Clearwater National Forest were found to be road related. We can conclude that land management practice which increases water runoff may bring about a very large increase in sediment erosion (Bethlahmy 1967).

Krammes and Burns (1973) estimated that about 650 cubic yards (497 m^3) of erosion occurred on roads in the immediate vicinity of stream channels in their study. They also concluded that disturbance from road building changed the sediment/discharge relationship of the South Fork. It was changed from a supply dependent relationship to a stream power dependent relationship, resulting in substantial increases in suspended sediment discharges. In the mountains of the Western United States, forest roads contribute an estimated 85 to 90 percent of the sediment reaching streams in disturbed forest lands (Burroughs 1990, King and Gonsior 1981).

Roads appear to advance the time of peak discharge and increases magnitude, changing the flow routing of water (Jones and Grant 1996, Megahan and Ketcheson 1996). Four watersheds that had active road building had statistically significant increases in annual water yield (King 1989). King (1989) concluded that increases in short duration high flows following road building are more important in terms of potential channel erosion and bedload transport than increases in longer duration high flows, such as the maximum mean monthly streamflow.

It must be emphasized that existing roads greatly impact surface hydrology. Infiltration rates of roads are much lower than natural forest soils (4 versus 80 or more mm/hr) (Luce 1996, Wemple 1994), hence, the surface area of roads within a watershed can directly contribute to surface runoff from storms or snowmelt. In most steep forests, much of the water flowing from that forest moves downslope through the soil until it intersects an incised channel (Luce 1999) where roads can intersect or block such flow paths. This subsurface flow is then available to cause instability, direct surface erosion, or to increase erosion when a storm or snowmelt event does occur. When soils in the vicinity of a seep area are saturated, weak, easily detached, and have low to no infiltration, greater local runoff and erosion will occur if crossed by a road (Elliot et al. 1996b).

Several other studies show several characteristics of roads that cause increased erosion potential. Burroughs (1990) and Amaranthus (et al. 1985) showed that wheel ruts increase the erosion rate on roads. Erosion rates were 100 times those on undisturbed areas and produced sediment 2.1 times that of an unrutted travelway. Foltz (1996) found that the wheel track (road tread) had reduced infiltration compared to the non-tracked (road center) portion and, therefore, produced more surface runoff. This may be due to the fact that road materials are more compacted on the road treads, lack organic matter and biological activity, have no surface duff layer, and are mainly mineral soil that are subject to surface sealing (Elliot et al. 1996a). Road treads produce runoff derived from precipitation and may cause gullying of the road surface and the conversion of subsurface water to surface water (Harper and Lider 1998). Concentrated flow causes more erosion than dispersed flow and road treads and ditches are primary sites of concentrated flow on low-volume roads (Elliot et al. 1999).

There is also a relationship between sediment production and road attributes such as distance between drainage relief culverts, road slope, soil texture, and cutslope height (Luce and Cundy 1993). Reid and Dunne (1984) found that multiple regression of average sediment yield against a variety of basin variables showed that sediment production is positively correlated with road length.

From past studies, several researchers determined that on native-surfaced roads, the inter-rill erodibility is similar to that of cropland soils, the rill erodibility is similar to that of rangeland soils, and the hydraulic conductivity is near zero (Elliot et al. 1999, Burroughs et al. 1992). The hydraulic conductivity of native-surfaced roads is much lower than for all other soils, including graveled roads, agricultural soils, and forest soils (Elliot et al. 1999). The conductivity varies from less than 1 mm/h for a native-surfaced or non-graveled road, to more than 80 mm/hr in an undisturbed forest (Elliot et al. 1999).

When abandoned roads are still intact, they are part of the road network that continuously contributes to the detriment of the forest environment. Some of the biggest concerns with abandoned roads are the problems associated with culverts. Often when a road is abandoned, the road drainage system can no longer be maintained and may fail, leading to significant gully erosion problems as water is concentrated by road prisms or backed up by plugged culverts (Elliot et al. 1996a).

Culverts may fail due to blockage or deterioration. If a failed culvert was intended to carry water through a large embankment, drain failure can lead to water backing up and saturating the embankment (Elliot et al. 1996b). Once a large embankment is saturated, it is far less stable than it is in the drained condition, resulting in potential mass failure (Elliot et al. 1994). In other cases, accumulated runoff can saturate segments of road, leading to road-fill failure and debris flow, which can add thousands of tones of sediment to streams (Elliot et al. 1996a). In King and Gonsior's (1981) study of the ditch system, which contributes to the culvert inlet, the amount of sediment in the stream approximately doubled when compared to undisturbed or preroad levels. They also found their primary source of the sediment to be from the roads surface, ditch system, and cutslopes.

Most of the forest road system, particularly local roads, were built to facilitate timber harvest and logging operations. They also provide access for administrative operations like reforestation, surveys, monitoring and fire control, as well as recreation access for the public. Older roads were often built for operator convenience without engineering, location or construction control, or any long-term plan for their use, maintenance, or rehabilitation (Clearwater National Forest 1999). Based on their location and condition, all currently unclassified roads will be either tracked as a non-road feature (already closed and revegetating), will be removed/obliterated (need some stabilization), or will be put on the forest system if needed for long-term access[1].

Many older roads, including those that are overgrown, contain serious mass failure risk factors, like log drainage structure, logs or slash in fills, or saturated fills. They can also have live stream culverts of inadequate size, streams diverted from their normal channels, or fills built on slopes too steep to remain stable (Clearwater National Forest 2000). Considering the arguments there is a strong need to determine how to remove or restore the forest road system.

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[1] Skip Hegman, Personal Communication, 2000.

2.3. Road Decommissioning – The Removal of Forest Roads

The old paradigm of building roads and gating them to control access, but keeping them drivable, is no longer appropriate in all situations. New knowledge and concepts in the area of landscape ecology, managing for healthy ecosystems, habitat fragmentation, etc., give the Forest Service cause to reevaluate the road paradigm (Lolo National Forest 1991). It is not enough to merely consider whether an area should be open or closed to motor vehicles; all forms of access (foot, horse, mountain bike, snowmobile, etc.) must be considered. It may very well turn out that the best road management alternative for one resource concern may not be the best for other resources (Lolo National Forest 1991).

Roads exist to provide access and allow utilization of land and resources. Many forested watersheds exhibit accumulated adverse hydrological and environmental effects from past resource utilization and road building (Moll 1996). Road decommissioning is an increasingly common practice for the purpose of a variety of management goals. Typical road decommissioning objectives are[2]:

- Reduce road maintenance efforts and costs
- Reduce erosion from road surfaces and related sedimentation to streams and aquatic habitat
- Reduce road influences on natural stream and floodplain functions
- Restore natural surface and subsurface drainage patterns
- Reduce the risk of mass failure and slumping and subsequent impact on streams
- Reduce the impact that stream crossings can have on fish passage
- Accelerate successional development towards later seral stage

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[2] Traci Sylte, Personal Communication, 2000

- Change access for wildlife, recreation, etc.
- Change visual quality
- Eliminate or slow down the spread of noxious weeds

When a road is decommissioned, there are at least six fundamental criteria that must be fulfilled:

1) The road is no longer a sediment source
2) There is little to no potential for mass failure other than that which would occur naturally
3) Hydrologic function is returned to all stream crossing areas
4) Natural surface and subsurface drainage patterns are returned to more natural patterns. This is dependent on site-specific variables and closure options
5) The desired access is achieved
6) Noxious weeds have been considered an an eradication plan is established if needed

There are several different levels of road decommissioning. The following is a list of road access management options for Lolo National Forest roads. It is not intended to be all inclusive and combinations of these methods may also be appropriate (Lolo National Forest 1991):

GATE

Definition: A physical structure designed for closure, meeting specific dimensions

Intent: Prohibit non-administrative motorized access, while permitting motorized administrative and most other types of uses, by installing a gate device and affecting a legal closure behind the gate.

Considerations: Appropriate if routine administrative or other authorized access is needed.
Appropriate for seasonal closure.
Relatively high maintenance and enforcement costs.
Does little to reduce non-motorized use; i.e., mountain bikes, horses, or walking.
Must be located on steep terrain to be effective in stopping vehicles from bypassing gate.
Continues to provide for sources of noxious weed introductions and surface erosion though less risk than unrestricted access.

PHYSICAL BARRIER

Definition: About the first 50-100 feet of road entrance is obliterated or large boulders are embedded in roadway.

Intent: Prohibit all motorized access, including administrative, by placing barriers and legal closure behind barrier. May permit other forms of access.

Considerations: Reduced flexibility for administrative use, i.e. fire, road maintenance, post sale work.

Reduced maintenance and enforcement costs compared to a gate.

Less initial cost than a gate, although it may increase costs for pot-sale work.

Provides for continued non-motorized use.

Greater public acceptability than a gate because administrative and unauthorized use is virtually eliminated.

Less likely to have noxious weed spread by motorized vehicles.

No vehicular access for maintenance of drainage structures, which may increase the risk of surface erosion and "washouts".

DEBRIS ON ROAD PRISM

Definition: Placement of enough continuous or intermittent slash or down woody debris to prohibit motorized use and discourage other users of the road prism as a travel corridor.

Intent: Prohibit and discourage all forms of human travel, while not destroying the road prism.

The road prism would remain intact for future uses when necessary, and would be reopened by removal of the debris. Assumes a legal closure is needed as well to prevent people from reopening the road with equipment. If culverts are left in place, it is required to have the ability to drive to area in order to inspect culverts. Used in conjunction with scarification and seeding. Slash shades seed encouraging germination and growth and adds organic matter to the soil as it decoposes.

Considerations: Eliminates all human traffic, including administrative use.

Effective in eliminating most sources of noxious weed introductions.

Shade created by debris may reduce site suitability for weeds.

Aesthetically offensive to some people.

More appropriate for roads with shorter reentry periods than total recontouring.

Avoids secondary sediment peak sometimes associated with total recontouring.

May increase fuel loading.

No access for maintenance of drainage structures.

Little or no maintenance or enforcement costs.

PARTIAL RECONTOURING

Definition: Recontouring the first 100 feet + or intermittent sections of road, leaving the remainder of the prism in place, except where other forms of scarification may be needed to establish vegetation to the road surface. In practice, refers to intermittent sections combined with other obliteration practices from ripping.

Intent: Prohibit all motorized use and discourage foot travel by physical changes to the road prism and legal closure to prevent motorized use.

Considerations: Appropriate where no short term use of the road (less than 20 years) is necessary and where continued access needs to be severely discouraged.
High initial cost, but less cost than total recontouring.
Little or no maintenance or enforcement costs.
In most cases, would be inappropriate for areas where a road is anticipated to be needed again for reentry in a short time period.
Less cost to reconstruct than total recontouring.
Minimizes introduction of noxious weeds.
Potential for increased sediment effects of second disturbance, but less sediment contribution than total recontouring.
Greatest benefits for wildlife species affected by human disturbance.

TOTAL RECONTOURING

Definition: Recontouring the entire length of the roadbed to near-original contour, especially at stream crossings where fill is all removed and flood plain is re-established. Also at other locations judged as impractical or likely to cause unacceptable damage to forest resources.
Intent: As far as practical, remove all evidence of the presence of a road. The objectives can be combinations of discouraging access, enhancing visuals, restoring roadless conditions, restoring native vegetation, etc. One of the more important considerations is sediment reduction and re-establishment of natural drainage.
Considerations: Appropriate where no short term use of the road (currently considered to be less than 20 years) is necessary, and where the continued presence of the road has serious consequences to one or more Forest resources.
High initial cost.
Little or no maintenance or enforcement costs.
In most cases, would be inappropriate for areas where a road is anticipated to be needed again for reentry in a short time period.
Minimizes introduction for noxious weeds.
Minimizes surface erosion and runoff.
Greatest benefits for wildlife species affected by human disturbance.

AREA CLOSURE

Definition: Prohibit use of roaded areas using 36 CFR regulation to restrict various types of entry.
Intent: Use of regulation rather than physical devices as the primary means to restrict use of roads and/or area.
Considerations: Less initial cost than closure devices.
Requires extensive signing.
Lower effectiveness with normal law enforcement effort.
May be adapted to a wide variety of situations.
Locally, this has not been effective where physical closures were not also present.

Each closure level has a range of possible costs (Appendix A).

Few natural resource issues in recent years have attracted as much public scrutiny as the management of the forest road system (USDA Forest Service 1998). The annual maintenance need is estimated to be over $500 million for all forest system roads. This is 5 times the annual maintenance funding. Thus, very few roads are maintained to US Forest Service standards (USDA Forest Service 1998). From 1991 to 1998, funding for decommissioning roads has only financed a reduction of about 0.5% of the National Forest Transportation System per year (USDA Forest Service 1998).

The decision to maintain or decommission a road should be based on the maintenance required, transportation system needs, and potential environmental risks. It is often chosen to just gate a road due to lack of funding for maintenance. One concern with closures of this sort is that after a road is gated, the road drainage system is not often maintained and may fail, leading to significant gully erosion problems as water is concentrated by road prisms or backed up by plugged culverts (Elliot et al. 1996). Culverts can be inspected, but often they are not due to lack of funding, time to do inspections, or available funds put into physical maintenance. In other cases accumulated runoff can saturate segments of a road, leading to road-fill failure and debris flow that can add thousands of tones of sediment to streams. Careful planning and management are necessary to prevent such catastrophic problems. Individuals contemplating road abandonment should consider if the reduced sediment yields without traffic are sufficiently low to protect the forest resources.

In many national forests, much watershed restoration work involves road removal. Most national forests have more roads than can be maintained, and with decreased budgets the amount of unmaintained roads that can be removed is limited (Elliot et al. 1996b). Setting priorities for road closure based on the impacts and risks involved in closing, removing, or discontinuing maintenance has become a major challenge for forest managers. Moll (1996), of the San Dimas Technology and Development Center, created a guide for road closure in the Forest Service. It is a compilation of information on road closure and obliteration and related watershed restoration work. It is meant to work as an aid to resource specialists, engineers, and the interdisciplinary team process. This guide is based largely on submission from Forest Service field units for the Road Closure and Obliteration Project (Road C & O).

Road C & O and related watershed restoration work are steps in environmental healing and initiating return to natural processes (Moll 1996). Many resource specialists consider this work to be a critical component of ecosystem management. The top priority is management goals and depends on the integrated resource needs of the project leaders. As an example, if your top priority was erosion control, then your target would be to: reduce soil and organic loss, embankment washout, sedimentation, turbidity, and damage to the fluvial system and fish habitat; to reduce or eliminate erosion induced damage resulting in reductions to in-situ moisture conservation; and to control eroded sediments so that they do not enter streams (Moll 1996).

Reconditioning worn-out native surface roads, especially in areas of rocky terrain, has always been a problem for road managers (Hegman and Kreyns 1993). More and more specialists are choosing to remove or "obliterate" the roads. Road obliteration is the removal of a road by recontouring it to "approximate original contour" (AOC) of the natural slope (Bell et al. 1989). It is part of the road decommissioning process and is also called road removal, road recontouring, or road restoration.

Many forests are creating road obliteration programs, but they have insufficient data on which to rely. These forests, such as the Clearwater National Forest, Idaho Panhandle National Forest, and Lolo National Forest are the leading contributors to the obliteration process. In the past few years, they have begun to look for more solid and adequate design techniques with supportive data.

The reasons for obliterating roads are based on the objectives of that forest in that particular area and can be the same or different for each forest. In some areas obliteration is driven by wildlife concerns, such as for elk or grizzly bear habitat, and in other areas it is done for watershed and fishery concerns. For example, the objectives for the Clearwater National Forest obliteration program are (Clearwater national Forest 2000):

- Reduce erosion from road surfaces, slopes and related sedimentation of streams
- Reduce the risk of mass failure and subsequent impact on streams
- Restore natural surface and subsurface drainage patterns
- Use road maintenance funds more effectively by concentrating the available funds on roads that are needed for long-term access

The objectives of the Idaho Panhandle National Forest obliteration program are (Harper and Lider 1998):

- Trend the watershed from a "press" disturbance regime toward conditions of a "pulse" disturbance regime[3]
- Increase the resilience of existing fish habitat to existing stresses (riparian harvest, elevated sediment supply, and water yields)
- Increase elk and other wildlife security

The objectives of the Lolo National Forest obliteration project of O'Brien Creek Watershed are (Hegman, Personal Communication, 2000):

- Restore elk habitat
- Restore aesthetic quality
- Use road maintenance funds more effectively
- Reduce the risk of "slumping" from failing road sites

The Clearwater National Forest had many problems with landslides and slumping due to road failure and wetter climate. Road inventories on the Idaho Panhandle National Forest indicated that the greatest problem was the failure of road fills near stream channel crossings (Harper and Lider 1998). A secondary problem on this forest was the gullying of road surface from runoff derived from precipitation and the conversion of subsurface water to surface water at road cuts. The Lolo has some problems with slumping of failing road systems. But the biggest problems with roads on the Lolo National Forest are surface erosion of roads in close proximity to streams, undersized culverts, and

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[3] Press disturbances are permanent or persistent changes to the watershed such as road development and the application of widespread clear-cutting over several decades. Pulse disturbances are described as those that cause relatively instantaneous, local alteration without persistent changes in the physical structure of the system.

insufficient drainage control. Total recontouring (or obliteration) is often chosen so as to prevent mass failures and decrease surface erosion at the same time. In 1998 alone, the Clearwater National Forest (1999) obliterated 134 miles of road. The Idaho Panhandle National Forest decompacted or recontoured 75 miles of road in 1994 and 1995 (Harper and Lider 1998). The Lolo National Forest has obliterated approximately 40 miles of road from 1994 to 2000[4].

Average costs for road obliteration vary depending on the site. Each site has a different soil type, precipitation rate, geologic type, number of stream crossings, etc. Many factors determine how difficult and time consuming a road obliteration project will be. This will vary depending on the width, length, and type of road terrain, number and sizes of stream crossings, culverts, and bridges, and number of erosion problems, such as severe erosion gullies or road slumping.

Clearwater National Forest (2000) estimated an average cost for total obliteration, including planning costs, to be about $10,000 per mile. The Idaho Panhandle National Forest estimated an average cost of $4,640 to $7,550 per mile, depending on the severity of the conditions (Harper and Lider 1998). The Lolo National Forest estimated an average cost for total obliteration on the O'Brien Creek Watershed to be a little over $5,000 per mile, or about $1.00 per foot[5].

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[4] Skip Hegman, Personal Communication, 2000
[5] Skip Hegman, Personal Communication, 2000

To obliterate a road, generally, the following work is performed (Clearwater National Forest 1999, Harper and Lider 1998, Moll 1996):

- Culverts are removed
- Fills are removed in the area around live streams, and stream channels are restored to their original grade
- Ditches are eliminated and the road surface is strongly outsloped or recontoured to provide continuous drainage
- The road surface may be decompacted to promote tree and other vegetative growth
- Disturbed areas are grass-seeded and fertilized
- Erosion control blankets are installed at sensitive locations, such as stream crossings, to control surface erosion
- Other disturbed areas receive straw mulch, native woody debris, or a scattering of logs and stumps
- Native shrubs excavated during outsloping or recontouring are transplanted into the disturbed area

Stability and erosion risks are associated with unmaintained roads, and the same risks are associated with various removal strategies, such as culvert removals, surface ripping, outsloping and recontouring. Several mitigation measures can be taken to prevent damaging levels of sediment from entering streams during the road obliteration process (Clearwater National Forest 1999):

- Placing removable sediment traps below work area to trap fines during obliteration work
- Where necessary, using drainage or diversion pipe in wet areas or when removing large fills
- Utilizing erosion control mats on stream channel slopes and slides
- Constructing road or log weirs to dissipate energy in newly constructed stream channels
- Armoring channel banks and dissipating energy with large rock whenever possible
- Coordinating obliteration activities to avoid spawning times and locations

One of the most important factors in road removal, especially with road obliteration, is the use of vegetation. It was found that percent ground cover is the principal variable to reduce surface runoff (Burroughs 1990). Bell and his colleagues (1989) concluded that rapid vegetation establishment immediately after final recontouring is essential to maintain soil productivity and prevent excessive sedimentation on steep sloped approximate original contour backfills. They found that 80% grass cover should reduce soil loss to approximately the same level as existed prior to disturbance, where topographic conditions are identical.

Site-specific treatments supporting revegetation include:

- Scarification
- Placement of organic debris, soil, logs, and rock
- Fertilizing, mulching, chiping and spreading of slash
- Seeding, vegetative plantings, transplantings

Vegetative cover maintains infiltration capacity, stabilizes the road prism, and protects against erosion (Luce 1997), it also reduces the effects of rainfall impact on soil erosion (Burroughs and King 1989). One year after treatment, litter appeared to be more effective in favoring infiltration of rain into the soil (Lowdermilk 1930). Other researchers have shown the advantages of plant cover, litter, or both for surface erosion control on granitic soil (Packer 1951, Bethlahmy 1967). Yet, reseeding alone does little to control surface erosion until germination and growth of the new plants, and then only if the seed has not been washed from the slope (Burroughs and King 1989, Megahan and Kidd 1972).

Research has shown that surface erosion on recontoured roads can be greatly reduced and areas of mass erosion can be stabilized by deep-rooted vegetation (Megahan 1974). The difficulty is in finding a way of establishing vegetation that will reduce both types of erosion (Megahan 1974, Megahan and Kidd 1972). Gifford (1973) found that chaining and burning of slash, followed by seeding, will cause an increase in runoff for the first few years following treatment, then runoff decreases as the new plants establish themselves. The debris left scattered on the soil surface acts as both retention and detention storage, the magnitude of which is large enough to nearly eliminate all runoff (Megahan and Kidd 1972). The soil under the debris-in-place treatment is not able to absorb water any faster than is the soil under the woodland, but it is held on the landscape until the water is absorbed (Gifford 1973). Mulches caused a highly significant reduction in erosion that averaged about 95 percent of that occurring on the control plots for the 3 years of Megahan's study (1974). He found that planted trees alone provided surprisingly large decreases in annual erosion rates, ranging from 32 to 51 percent.

The filter windrow was found to be one of the most cost-effective methods to reduce surface erosion on disturbed sites (Burroughs 1990). Filter windrows are barriers constructed of logging slash, or any other woody materials around, that slow the velocity of any surface runoff, causing deposition of most sediments (Burroughs and King 1989). It was found that these dense barriers of slash reduced sediment that leaves the fillslope by 75 to 85% over a three-year period following road deconstruction. King and Gonsior (1981) found that the filter windrows in their study captured all of the eroded fill material. They also found that the downslope transport distance of material from unprotected fills was one to two orders of magnitude greater than from windrowed fills.

To reduce watershed degradation by roads that are no longer needed, many roads are being closed and obliterated. Roads are being considered for obliteration, due to budget constraints, access management planning, sediment risks, visual impacts, existing stability, or degree of re-vegetation. (Luce 1997). Ripping is considered so fundamental that few studies have addressed it directly (Luce 1997), and many are using it as a common practice to increase the infiltration capacity of roads during closure. Gifford (1975) reviewed a few studies on the effectiveness of ripping in decompacting rangeland soils. The article reviewed showed that deep ripping could greatly decrease runoff from natural events, while shallow ripping with little surface disturbance had little effect.

If the purpose of the ripping is, in part, to prevent surface runoff, it must increase the infiltration capacity of the soil. A rough surface promotes better water retention for plant establishment, resists erosion, and may even reduce the need for mulching or netting treatments. Rose (1962) has shown that infiltration and percolation are higher on disturbed soils than on undisturbed soils. The only effective method to remove very fine particles from ditchflow is increased infiltration through the soil. This is emphasized by the work of Bilby and his colleagues (1989). Their work showed that retention of the finest size fractions of the material introduced into the two small tributaries occurred only when the flow percolated through the streambed. One of the leading researchers in road reclamation found that ripping and subsoiling alone provide only temporary and marginal improvements reducing surface erosion (Luce 1997). It is for this reason that many have chosen to fully recontour roads, incorporating ripping in their projects with the total removal of the roads.

Swift (1984) studied the sediment production from treated and untreated road segments subject to natural climatic events. In 13.3 months, the treated road segment reduced sediment production by over 85 percent. McClelland and colleagues (1999) reviewed 9.65 km (6 miles) of obliterated roads where treatments ranged from merely closing the road to traffic to full recontouring. They were not aware of any road-associated landslides occurring on the treated roads. Slides did occur on adjacent untreated roads on the same landforms. On the basis of these observations, it was concluded that road obliteration has successfully reduced road-related landslides. About 22.5 miles of road obliteration had been completed on the North Fork drainage prior to the landslide events of 1995/96, and about 5.3 miles had just been completed in the Pine/Fir Creek area of the Orogrande Watershed. No obliterated roads are known to have failed during the floods or since (Clearwater National Forest 1999). All those who have worked with road obliteration and removal in any way strongly agree on the importance of monitoring the completed projects. With little information available, many will look to the data from monitoring to support future road decommissioning projects.

Results of Wemple's study (1994) suggest that removing roads from the drainage network may be an effective first step toward watershed restoration. It is necessary to understand the effects of roads and other disturbances on natural hydrology and identify problem areas in the field prior to designing effective closure and obliteration projects. Roads can concentrate water and inflict damage on natural fluvial systems that can accumulate when combined with other disturbances in the forest. That is why consideration of all possible consequences is critical before deciding to select abandonment. It is expected that nearly all new local roads will be “stored” (not acted upon) for a significant period of time or returned to vegetative production shortly after their use (USDA Forest Service 1993, Clearwater National Forest 2000). Road decommissioning will continue to be done by the Forest Service. It is with this understanding that all options must be reviewed in order to make well-supported decisions.

2.4. The Effects of Rainfall on Soil Erosion and the Use of Rainfall Simulators

"Soil detachment: The removal of transportable fragments of soil material from a soil mass by an eroding agent, usually falling raindrops, running water or wind" (Farmer 1973). The effects of rainfall and raindrop impact on soil, is an important factor in understanding the soil erosion process. For the most part, raindrops provide the detaching force prerequisite for transporting soil particles by the sheet of surface detention water (Farmer and Van Haveren 1971). The process of erosion by water comprises four phases: the detachment of soil particles from the soil by raindrop impact; detachment by runoff; the transport of the detached particles by raindrop impact; and transport by runoff. Through its ability to detach soil particles, raindrop impact is, along with weathering, the first stage in the soil/water erosion process (Quansah 1981, Rose 1960). Where intense rainfall is experienced, this process of raindrop detachment and runoff transportation can give rise to serious agricultural, animal grazing, or engineering problems.

Quantitative measurement of soil detachment due to raindrop impact is needed for a better understanding of soil erosion and rainfall effects. Several researchers have made it clear that before the stage of "rill" or "gully" erosion is reached, raindrop impact is a more important cause of soil detachment than runoff water (Ekern 1950, Ellison 1947, Ellison 1952, Laws, 1941). Research of this nature began as early as 1944 by Ellison (Al-Durrah and Bradford 1981). Since then, many studies on soil splash have been conducted using different devices and techniques. In general, two problems restrict researchers from being able to directly measure the amount of soil splash from a single raindrop at terminal velocity. These are the horizontal drifting of a waterdrop at its terminal velocity and the difficulty in collecting the soil splash (Al-Durrah and Bradford 1981). In order to obtain energies similar to those occurring in natural rainfall, drop towers 8 meters or more must be used. But, at these heights, the drift of free-falling waterdrops becomes a serious problem (Al-Durrah and Bradford 1981). The wind affects the raindrop fall vector and velocity near impact with the soil (Mutchler and McGregor 1979).

Four aspects of drop impact erosion were also investigated by Ekern (1950): the influence of the total amount of impact energy applied to the area eroded; the influence of the energy applied per unit impact; the influence of the slope of the area; and the influence of the size of the particles exposed to the impact. The amount of soil splash from drop impact depends upon forces, which tend to detach material, and opposing forces, which resist particle movement (Al-Durrah and Bradford 1981).

Upon striking bare soil these drops detach particles from the soil mass and the resulting splash carries them as far as two or three feet from their original site (Meeuwig 1970). Farmer and Van Haveren (1971) have also shown that a potentially large amount of soil material can be moved (eroded) downslope by the action of raindrop splash. As previously stated, other studies have show that maximum detachability of soil occurs for particles between diameters of 0.3 to 0.1 mm, and when the size of the soil particle increases, there is a reduction in detachability due to increasing particle mass (Farmer 1973).

Following this direction of findings, several researchers have indicated that the amount or rate of soil particle detachment is directly related to rainfall intensity (Rose 1960, Ekern 1950, Ellison 1947). The potential effects of rainfall can be characterized by a summation of the kinetic energy of the falling drops. Ekern (1950) observed a 7.2 mm maximum diameter in natural rain and determined the terminal velocity as that expressed by Gunn and Kinzer (1949). Ekern discovered that when drop shape, size, and velocity were held constant, the amount of sand transported was directly proportional to the intensity.

Rainfall is made up of water drops of various sizes and shapes falling in an atmosphere of various temperatures, humidity, and wind (Mutchler and McGregor 1979). The erosive capacity of a raindrop depends on the energy per unit area of the individual drop. Laws (1941) observed a 1,200 percent increase in the erosion rate when he increased the drop size from 1 to 5 mm. He attributed this erosion-rate increase to the greater kinetic energy of the larger drops. The kinetic energy of the falling drop determines the force of the blow that must be absorbed at each impact, while the horizontal area of the drop determines the amount of soil that must sustain that blow (Ekern 1950). Many studies of splash erosion have been largely concerned with the establishment of power equations relating splash detachment to the intensity and/or kinetic energy of rain (Bryan 1969, Bubenzer and Jones 1971, Ellison 1952, Quansah, 1981). The kinetic energy computations depend on the mass and velocity of the falling raindrop (Mutchler and McGregor 1979).

Laws (1941) conducted an extensive study of the fall velocity of water drops falling through still air as a function of drop size and fall distance. Gunn and Kinzer's work (1949), although obtained using a different experimental technique, substantiated Laws' data. The fall distance required to reach terminal velocity is dependent upon the size of the drop. For example, a 1.0 mm drop will reach terminal velocity after falling about five meters, whereas a 4.0 mm drop requires more than 10 meters free fall to reach terminal velocity. Bubenzer (1979) obtained results that indicated that there is a rapid increase in mean drop diameter with intensity for rainfall rates up to about 50 mm/hr. There is also strong evidence that at higher intensities the mean drop diameter tends to remain nearly constant or decrease slightly (Meyer 1979).

Rainfall drop size distributions have been parameterized with the D_{50} drop size, where 50 percent of the total volume is less than D_{50}, and 50 percent is greater (Mutchler and McGregor 1979). Laws and Parsons (1943) established an equation to relate median drop sizes to intensities in inches per hour: $D_{50} = 2.23\ I^{0.182}$. Raindrop impact velocities are estimated to be equal to the terminal velocities of water drops. And terminal velocity is often referred to as the square root function of drop diameter for diameters smaller than 3 mm (Mutchler and McGregor 1979). Terminal velocities of waterdrops based on measurements have been well accepted. Laws (1941) reported velocities for drops with diameters from 1.2 to 6.1 mm; and Gunn and Kinzer (1949) studied drop sizes ranging from 0.08 to 5.8 mm, which are both still used as guidelines today.

For most point measures of soil erosion at a given time, the precipitation factors of greatest interest are rainfall intensity, raindrop size distribution, impact velocity, and total rainfall (Farmer and Van Haveren 1971). These factors are not independent of each other. In nature the four parameters are inter-related in a complex manner. Review of past literature indicates that the interaction is highly variable within and between storms and across geographic regions (Barnett and Dooley 1972, Bubenzer 1979, Ekern 1950, Ellison 1952, Fogel et al. 1979, Kinnell 1973, McCool et al. 1978, Mutchler and McGregor 1979.) Kinnell (1973) reported a study of the erosivness of rainfall based on data from Florida, New Jersey, and the Marshall Islands. He calculated values of three parameters: momentum, kinetic energy, and kinetic energy per unit of horizontal area of the drop. He concluded that these parameters vary both for rain type and location. The best example we know of representing regional differences in rainfall is the derivation of the R-factor by Wischmeier for use in the Universal Soil Loss Equation (Mutchler and McGregor 1979, Wischmeier 1962).

No single parameter has surfaced as the best parameter to describe rainfall erosivity over a wide range of conditions; yet, choices must be made among the rainfall parameters as to which is of most importance to simulate (Bubenzer 1979). The need to simulate rain is strong for research purposes. Rainfall simulation was widely used in the past, with some question as to the credibility of its use. With increasing knowledge and improvement of rainfall simulators, it is becoming more widely accepted and thus, used more frequently in scientific studies.

> "Simulate: 1. To give false indication of, pretend, feign.
> 2. To have the external characteristics of. Look or act like."
> (Bubenzer 1979).

Rainfall simulators are devices that apply water to research plots in a manner similar to natural rainfall (Neff 1979). The need for rainfall simulation to conduct scientific testing is increasing. Collecting adequate research data involving natural rainfall is very time consuming because natural weather is so variable. Rainfall simulators can be used to collect data in a relatively short period of time, rather than the 10 to 20 years needed to collect sufficient information from natural rainfall events. To be able to "control" rain and call upon it when needed, as opposed to waiting for nature to take its course, is invaluable.

There are many advantages to using rainfall simulators (Neff 1979): They are cost efficient, and provide a maximum of control over when and where data are to be collected; control over plot conditions at test time; and within design limitations, simulated rainfall may be applied at selected intensities, for selected durations, and at selected treatment conditions. Because of the degree of control that can be exercised over simulator operation, the cost per unit of data collected is quite low when compared to unit costs of long-term experiments depending on natural rainfall. Results from only a few simulated storms at selected conditions often provide desired information (Meyer 1965). Long-term experiments require not only the cost of initial instrumentation but also a great deal of personnel time for plots and instrument maintenance. The degree of control afforded by rainfall simulators provides a technique for collecting a large amount of data in a relatively short period of time. Watershed and simulator studies can compliment each other to accomplish several things: watershed data can be used to verify simulator results and to develop methods for expanding results from plot size to watershed size area; simulators may be used to expand the results of watershed studies over a wider range of rainfall events; and simulators may be used to extrapolate watershed results to other areas (Neff 1979).

There are some disadvantages to rainfall simulation as well (Neff 1979): they can be expensive to construct, depending on the size needed which affects the materials price and the number of people required to operate them; and the areas are small, thus, they may or may not be representative of the general area of concern. They do not produce drop size distributions that are identical to natural rainfall; they are not always able to produce rainfall intensities with the temporal variations of natural rainfall; and some do not produce drops that approach the terminal velocity of corresponding size drops of natural rainfall. The lower velocities in combination with smaller drop size distributions result in lower kinetic energy than that produced by natural rainfall, and this may require some form of compensation (Barnett and Dooley 1972). Although imperfect, rainfall simulators are essential tools for investigation of hydrologic processes on arid and semiarid rangeland where rainfall events are sporadic (Wilcox et al. 1986). Infiltration and erosion studies by rainfall simulator methods are needed to compliment historical and ongoing watershed research.

Rainfall simulators have been used in the United States for about 70 years in many areas of study (Neff 1979). In the early days, primary use of this tool was on cultivated farmland in the East and Midwest (Lal 1994). Other research studies have been done with testing the effect of row spacing (Wischmeier and Mannering 1969), the cropping intensity on soil erosion (Moldenhauer 1979), the effectiveness of various covers on erosion from highway backslopes (Meyer 1960) and construction sites (Meyer 1979), and water pollution from cropland (Moldenhauer 1979, Basta et al. 1997). Numerous erosion studies have produced valuable lasting data since the 1930s (Adams et al. 1957, Barnett and Rogers 1966, Borst and Woodburn 1940, DeLuca et al. 1998, Ekern 1950, Ellison 1947, Ellison 1952, Gifford 1973, Lacey and Marlow 1990, Lowdermilk 1930, Meyer 1960, Meyer 1965, Schmid 1988, Wilcox et al. 1986). Studies involving separation of rill from interrill erosion have been conducted (Mutchler et al. 1994, Young 1979), as well as research on particle movements, infiltration, aggregate stability, soil crusting, detachment, and effectiveness of soil condition in controlling erosion. Using rainfall simulators, size distribution of erosion material has been studied (Weakly, Swanson, Dederick, Young, and Onstad) (Moldenhauer 1979).

Rainfall simulation studies for field use have certain common features: they are portable; can supply "rainfall" when and where needed; have defined field plots that are treated or maintained according to the study objectives; and have procedures for measuring the output from the plots (Neff 1979). The size of simulators varies from small laboratory systems to those covering several acres. They have been used on plots ranging from small cans filled with soil to greater than a hectare (Laflen 1979, Meyer 1979). A large rainfall simulator can apply dozens of rainfall intensities to several large plots at once. A small rainfall simulator can apply several rainfall intensities from less than 10 mm/hr to more than 100 mm/hr on interrill areas of about one meter square or less. It can be set up and taken down in less than an hour and is usually hauled in a truck (Meyer 1979). Uniformity suffers as plot size increases because of edge effects; however, uniformity is very good for plots up to about 3000 square feet and is satisfactory for plots up to 4200 square feet (Neff 1979).

Researchers have invented a wide range of techniques and equipment for simulating rainfall ranging from walking up and down the slope with common sprinkler cans, to elaborate, pushbutton operated electronic and hydraulic machines (Meyer 1979, Meyer and McCune 1958, Mutchler and Hernsmeier 1965). The artificial rainfall factors fall into two main categories: laboratory simulator and outdoor or field plot simulators (Young 1979). And the major techniques used to produce simulated raindrops for erosion and hydrologic studies can be grouped into two broad categories: those involving nozzles from which water is forced at a significant velocity by pressure, and those where drips form and fall from a tip, starting at essentially zero velocity (Meyer 1979).

The "drips from tips" method is the formation of drops on the tip of a material until the weight of the drop overcomes its surface tension to the drop former and the drop falls. It is, therefore, gravity activated. Early forms of this approach used short lengths of yarn hanging through holes in the bottom of a water container (Meyer 1979, Bubenzer 1979). The drop formers were evenly spaced to give a uniform intensity distribution over the test area. However, to prevent the drops from repeatedly falling in the same spot, either the applicator unit or test plot was moved. This rainfall simulator was called the "dripolator" (Mutchler and Hermsmeier 1965). More recently, hollow glass capillary tubes, hypodermic needles, polyethylene tubing, brass or stainless tubes have been used as drop formers. Rate of drop formation is controlled by the length of the tubes, the diameter of the tubes, and/or airtight models into which flow or pressures are controlled (Bubenzer 1979).

Several parameters have been suggested for use in simulator design, but modeling criteria have not yet been accurately delineated. The degree of simulation for any simulator varies according to the criteria used (Meyer 1965, Bubenzer and Jones 1971). Here are the criteria most widely accepted:

1. Drop size distribution is similar to that of natural rainfall (Borst and Woodburn 1940, Meyer and McCune 1958, Nassif and Wilson 1975, Meyer 1965, Shriner et al. 1977).
2. Drop velocity and impact are near terminal velocity (Meyer and McCune 1958, Nassif and Wilson 1975, Meyer 1965).
3. Rainfall intensity corresponds to natural conditions (Meyer and McCune 1958, Shriner et al. 1977, Meyer 1965).
4. Research area is of sufficient size to represent the treatments and conditions to be evaluated (Meyer 1979, Meyer 1965).
5. Rainfall is uniform and has random drop size distribution (Borst and Woodburn 1940, Meyer and McCune 1958, Meyer 1965, Shriner et al. 1977).
6. Raindrop application is nearly continuous throughout the study area (Meyer 1979, Meyer 1965).

7. Angle of impact is nearly vertical for most drops (Meyer 1979, Meyer 1965).
8. Total energy approaches that of natural rainfall (Munn and Huntington 1976).
9. The storm patterns are reproducible (Meyer and McCune 1958, Shriner et al. 1977, Meyer 1965).
10. The simulator is portable for movement from site to site (Meyer 1979, Meyer 1965).

Perhaps the most widely used study in the United States is that of Laws and Parsons (1943). The data from their study has been used in the design of many of the current rainfall simulators and sprinkling infiltrometers (Meyer and McCune 1958, McCool 1979).

Approximating natural drop size and kinetic energy (terminal velocity) characteristics while retaining desirable intensity has been one of the most difficult problems in rainfall simulator design. Results of a study at Pullman, Washington, and Corvallis, Oregon (McCool 1979) have shown a drop size vs. intensity relationship quite similar to that developed by Laws and Parsons (1943), although the intensities were much lower than most of the Laws and Parsons data. Kinetic energy at impact is the characteristic most often used to compare rainfall simulators with natural rain. Most rainfall simulation studies use intensities of about 12 cm/hr, which is far in excess of normal rainfall rates (Bryan 1969, Quansah 1981, Wischmeier and Mannering 1969). Such high intensity rainfall simulation is desired for two reasons: to produce adequate runoff to make up for limited overland flow; and to make up for the low kinetic energy associated with the rainfall simulator (DeLuca et al. 1998).

These studies using field rainfall simulation on small plots have indicated the importance of slope and rainfall intensity in estimating interrill erosion (Bajracharya et al. 1992). And it is these studies that have led to the advancement of knowledge in the area of rainfall characteristics and erosion. For example, studies of the effect of slope shape on soil loss have allowed considerable refinement of the combined slope length and degree (LS) factor of the Universal Soil Loss Equation (Mutchler et al 1994, Young 1979). The single most reliable parameter for relating simulated rainfall characteristics to soil erosion has been the EI factor (the kinetic energy of the applied rainfall times the maximum 30-minute intensity), which was devised by Wischmeier as the best predictor of erosion from a given simulated storm (Wischmeier and Smith 1965, Young 1979):

$$KE = 916 + 331\log_{10} I$$ where KE = kinetic energy and I = intensity

The EI of a simulator application is proportional to the application intensity squared, assuming the simulator applies rainfall at a constant energy per unit of water.

The formation of drop size by the rainfall simulator is of most importance. Drop size and fall distance determine the fall velocity of the simulated rain. Laws and Parsons (1943) reported the average drop diameter for a 10 cm/hr intensity natural rainfall event is about 2.8 mm. Because of the small drop size, kinetic energy of a simulated rainfall of 10 cm/hr is only about 36% of that of a natural event of the same intensity. So, compensations must be made when using a simulator. This is just one of the considerations that needs to be addressed when deciding to use a rainfall simulator for research. Other considerations are test area size, type of erosion or infiltration testing for, plot conditions, water supply, handling convenience, cost, safety, etc. Test procedures have an impact on the results of analysis of rainfall simulator data (Laflen 1979). Data accumulated with rainfall simulation may be subject to some misinterpretation depending upon the type of simulator used and the conditions under which the tests were made (Young 1979).

Rainfall characteristics, such as intensity, drop-size distribution, energy, and duration relationships vary widely across the United States (McCool 1979). Thus, a rainfall simulator should approximate the intensity characteristics of the storms of concern in a region. This will also help in determining what type of simulator one should use. Rainfall simulation is a valuable tool that will only help to further our knowledge of soil erosion processes and characteristics and the effects of our current and future management practices on the land. However, characteristics of natural rainfall must be accurately simulated, data must be judiciously analyzed, and limitations must be clearly recognized for proper interpretation of the results.

Chapter 3: Measuring the Effects of Existing and Recontoured Forest Service Roads on Surface Erosion

3.1. Purpose and Objectives

The purpose of this work was to monitor sediment generation from native surface, timber harvest access roads and decommissioned access roads on National Forest land. The specific objectives of this study were to:

I. Determine if surface erosion and water runoff from these existing native-surface timber harvest access roads differed from surface erosion and water runoff from fully recontoured forest service access roads, taking into account several variables that can affect sediment runoff.

II. Determine the influence of specific road decommissioning treatments (and resultant vegetative cover) on sediment detachment rates across different geologic formations and slopes.

3.2. Description of Study Area

Location

This study was conducted at the O'Brien Creek Watershed in the Lolo National Forest. The O'Brien Creek area in which this project was carried out is approximately 5,760 acres, and lies five miles west of Missoula, Montana. It is bordered on the south by Blue Mountain, on the east by the Bitterroot River, on the north by the Clark Fork River and on the west by the Deep Creek/Albert Creek Divide (Henderson and Hillis 1998). Plots established in this study fell within Sections 19, 20, 29, and 29 of Township 13 North, Range 21 West and Sections 23, 24, 25, 26 of Township 13 North, Range 20 West on the Blue Mountain Quadrangle (Appendix B). The elevation of O'Brien Creek Watershed ranges from 3,000 to 6,800 feet above sea level. Second and third order drainages are deeply incised.

In 1993 and 1994, Owens and Hurst Timber Company built roads, logged most of the property and sold about 600 acres to a neighboring homeowner (Henderson and Hillis 1998). The National Forest portion of this watershed was in private ownership until 1996. Most current private landowners are at lower elevations. The O'Brien Creek map in Appendix B shows the location of the individual plots along with the geologic formation types, the main road, the recontoured roads, and roads that will be recontoured in the future. An extensive road network exists on federal lands. Approximately 40 miles of roads have been recontoured since 1996, with many more miles of road to be recontoured in the future. Prescribed burning is also planned on about 800 acres in the O'Brien Creek Watershed. The 11.7-mile main loop road will be left opened for non-motorized use. Lolo National Forest and Plum Creek Timber, Inc. are the primary land managers.

CLIMATE

The climate of the study area is typical of higher elevation regions. Atmospheric conditions are modified by aspect and slope, and become progressively cooler and moister as elevation increases. Summers are usually dry but occasional thunderstorms are not uncommon. Climatic data, recorded approximately 5 miles south of Missoula Airport, for average high and low temperatures and precipitations are listed in Table C.1 in Appendix C. Rain events are listed in Table C.2 in Appendix C. The average precipitation, for 1961 to 1990, was the highest in June with 2.20 inches and lowest in November, with 0.65 inches. Since 1961 the maximum hourly precipitation rate recorded for a single rainfall event during the months of June through September was 2.87 cm (1.13 inches) (Jim Ashby)[1]. At times the summer temperatures can reach 100 °F, but the average high temperature (for 1961-1990) was only 85.1 °F in July, with the average low temperature being 15.2 °F in January.

[1] Correspondence with Jim Ashby of the Desert Research Institute, Western Regional Climate Center.

SOILS AND GEOLOGY

Source of the soils are formed of thick, very cobbly alluvial, tertiary period deposits, which underlie some of the soils within the area of the study. In other areas soils are formed in weakly weathered quartzite, siltite, and argillites colluvial of the Belt Supergroup. The alluvium consists of stratified sands, gravels and cobbles, and silts. The alluvial gravels and cobbles are primarily made of argillite, siltite and quartzite from the Belt Supergroup. Included are up to 5 percent rock outcrop. Belt Supergroup metasedimentary bedrock can occur along stream channels or near steep mountain slopes. The bedrock is highly fractured and rock fragments have been churned upward by frost action producing extremely rocky soils along with intermittent patches of rubbles on the surface. All of the soils fall within the Ochrept sub-order. Most are sandy soils, but some have a thin volcanic ash mantle (those in the Andic sub-group) providing a loose, fine textured surface soil.

Some of the bedrock also consists of weakly weathered layers of metasedimentary rock that produces hard, angular rock fragments. Upper bedrock layers are usually fractured and permeable to water. They may also be fractured and form talus stringers in drainage ways and toeslopes (USDA 1998). The soil classification from the Land Systems Inventory (Sasich and Lamotte-Hagen 1988) is mapped in Appendix D. The existing and obliterated/recontoured roads are also marked along with the plots. More in-depth analyses of the soil geology are listed in the tables in Appendix E, which also contain the thorough descriptions of the LSI types labeled on the map in Appendix D.

VEGETATION AND WILDLIFE

There is approximately 4,500 acres of O'Brien Creek Watershed that are within the winter range of 100-140 elk and a large number of deer (Henderson and Hillis 1998). The pileated woodpecker, a management indicator species, and the flammulated owl, a sensitive species, also occur in the area. These populations are at extreme risk due to a combination of weed invasion and fire exclusion (USDA 2000). Montana Department of Fish, Wildlife and Parks (MDFWP) and the Rocky Mountain Elk Foundation (RMEF) have supported prescribed burning and road decommissioning activities as a means to help these habitats (USDA 2000). Without weed control and prescribed burning some of these populations are expected to substantially decline in the next decade (USDA 2000).

O'Brien Creek Watershed is also within Land Type Association (LTA) 7: open grown bunchgrass and scattered forest. The fire regime indicates that the historic fire interval has been estimated at 5-25 years (USDA 2000). Vegetation types range from a drier Douglas-fir/Idaho fescue habitat type to a more mesic Douglas-fir/Ninebark habitat type, pinegrass phase, with weeds posing the greatest problem on the open grasslands in the Douglas-fir/Idaho fescue habitat type. Approximately 2,000 acres of the O'Brien Creek Watershed are in a timber/shrub cover type, where weeds are abundant but do not threaten forage productivity. The remaining acres of O'Brien Creek are in a timber/bunchgrass cover type where weeds are dense and severely decreasing forage productivity. The predominant weeds that occur at O'Brien Creek are the spotted knapweed and houndstongue, with pockets of Canada thistle, common tansy, and musk thistle (USDA 2000).

The recontoured roads on the O'Brien Creek Watershed were all seeded and fertilized immediately after recontouring. The current and future seed mixes are listed on the first page of Appendix F. The current seed mix is not an all native seed mixture, thus a new seed mix was created to incorporate only native seed species.

3.3. Plot Layout

Separate field procedures were completed for site characterization purposes and for sediment runoff analysis.

First, plots were chosen with certain variables established:

Table 3.1. Established variables

Slope Category	Geologic Formation	Land Treatment
<45%	Bonner	Natural Slope (control)
>45%	Mount Shields	Recontoured Road (0 months)
		Recontoured Road (12 months)
		Existing Road i. Cutslope ii. Fillslope iii. Road Center iv. Road Tread

Rainfall amount, intensity, duration, and EI were the same for all plots and, therefore, are not variables.

There were 14 different plot types, labeled Plots A-N. Plots A and D need more detailed explanation due to their uniqueness. Plots A and D were road segment plots on different soils, and were broken into 4 smaller sections (cutslope, fillslope, road center, road tread) at five repetitions each, for a total of 20 road segment plots. Then combining the variables into every combination: four natural slope plots labeled as controls, two road plots broken into four sections, four recontoured roads (0 months), and four recontoured roads (12 months), all with five replications each, yielded a total of 100 plots (refer to Table 3.2 below).

Table 3.2. Plot Details

Plot	Geologic Formation	Slope Category	Land Treatment	Time (months)	Replications
A-cutslope	Bonner	n/a	Existing road	n/a	5
A-fillslope	Bonner	n/a	Existing road	n/a	5
A-road tread	Bonner	n/a	Existing road	n/a	5
A-road center	Bonner	n/a	Existing road	n/a	5
B	Bonner	<45%	Recontoured road	0	5
C-(control)	Bonner	<45%	Natural slope	n/a	5
D-cutslope	Mt. Shields	n/a	Existing road	n/a	5
D-fillslope	Mt. Shields	n/a	Existing road	n/a	5
D-road tread	Mt. Shields	n/a	Existing road	n/a	5
D-road center	Mt. Shields	n/a	Existing road	n/a	5
E	Mt. Shields	<45%	Recontoured road	0	5
F-(control)	Mt. Shields	<45%	Natural slope	n/a	5
G	Bonner	>45%	Recontoured road	0	5
H-(control)	Bonner	>45%	Natural slope	n/a	5
I	Bonner	<45%	Recontoured road	12	5
J-(control)	Mt. Shields	>45%	Natural slope	n/a	5
K	Mt. Shields	>45%	Recontoured road	0	5
L	Mt. Shields	<45%	Recontoured road	12	5
M	Bonner	>45%	Recontoured road	12	5
N	Mt. Shields	>45%	Recontoured road	12	5

The locations of these plots within the watershed are labeled in Appendices B and D. A 100-foot uniform segment was measured for each site, using maps and walking out the area for the locations based on expected variables for each site. A random number generator (from 1-100) was used to establish the horizontal positioning (length) of the plot; while a random number was chosen for the vertical positioning of the plot based on the width of the recontoured or established area. Five replications were chosen for each plot site. A 3-foot radius around the plot was allowed for repositioning of the repetition in case of large obstacles (tree stumps, boulders, etc.).

The site characterization plots were run within the same 100-foot segment as the repetition plots for the surface erosion analysis. One site characterization plot was run for each plot for a total of 20 plots, one test per 100-foot segment.

The locations of these plots within the watershed are labeled in Appendices B and D. A 100-foot uniform segment was measured for each site, using maps and walking out the area for the locations based on expected variables for each site. A random number generator (from 1-100) was used to establish the horizontal positioning (length) of the plot; while a random number was chosen for the vertical positioning of the plot based on the width of the recontoured or established area. Five replications were chosen for each plot site. A 3-foot radius around the plot was allowed for repositioning of the repetition in case of large obstacles (tree stumps, boulders, etc.).

The site characterization plots were run within the same 100-foot segment as the repetition plots for the surface erosion analysis. One site characterization plot was run for each plot for a total of 20 plots, one test per 100-foot segment.

3.4. METHODOLOGY

PART I: FIELD METHODS

SITE CHARACTERIZATION MEASUREMENTS

For site characterization analysis, the in-place density of soil was determined using the sand-cone method in accordance with the AASHTO Designation: T 191-93 (AASHTO 1998). Because of sloping on some of the sites, the sand-cone method was slightly modified, by opting to pour sand from a separate container in lieu of attaching a gallon mason jar to the sand-cone apparatus (Calcaterra 1999)[2].

Figure 3.3. Sand-cone apparatus.

The approved sand-cone apparatus with the metal base was used (see Figure 3.3). Bulk density samples were sealed in plastic bags and taken to the lab for analysis (see Figure 3.4). The bulk density of the sand and volume of the sand-cone apparatus were determined in the lab using the procedure described in AASHTO Designation: T 191-93 (AASHTO 1998). This sand information was used to establish the volume of the testing holes in the field.

[2] Jim Calcaterra, Personal Communication, 1999

The locations of the in-place soil density plots were selected via a random number generator. All material (soil and organic matter) from approximately two inches deep was removed from the hole using a metal spoon and placed in a plastic bag (see Figure 3.4 left). The material removed from the test hole was weighed in the field, as was the sand container and sand. The sand-cone apparatus was then placed on the metal plate, with the valve securely closed.

Figure 3.4. Bulk density sample collected in the field.

While one person poured the sand from the container into the sand-cone, the other person steadily opened the valve. Pouring at a constant rate, the person stopped when the sand reached the top of the small cone (see Figure 3.5 right). The sand was then carefully leveled and the sand container was weighed, as it was prior to pouring. The sand-cone apparatus was then removed, and the sand put back into the container, being careful so as not to

Figure 3.5. Pouring sand into sand cone apparatus.

contaminate the sand.

The moisture content and dry mass of the material removed from the test hole was determined by AASHTO Designation: T 265-93 (AASHTO 1998). The samples were then cooled in a desiccator before final weighing. The in-place moist density and dry density of the material were determined by the methods described in this test procedure T 265-93 (AASHTO 1998). The in-place soil density was measured for each site characterization plot, for a total of 20 plots, one test per 100-foot segment length.

Soil sieving test methods for soil texture analysis were also completed for site characterization purposes. Although the majority of the sieving was done in the laboratory, the reduction of large samples of aggregate to the appropriate size for testing was done in the field. Larger samples will tend to be more representative of the total area (AASHTO: T 248-95). This reduction method was done to reduce the large sample obtained in the field to a convenient size while assuring that the test sample was representative of the large sample and thus the site. This procedure still allows for a number of tests to be conducted to describe the material and measure its quality.

Proper randomizations of plots were established for each of the plot characterization sites. A 3-foot by 3-foot plot, approximately 6-12 inches deep, was established. A minimum of 200 pounds of soil aggregate was collected. The total sample was sieved through a 3-inch sieve then a 2-inch sieve, and the rocks collected on the sieves were counted and weighed. The 200-pound sample was placed on a canvas blanket (due to uneven ground surfaces-AASHTO Designation: T 248-95 Method B-

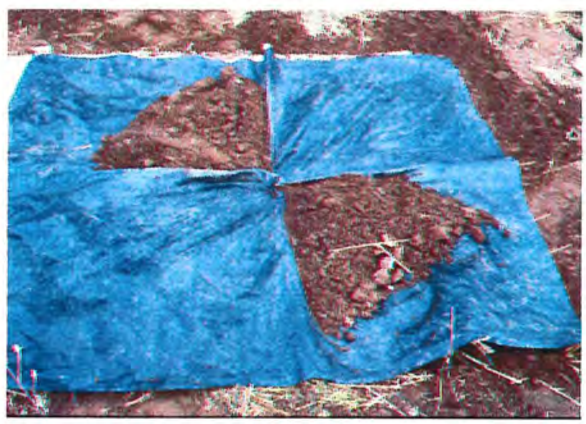
10.1.2), and mixed by rolling. A conical pile was formed on the blanket and flattened to a uniform thickness and diameter (Figure 3.6.). The material was mixed and quartered twice for each sample. Quartering was done in accordance with AASHTO Designation: T 248-95 Method B (AASHTO 1998).

Figure 3.6. Quartering of the samples for sieve analysis.

(a). Soil sample ready to be quartered.

(b). Halving of sample.

(c). Quartering of sample



(d). Opposite sides were removed, using a paint brush to remove any fines.

Approximately 50 pounds of soil aggregate were collected for each site, and brought back to the lab.

SEDIMENT AND RUNOFF MEASUREMENTS

The next set of methods was developed to study sediment generation from existing and recontoured forest service roads. The primary goal of this test was to compare different road and land conditions. It was more efficient to run small rainfall plots in order to control the parameters of the erosion process. In the past, most rainfall simulation work has been conducted during the fall, winter, or spring periods, yet almost all of the runoff result from summer thunderstorms where the cold precipitation (i.e. 50°F) strikes soil surfaces with temperatures well over 100°F (Renard 1979). This project was done in correlation with the Forest Service field season from late May until late October.

Figure 3.7. Modified Meeuwig Rainfall Simulator.

A modified Meeuwig rainfall simulator was borrowed from Henry Shovic of the Gallatin National Forest (Figure 3.7). It is a gravity controlled, modulator-type infiltrometer with a small motor for constant rotation (Meeuwig 1971b). This simulator produces a drop size of 2.8 mm, with a KE roughly one third that of natural rain when suspended from a drop height of 1.5 meters (Meeuwig 1971b). The amount of rain used for each plot was roughly 8.53 cm/hr (3.36 inches/hr). This intensity was roughly three times greater than the maximum hourly precipitation event for the area (Jim Ashby)[3]. This amount correlates to a 100-year storm event for the Missoula area[4].

Figure 3.8. Raindrops formed from the hypodermic needles of the simulator.

To be consistent with previous research and to ensure generation of adequate volumes of runoff, 8.53 cm/hr simulated rainstorm event was applied to all plots for a 20-minute period. This is a lesser amount of rain and a longer duration than the most commonly used values of 12 cm/hr for 15 minutes. This was to both compensate for the lower height of the simulator apparatus, thus a lower impact velocity, and provide adequate runoff. Due to the shorter height of the simulator, less rain than the commonly

[3] Correspondence with Jim Ashby, Desert Research Institute, Western Regional Climate Center.
[4] Correspondence with NOAA Weather Service of Montana

used 12cm/hr intensity had to be used in order to avoid rain streaming[5] (se Figure3.9), leading to an increase in the duration of the simulated storm.

Figure 3.9. Checking the rainfall intensity for rain streaming.

The simulator is made up of a 61.0 x 61.0x 3.0 cm plexiglass box water chamber. It has a motor attached to it powered by a 12-volt portable battery. The motor horizontally rotates the simulator to evenly distribute raindrop positions, which simulates natural rainfall more accurately, and stops constant impact of the drops on the same spot. Twenty-four rows of staggered stainless steel hypodermic needles protrude from the bottom of the water chamber. The tubes project 3.2 mm above and 9.5 mm below the plexiglass base of the chamber (See Figure 3.8). Tubing was attached to the top center of the box for connection to the water supply. Five-gallon (18.93 liters) water boxes (Figure 3.10) filled with distilled and dionized water were used for the water source, so as to avoid clogging of the needles caused by hard water. Three boxes (15 gallons, 56.78 liters) of water were used for each individual plot. The water supply was positioned above the rainfall simulator with 2-feet of head, so as to produce a constant pressure from gravitational flow (avoiding rain streaming) (se Figrue 3.10). Tubing

[5] Rain streaming is when the water released from the needles consistently pours out and does not drip.

adaptors were used to simultaneously connect the three water boxes to the rainfall simulator. Constant rainfall was administered for 20 minutes at each individual site.

A metal tripod, designed and built by Steve Monlux, the Northern Region Materials and Geotechnical Engineer, was used as a stand for the simulator. The tripod was lightweight and able to be taken apart, allowing for easier transport (Figure 3.10). Small chains were attached to the simulator, which were then attached to the tripod, allowing the simulator to hang from the center. The least distance from the simulator to the ground was 1.1 meters (3.5-feet) at the lowest side, with an average height of 4.5 feet. Three collapsible metal panels (made by Missoula Sheet Metal) were used to form the 1-m^2 plots. The metal was driven deep enough into the ground to avoid major subsurface water movement, and extended above the ground far enough that water from outside the plot did not enter and vice versa (Meyer 1965). To prevent seeping, the metal edging was sealed to the ground with bentonite.

Figure 3.10. Simulator setup with materials: simulator, metal tripod, water source, battery, metal panels collection jug.

Figure 3.11. Bentonite seal on triangle edge.

A triangular piece of metal was used for the fourth side of the square plot. The triangular piece had tubing attached to its bottom point where the runoff was to escape. The long edge of the triangular piece closed off the square box. The long side was sealed with bentonite (Figure 3.11) where the metal edge was driven into the ground. The other two sides of the triangle had raised edges, which prevented the runoff from flowing off the triangle (Figure 3.12). A plum bob was used to square up the simulator with the 1-m^2 plot.

All runoff was funneled into gallon milk jugs set at the bottom of the plot to be taken to the lab. The tubing connected to the triangle pan was inserted into the milk jugs. New jugs were switched in when necessary (Figure 3.13). Total volume of runoff collected was measured and subtracted from the amount of water applied to the

Figure 3.12. Raised edges on the triangle piece to catch runoff.

plot in order to determine infiltration. In case of wind, a tarp was wrapped around the simulator for protection (Figure 3.14). a sign was placed on the plot when raining began until a constant rainfall rate was established. The sign was then removed and the timing began (Figure 3.15).

Figure 3.13. Switching collection containers (milk jugs).

The rainfall simulator was tested at the lab in order to determine the average amount of water used per run. The simulator was tested every 2 weeks for 10 weeks. Five trials were run for each of the 5 water usage tests, for a total of 25 trial runs. Head height was 0.61 meters (2 feet) above the simulator, the simulator was set up at 1.1 meters (3.5-feet) above the plot, and constant rain was maintained for 20 minutes. All the rain was collected and measured to determine the volume used per run. The average amount of water

Figure 3.14. Tarp used to block wind.

Figure 3.15. Sign used to cover plot until constant rain was established.

collected from the 25 water usage tests was 27.78 liters with a standard deviation of 0.36. Under these established specifications, approximately 2.84 (1.12 inches) of water "rained" on each plot in the field.

This simulator proved to be very durable on steep slopes, easily transportable, fairly lightweight, relatively inexpensive, and can be administered by one person, although more than one person is highly recommended.

PART II: LABORATORY METHODS

SITE CHARACTERIZATION ANALYSIS

Separate laboratory procedures were completed for site characterization purposes and for sediment runoff analyses. Further testing for the in-place soil density and sieve analysis (of the quartered samples) was continued in the lab in order to complete the analysis.

The total mass of each moist bulk density sample (Figure 3.16) was weighed on balances conforming to AASHTO Designation: M 231-95 (AASHTO 1998). All samples were dried overnight in a drying oven controlled at 230° F, in accordance with AASHTO Designation: T 265-93 (AASHTO 1998; AASHTO 1998) and then weighed again. A sieve analysis was done on the total amount of dried material removed from holes, in order to establish a particle size distribution of the in-place soil density sample. This test method followed AASHTO Designation: T 27-97 (AASHTO 1998). All sieves conformed to the AASHTO Standards: M 92 (AASHTO 1998). The sieve sizes used for the in-place soil density analysis were: 3", 2", 1 ½", 1", ¾", ½", 3/8", and a #4, nesting the sieves in order of decreasing size of opening from top to bottom.

Figure 3.16. In-place (bulk) density samples.

Figure 3.17. Organic matter content samples for each site.

The organic content of the in-place density soil samples was determined by the loss on ignition procedure, AASHTO Designation: T 267-86 (AASHTO 1998). A representative sample of 10 to 40 g was selected for each of the site characterization plots in accordance with AASHTO Designation: T 2-91 (AASHTO 1998) (Figure 3.17). The samples were placed into the muffle furnace overnight at a constant temperature of 851 °F (AASHTO 1998). These samples were prepared before the ignition phase by drying in a 230 °F oven during the in-place soil density analysis phase in AASHTO Designation: T 265-93 (AASHTO 1998). The percent organic matter was then calculated.

The quartered samples that were collected in the field were then prepared for the sieve analysis. Each of the site characterization samples weighed approximately 40-65 pounds after quartering. The total amount of each sample was weighed and dried according to AASHTO Designation: T 87-86, and M 231-95 (AASHTO 1998). The samples were then put in the drying oven at a constant temperature of 140 °F, for 3 days (AASHTO 1998).

The total samples were then placed, individually, in a large mechanical sieve shaker for 20 minutes. The sieves used were: 1½", 1", ¾", ½", 3/8", and #4. The individual weight retained on each sieve was recorded, as was the percent retained and percent passing, AASHTO Designation: T 27-97 (AASHTO 1998). All sieves conformed to the AASHTO Standards: M 92 (AASHTO 1998).

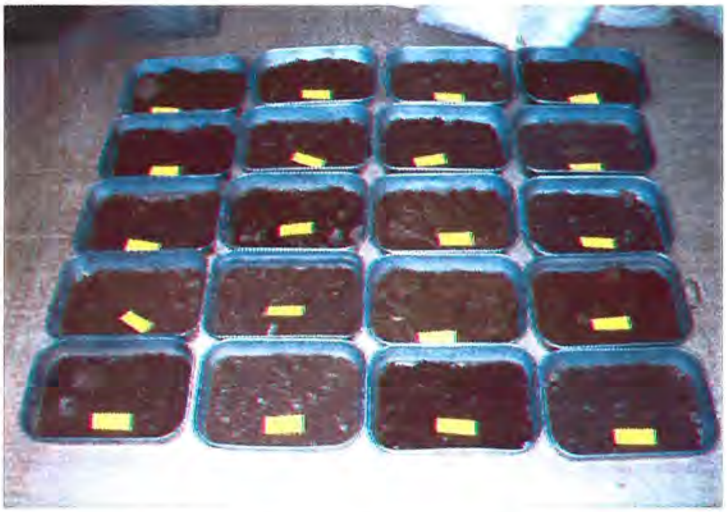


Figure 3.18. Sieve sub-samples for each site.

These samples were then split to an approximate size of 450-550 grams following the specification of AASHTO Designation: T 2-91 (AASHTO 1998) (Figure 3.18). A medium, closed-type mechanical splitter meeting the splitter specifications of AASHTO Designation: T 248-95 Method A (AASHTO 1998) was used.

The next test method, washing the aggregate, was to determine the mount of material finer than a 75-µm (No. 200) sieve. Clay particles and other aggregate particles that are dispersed by the wash water will be removed from the aggregate during the AASTHO Designation: T 11-91 test method (AASHTO 1998). Materials finer than the 75-µm (No. 200) sieve are separated from larger particles more efficiently and completely by wet sieving than through the use of dry sieving (AASHTO 1998). AASHTO Designation: T 87-86 was used for balance specifications. A nest of two sieves were used, the lower being a 75-µm (No. 200) sieve and the upper being a sieve with an opening of 1.18 mm (No. 16), both conforming to the ASHTO Designation: M 92. The sample was then dried in a 230°F oven over-night.

The dried samples were then sieved in accordance to AASHTO Designation: T 27-97 (AASHTO 1998). The sieve sizes used for the final step in the completed sieve analysis were: #8, #16, #30, #50, #100, #200, and a -#200, nesting the sieves in order of decreasing size of opening from top to bottom. This was done for each site characterization plot for a total of 20 plots.

Two sub-samples of each site characterization sample were measured out for the hygroscopic moisture analysis and the hydrometer analysis, AASHTO Designation: T 88-97 (AASHTO 1998). The purpose of these analyses is to obtain a "grain size accumulation curve" by using the accumulated percentages of grains of different diameters. This information is then graphed on semilogarithmic graph paper. The samples were obtained from the previously sieved material collected in the -#4 pan. The samples were split in accordance with AASHTO Designation: T 2-91 (AASHTO 1998). A 10-25 gram sample was obtained for the hygroscopic moisture analysis. The samples plus the beaker were weighed on regulation scales, and then placed in the drying oven at 230 °F overnight (AASHTO 1998). The samples were then cooled in the desiccator and weighed again. The hygroscopic moisture content was then calculated.

The hydrometer analysis was run on the sieve samples collected for the site characterization analysis (Figure 3.19). The samples were split in accordance with AASHTO Designation: T 2-91 (AASHTO 1998). A 45-80 gram sample was obtained for the hydrometer analysis. Preparation of the sample was conducted in accordance with the

AASHTO Designation: T 88-97 (AASHTO 1998). The mixture was allowed to soak for a minimum of 12 hours (AASHTO 1998).

Several sub-samples were prepared before beginning the hydrometer analysis, five samples if only one person was running the test, and ten samples if two people were running the test.[6] Agitation of the slurry, and proper reading techniques and use of the hydrometer were followed in accordance with the AASHTO Designation: T 88-97 (AASHTO 1998). A 152H-calibrated hydrometer was used and subsequent readings were taken at intervals of 5, 15, 30, 60, 250, and 1440 minutes after the beginning of settling. Analysis of the hydrometer readings is temperature dependent.

Figure 3.19. Hydrometer analysis.

Hydrometer readings were corrected by applying the approximate composite correction for the dispersing agent used, temperature of the suspension, and height of the meniscus on the stem of the hydrometer (AASHTO 1998). The soil hydrometer was calibrated at 68 °F, and variations in temperature from this standard temperature produce

[6] It was too difficult for one person to run more than 5 samples alone; there is a much greater chance of error. With two people running the test method, more samples could be run in one day with less chance of error.

inaccuracies in the actual hydrometer readings. The amount of the inaccuracy increases as the variation from the standard temperature increases.

Sediment and Runoff Analysis

Upon completion of the site characterization analysis, laboratory tests were conducted on the sediment and water runoff collected. The milk jugs containing all samples collected were allowed to settle for two months (Figure 3.20). The water was

Figure 3.20. All sediment and runoff samples collected. The number of jugs per site was dependent upon the treatment conducted on the site.

poured off (Figure 3.22), leaving the sediment, and then weighed, AASHTO Designation: M 231-95 (AASHTO 1998). A sub-sample was taken from the thoroughly agitated water runoff (poured out of the milk jugs) and poured into a pre-weighed drying pan. The sub-samples were then placed in a 230° F oven overnight to dry. The samples were cooled in the desiccator, and then weighed again. The amount of sediment in suspension from the

Figure 3.21. Sub-samples for sediment in suspension.

sub-sample was measured and used to correlate back to the total amount of sediment in suspension in the total amount of water runoff collected (Figure 3.21).

The milk jugs containing the sediment erosion, were cut (fore better drying), then placed in the drying oven at 140°F for 4 days, AASHTO Designation: T 87-86 (AASHTO 1998) (Figure 3.22a and b). The dried sediment was removed from the milk jugs by scraping. The total mass in grams of sediment collected from each rainfall simulation plot was used as a measure of the relative erosion potential of different land treatments/conditions. The sediment collected was weighed and then pulverized with a mortar and rubber pestle.

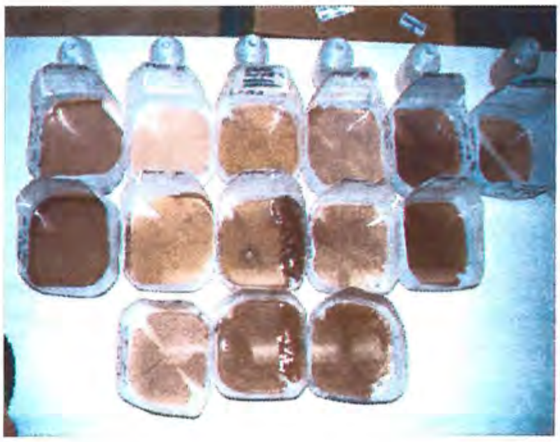


Figure 3.22a. Top view of cut milk jugs containing sediment erosion only (without runoff).

Figure 3.22b. Front view of cut milk jugs and suspended sediment sub-samples.

The samples were split in accordance with AASHTO Designation: T 2-91 (AASHTO 1998), and a hygroscopic moisture analysis was completed, AASHTO Designation: T 88-97 (AASHTO 1998).

The samples were then split for the hydrometer analysis, AASHTO Designation: T 88-97 (AASHTO 1998) (see Figure 3.19). After the hydrometer analysis was completed, a fine sieve analysis was conducted AASHTO Designation: T 11-91 (AASHTO 1998) in order to find the largest particle size removed from the plot site. The sediment used in the hydrometer analysis was washed over a 75-μm (No. 200) sieve, and dried in a 230° F oven, overnight. The dried samples were then sieved on #8, #16, #30, #50, #100, #200, and a -#200 sieves, nesting the sieves in order of decreasing size of opening from top to bottom. The samples were of much finer material, thus the need for a more precise balance, AASHTO Designation: M 231-95 (AASHTO 1998). Percent passing, total percent retained, percent in various size fractions, and total weight retained per individual sieve were calculated. The accumulated percentages of grains of different diameters were plotted on semilogarithmic paper to obtain a "grain size accumulation curve". This was completed for each plot repetition for a total of 100 samples.

Figure 3.23. Samples in various stages of analysis.

PART III: STATISTICAL METHODS

SITE CHARACTERIZATION ANALYSIS

Statistical analyses were not run on the site characterization data. The data was for general site descriptive purposes and only one sample was taken for each site.

SEDIMENT AND RUNOFF ANALYSIS

This experiment was considered to be a case of psuedoreplication, because although replications were chosen in a completely randomized manner, the replication within treatment units were chosen specifically to meet the factor criteria of slope, treatment and geologic formation. The statistical package SPSS 10.0 was used to analyze all results.

The data analysis were separated into water runoff and surface erosion categories. This was further separated by geologic formation, due to the unequal variances of the Mount Shields data. The categories were Bonner and Mount Shields geologic formation-high (>45% slope) and Bonner and Mount Shields geologic formation-low (<45%) for surface erosion and runoff. The same road segment was tested against both the Bonner and Mount Shields-high slope and Bonner and Mount Shields-low slope, due to the inapplicability of the slope criteria on the road prism. The purpose was to compare the effects of roads on the land against natural slopes and recontoured roads; high and low slopes do have an effect on the natural slope and recontoured road conditions.

The analysis of variance (ANOVA) procedure of SPSS 10.0 was used to test the significance of treatment and slope for the dependent variables, surface erosion and water runoff, for Bonner geologic formation only. Levene's test, at alpha $\geq$ 0.05, was used to evaluate the degree to which the data met the assumption of homogeneity of variance required by ANOVA. The Bonner surface erosion data was transformed, using a cubic root transformation, in order to equalize the variances and meet a Levene's criteria of alpha $\geq$ 0.05. The Bonner water runoff data was transformed, using a square root transformation, in order to equalize the variances and meet a Levene's criteria of alpha $\geq$ 0.05. The Tukey's Honestly Significant Difference (HSD) post hoc test was used.

The Mount Shields data was unable to meet the criteria set for the Levene's test. Thus, ANOVA was not run on the Mount Shields data. Instead two-sampled T-tests were used to compare selected treatments for sediment erosion and water runoff. No transformations of data were necessary. Control was compared to recontoured road (0 months), recontoured road (12 months), and road-fillslope. Recontoured road (12 months) was compared to recontoured road (0 months) and road-fillslope, as well. And recontoured road (0 months) was compared to road-fillslope, along with the other comparisons. This made for six treatment comparisons. Fillslope of the road was chosen over the other road segments because it had the least amount of sediment and runoff production. The confidence interval was set at alpha $\geq$ 0.05, and divided by 6 (the number of comparisons). This gives a confidence interval of 0.008, allowing for a more conservative estimation. For each of the two slope categories, both with sediment and runoff, the following hypothesis were tested with a two-sided T-test:

- H_0: No road = Recontoured road at 12 months
- H_0: No road = Recontoured road at 0 months
- H_0: No Road = Fillslope
- H_0: Recontoured road at 12 months = Fillslope
- H_0: Recontoured road at 0 months = Fillslope
- H_0: Recontoured road at 12 months = Recontoured road at 0 months

CHAPTER 4: RESULTS

4.1. SITE CHARACTERIZATION RESULTS

To reiterate, the bulk density was taken for site characterization reasons only and not for statistical purposes, thus only one sample was taken for each site.

Table 4.1. Dry in-place (bulk) density for all sites

PLOT	Soil/Aggregate Dry Bulk Density		Soil Dry Bulk Density	
	(lbs/ft^3)	(g/cm^3)	(lbs/ft^3)	(g/cm^3)
A-Cutslope	85.14	1.37	46.00	0.74
A-Fillslope	59.51	0.95	40.29	0.65
A-Road Center	76.43	1.23	58.33	0.94
A-Road Tread	76.67	1.23	63.79	1.02
B-(0 months)	77.19	1.24	55.60	0.89
C-Control	17.42	0.28	14.67	0.24
D-Cutslope	71.35	1.14	49.00	0.79
D-Fillslope	38.30	0.61	11.59	0.19
D-Road Center	73.75	1.18	61.72	0.99
D-Road Tread	97.14	1.56	79.10	1.27
E-(0 months)	105.95	1.70	75.20	1.21
F-Control	92.06	1.48	73.57	1.18
G-(0 months)	78.24	1.25	60.00	0.96
H-Control	46.49	0.75	37.14	0.60
I-(12 months)	43.33	0.69	29.39	0.47
J-Control	44.57	0.71	15.36	0.25
K-(0 months)	80.26	1.29	49.29	0.79
L-(12 months)	61.54	0.99	27.50	0.44
M-(12 months)	61.58	0.99	43.44	0.70
N-(12 mnonths)	81.14	1.30	46.80	0.75

Figure 4.1. Soil/aggregate dry in-place (bulk) density

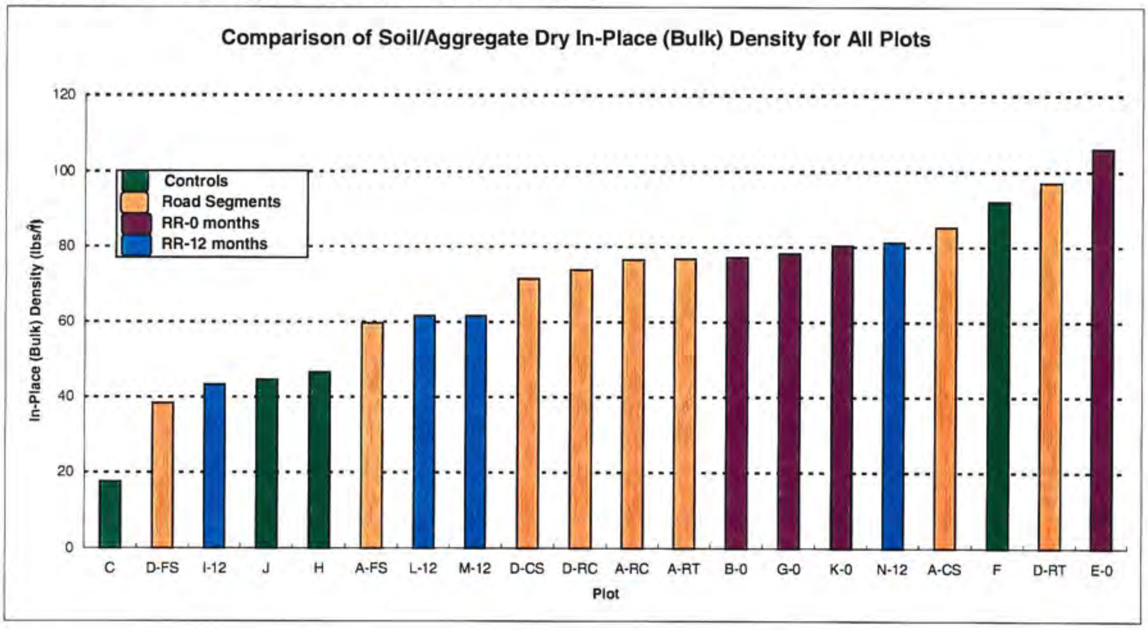
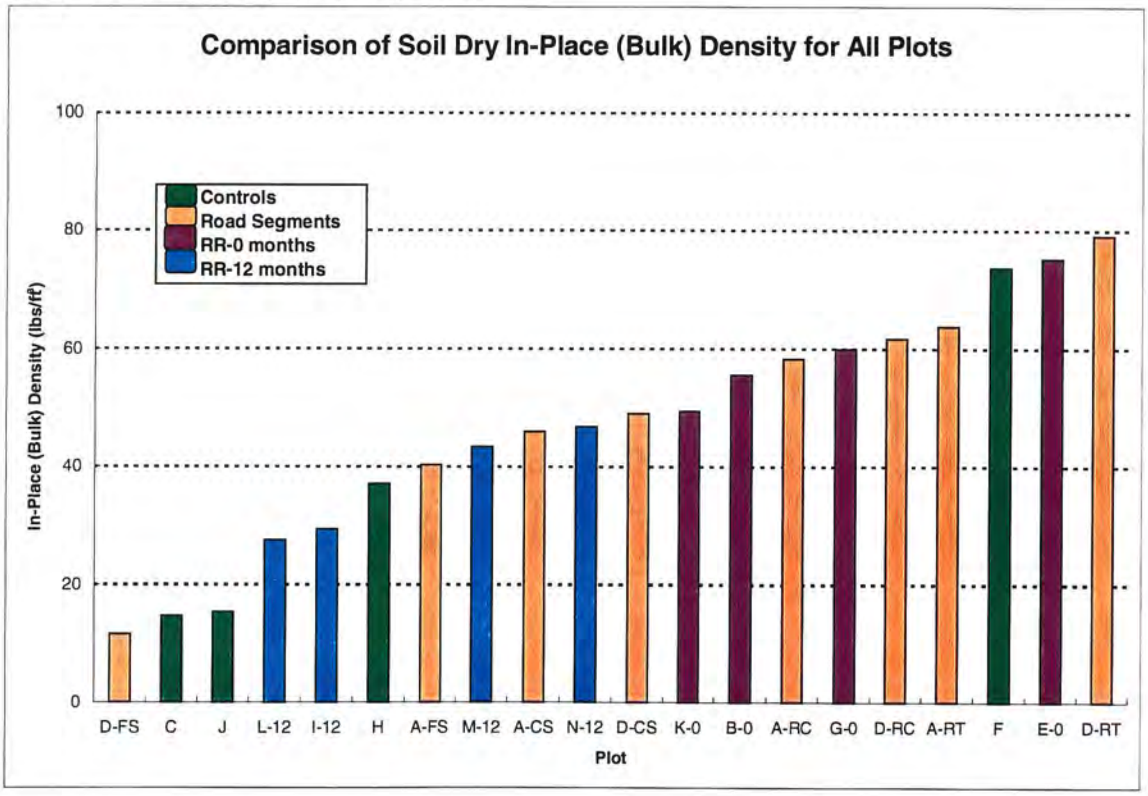


Figure 4.2. Soil dry in-place (bulk) density



As the Table 4.2, and Figures 4.1 and 4.2 show, the control plots tended to have lower bulk density values than the rest of the plot sites, with the exception of control plot F. This was true for both the soil/aggregate analysis and the soil analysis alone (Figures 4.1 and 4.2). Both of the fillslope plots (A and D) had low bulk density values. They were comparable to the control bulk density values. This was true for both the soil/aggregate analysis and the soil analysis alone (refer to Figures 4.1 and 4.2). This may be the result of large amounts of vegetation on the fillslopes.

The recontoured road (12 months) plots had lower bulk density values, also. This may be related back to vegetation, as well. These plots were highly disturbed when recontoured, but then seeded and fertilized and allowed to revegetate for one year. In the soil/aggregate analysis for recontoured road (12 months) plots, three of the four plots had lower bulk density values when compared to all other plots (Figure 4.1). The exception was Plot N, which had a much higher value. This may be due to the lack of revegetation, higher slope category, and higher coarse fragment content of the site. But, without the aggregate factor, the bulk density value decreased, having lower values.

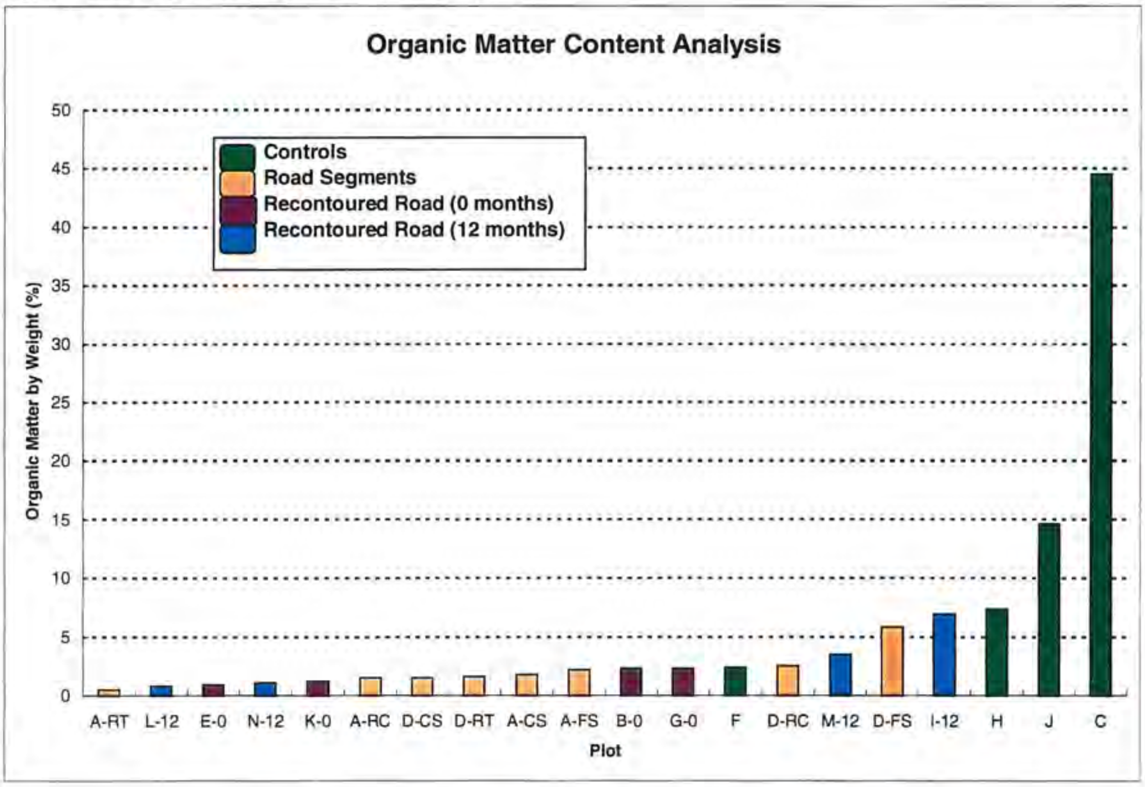
The rest of the road segments (cutslope, road center, road tread) tended to be clustered around the middle of the graph, with only two plots located on the high end of the scale. This is only true for the soil/aggregate analysis (Figure 4.1). For the bulk density of the soil analysis alone, the plots were fairly evenly spread out with middle to high bulk density values. There was a high variability of aggregate content for the various road segments. For the recontoured road (0 months) plots, the bulk density values were high when compared to all other plots. In the soil/aggregate analysis there was some clustering of the values, but when focusing on the soil alone, the values tended to be more spread out (Figure 4.2). The bulk density values seemed to create a trend with the controls being the lowest, followed by the fillslopes, the recontoured roads (12 months), the rest of the road segments, and the recontoured roads (0 months) having the highest values.

An organic content analysis was conducted for each site (Table 4.2).

Table 4.2. Organic Content Analysis

Plot	% organic Matter by Weight
A-Cutslope	1.8
A-Fillslope	2.2
A-Road Center	1.5
A-Road Tread	0.5
B-(0 months)	2.3
C-Control	44.5
D-Cutslope	1.5
D-Fillslope	5.8
D-Road Center	2.5
D-Road Tread	1.6
E-(0 months)	0.9
F-Control	2.4
G-(0 months)	2.3
H-Control	7.3
I-(12 months)	6.9
J-Control	14.6
K-(0 months)	1.2
L-(12 months)	0.8
M-(12 months)	3.5
N-(12 months)	1.1

Figure 4.3. Organic Matter Content Analysis



Organic Matter content was highest for the control plots, with plot F being slightly lower than the other three control plots (Figure 4.3). This is the result of the large difference in vegetative cover at each of the sites. Site F had barren ground with approximately 80% knapweed covering the site. No other vegetation was present on site F. The other three control plots had small green plants, duff, pine needles, grasses, etc., covering most of the area. See Figure 4.4 (a-d) for the differences in the control plot sites.

Figure 4.4 (a-d) Control (natural slope) sites

(a) Control Plot H
Bonner, >45% slope

(b) Control Plot C
Bonner, <45% slope

(c) Control Plot J
Mount Shields, >45% slope

(d) Control Plot F
Mount Shields, <45% slope

Two recontoured road (12 months) plots also had high organic matter content when compared to all other plots. Both of these plots, M and I, happened to be located in the Bonner geologic formation. The other two recontoured road (12 month) plots, L and N, were on the Mount Shields geologic formation. Plot D-road center and Plot D-fillslope, had relatively high organic matter contents, as well. These two plots had higher amounts of vegetation and were of the Mount Shields geologic formation. The rest of the road segment plots were clustered around the middle to lower values.

The results for recontoured road (0 month) plots were divided with two plots having middle values and two having lower values. The two middle valued plots, B and G, were of the Bonner geologic formation, while the two low valued plots, Plots E and K, were of the Mount Shields geologic formation (Figure 4.3).

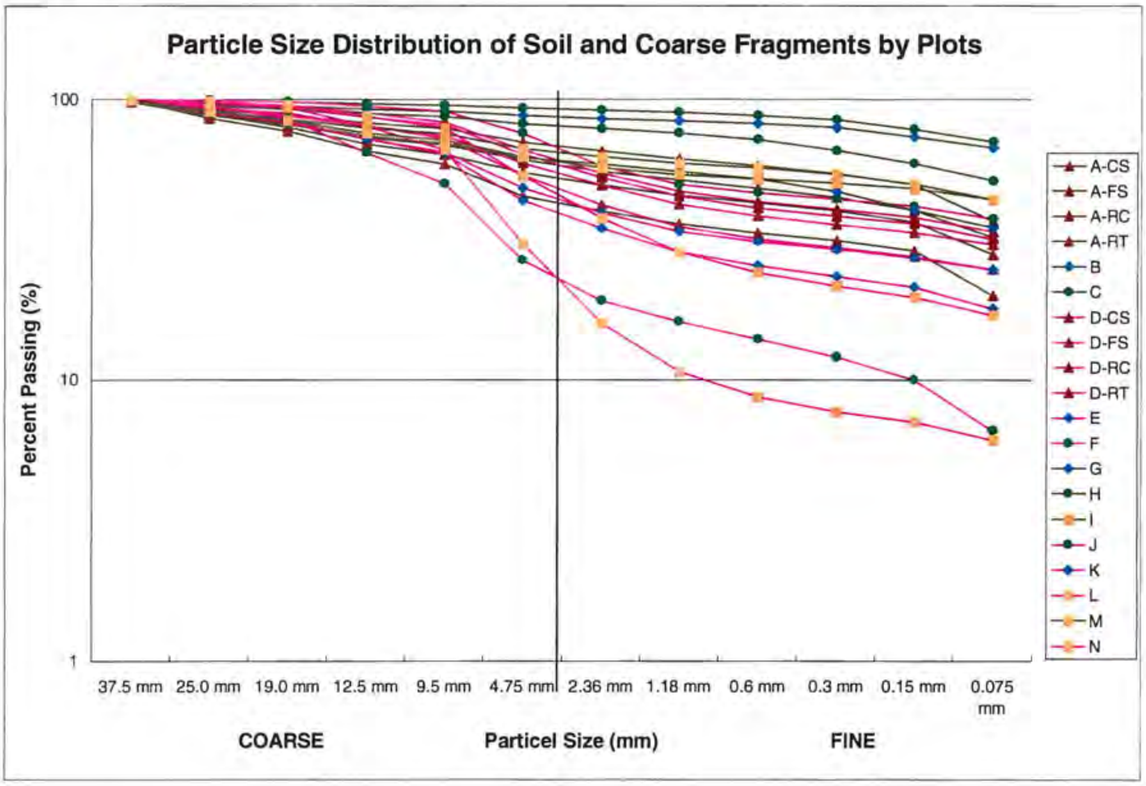
A sieve analysis was also conducted as part of the site characterization procedures. As with the other site characterization tests, only one sample was taken for each of the sites, for a total of 20 samples.

Table 4.3. Sieve analysis of soil and coarse fragments – (% passing each sieve)

Plot	37.5 mm (11/2")	25.0 mm (1")	19.0 mm (¾")	12.5 mm (½")	9.5 mm (3/8")	4.75 mm (#4)	2.36 mm (#8)	1.18 mm (#16)	0.6 mm (#30)	0.3 mm (#50)	0.15 mm (#100)	0.075 mm (#200)
A-CS	97.9	87.9	81.4	73.2	69.0	61.2	55.6	51.7	48.3	44.8	40.3	32.3
A-FS	98.0	89.0	79.7	69.6	63.7	55.1	49.6	45.7	42.9	40.1	36.6	28.0
A-RC	100.0	92.1	88.1	82.7	78.9	70.6	65.8	61.6	58.2	54.5	49.8	36.8
A-RT	99.5	85.7	77.1	65.8	59.0	45.2	40.0	36.0	33.4	31.4	28.9	20.0
B	99.2	96.5	94.8	92.5	90.9	87.5	85.5	84.0	82.3	79.5	73.9	67.4
C	100.0	99.4	98.3	96.8	95.4	93.0	91.5	90.0	87.9	84.7	78.5	70.8
D-CS	100.0	93.7	89.6	80.8	73.0	53.7	42.1	35.2	31.9	29.7	27.6	24.9
D-FS	100.0	96.0	93.0	87.1	81.3	63.9	52.8	45.3	41.1	38.4	36.1	31.9
D-RC	100.0	93.2	87.9	80.8	74.7	59.5	49.4	42.4	38.5	35.8	33.6	30.4
D-RT	100.0	98.2	95.3	89.7	83.4	66.5	54.6	47.2	43.2	40.6	38.2	33.8
E	99.9	90.8	83.7	72.7	65.2	48.4	39.4	33.9	31.2	29.3	27.3	24.7
F	100.0	99.6	98.4	95.0	90.9	76.1	57.9	49.9	46.5	44.2	41.7	37.6
G	100.0	89.2	82.3	74.3	70.1	62.1	58.8	55.6	52.3	47.0	40.3	34.9
H	100.0	94.9	92.5	89.3	86.8	82.0	78.8	76.1	71.9	66.0	59.1	51.4
I	99.6	90.7	85.3	79.2	75.6	67.1	62.6	59.4	57.1	54.2	49.9	44.0
J	100.0	94.9	85.6	64.8	50.1	26.7	19.2	16.2	14.0	12.1	10.0	6.6
K	100.0	89.9	82.9	72.8	64.2	43.5	34.7	28.7	25.6	23.5	21.5	18.0
L	100.0	98.4	94.2	80.6	66.4	30.6	16.0	10.7	8.7	7.7	7.1	6.1
M	99.7	90.8	84.5	76.1	71.7	62.7	57.1	54.1	52.2	50.4	48.2	44.1
N	100.0	98.3	95.3	87.4	79.2	53.6	37.8	28.6	24.2	21.7	19.8	17.1

Coarse **Fine**

Figure 4.5. Sieve analysis on log scale



The red triangles are the road segment plots, the green circles are the control plots, the blue diamonds are the recontoured road (0 month) plots, and the orange squares are the recontoured road (12 month) plot. The violet lines are the Mount Shields geologic formation, and the dark olive green lines are the Bonner geologic formation.

Control plot C appears to have fewer coarse fragments than the rest of the plots, while recontoured road (12 months) plot L appears to have the greatest amount of coarse fragments. The road segments of plots A and D are fairly clustered together. The amount of coarse vs. fine sediment appears to be quite comparable. The controls tended to have the greatest amount of fine sediments, while the recontoured roads, in general, have the least amount of fine sediments when compared to all other plots.

The Mount Shields geologic formation appears to have greater amount of coarse fragments and lower amount of fine fragments, than the Bonner. Ant the recontoured roads (0 and 12 months) seem to have less of the fine fragments than the other treatments.

Hydrometer analyses were run on each of the sieve samples to obtain the percent soil that remained in suspension and to acquire the diameter of soil particles in suspension. This analysis was for site characterization purposes, as well.

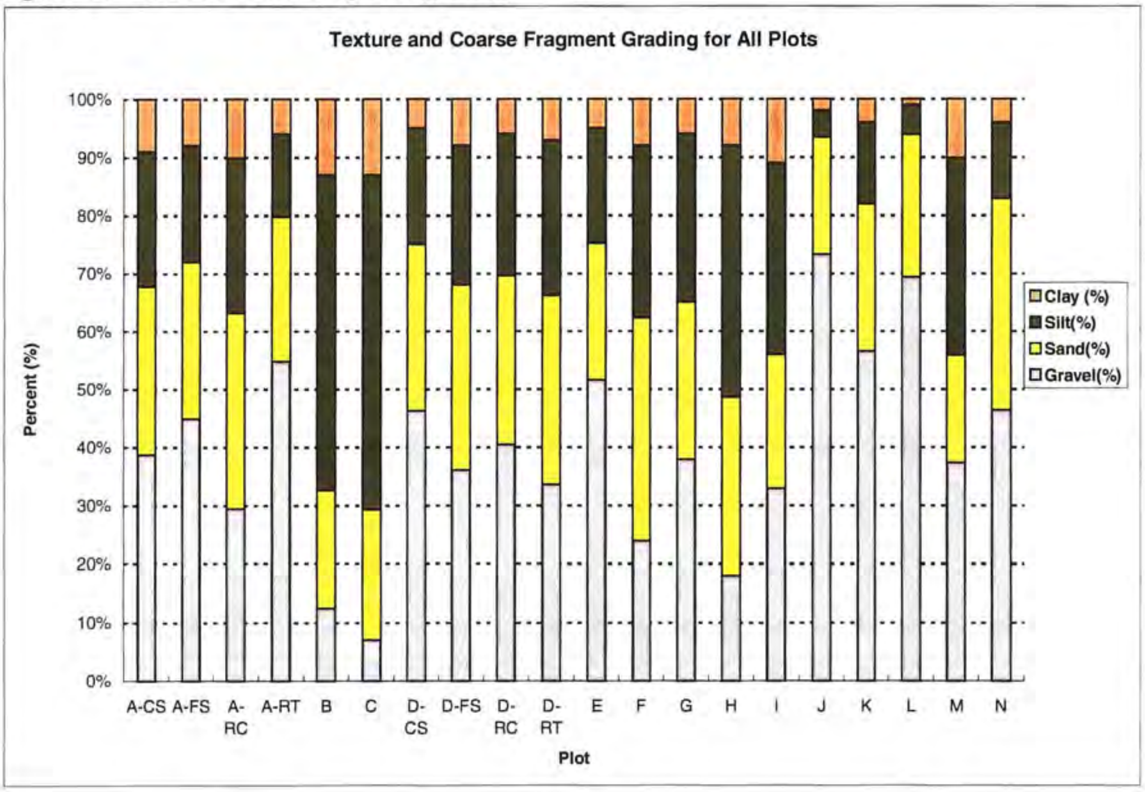
Table 4.4. Hydrometer analysis for sediment in suspension

Plot	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Total (%)
A-CS	38.8	29.0	23.2	9.0	100.0
A-FS	44.9	27.1	20.0	8.0	100.0
A-RC	29.4	33.8	26.8	10.0	100.0
A-RT	54.8	25.0	14.2	6.0	100.0
B	12.5	20.1	54.4	13.0	100.0
C	7.0	22.2	57.8	13.0	100.0
D-CS	46.3	28.8	19.9	5.0	100.0
D-FS	36.1	32.0	23.9	8.0	100.0
D-RC	40.5	29.1	24.4	6.0	100.0
D-RT	33.5	32.7	26.8	7.0	100.0
E	51.6	23.7	19.7	5.0	100.0
F	23.9	38.5	29.6	8.0	100.0
G	37.9	27.2	28.9	6.0	100.0
H	18.0	30.6	43.4	8.0	100.0
I	32.9	23.1	33.0	11.0	100.0
J	73.3	20.1	4.6	2.0	100.0
K	56.5	25.5	14.0	4.0	100.0
L	69.4	24.5	5.1	1.0	100.0
M	37.3	18.6	34.1	10.0	100.0
N	46.4	36.5	13.1	4.0	100.0

Table 4.5. Soils and coarse fragment grading chart [1]

Cobbles (mm)	Gravel (mm)	Sand (mm)	Silt (mm)	Clay (mm)
300 to 75 (12" to 3")	75 to 4.75 (3" to #4)	4.75 to .075 (#4 to #200)	.075 to .005	Finer than .005

Figure 4.6. Soil and coarse fragment grading



[1] ASTM (American Society for Testing and Materials). Volume 4.08. 1999. "Calculations of Soils for Engineering Purposes (Unified Soil Classification System)."

Figure 4.7. Textured and coarse fragment grading by geologic formation

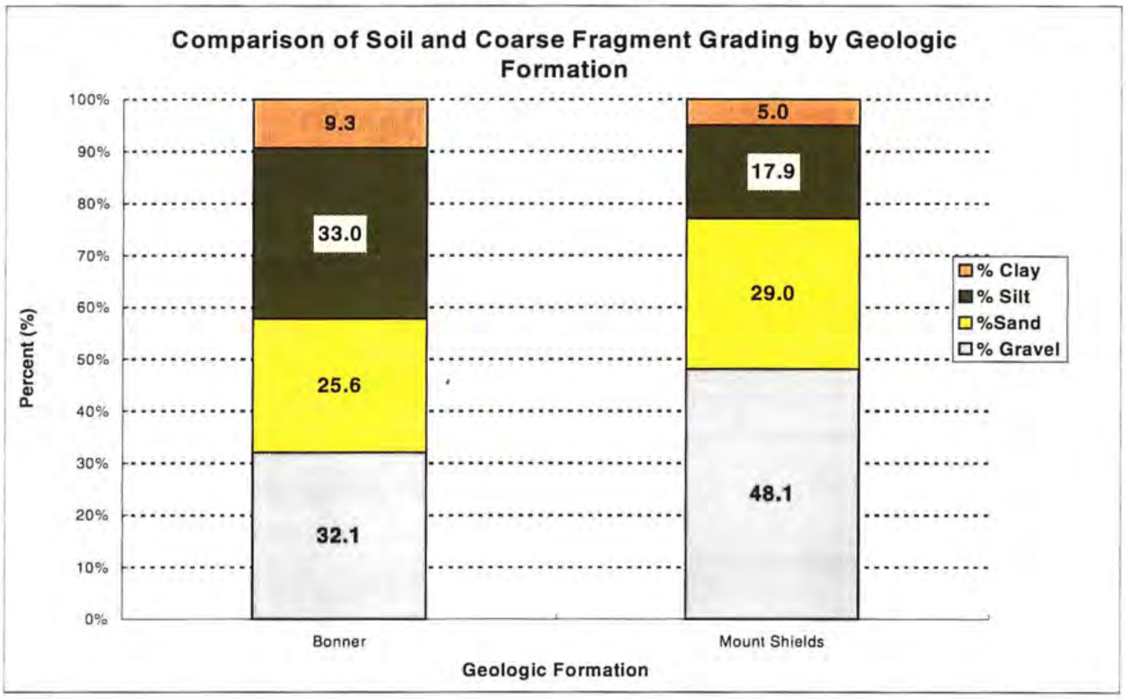
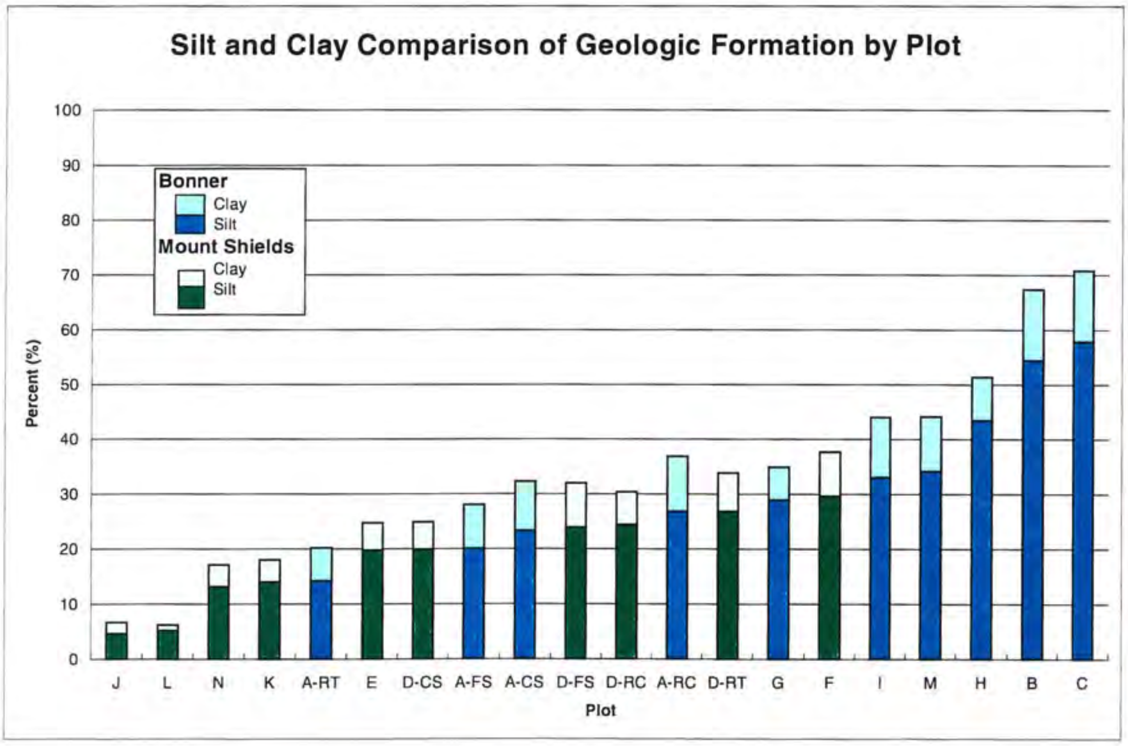


Figure 4. 8. Silt and clay comparisons by plots

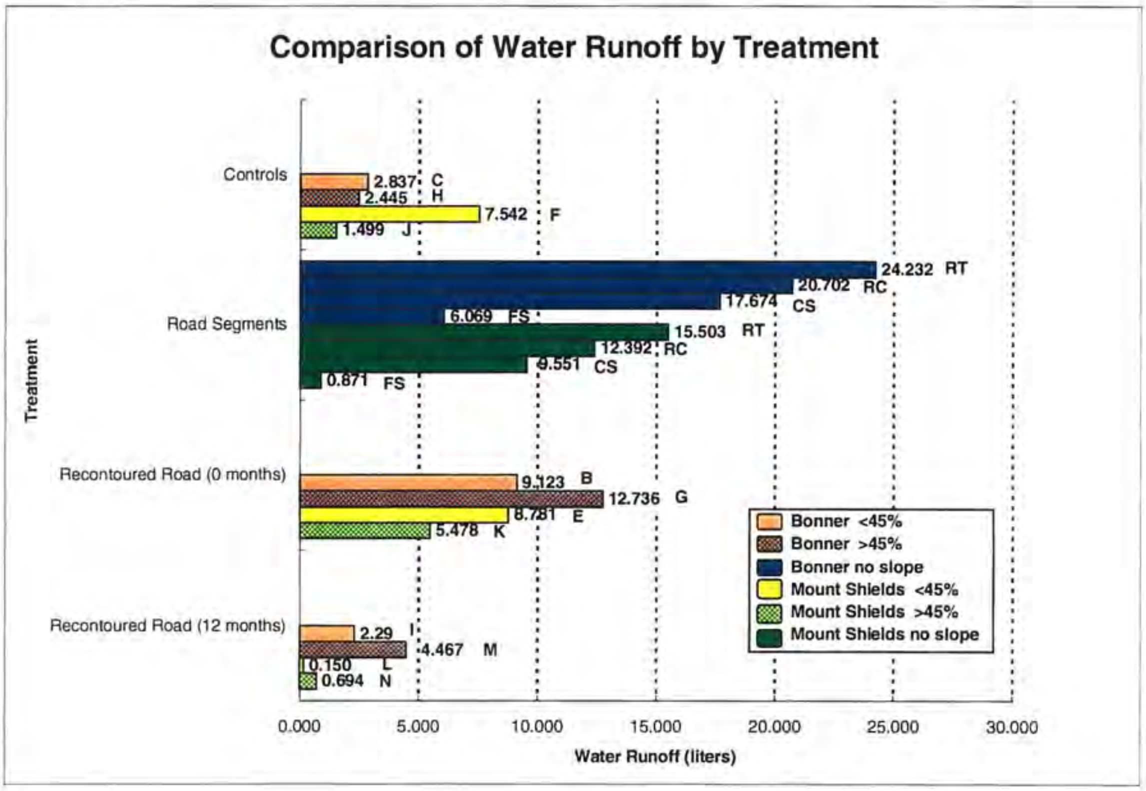


Using the ASTM grading chart for soil and aggregate (coarse fragement) distribution by percent, it appears that the Bonner geologic formation contains a higher percent clay and silt content than the Mount Shields. As shown in Figure 4.5 and 4.7, Bonner shows percent clay of 9.3 % and percent silt of 33.0%, while the Mount Shields shows percent clay of 5.0 % and percent silt of only 17.9%, a difference of 4.3% and 15.1% respectively. When looking at the sand and gravel content, it is the Mount Shields geologic formation with the higher percentages (Figure 4.6). The Mount Shields contains 29.0% sand and 48.1% gravel, while the Bonner only has 25.6% sand and 32.1% gravel, a difference of 3.5% and 16%, respectively. Figure 4.5 deals with the soil and aggregate content as a whole for all plots categorized by geologic formation. This allows for a generalized comparison of the geologic formation of the O'Brien Creek Watershed. Figure 4.7 pulls out the silt and clay contents from the gravel and sand, as it is the finer sediment that is of most concern when dealing with stream health. This information was broken down into individual plots so as to better view the clustering of plots by geologic formation. It is also helpful in showing that the Bonner geologic formation (in blue) tends to show higher silt and clay percentages, on average, per plot.

4.2. SEDIMENT EROSION AND WATER RUNOFF RESULTS

Runoff results were obtained from the water runoff collected for each plot. The raw data for runoff collected (liters) is listed in Appendix F as Table F.4. Figure 4.9 provides an overall comparison of the runoff separated by treatment. The plot/treatment details are listed in Appendix F, Table F.1.

Figure 4.9. Water runoff comparison of all plots (Each value is an average of 5 plots)



In viewing the overall runoff results (Figure 4.9) it is clear that road segments have the greatest amount of runoff. In general, runoff rates appear to be the highest on the Bonner geologic formation. The control plots as a group, tended to have a low rate of runoff but were actually slightly higher than the recontoured road (12 month) plots. These 12-month plots had the least amount of runoff, with the higher rates being from the Bonner. The control plots had low rates of runoff, but Plot F seemed to have an unusually high rate when compared to the other controls. Plot F is the site that had significant amounts of knapweed with no other vegetation. It also had large areas of barren ground, which could explain why it produced the most amount of runoff (thus, least amount of infiltration) when compared to the other controls and the recontoured road (12 months) plots (Figure 4.9).

The recontoured road (0 month) plots in general, produced the second largest volume of runoff, with most coming from the Bonner sites. In describing the three treatments mentioned (controls, recontoured (0 months), recontoured (12 months)), the highest runoff on the Bonner was mostly in the >45 % slope category; but this wasn't the case for the Mount Shields. Also, the recontoured roads (0 months) did have a much larger rate of runoff when compared to the controls (natural slopes). But after 12 months of revegetation, the recontoured roads had significantly lower runoff rates than either the controls or the newly recontoured roads, in the Mount Shields geologic formation (refer to Figure 4.9).

The existing road segments, as a whole, had the highest amounts of water runoff, with the highest produced from the Bonner geologic formation. In both geologic formation cases, the road tread had the highest rate of water runoff, with the road centers having the second highest (Figure 4.8). The cutslopes also tended to have high rates of runoff, coming pretty close to the rates from the newly recontoured roads. The fillslopes, on the other hand, had significantly lower rates of runoff, being comparable to the controls and the (12 month) recontoured road plots. This may be due to the fact that the fillslopes had large amounts of vegetative cover.

Table 4.6. Infiltration rates of plots

Plot	Geologic Formation	Slope	Treatment	Percent Infiltration (%)
A-CS	Bonner	N/A	Road Segment-Cutslope	36
A-FS	Bonner	N/A	Road Segment-Fillslope	78
A-RC	Bonner	N/A	Road Segment-Road Center	25
A-RT	Bonner	N/A	Road Segment-Road Tread	13
B	Bonner	<45%	Recontoured Road-(0 months)	67
C	Bonner	<45%	Control-natural slope	90
D-CS	Mount Shields	N/A	Road Segment-Cutslope	66
D-FS	Mount Shields	N/A	Road Segment-Fillslope	97
D-RC	Mount Shields	N/A	Road Segment-Road Center	55
D-RT	Mount Shields	N/A	Road Segment-Road Tread	56
E	Mount Shields	<45%	Recontoured Road-(0 months)	68
F	Mount Shields	<45%	Control-natural slope	73
G	Bonner	>45%	Recontoured Road-(0 months)	54
H	Bonner	>45%	Control-natural slope	91
I	Bonner	<45%	Recontoured Road-(12 months)	92
J	Mount Shields	>45%	Control-natural slope	95
K	Mount Shields	>45%	Recontoured Road-(0 months)	80
L	Mount Shields	<45%	Recontoured Road-(12 months)	99
M	Bonner	>45%	Recontoured Road-(12 months)	84
N	Mount Shields	>45%	Recontoured Road-(12 months)	97

* Those in red are $\geq$ 90 percent

One aspect studied for all 100 plot samples was the water runoff collected vs. the water infiltrated. From the runoff values, the percent of water infiltration was calculated using a single average value for water used on each plot. The total amount of water used for each plot was 27.78 liters of water with a standard deviation of 0.36

The control plots were fairly similar in the percent of water infiltrated. Ninety percent, 91%, and 95% of water infiltrated for control plots C, H, and J respectively, while 73 % of water infiltrated for control plot F. The lower infiltration amount in control plot F (Figure 4.6) may be due to the fact that site F was completely covered in knapweed with no other vegetation. It was barren ground with approximately 80-85% knapweed. The three other control plots contained grasses, pine needles, duff, plants, and other types of vegetative cover, with little or no barren ground. (See Figure 4.4).

Cutslope plots for both geologic formations showed a lesser amount of water infiltration in comparison to the control plots (Table 4.6). This may be due to the fact that there was little or any, vegetation on the cutslope sites, on steep slopes. Yet, fillslope plots for both geologic formations were more comparable to the control plots in Figure 4.6. Seventy-eight percent of water infiltrated in fillslope plot A, while 97 percent of water infiltrated for fillslope plot D. There was a significant amount of vegetation on the fillslopes, creating a dense vegetative cover.

Road tread plots for both geologic formations showed significantly less infiltration rates than the control plots, as did the road center plots. On the Bonner sites, road center had more infiltration than did road tread; this may be due to the greater amount of vegetation on the road center than the road tread. In contrast, on the Mount Shields sites, road tread and road center infiltration values were fairly similar. In all road cases, it appears that the Bonner geologic formation was more prone to excessive runoff and less infiltration than compared to the Mount Shields.

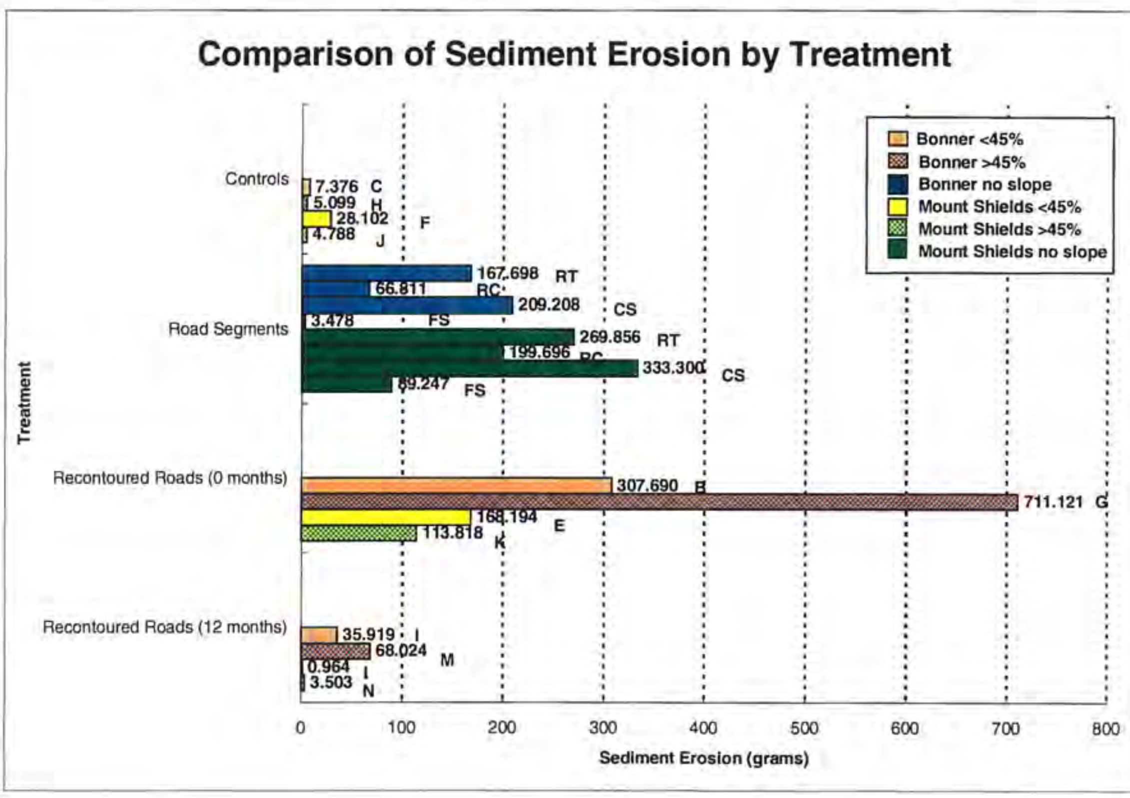
On a newly recontoured road, infiltration tended to be significantly lower than all control plots. This may be due to the significant lack of vegetation and the highly disturbed, loose soil. Yet, these newly recontoured road plots did have greater infiltration rates than the road tread and road center plot segments. This could be a response to the area being disturbed. The road tread and road center plots were compacted due to time and use, while the newly recontoured roads were decompacted, and highly disturbed, thus increasing the infiltration rate and capacity of the soil.

After 12 months, the amount of runoff vs. infiltration on recontoured roads is extremely different (Table 4.6). Infiltration rates are highly comparable to the control plots and substantially higher than any of the other plots. The recontoured road plots (12 months) had significantly higher infiltration rates than did the recontoured road plots (0 months). This could be because the 12 months plots were left undisturbed for one year and allowed to revegetate. Although visually it may not seem as if these 12 month plots had much vegetation, the amount was much greater than the 0 month plots. The increased vegetation and decreased access and use of the area could have led to the soil having a greater infiltration capacity. Also, plots I and M were both of the Bonner geologic formation, while plots L and N were of the Mount Shields geologic formation.

The recontoured road plots (12 months) on the Bonner, had lower infiltration rates than did the recontoured road plots (12 months) on the Mount Shields (Figure 4.6).

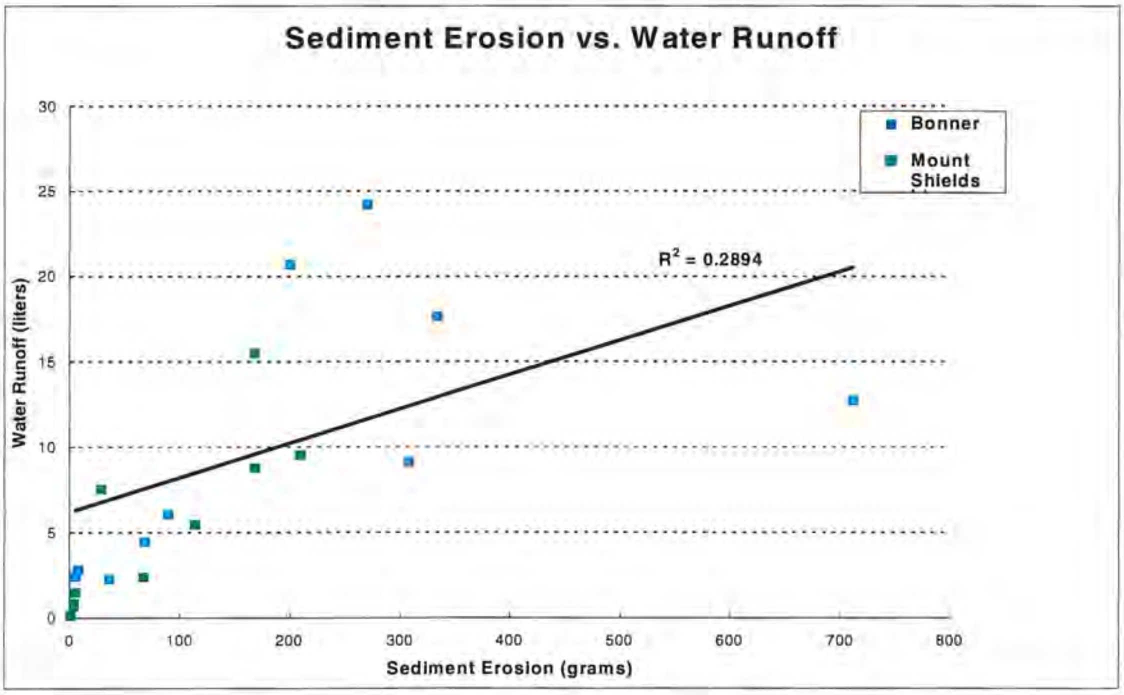
When comparing the amount of water runoff to the amount of sediment erosion generated, the data appears to be quite comparable. The plots which had the highest rates of runoff, tended to produce the greatest amount of sediment erosion, when viewing the results by treatment groups. The raw data for sediment erosion collected (grams) is listed in Appendix F as Table F.5. Figure 4.9 is an overall comparison of the sediment erosion separated by treatment. The plot/treatment details are listed in Appendix F, Table F.1.

Figure 4.10. Sediment yield comparison of all plots (Each value is an average of 5 plots)



The controls (natural slopes), on average, produced the least amount of sediment erosion. Plot F produced greater than average amounts of sediment, due to the site conditions described earlier. The existing road segments produced large amounts of detached sediment with most coming from the cutslopes and the road tread. The fillslopes and road centers produced smaller amounts of erosion, due to the amount of vegetation available on both site categories. The recontoured roads (0 months) produced the greatest peak in sediment discharge, with most coming from the Bonner geologic formation. Yet, after 12 months the recontoured roads had a significant drop of sediment production. This may be a result of vegetation establishment. Sediment erosion from Bonner formation was affected by slope, with higher slopes (>45%) generating more sediment erosion.

Figure 4.11. Sediment and runoff correlation by geologic formation

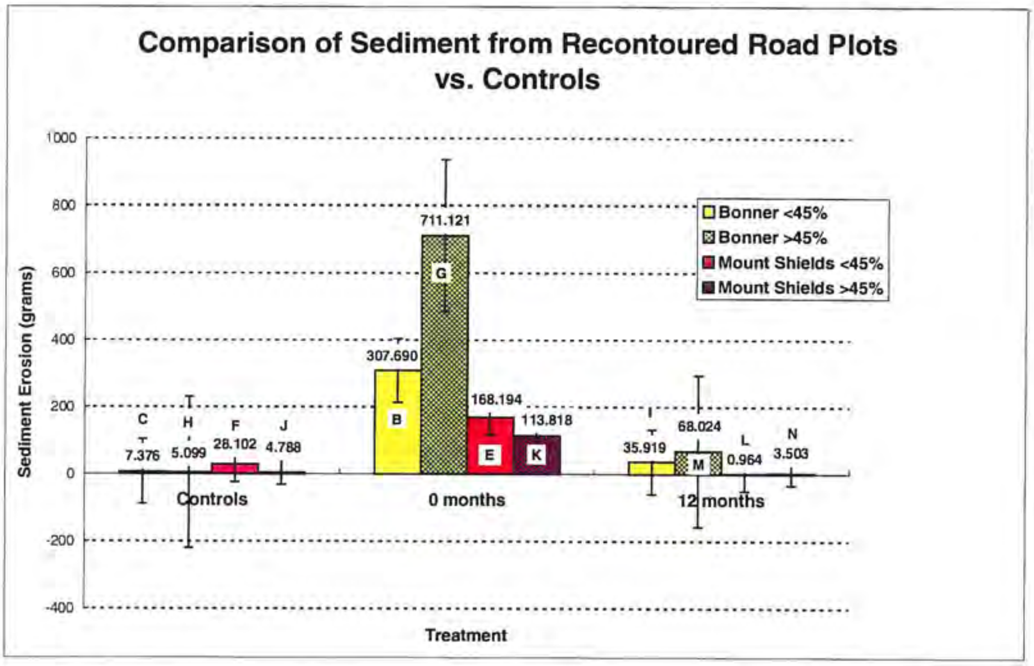


Taking a generalized approach by using the averages of all plots, sediment erosion and water runoff appear to be correlated (Figure 4.11) for both geologic formations. The largest sediment erosion value is plot G (Bonner, >45% slope, recontoured road (0 months)), at 711.121 grams of sediment and 12.736 liter of runoff. The results of this plot may be due to the steeper slope. As runoff increases, sediment erosion increases in most cases.

When comparing the slope factor for each geologic formation, the slope factor was not applicable for the existing road segments. All roads prisms had tread and centers <45% and cutslopes and fillslopes >45%. But, the slope factor does have an effect on the recontoured roads. Figure 4.11 and 4.12 shows that the steeper slopes consistently generated a larger amount of sediment erosion for the Bonner geologic formation, for control, recontoured road (0 months) and recontoured roads (12 months).

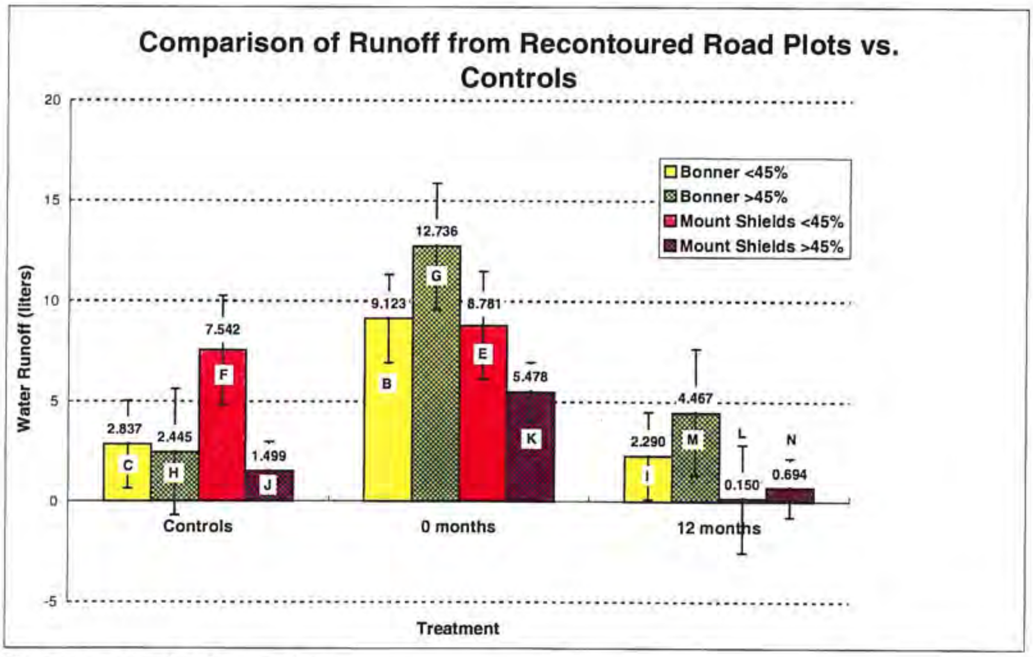
The geologic formation also had an affect on the erosion and runoff. In all treatment situations, the Bonner geologic formation produced the greatest amount of sediment erosion and water runoff when compared to the Mount Shields.

Figure 4.12. Sediment yield comparison on recontoured road plots vs. controls



*Bars are standard error bar

Figure 4.13. Water runoff comparison on recontoured road plots vs. controls

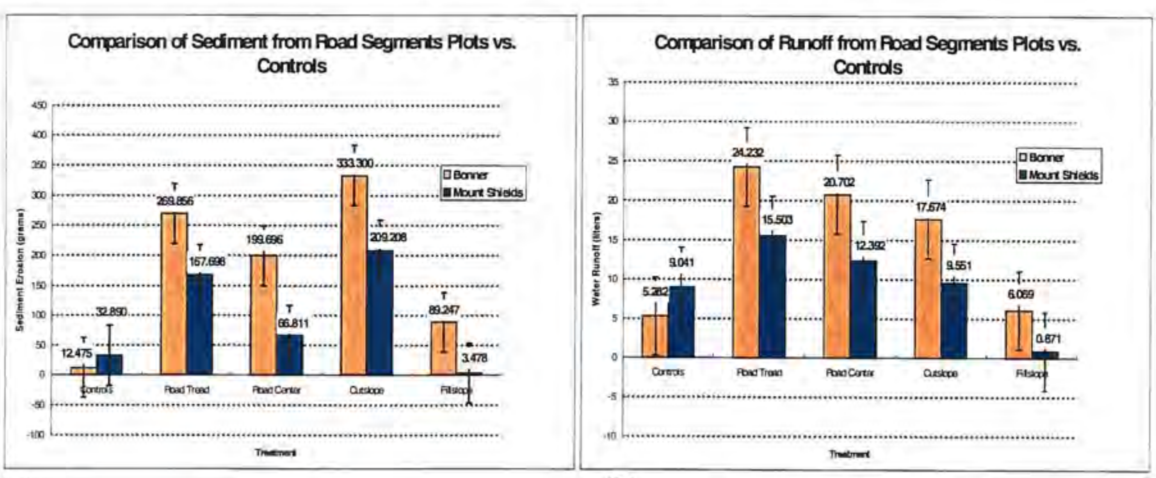


*Bars are standard error bars

In viewing the recontoured road treatments, it is clearly evident that the (0 month) plots have a much greater amount of sediment erosion and water runoff than the controls or the (12 month) plots. There is a large increase in the total amount of sediment yield and runoff, when a road is recontoured but, 12 months later, there is a significant decrease in the amount of runoff and erosion produced. In fact, the numbers for recontoured road (12 months) are quite comparable to the controls, with Mount Shields even generating less erosion and runoff than the controls (natural conditions) (See Figures 4.12 and 4.13). For sediment erosion, the 0 month and 12 month plots generated more sediment on the Bonner than the Mount Shields, while in the controls it was the opposite. This was the case for runoff, as well.

In the existing road plots, the segment of road prism sampled did have an affect on the amount of sediment erosion and water runoff generated.

Figure 4.14. Erosion and runoff comparison of road segments (Standard error bars shown)



(a) (b)

In looking at the individual road segments, there appears to be a correlation between road section and water runoff. The greatest volume of runoff comes from the road tread, with road center, cutslope and fillslope following in decreasing volume (Figure 4.14b). This is true for both geologic formations. This may be due to the fact that the road treads and road centers are more compacted than the cutslopes or fillslopes, thus allowing for more water to runoff. For sediment erosion, the greatest amount is generated from the cutslope, then the road tread, roads center and fillslope, respectively (Figure 4.14a). This could be in response to the much higher slope factor on the cutslope than the road level. Although the fillslope may have a higher slope percentage it is often vegetated unlike the road treads or centers.

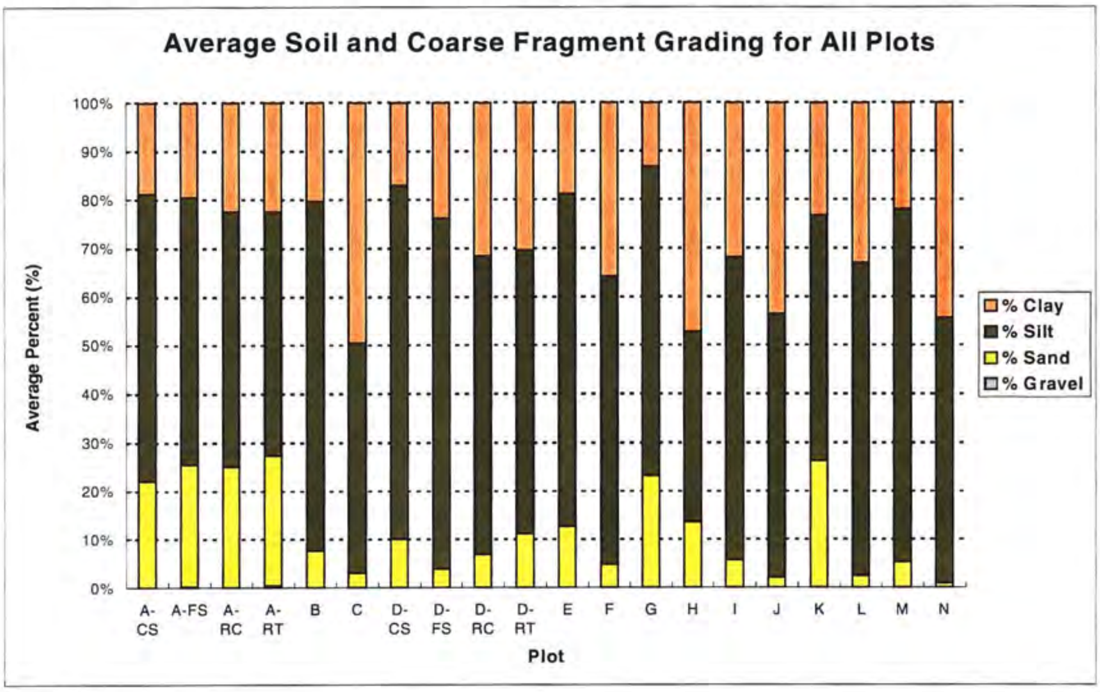
In both cases, erosion and runoff was significantly greater on the roads than on the control (natural slope) plots. When taking into account the geologic formation, the Bonner produced the greatest amount of runoff and erosion for all road segments. This is not true for the controls, in which the slope has an effect on the geologic formation.

The cutslope generated the most sediment, with road tread, road center, and fillslope following in both geologic formations. Yet, the greatest volume of water runoff came from the road tread, with road center, cutslope, and fillslope following. In both situations, it was the Bonner geologic formation that produced the most overall erosion and runoff.

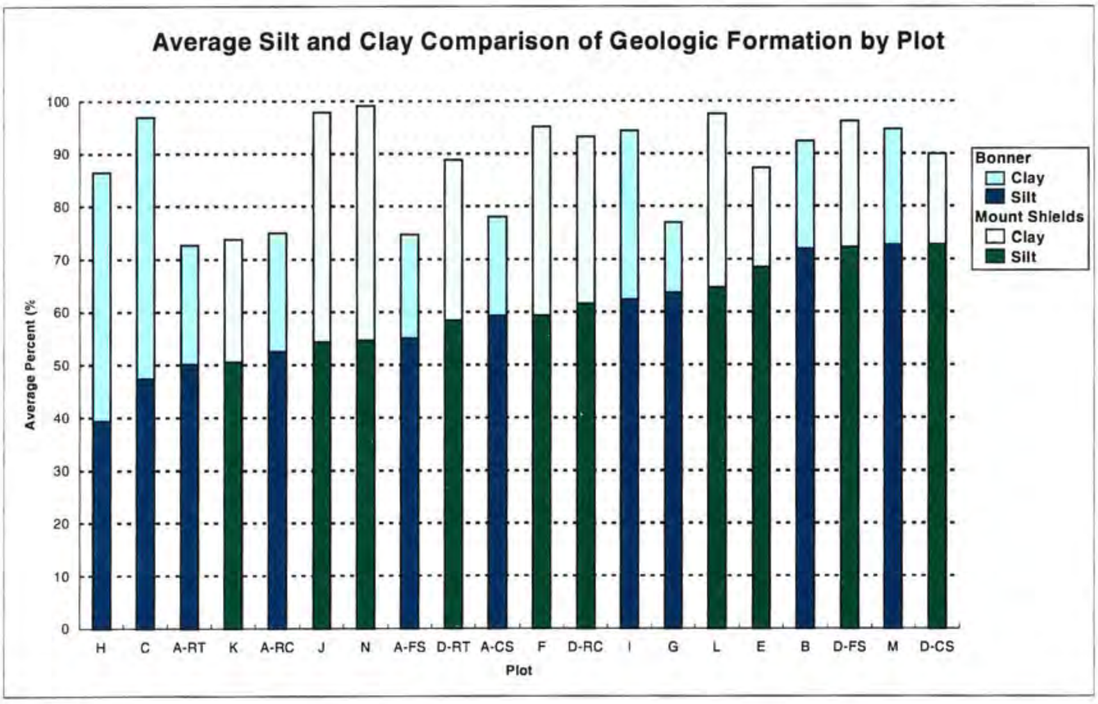
In comparing all plots, it is the road segment and recontoured road (0 months) that contained the most percent gravels (See Figure 4.15a below) compared to the controls or the recontoured roads (12 months). The recontoured roads (12 months) and controls had the smallest percent gravel and were all fairly close in their values. This is due to the high gravel content on road prisms, which often leads to gravel accumulation on the surface of the newly recontoured roads.

Breaking the plots down into silt and clay percent only, the plots appear to be evenly spread out, with an equal spread by treatment (plot) and an equal spread in geologic formation. But, looking closer at Figure 4.15b, the controls did tend to have higher clay content values as a whole.

Figures 4.15. Soil and coarse fragment grading and silt and clay comparisons



(a)



(b)

4.3. STATISTICAL RESULTS

BONNER

The Bonner geologic formation results will be discussed first. The sediment erosion data was transformed using the cubic root of sediment, in order to equalize the variance and meet a Levene's criteria of alpha $\geq$ 0.05. As stated in the statistical methods section, the Bonner geologic formation was divided into two categories, Bonner-High (>45%) slope and Bonner-Low (<45%) slope. For each slope category, comparisons were made between the treatments of control (natural slope), recontoured road (0 months), recontoured road (12 months), and road segments (cutslope, fillslope, road tread and road center). The same Bonner road data was used for both slope categories.

Table 4.7. Tukey HSD mean differences of sediment yield (values shown are cubic root of sediment data) Bonner-low slope

Treatment and Slope (Bonner)	Control Low	Rec. Road (0 month) Low	Rec. Road (12 month) Low	Road Cutslope	Road Fillslope	Road Center	Road Tread
Control Low	---	-4.8272	-1.169*	-5.0019	-2.5216	-3.8783	-4.5145
Rec. Road (0 month) Low	-4.8272	---	3.6585	-0.1747*	2.3056	0.9489*	0.3127*
Rec. Road (12 month) Low	1.1687*	-3.6585	---	-3.8333	-1.3529	-2.7097	-3.3458
Road Cutslope	5.0019	0.1747*	3.8333	---	2.4804	1.1236*	0.4874*
Road Fillslope	2.5216	-2.3056	1.3529	-2.4804	---	-1.3568	-1.9929
Road Center	3.8783	-0.9489*	2.7097	-1.1236*	1.3568	---	- 0.6362*
Road Tread	4.5145	-0.313*	3.3458	-0.4874*	1.9929	0.6362*	---

*** Means for groups that are homogeneous at alpha $\geq$ 0.05**

Table 4.8. Means for groups in homogeneous subsets-sediment yield for Bonner-low slope

Plot	Mean Sediment Erosion (grams)	Treatment and Slope (Bonner)	Subset for alpha ≥ 0.05 (values are cubic root of sediment)		
			1	2	3
C	7.376	Control-Low	1.9117		
I	35.919	Rec.Road (12 months)-Low	3.0804		
A	89.247	Road-Fillslope		4.4333	
A	199.696	Road-Center			5.7900
A	269.856	Road-Tread			6.4262
B	307.690	Rec.Road (0 months)-Low			6.7389
A	333.300	Road-Cutslope			6.9136
		Significance	**0.116**	**1.000**	**0.143**

Table 4.9. ANOVA summary for cubic root of sediment yield (Bonner-low slope)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	114.377	6	19.063	43.149	0.0005
Within Groups	12.370	28	0.442		
Total	126.747	34			

An ANOVA test found a significant difference between treatments at p-values $\leq$ 0.001 (Table 4.8). The low-slope-Bonner control and recontoured road (12 months) appeared to generate the least amount of sediment erosion (cubic root), with no significant difference between them with Tukey's HSD test with 95 percent confidence (Table 4.8). There was no significant difference between the Bonner road center, road tread, road-cutslope, or recontoured road (0 month) means, all producing significantly more sediment (cubic root) than the controls, recontoured road (12 months) and the fillslope. The road-fillslope appears to be significantly different from all other treatments, including the control.

Bonner geologic formation-high slope was analyzed separately.

Table 4.10. Tukey HSD mean differences of sediment yield (values shown are cubic root of sediment data) Bonner high slope

Treatment and Slope (Bonner)	Control High	Rec. Road (0 month) High	Rec. Road (12 month) High	Road Cutslope	Road Fillslope	Road Center	Road Tread
Control High	---	-7.2298	-2.2991	-5.2531	-2.7727	-4.1295	-4.7657
Rec. Road (0 month) High	7.2298	---	4.9308	1.9767	4.4571	3.1003	2.4642
Rec. Road (12 month) High	2.2991	-4.9308	---	-2.9540	-0.4737*	-1.8304	-2.4666
Road Cutslope	5.2531	-1.9767	2.9540	---	2.4804	1.1236*	0.4874*
Road Fillslope	2.7727	-4.4571	0.4737*	-2.4804	---	-1.3568*	-1.9929
Road Center	4.1295	-3.1003	1.8304	-1.1236*	1.3568*	---	-0.6362*
Road Tread	4.7657	-2.4642	2.4666	-0.4874*	1.9929	0.6362*	---

*** Means for groups that are homogeneous at alpha $\geq$ 0.05**

Table 4.11. Means for groups in homogeneous subsets-sediment for Bonner high slope

Plot	Mean Sediment Erosion (grams)	Treatment and Slope (Bonner)	Subset for alpha ≥ 0.05 (values are cubic root sediment)				
			1	2	3	4	5
H	5.099	Control-High	1.6605				
M	68.024	Rec.Road (12 months)-High		3.9596			
A	89.247	Road-Fillslope		4.4333	4.4333		
A	199.696	Road-Center			5.7900	5.7900	
A	269.856	Road-Tread				6.4262	
A	333.300	Road-Cutslope				6.9136	
G	711.121	Rec.Road (0 months)-High					8.8904
		Significance	**1.000**	**0.930**	**0.062**	**0.181**	**1.000**

Table 4.12. ANOVA summary for cubic root of sediment yield (Bonner-high slope)

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	163.306	6	27.218	56.038	0.0005
Within Groups	13.600	28	0.486		
Total	176.906	34			

An ANOVA test for the high slope category, Bonner formation also found differences between treatments. All treatments differed from the controls or natural slopes using a Tukey's HSD test with alpha ≥ 0.05 (Tables 4.10 and 4.11). The Bonner-high slope recontoured road (12 month) and the fillslope, appear to have homogeneous means, with 95 percent confidence, and the fillslope and road center seem to be homogeneous, as well. This could be due to the vegetation present at these sites. The Bonner road center, road tread, and road cutslope are all homogeneous. The newly recontoured road (0 months) on the Bonner, with steep slopes, is different than all other treatments. It produced the greatest amount of sediment erosion, with a much higher mean than all other treatments.

The only similarities from the Bonner-low to the Bonner-high when looking at sediment erosion (cubic root), appear to be that road center, tread and cutslope all produce greater amount of sediment, and are in homogeneous subsets. The Bonner-high slope appears to put the recontoured road (0 months) in a different subset, unlike the low slope, which leads us to believe that the slope plays a significant role in the sediment erosion process.

Water runoff analysis for the Bonner formation was divided into subgroups as well, with road values grouped with either low slope (<45%) or high slope (>45%). The water runoff data was transformed using a square root of runoff, in order to meet the alpha level of Levene's test for homogeneity of variance. Once again, the same road data for runoff was used for both slope categories.

Table 4.13. Tukey HSD mean differences for water runoff (values shown are square root of water runoff data) Bonner low slope

Treatment and Slope (Bonner)	Control Low	Rec. Road (0 month) Low	Rec. Road (12 month) Low	Road Cutslope	Road Fillslope	Road Center	Road Tread
Control Low	---	-1.3485	0.3511*	-2.5419	-0.7584	-2.8876	-3.2540
Rec. Road (0 month) Low	1.3485	---	1.6996	-1.1934	0.5901*	-1.5391	-1.9055
Rec. Road (12 month) Low	-0.351*	-1.6996	---	-2.8930	-1.1095	-3.2387	-3.6051
Road Cutslope	2.5419	1.1934	2.8930	---	1.7835	-0.346*	-0.712*
Road Fillslope	0.7584	-0.5901*	1.1095	-1.7835	---	-2.1292	-2.4956
Road Center	2.8876	1.5391	3.2387	0.3457*	2.1292	---	-0.366*
Road Tread	3.2540	1.9055	3.6051	0.7121*	2.4956	0.3664*	---

*** Means for groups that are homogeneous at alpha = 0.05**

Table 4.14. Means for groups in homogeneous subsets-water runoff for Bonner low slope

Plot	Mean Water Runoff (liters)	Treatment and Slope (Bonner)	Subset for alpha ≥ 0.05 (values are square root of runoff) 1	2	3
I	2.290	Rec.Road (12 months)-Low	1.3073		
C	2.837	Control-Low	1.6584		
A	6.069	Road-Fillslope		2.4168	
B	9.123	Rec.Road (0 months)-Low		3.0069	
A	17.674	Road-Cutslope			4.2003
A	20.702	Road-Center			4.5460
A	24.232	Road-Tread			4.9124
		Significance	**0.725**	**0.174**	**0.058**

Table 4.15. ANOVA summary for square root of water runoff (Bonner-low slope)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	61.683	6	10.281	78.049	0.0005
Within Groups	3.688	28	0.132		
Total	65.371	34			

An ANOVA test found differences in runoff between the treatments. The runoff on Bonner formation-low slope showed that recontoured road (12 months) and control were not significantly different (Tables 4.13 and 4.14). The fillslope and recontoured road (0 months) also appear to be homogeneous, both producing less runoff than the other road segments. The road cutslope, center, and tread all appear to be homogeneous, and producing the largest volume of runoff, with road tread producing the greatest.

The water runoff for the Bonner-high has somewhat similar results as the water runoff for Bonner-low (Tables 4.13 and 4.14). As with the Bonner-low, the Bonner-high control and recontoured road (12 months), showed no significant difference at alpha $\geq$ 0.05. Similar results were found for the road cutslope, center, and tread for both high and low slopes, with the three treatment means being homogeneous. The difference comes in where the recontoured road (12 months)-high and the fillslope appear to be homogeneous, as with the recontoured road (0 month)-high and cutslope. In the Bonner-low slope, it is the fillslope and recontoured road (0 months)-low that are homogeneous with 95 percent confidence.

Table 4.16. Tukey HSD mean differences for water runoff (values shown are square root of water runoff data) Bonner-high slope

Treatment and Slope (Bonner)	Control High	Rec. Road (0 month) High	Rec. Road (12 month) High	Road Cutslope	Road Fillslope	Road Center	Road Tread
Control High	---	-2.0246	-0.5042*	-2.6649	-0.8814	-3.0106	-3.3770
Rec. Road (0 month) High	2.0246	---	1.5204	-0.6403*	1.1432	-0.9860	-1.3524
Rec. Road (12 month) High	0.5042*	-1.5204	---	-2.1608	-0.3773*	-2.5065	-2.8729
Road Cutslope	2.6649	0.6403*	2.1608	---	1.7835	-0.3457*	-0.712*
Road Fillslope	0.8814	-1.1432	0.3773*	-1.7835	---	-2.1292	-2.4956
Road Center	3.0106	0.9860	2.5065	0.3457*	2.1292	---	-0.366*
Road Tread	3.3770	1.3524	2.8729	0.7121*	2.4956	0.3664*	---

*** Means for groups that are homogeneous at alpha = 0.05**

Table 4.17. Means for groups in homogeneous subsets-water runoff for Bonner geologic formation

Plot	Mean Water Runoff (liters)	Treatment and Slope (Bonner)	Subset for alpha ≥ 0.05 (values are square root of runoff)			
			1	2	3	4
H	2.445	Control-High	1.5354			
M	4.467	Rec.Road (12 months)-High	2.0396	2.0396		
A	6.069	Road-Fillslope		2.4168		
G	12.736	Rec.Road (0 months)-High			3.5600	
A	17.674	Road-Cutslope			4.2003	4.2003
A	20.702	Road-Center				4.5460
A	24.232	Road-Tread				4.9124
		Significance	**0.407**	**0.722**	**0.162**	**0.091**

Table 4.18. ANOVA summary for square root of water runoff (Bonner-high slope)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	52.558	6	8.760	58.060	0.0005
Within Groups	4.224	28	0.151		
Total	56.782	34			

In the Bonner high slope category, the control and recontoured road (12 months) produced the least amount of water runoff; while the fillslope produced similar results to both of these treatments, but was only significantly different from the control. The cutslope, center and tread produce the most runoff, with the tread producing the greatest volume; similar to the Bonner-low slopes.

When comparing all four Bonner groupings together, it was found that runoff-high slope, runoff-low slope, and sediment-low slope data all showed homogeneity between the controls and recontoured roads (12 months). Runoff-high slope and sediment-low slope show homogeneity between recontoured road (0 months) and road-cutslope. Runoff-high slopes and sediment-high slopes, both show homogeneity between recontoured roads (12 months) and road-fillslopes. Finally, all four groups show homogeneity between road cutslopes, centers, and treads in the amount of sediment erosion and water runoff produced.

MOUNT SHIELDS

The Mount Shields geologic formation was analyzed separately due to the unequal variances of the samples. A two-sampled T-test was chosen, using SPSS, to compare selected treatments for sediment erosion and water runoff. No transformations of data were necessary, as the unequal variances were not correctable in meeting Levene's tests of homogeneity. As stated in the statistical methods section, the Mount Shields geologic formation was divided into two categories: Mount Shields-High (>45%) and Mount Shields-Low (<45%).

For each of the two slope categories, both in sediment and runoff, the following hypothesis were test with a two-sided T-test:

- H_o: No road = Recontoured road at 12 months
- H_o: No road = Recontoured road at 0 months
- H_o: No road = Fillslope
- H_o: Recontoured road at 12 months = Recontoured road at 0 months
- H_o: Recontoured road at 12 months = Fillslope
- H_o: Recontoured road at 0 months = Fillslope

The same Mount Shields road data was used for both slope categories. The confidence interval was set at alpha=0.05, and divided by 6 (the number of comparisons). This gives a confidence interval of 0.008, allowing for a more conservative estimation. Fillslope of the road was chosen over the other road categories because it had that least amount of sediment and runoff production.

Table 4.19. Two-sampled T-test for sediment yield Mount Shields-low slope

Plot	Treatment and Slope	N	Mean	Std. Deviation	Std. Error Mean
F	No road-Low	5	28.10240	15.67873	7.01174
L	Rec.12-Low	5	0.96420	0.67471	0.30174
t	**df**	**Sig. (2-tailed)**		**Mean Difference**	
3.867	4.015	0.018		27.13820	

(a)

Plot	Treatment and Slope	N	Mean	Std. Deviation	Std. Error Mean
F	No road-Low	5	28.10240	15.67873	7.01174
E	Rec.0-Low	5	168.19360	50.90088	22.76356
t	**df**	**Sig. (2-tailed)**		**Mean Difference**	
-5.881	4.752	0.002		-140.09120	

(b)

Plot	Treatment and Slope	N	Mean	Std. Deviation	Std. Error Mean
F	No road-Low	5	28.10240	15.67873	7.01174
D	Road-Fillslope	5	3.47760	2.75698	1.23296
t	**df**	**Sig. (2-tailed)**		**Mean Difference**	
3.459	4.247	0.023		24.62480	

(c)

Plot	Treatment and Slope	N	Mean	Std. Deviation	Std. Error Mean
L	Rec.12-Low	5	0.96420	0.67471	0.30174
E	Rec.0-Low	5	168.19360	50.90088	22.76356
t	**df**	**Sig. (2-tailed)**		**Mean Difference**	
-7.346	4.001	0.002		-167.22940	

(d)

Plot	Treatment and Slope	N	Mean	Std. Deviation	Std. Error Mean
L	Rec.12-Low	5	0.96420	0.67471	0.30174
D	Road-Fillslope	5	3.47760	2.75698	1.23296
t	**df**	**Sig. (2-tailed)**		**Mean Difference**	
-1.980	4.477	0.111		-2.51340	

(e)

Plot	Treatment and Slope	N	Mean	Std. Deviation	Std. Error Mean
E	Rec. 0-Low	5	168.19360	50.90088	22.76356
D	Road-Fillslope	5	3.47760	2.75698	1.23296
t	**df**	**Sig. (2-tailed)**		**Mean Difference**	
7.225	4.023	0.002		164.71600	

(f)

Figure 4.35 shows all comparisons, with the selected road segments, between treatments for sediment erosion-low slopes. With an alpha level of 0.008, the t-values for comparisons (a), (c), and (e) are significant to 0.018, 0.023, and 0.111, respectively, all of which are greater than 0.008. Thus, there were no significant differences between natural slopes (control) and recontoured road (12 months), natural slopes (control) and road-fillslopes, and recontoured road (12 months) and road-fillslopes. Figure 4.35 also shows that the t-values for comparisons (b), (d), and (f) are all significant to 0.002, indicating a significant difference between the means of comparisons natural slopes (control) and recontoured roads (0 month), recontoured roads (12 months) and recontoured roads (0 month), and recontoured (0 months) and road-fillslopes.

Table 4.20. Two-sampled T-test for sediment yield Mount Shields-high slope

Plot	Treatment and Slope	N	Mean	Std. Deviation	Std. Error Mean
J	No road-High	5	4.78760	1.80214	0.80594
N	Rec.12-High	5	3.50340	1.40891	0.63008
T	**df**	**Sig. (2-tailed)**		**Mean Difference**	
1.255	7.560	0.247		1.28420	

(a)

Plot	Treatment and Slope	N	Mean	Std. Deviation	Std. Error Mean
J	No road-High	5	4.78760	1.80214	0.80594
K	Rec.0-High	5	113.82740	53.67116	24.00247
t	**df**	**Sig. (2-tailed)**		**Mean Difference**	
-4.540	4.009	0.010		-109.03980	

(b)

Plot	Treatment and Slope	N	Mean	Std. Deviation	Std. Error Mean
J	No road-High	5	4.78760	1.80214	0.80594
D	Road-Fillslope	5	3.47760	2.75698	1.23296
t	**df**	**Sig. (2-tailed)**		**Mean Difference**	
0.889	6.891	0.404		1.31000	

(c)

Plot	Treatment and Slope	N	Mean	Std. Deviation	Std. Error Mean
N	Rec.12-High	5	3.50340	1.40891	0.63008
K	Rec.0-High	5	113.82740	53.67116	24.00247
t	**df**	**Sig. (2-tailed)**		**Mean Difference**	
-4.595	4.006	0.010		-110.32400	

(d)

Plot	Treatment and Slope	N	Mean	Std. Deviation	Std. Error Mean
N	Rec.12-High	5	3.50340	1.40891	0.63008
D	Road-Fillslope	5	3.47760	2.75698	1.23296
t	**df**	**Sig. (2-tailed)**		**Mean Difference**	
0.019	5.956	0.986		2.5800E-02	

(e)

Plot	Treatment and Slope	N	Mean	Std. Deviation	Std. Error Mean
K	Rec. 0-High	5	113.82740	53.67116	24.00247
D	Road-Fillslope	5	3.47760	2.75698	1.23296
t	**df**	**Sig. (2-tailed)**		**Mean Difference**	
4.591	4.021	0.010		110.34980	

(f)

Figure 4.36 shows all comparisons, with the selected road segments, between treatments for sediment erosion-high slopes. With an alpha level of 0.008, the t-values are significant to 0.247 (a), 0.010 (b), 0.404 (c), 0.010 (d), 0.986 (e), and 0.010 (f), all of which are greater than 0.008. Thus, there are no significant differences between all the mean comparisons for Mount Shields' sediment high slopes.

Table 4.21. Two-sampled T-test for water runoff Mount Shields-low slope

Plot	Treatment and Slope	N	Mean	Std. Deviation	Std. Error Mean
F	No road-Low	5	7.54200	0.23175	0.10364
L	Rec.12-Low	5	0.15040	8.9651E-02	4.0093E-02
t	**df**	**Sig. (2-tailed)**		**Mean Difference**	
66.515	5.171	0.0005		7.39160	

(a)

Plot	Treatment and Slope	N	Mean	Std. Deviation	Std. Error Mean
F	No road-Low	5	7.54200	0.23175	0.10364
E	Rec.0-Low	5	8.78060	1.30757	0.58476
t	**Df**	**Sig. (2-tailed)**		**Mean Difference**	
-2.086	4.251	0.101		-1.23860	

(b)

Plot	Treatment and Slope	N	Mean	Std. Deviation	Std. Error Mean
F	No road-Low	5	7.54200	0.23175	0.10364
D	Road-Fillslope	5	0.87100	0.49586	0.22176
t	**Df**	**Sig. (2-tailed)**		**Mean Difference**	
27.253	5.668	0.0005		6.67100	

(c)

Plot	Treatment and Slope	N	Mean	Std. Deviation	Std. Error Mean
L	Rec.12-Low	5	0.15040	8.9651E-02	4.0093E-02
E	Rec.0-Low	5	8.78060	1.30757	0.58476
t	**Df**	**Sig. (2-tailed)**		**Mean Difference**	
-14.72	4.038	0.0005		-8.63020	

(d)

Plot	Treatment and Slope	N	Mean	Std. Deviation	Std. Error Mean
L	Rec.12-Low	5	0.15040	8.9651E-02	4.0093E-02
D	Road-Fillslope	5	0.87100	0.49586	0.22176
t	**df**	**Sig. (2-tailed)**		**Mean Difference**	
-3.198	4.261	0.030		-0.72060	

(e)

Plot	Treatment and Slope	N	Mean	Std. Deviation	Std. Error Mean
E	Rec. 0-Low	5	8.78060	1.30757	0.58476
D	Road-Fillslope	5	0.87100	0.49586	0.22176
t	**df**	**Sig. (2-tailed)**		**Mean Difference**	
12.647	5.127	0.0005		7.90960	

(f)

Figure 4.37 shows all comparisons, with the selected road segments, between treatments for water runoff-low slopes. With an alpha level of 0.008, the t-values for comparisons (b) and (e) are significant to 0.101 and 0.030, both of which are greater than 0.008. There is no significant difference between the mean comparisons for natural slopes (control) and recontoured roads (0 months). This figure also shows that the t-values for comparisons (a), (c), (d), and (f) are all significant to 0.0005, which is less than the 0.008 significance level. This results in a significant difference between the means of comparisons (a), (c), (d), and (f).

Table 4.22. Two-sampled T-test for water runoff Mount Shields-high slope

Plot	Treatment and Slope	N	Mean	Std. Deviation	Std. Error Mean
J	No road-High	5	1.49900	0.22097	9.8833E-02
N	Rec.12-High	5	0.69500	0.57785	0.25842
t	**df**	**Sig. (2-tailed)**		**Mean Difference**	
2.906	5.145	0.032		0.80400	

(a)

Plot	Treatment and Slope	N	Mean	Std. Deviation	Std. Error Mean
J	No road-High	5	1.49900	0.22097	9.8822E-02
K	Rec.0-High	5	5.47800	0.93483	0.41807
t	**df**	**Sig. (2-tailed)**		**Mean Difference**	
-9.262	4.446	0.0005		-3.97900	

(b)

Plot	Treatment and Slope	N	Mean	Std. Deviation	Std. Error Mean
J	No road-High	5	1.49900	0.22097	9.8822E-02
D	Road-Fillslope	5	0.87100	0.49586	0.22176
t	**df**	**Sig. (2-tailed)**		**Mean Difference**	
2.587	5.528	0.045		0.62800	

(c)

Plot	Treatment and Slope	N	Mean	Std. Deviation	Std. Error Mean
N	Rec.12-High	5	0.69500	0.57785	0.25842
K	Rec.0-High	5	5.47800	0.93483	0.41807
t	**df**	**Sig. (2-tailed)**		**Mean Difference**	
-9.732	6.667	0.0005		-4.78300	

(d)

Plot	Treatment and Slope	N	Mean	Std. Deviation	Std. Error Mean
N	Rec.12-High	5	0.69500	0.57785	0.25842
D	Road-Fillslope	5	0.87100	0.49586	0.22176
t	**df**	**Sig. (2-tailed)**		**Mean Difference**	
-0.517	7.820	0.620		-0.17600	

(e)

Plot	Treatment and Slope	N	Mean	Std. Deviation	Std. Error Mean
K	Rec. 0-High	5	5.47800	0.93483	0.41807
D	Road-Fillslope	5	0.87100	0.49586	0.22176
t	**df**	**Sig. (2-tailed)**		**Mean Difference**	
9.735	6.086	0.0005		4.60700	

(f)

Figure 4.38 shows all comparisons, with the selected road segments, between treatments for water runoff-high slopes. With an alpha level of 0.008, the t-values for comparisons (a), (c), and (e) are significant to 0.032, 0.045, and 0.620, respectively, all of which are greater than 0.008. Thus, there is no significant difference between the means of comparisons: natural slopes (control) and recontoured road (12 months), natural slopes (control) and road-fillslope, and recontoured road (12 months) and road-fillslope. This figure also shows that the t-values for comparisons (b), (d), and (f) are significant to 0.0005, which is less than the 0.008 significance level, resulting in a significant difference between the means of comparisons: natural slopes (control), and recontoured road (0 months), recontoured road (12 months) and recontoured road (0 months), and recontoured road (0 months) and road-fillslope.

When looking at all the comparisons as a whole, there doesn't appear to be much correlation. The only similarities found in all four groups (sediment-high, sediment-low, runoff-high, runoff-low) is that there is no significant difference in the recontoured roads (12 months) and road-fillslopes. Runoff–low slopes, runoff-high slopes, and sediment-low slopes did show significant differences in both recontoured roads (12 months) vs.

recontoured roads (0 month), and recontoured road (0 months) vs. road-fIllslopes. Sediment-high slopes, sediment-low slopes, and runoff-high slopes also showed that in all three groups, natural slope (control) vs. recontoured roads (12 months) and natural slopes (control) vs. road-fillslopes showed no significant difference.

Chapter 5: A Comparative Analysis of the Effects of Existing and Recontoured Forest Service Roads on Sediment Erosion and Water Runoff

5.1. Discussion

These results support existing literature showing that road obliteration does have an effect on surface erosion and water runoff production. To what extent, will be discussed in detail.

The total weight of sediment in the runoff from rainfall simulation plots was used as the measure of erosion potential. This measurement is practical in quantifying the relative effects of road obliteration treatments in terms of the readiness with which sediment may be detached and transported. Runoff was measured to determine how much water will be infiltrated due to treatments, and that which runs off has the potential to carry fine sediments that could end up in water systems. Interpretations of the results are limited to direct comparison among treatment types and geologic conditions in order to determine whether differences exist by specific road decommissioning choices.

Geologic formation was chosen as a factor, as opposed to soil types, because the soils are so completely disturbed by the road building and road obliteration processes that the soil becomes unrecognizable. The site isn't really classified by soil type any longer, thus, the geologic formations are a more logical site/substrate classification. Although the pedological development is greatly dependent upon the geologic material, it is also going to differ depending upon slope, aspect, and vegetation history at the sites. With mountain soils, the profile is typically very thin-often less than 3 feet deep.[1] Soils are classified by their horizons, which are the product of the underlying geology (in most cases) weathering processes, and biological processes. When a road is constructed in the mountains, most excavations are between 6 and 20 feet deep, well into the geology. In O'Brien Creek Watershed there were some cuts over 50 feet, therefore, the road material is not typically definable by standard pedological soil classification nominclature, since there are no horizons. When you recontour a road, soil material gets mixed up even more. The ratio of "soil" to excavated geologic material of a recontoured 14-foot road on 50% side slope is about 1 to 30. It is with this understanding that the geologic formation should be analyzed first. A detailed list of information about the soil make up of the study site area is listed in the several tables of Appendix E and the map in Appendix D.

The physical attributes of particle detachment occur regardless of the geologic formation. The geologic formation, however, influences the "soil" characteristics that control potential erosion (André and Anderson 1961). The Bonner geologic formation clearly produces more sediment erosion and runoff than the Mount Shields geologic formation (Figures 4.9 and 4.10). This may be due to the Bonner containing more clay materials and silt materials than the Mount Shields, which had larger percentages of sand and gravel (Figures 4.5, 4.6, and 4.7). This line of thinking may be supported by the findings of Anderson (1951), Barnett and Rogers (1966), Meeuwig (1970a), and Bryan

[1] Skip Hegman, personal Communication, 2000

1969). Even on the road segments, the Bonner always produced more erosion and runoff when compared to the Mount Shields.

Slope categories are also somewhat difficult to deal with in analyzing road obliteration effects vs. existing roads. In most high-density road areas, the cutslopes and fillslopes are most commonly steep, while the road-tread and center are almost always low to flat sloped. But this study took into consideration that no matter what slope these road were at, they were continuously producing sediment and runoff. But, in looking at the slopes of recontoured roads, high slopes on average produced more sediment erosion and water runoff than low slopes, supporting the data of Lal (1994).

Road recontouring made more sediment available for erosion and runoff than did roads, consistent with the data of King and Gonsior (1981). These findings are similar to those of the WATSED prediction model, which found that recontoured roads produced greater amounts of sediment and runoff than did roads[2]. But, this study clearly shows that recontoured roads produce levels of sediment higher than roads, initially, then decrease significantly after only one year, at times reaching natural slope conditions. So, recontouring roads does impact the environment, but not in the same way that roads do. Roads produce a continuous amount of sediment and runoff often with little or no decrease over time (Elliot et al. 1999, Trimble and Weitzman 1953, Luce and Cundy 1993), unlike recontoured roads in this study.

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[2] Skip Hegman, Personal Communication, 2000

Previous soil erosion research on roads has demonstrated the difficulty of identifying the contributions of the many variables influencing sediment yield and runoff (Anderson 1951, André and Anderson 1961, Burroughs 1991, Elliot et al. 1996, Gifford 1975, Willen 1965). This study also factored in variables interpreted as most beneficial for determining treatment effects.

Sediment yield increased as water runoff increased (Figure 4.11), suggesting that loosening of soil aggregates by intense rainfall made sediment more easily detached and transported (Meeuwig 1970b, Ekern 1950). The high sediment erosion means for the recontoured roads (0 months) may be due to the loosening of soil and geologic formation due to extreme disturbances with inadequate time to settle and revegetate (Meeuwig 1971, Moll 1996). It is these disturbed, loose particles that are more easily transported by moving water (Wischmeier and Mannering 1969).

On recontoured road sites the results clearly show that after adequate revegetation time, sediment yield and runoff significantly decreases (Figure 4.12 and 4.13). Research has shown that surface erosion on recontoured roads can be greatly reduced and areas of mass erosion can be stabilized by deep-rooted vegetation (Megahan 1974). Revegetation speeds recovery of disturbed sites and prevents further off-site degradation by a number of reasons (Bagley 1998): vegetation controls surface erosion, enhances soil structure, enhances slope stability, and enhances biological activity.

The difficulty is in finding a way of establishing vegetation that will reduce both types of erosion (Megahan 1974, Megahan and Kidd 1972). Increased vegetative cover and porosity of the geologic formation due to the recontouring disturbance could best be explained by the greater amount of time allowed for revegetation (Rose 1962). Gifford (1973) found that chaining and burning of slash, followed by seeding, will cause an increase in runoff for the first few years following treatment, then runoff decreases as the new plants establish themselves. The debris left scattered on the soil surface acts as both retention and detention storage, the magnitude of which is large enough to nearly eliminate all runoff (Megahan and Kidd 1972, Bradley 1997, Bagley 1998). The runoff and sediment results after 12 months time are clearly evident in Figures 4.12 and 4.13. Most researchers attribute lower sediment yield to higher vegetation (Middleton (1930), Bryan (1968), Burroughs (1990), Elliot et al. (1996b), Lowdermilk (1930), and Meeuwig (1972)).

A marked difference in the amount of sediment yield and runoff on the road plots was observed. This suggests that the amount of erosion and runoff collected was dependent on differences in sediment made available by the different road prism segments, supporting the studies conducted by Megahan and Kidd (1972) and Foltz (1996). It is obvious that sediment yield and runoff from cutslope and road tread plots were greater than from the fillslope and road center plots. This may be the result of higher levels of revegetation most commonly found on fillslope and road center segments.

There was also a marked difference in the comparisons of the control plots. As the results show, three of the control plots were very similar in the amount of sediment and runoff produced. Control plot F had significantly higher values of sediment and runoff than control plots C, H, or J. This is clearly the result of the different vegetative covers of the sites, see Figure 4.4 (a-d). Control plot F contained only high levels of knapweed on the site area with no other vegetation present. Whereas, the other control plots had plants, grasses, duff, pine needles, sticks, etc. These results are consistent with the findings of Lacey and Marlow (1990), who found sediment erosion and runoff to be higher on knapweed infested sites than on bunchgrass covered sites.

Statistical analyses for each geologic formation needed to be approached differently. The Bonner data met the qualifications of the Levene's test, but only after transforming the data. Yet, no transformation was found that would help Mount Shields to meet the Levene's requirement. This could be due to the fact that the Bonner geologic formation was much more uniform in its soil/aggregate makeup. There was much more silt and clay material in the Bonner and the sediment erosion and runoff amounts were more similar. The variances were more equally distributed than for the more irregular Mount Shields data. Equal variance was not met with the Mount Shields geologic formation. This could be the result of high gravel and sand content of the geologic formation. The sites were quite rocky and it was clearly random as to how rocky of a section the plots would end up in. The soil sieve analysis showed the road segments, as a whole, tended to have the most gravel and sand content.

The decision to recontour is complicated and sediment production is only one element of that decision. As discussed in the first part of this thesis, sediment measurements don't translate directly into sediment transported into a stream. We know little about the potential for mass wasting events with recontoured roads. And finally, there are many other factors involved in recontouring decisions, including cost and public access. This study was done on small sediment erosion plots within a single watershed. Extrapolating the data to encompass all watersheds and decommissioning treatments is not advisable, as this study used pseudoreplication. The data results are very site specific. A generalized approach can be taken, though, as to what variables one should look for when recontouring a road.

Results of Wemple's study (1994) suggest that removing roads from the drainage network may be an effective first step toward watershed restoration, and this study gives ample reason to continue research into road decommissioning practices. Taking several soil samples, through rainfall simulator techniques, to determine the erosive potential of the soils and geologic formations that will be within the site area gives an inclination on how fast and to what amounts the sediment will erode, allowing for the assumptions of potential hydrologic risks. One could always eliminate factors to identify differences among treatments more accurately. This study gives guidance as to how one can obtain adequate information so as to predict the response of road obliteration decommissioning treatments.

5.2. Conclusion

There is no question that roads and road removal activity affect land response to sediment erosion and water runoff production (Megahan and Kidd 1972, Packer 1967, Elliot et al. 1999, King and Gonsior 1981, Wemple 1994, Luce 1996). To what degree this can effect water quality, stream habitat, and the hydrologic environment is a question relevant to road management practices and programs of the National Forests. The objective of this study was to assess differences in sediment erosion and water runoff production in response to various treatments, by using a rainfall simulator on small erosion plots.

In this watershed, total reduction in sediment yield and water production from total recontouring was greater on higher slopes in the Bonner geologic formation. If managers look towards road obliteration as the method of choice for road decommissioning, they might perhaps consider targeting steeper slopes on geologic formations high in silt and clay content. This would to obtain the greatest benefits from total recontouring. It is the steeper slopes (i.e. the cutslopes) that are producing substantially higher amounts of runoff and sediment erosion. If there is an urgent need to decrease sediment and runoff, then total obliteration should be the management direction, with the understanding that the recontoured roads must be adequately seeded in order to allow for significant revegetation. The road obliteration on the O'Brien Creek sites were seeded significantly higher amounts of seed than the average recommended dose. This had led to the more positive results in shorter time periods. There will be short-term impacts that need to be addressed, but the long-term impacts are worth the risks.

It is important to note that this experiment looked at only one of the road decommissioning practices, Level V - total road obliteration. While it is possible to say that revegetated-recontoured roads have less erosion potential than existing road prisms, these results should be considered together with the environmental factors specific to each site. It must be emphasized again, that the recontoured/obliterated roads on the O'Brien Creek Watershed were seeded and fertilized much greater than the "recommended" seed amount. This is part of the reason for the excellent revegetation rates on the recontoured roads (as seen in Chapter 1, Figure 1.1 a-e, the road obliteration sequence). Every site is different in slope length and steepness, geologic formation, rainfall and hydrologic regime, existing culverts and stream crossings, etc., which need to be considered before deciding on which level of road decommissioning should be chosen.

Other road decommissioning practices, such as scarification and partial obliteration, should be sampled in order to see if their effects are significantly different from total recontouring and existing roads. It is not correct to take these results and assume that they will be equal to the results of "similar " road decommissioning methods. For example, one cannot assume that total obliteration will have the same results as ripping/scarifying and seeding. Although the concept may seem the same, for a lower cost value, the results are not equal. Few studies have addressed ripping directly (Luce 1997, Bradley 1997), although many people are using it as a common practice to increase the infiltration capacity of roads during closure. Gifford (1975) reviewed a few studies on the effectiveness of ripping in decompacting rangeland soils. The article reviewed showed that deep ripping could greatly decrease runoff from natural events, while shallow ripping with little surface disturbance had little or short-term effects (Bradley 1997).

One of the leading researchers in road reclamation found that ripping and subsoiling alone provide only temporary and marginal improvements reducing surface erosion (Luce 1997). Bradley (1997) found that ripping creates large water conducting channels and thereby accelerates water infiltration, which is of particular significance in erosion control (see Table 4.6). She found that due to the scarification of the site when recontouring, each scarified treatment supported more seeded individuals than its nonscarified counterpart. But, it is difficult to predict the effect of scarification on soil physical properties into future years. Surface sealing (due to the filling of macropores with transported fine particles) and soil settlement occur to some extent on all scarified soils (Bradley 1997). The surface of a number of roads in Idaho forest returned to original bulk densities and poor infiltration capacities one year after scarification (Luce 1997). It is for this reason that many have chosen to fully recontour roads, incorporating ripping in their projects with the total removal of the roads, in lieu of ripping and scarifying alone. One of the reasons to support this choice is, with total obliteration, the "scarifying" or ripping is at a much greater depth, thus, more long-term results.

Important future studies that are highly recommended should include measuring how far the sediment travels and under what storm intensity. Also more types of geologic formation should be analyzed for their effects on sediment production so as to have a greater range of data in which to reference to. Dividing the slopes into more than two categories may also help in determining more precise slope effects. It would be beneficial to know more about the effects of recontouring on the probability of mass wasting events. Monitoring is always strongly recommended. Evaluating overall watershed recovery should be part of larger monitoring programs, while site-specific monitoring should be planned as part of individual road removal projects (Bagley 1998). Monitoring actions should include establishing permanent photo points, conducting qualitative surveys, and quantitative measurements. Returning to the same sites to take samples one, two or three years later would be highly beneficial in determining the long-term effects of recontouring. It would be important to discover if the amount of erosion and runoff decreases more, increases, or remains steady after years of revegetation and changing soil conditions. Testing for time factors, every month or so for several years, would give a good indication of sediment reduction over a time scale. It would give insight as to when or if the sediment erosion levels out.

Immediately after recontouring (0 months), there can be a large increase in sediment production, equivalent to sediment produced from roads. But, based on the statistical analysis, it is clearly evident that recontouring can be successful in decreasing sediment erosion and water runoff, to near natural conditions, if allowed to revegetate (12 months) for one year. The data also supports the fact that roads tend to produce a greater amount of sediment erosion than natural slopes or recontoured road (12 months), but at a steady rate and will continue to impact aquatic ecosystems (Bagley 1998).

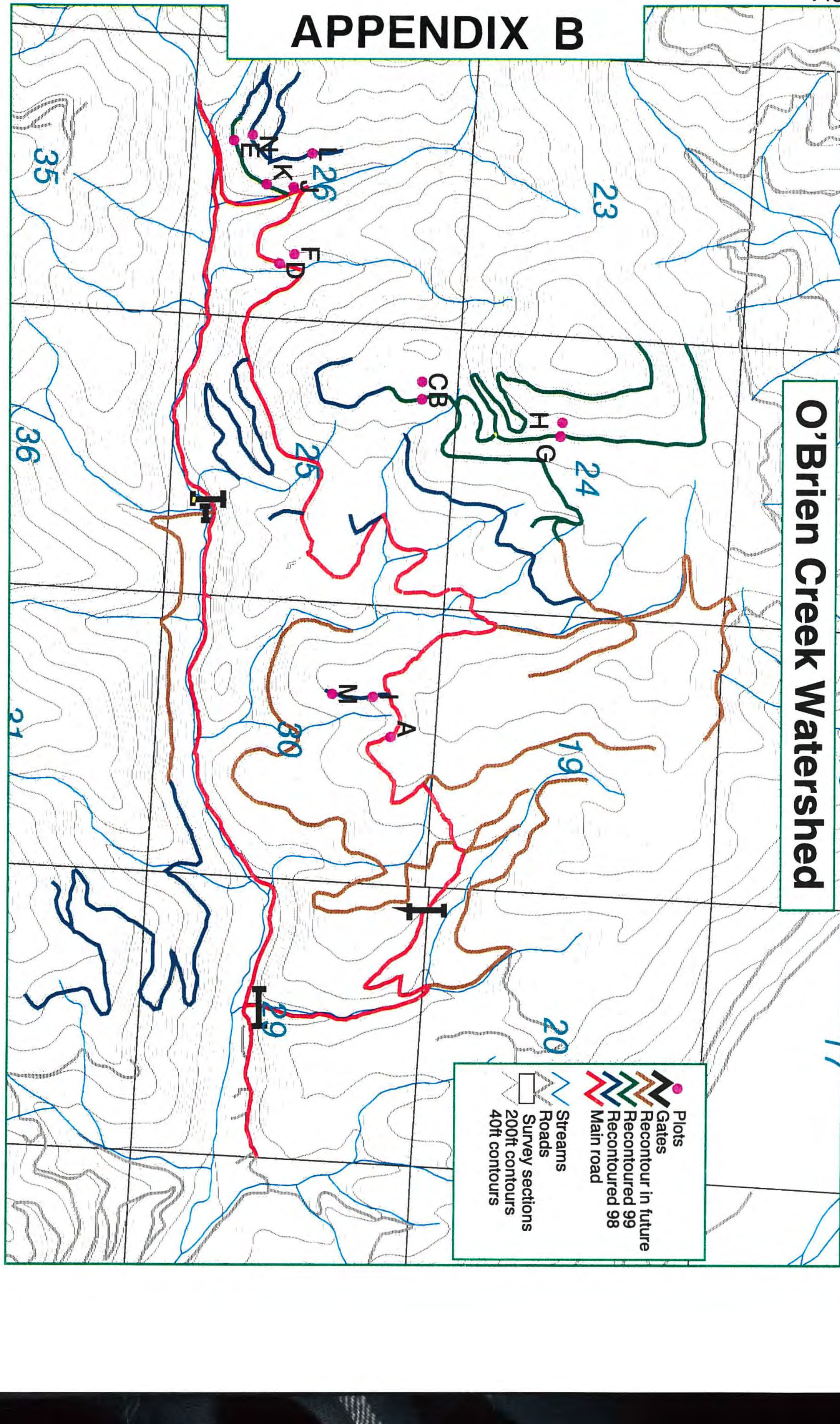
It is also clearly evident that different geologic formations have a significant effect on erosion and runoff rates, with Bonner producing greater amounts than Mount Shields. The gravel, sand, silt, and clay composition of the geologic formation appears to have affected the erosion potential of the land.

Adding more site-specific factors to the study could possibly allow enough information to build an erosion and runoff prediction model for decommissioned-recontoured roads with more accuracy than some models currently being used. Other models base their conclusions on the effects of existing roads and not on the effects of obliterated/recontoured roads.

Appendix A

LEVEL	DEVICE	MITIGATION	STATUS	COST RANGE
I	Gate	Blade, seed, fertilize. Normal drainage. Treat noxious weeds.	Remains on FDR system; Maintenance Level I.	$500-$1,000/mi. $300-$600/km
II	Gate, guardrail, concrete or earth barrier, or recontour at intersection	Type III dip, drivable waterbars, or outslope. Scarify 2-3 inches, seed and fertilize. May scatter slash on roadway. Treat noxious weeds.	Remains of FDR system; Maintenance Level I; if custodial care won't be performed, consider Closure Level 3 (self-maintaining)	$800-$2,000/mi. $500-$1,400/km
III **S** **Storage** **O** **Obliteration**	Recontour at intersection or rock or earth barrier	Waterbar or intermittent outslope. Remove CMP's & restore all watercourses to natural channels & floodplains. Rip 6-12 inches, seed and fertilize. May scatter slash on road. Treat noxious weeds.	**S**—Retain on FDR system in long-term storage (self-maintaining); generally up to approx. 20 years **O**—Remove from FDR system, retain on HIR system; road not needed for 20+ years.	$2,000-$3,500/mi. $1,200-$2,200/km
IV	Recontour at intersection or rock or earth barrier	Waterbar or intermittent outslope. Selective recontou along the road.Remove CMP's & restore all watercourses to natural channels & floodplains. Rip 12-18 inches, seed and fertilize. Scatter slash on recontoured slope. Treat noxious weeds.	Remove from FDR system, road not needed fo r30+ years. Retain on HIR system until no longer having any effects AND road is determined to be no longer needed.	$3,000-$7,500/mi. $1,900-$4,700/km
V	Recontour	Recontour the entire road prism to almost pre-road conditions. Remove CMP's & restore all watercourses to natural channels & floodplains. Seed & fertilize. Scatter slash on recontoured slope. Treat noxious weeds.	Remove from FDR system; road access not needed for 40+ years. Retain on HIR system unitl no longer having any effects.	$5,000-$7,500+ /mi. $3,100 -$4,700+ /km

APPENDIX B


O'Brien Creek Watershed
Plots
Gates
Recontour in future
Recontoured 99
Recontoured 98
Main road
Streams
Roads
Survey sections
200ft contours
40ft contours
35
26
23
36
25
24
30
19
29
20
A
B
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D
E
F
G
H
I
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N

APPENDIX C

Precipitation and temperature data for Missoula, Montana and the surrounding area for the years of 1961-1990 (Internet source)[1].

Table C.1. Average precipitation and temperatures for Missoula and the surrounding site area

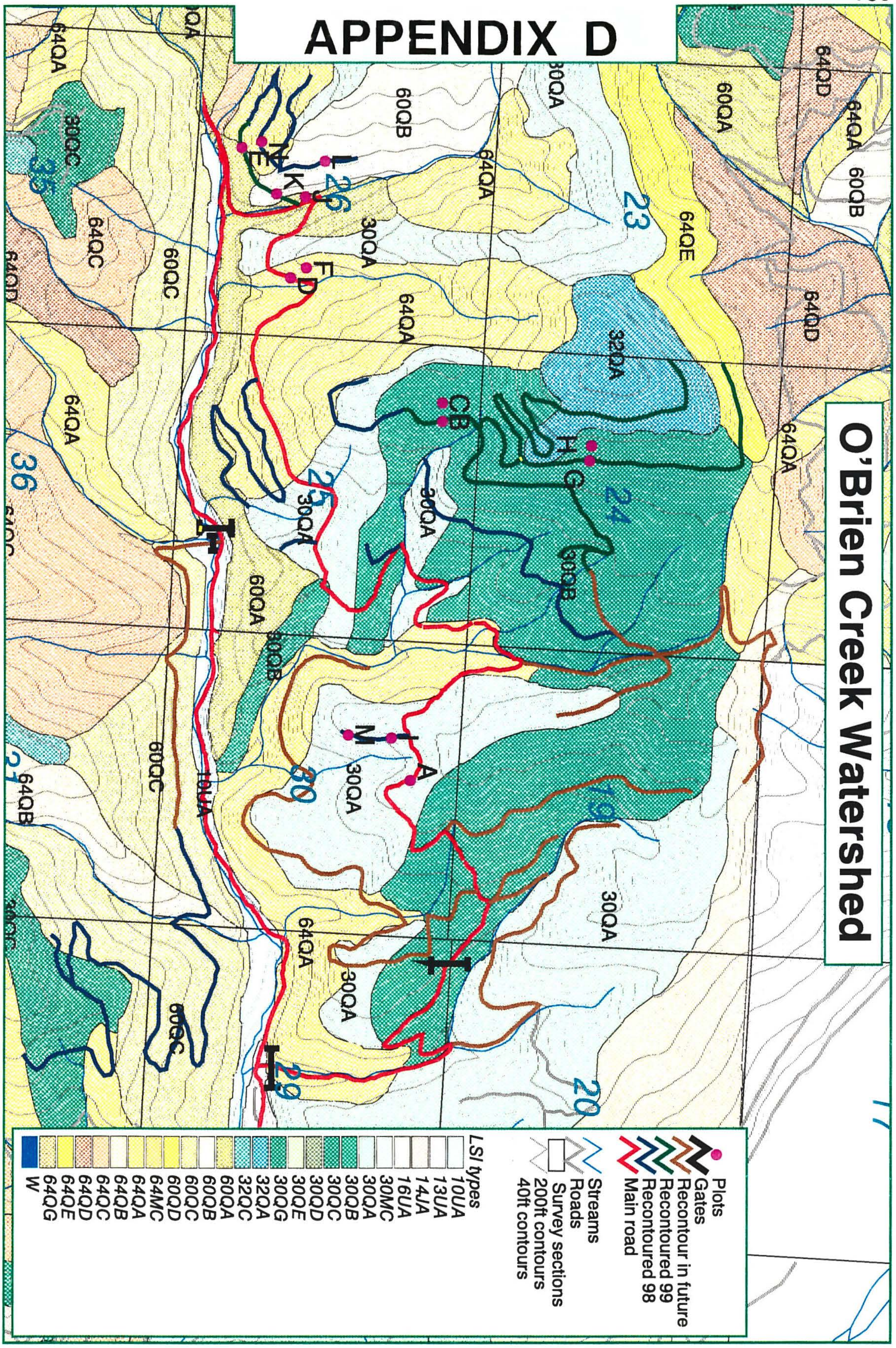
Month	Average Max. Temperature (°F)	Average Min. Temperature (°F)	Average Total Precipitation (inches)
January	32.5	15.2	1.20
February	38.7	20.4	0.94
March	46.9	23.8	0.82
April	58.5	31.2	1.04
May	68.1	38.2	1.40
June	76.5	44.8	2.20
July	85.1	48.4	1.20
August	83.3	47.2	1.46
September	69.9	38.4	1.50
October	59.2	31.9	0.84
November	42.5	24.8	0.65
December	33.5	18.2	1.47
TOTAL	58.1	32.0	14.72

Table C.2. Rain events for Missoula and the surrounding site area

Year – hour	Precipitation (inches)
100 year – 24 hour	4.2-3.4
50 year – 24 hour	3.6-3.4
25 year – 24 hour	3.8-3.0
10 year – 24 hour	2.8-2.6
5 year – 24 hour	2.4-2.2
2 year – 24 hour	2.0-1.8
100 year – 6 hour	2.1-2.0
50 year – 6 hour	1.9-1.8
25 year – 6 hour	1.7-1.6
10 year – 6 hour	1.6-1.4
5 year – 6 hour	1.4-1.3
2 year – 6 hour	1.0-0.9

[1] http://www.wrcc.dri.edu

APPENDIX D


O'Brien Creek Watershed
Plots
Gates
Recontour in future
Recontoured 99
Recontoured 98
Main road
Streams
Roads
Survey sections
200ft contours
40ft contours
LSI types
10UA
13UA
14JA
16UA
30MC
30QA
30QB
30QC
30QD
30QE
30QG
32QA
32QC
60QA
60QB
60QC
60QD
64MC
64QA
64QB
64QC
64QD
64QE
64QG
W

APPENDIX E

USDA Land Systems Inventory 1988 (Sasich and Lamotte-Hagen 1988)
Lolo National Forest
Quad Number: 121
Quad Name: Blue Mountain
Northern Region Number: 614-1-1-3

The tables list the map unit symbols and their characteristic summaries for the study area only. It also consists of the unit description index. The tables list the engineering properties and classification, road construction limitation and suitability ratings, and the road location factors. The timber productivity and natural regeneration of the site, the timber and silvicultural management limitations, and the properties affecting sediment yield are also listed in these tables.

Table E.1. Soil map unit symbols within the study site area

Section 23	Section 24	Section 19	Section 20	Section 26	Section 25	Section 30	Section 29
30QA	30QB	30QA	30QA	30QA	30QA	30QA	10UA
30QG	32QA	30QB	64QB	60QA	30QB	30QB	13UA
32QA	64QA	64QA		60QB	60QA	60QA	30QA
60QA				60QC	60QC	60QC	30QB
60QB				64QA	64QA	64QA	60QC
64QA				64QC		64QB	64QA
64QD							
64QE							

Table E.2. Soil map unit characteristics summary within the study site area

Map Unit	Landform	Slope %	Parent Material	Vegetation	Aspect	Elevation	Rock Outcrop %
10UA	Stream bottoms	1-10	Alluvium	Warm forested riparian	Variable	2800-4400	0-5
13UA	Terraces	1-45	Alluvium	Dry, mixed coniferous forest	Variable	2800-4400	0-5
30QA	Moderate relief mountain slopes	35-55	Weakly weathered metasedi-mentary rocks	Open grown forest	Southerly	3000-4800	0-5
30QB	Moderate relief mountain slopes	35-55	Weakly weathered metasedi-mentary rocks	Dry Douglass-fir	S, E, W	3000-5800	0-5
30QG	Moderate relief mountain slopes	35-55	Weakly weathered metasedi-mentary rocks	Cool, somewhat dry Douglas-fir	Southerly	4600-60000	0-5
32QA	Broadly convex ridges	10-35	Weakly weathered metasedi-mentary rocks	Subalpine forest	Variable	5000-6800	0-5
60QA	Stream breaklands	65-100	Weakly weathered metasedi-mentary rocks	Open grown forest	Southerly	3400-4800	20-40
60QB	Stream breaklands	65-100	Weakly weathered metasedi-mentary rocks	Dry Douglas-fir forest	Variable	3400-4800	20-40
60QC	Stream breaklands	65-100	Weakly weathered metasedi-mentary rocks	Dry, mixed coniferous and cool somewhat dry Douglas-fir forest	N, E, W	3600-4800	20-40
64QA	Step Mountain slopes	55-75	Weakly weathered metasedi-mentary rocks	Open grown forest	Southerly	3000-4800	5-15
64QB	Step Mountain slopes	55-75	Weakly weathered metasedi-mentary rocks	Dry Douglas-fir forest	S, E, W	4000-5500	5-15
64QC	Step Mountain slopes	55-75	Weakly weathered metasedi-mentary rocks	Dry, mixed coniferous forest	Variable	3400-5500	5-15
64QD	Step Mountain slopes	55-75	Weakly weathered metasedi-mentary rocks	Moist, mixed coniferous forest	Northerly	3400-5500	5-15
64QE	Step Mountain slopes	55-75	Weakly weathered metasedi-mentary rocks	Subalpine forest	Northerly	5000-6600	5-15

Table E.3. Soil map unit description index within the study site area

Map Unit Code	Name
10UA	Orthents and Aquepts, stream bottoms
13UA	Andic Ustochrepts and Typic Ustochrepts, alluvial substratum
30QA	Typic Xerochrepts - Typic Haploxerolls complex, moderate relief mountain slopes
30QB	Typic Ustochrepts, moderate relief mountain slopes
30QG	Andic Dystric Eutrochrepts – Dystic Eutrochrepts complex, moderate relief mountain slopes
32QA	Andic Cryochrepts, broadly convex ridges
60QA	Typic Xerochrepts – Rock outcrop complex, stream breaklands, warm
60QB	Typic Ustochrepts – Rock outcrop complex, stream breaklands
60QC	Andic Dystric Eutrochrepts - Dystric Eutrochrepts – Rock outcrop complex, stream breaklands
64QA	Typic Xerochrepts - Typic Haploxerolls association, steep mountain slopes
64QB	Typic Ustochrepts steep mountain slopes
64QC	Andic Dystric Eutrochrepts and Dystric Eutrochrepts, steep mountain slopes
64QD	Andic Dystric Eutrochrepts, steep mountain slopes
64QE	Andic Cryochrepts, steep mountain slopes

Table E.4. Engineering properties and classification within the study site area

Map Unit	Soil Layer	USDA Texture	Unified Classific.	% Rock <3"	% Rock >3"	Rock Shape	Liq. Lim.	Plast. Index
10UA	Surface	Sil	SM	10	5	Rounded	--	NP
	Intermed.	Sil	SM, ML	10	5	Rounded	--	NP
	Substratum	Excbsl	GP/GW	30	30	Rounded	--	NP
13UA	Surface	Gl, gsil	ML, SM	5-15	0	Rounded	--	NP
	Subsurface	Vgsl	GM-GW	30-45	15-20	Rounded	--	NP
	Substratum	Vcbsl, exgsl	GM-GW	35-55	15-40	Rounded	--	NP
30QA	Surface	Gsl	GM	20-45	0-5	Angular	--	NP
	Subsurface	Exgsl	GM	45-65	20-30	Angular	--	NP
	Substratum	Exgsl	GM	45-65	20-30	Angular	--	NP
30QB	Surface	Gl	GM	20-45	0-5	Angular	--	NP
	Subsurface	Vgsl	GM	45-60	10-15	Angular	--	NP
	Substratum	Exgsl	GM	55-60	20-30	Angular	--	NP
30QG	Surface	Gsil, gl	ML	0-20	0-10	Angular	--	NP
	Subsurface	Exgsl, vgsl	GM	35-65	5-10	Angular	--	NP
	Substratum	Exgsl	GM	55-65	5-10	Angular	--	NP
32QA	Surface	Sil, l	ML	10-15	0-5	Angular	--	NP
	Subsurface	Vgsil, excbsl	GM	45-50	0-50	Angular	--	NP
	Substratum	excbsl	GM	25-65	0-50	Angular	--	NP
60QA	Surface	Vgsl	GM	35-65	5-35	Angular	--	NP
	Subsurface	Excbsl	GM	25-45	45-65	Angular	--	NP
	Substratum	Excbsl	GM	25-45	45-65	Angular	--	NP
60QB	Surface	Vgl, vgsil	GM, SM	15-35	5-25	Angular	--	NP
	Subsurface	Excbsl	GM	25-45	45-65	Angular	--	NP
	Substratum	Excbsl	GM	25-45	45-65	Angular	--	NP
60QC	Surface	Sil	ML	0-15	0-5	Angular	--	NP
	Subsurface	Excbsl	GM	25-45	35-65	Angular	--	NP
	Substratum	Excbsl	GM	25-45	35-65	Angular	--	NP
64QA	Surface	Vgl	GM	55-55	0-10	Angular	--	NP
	Subsurface	Exgsl, excbsl	GM	35-65	35-65	Angular	--	NP
	Substratum	Exgsl, excbsl	GM	35-65	35-65	Angular	--	NP
64QB	Surface	Vgl	GM	45-55	0-10	Angular	--	NP
	Subsurface	Exgsl, excbsl	GM	35-65	35-65	Angular	--	NP
	Substratum	Exgsl, excbsl	GM	35-65	35-65	Angular	--	NP
64QC	Surface	Sil, gsil	ML	15-45	0-10	Angular	--	NP
	Subsurface	Exgsl, excbsl	GM	35-65	35-65	Angular	--	NP
	Substratum	Exgsl, excbsl	GM	35-65	35-65	Angular	--	NP
64QD	Surface	Sil, gsil	ML	15-35	5-10	Angular	--	NP
	Subsurface	Exgsl, excbsl	GM	35-65	25-45	Angular	--	NP
	Substratum	Exgsl, excbsl	GM	35-65	25-45	Angular	--	NP
64QE	Surface	Sil, gsil	ML	10-30	0-25	Angular	--	NP
	Subsurface	Exgsl, excbsl	GM	35-65	25-45	Angular	--	NP
	Substratum	Exgsl, excbsl	GM	35-65	25-45	Angular	--	NP

Table E.5. Road construction limitation and suitability ratings within the study site area

Map Unit	Excavation (limits, types)	Cut and Fill Maintenance (limits, types)	Native Road Surface (suitability, limits)	Disturbed site Revegetation (suitability, limits)	Aggregate Source (suitability, limits)
10UA	Moderate, wet areas	Moderate, flooding	Fair, bearing strength and fragments >3"	Good, --	Good, --
13UA	slight	Moderate, Rock ravel	Fair, fragments >3"	Fair, droughty rocky	Fair, fragments >3"
30QA	Slight, --	Slight, --	Good, --	Poor, droughty soils	Fair, crushable bedrock
30QB	Slight, --	Slight, --	Good, --	Fair droughty soils	Fair, crushable bedrock
30QG	Slight, --	Slight, --	Good, --	Good, --	Fair, crushable bedrock
32QA	Slight, --	Slight, --	Good, --	Good, --	Fair, crushable bedrock
60QA	Severe, steep slopes, nonrippable rock	Moderate, Rock ravel	Good, talus stringers	Poor, droughty soils	Fair, crushable bedrock
60QB	Severe, steep slopes, nonrippable rock	Moderate, Rock ravel	Good, talus stringers	fair, droughty soils	Fair, crushable bedrock
60QC	Severe, steep slopes, nonrippable rock	Moderate, Rock ravel	Good, talus stringers	Good, --	Fair, crushable bedrock
64QA	Moderate, steep slopes, nonrippable rock	Slight, --	Good, --	Poor, droughty soils	Fair, crushable bedrock
64QB	Moderate, steep slopes, nonrippable rock	Slight, --	Good, --	Fair, droughty soils	Fair, crushable bedrock
64QC	Moderate, steep slopes, nonrippable rock	Slight, --	Good, --	Good, --	Fair, crushable bedrock
64QD	Moderate, steep slopes, nonrippable rock	Slight, --	Good, --	Good, --	Fair, crushable bedrock
64QE	Moderate, steep slopes, nonrippable rock	Moderate, brush	Good, --	Good, --	Fair, crushable bedrock

Table E.6. Road location factors within the study site area

Map Unit	Ave. Ann. Precip. (inches)	Freq. of wet areas	Hard bedrock (%)	Parent Material	Drainage channels (per mile)	Avalanche Hazard	Slope Complexity	Sed. hazard
10UA	20-30	Mod.	0	Undifferentiated Alluvium	4	None	Low	High
13UA	20-30	Low	5	Undifferentiated Alluvium	4	None	Low	High
30QA	20-30	Low	25	metasedimentary	4	Low	Low	Low
30QB	25-35	Low	15	metasedimentary	5	Low	Low	Low
30QG	35-45	Low	20	Loess over metasedimentary	4	Low	Low	Low
32QA	50-65	Low	15	Loess over metasedimentary	1	Low	Low	Low
60QA	20-30	Low	70	Metasedimentary	6	Low	Low	Mod.
60QB	20-30	Low	70	Metasedimentary	6	Low	Low	Mod.
60QC	25-35	Low	70	Loess over Metasedimentary	6	Low	Low	Mod.
64QA	20-30	Low	30	Metasedimentary	5	Low	Mod.	Low
64QB	25-35	Low	30	Metasedimentary	5	Low	Mod.	Low
64QC	30-45	Low	30	Loess over Metasedimentary	6	Low	Mod.	Low
64QD	35-55	Low	30	Loess over Metasedimentary	6	Low	Mod.	Low
64QE	45-55	Low	30	Loess over Metasedimentary	7	Low	Mod.	Low

Table E.7. Timber productivity and natural regeneration within the study site area

Map Unit	Representative Habitat Type(s)	Common Trees (aspect)	Yield (cu.ft/ac/yr)	Natural Regeneration (suitability; limitations)
10UA	PSMA Series	DF	High	Fair, grass competition wet areas
13UA	PSME/VACA PSME/PHMA	DF PP WL	High	Fair, grass competition
30QA	PSMA/AGSP PSME/CARU-AGSP	PP	Low	Poor, moisture, grass competition
30QB	PSME/PHMA-CARU	DF PP	Low/moderate	Fair, moisture, grass competition
30QG	PSME/VAGL-XETE	DF LPP	Moderate	Air, grass competition
32QA	ABLA/MEFE ABLA/XETE-VAGL TSME/MEFE	LPP	Moderate	Good
60QA	PSME/AGSP PSME/CARU-AGSP	PP	Low	Poor, moisture, rocky soils
60QB	PSME/PHMA-CARU	DF PP	Moderate	Fair, moisture, grass competition
60QC	PSME/PHMA-PHMA PSME/VAGL ABGR/XETE	DF WL LPP	Moderate	Fair, rocky soils
64QA	PSME/AGSP PSMF/FEID	P	Low	Poor, moisture, grass competition
64QB	PSME/PHMA-CARU	DF PP	Moderate	Fair, moisture, grass competition
64QC	PSME/PHMA-PHMA ABGR/XETE	DF PP WL	Moderate	Good
64QD	ABGR/CLUN ABGR/LIBO THPL/CLUN	DF WL LPP	High	Good
64QE	ABLA/MEFE ABLA/XETE TSME/MEFE	LPP	Moderate/high	Good

Table E.8. Timber and silvicultural management limitation within the study site area

Map Unit	Plant Competition	Displacement Sensitivity	Equipment Use	Stand Establishment Potential	Windthrow Hazard
10UA	Moderate, moisture	Moderate	Moderate, riparian	Fair	Moderate
13UA	Moderate, moisture	High	Slight	Good	Low
30QA	Severe, moisture	Moderate	Moderate, slope	Poor	Low
30QB	Moderate, moisture	Moderate	Moderate, slope	Fair	Low
30QG	Moderate, moisture	Moderate	Moderate, slope	Good	Low
32QA	Slight	Moderate	Moderate, compaction	Good	Low
60QA	Severe, moisture	Moderate	Severe, slope	Poor	Low
60QB	Moderate, moisture	Moderate	Severe, slope	Fair	Low
60QC	Slight	Moderate	Severe, slope	Good	Low
64QA	Severe, moisture	Moderate	Severe, slope	Poor	Low
64QB	Moderate, moisture	Moderate	Severe, slope	Fair	Low
64QC	Slight	Moderate	Severe, slope	Good	Low
64QD	Slight	Moderate	Severe, slope	Good	Low
64QE	Slight	Moderate	Severe, slope	Good	Low

Table E.9. Properties affecting sediment yield within the study site area

Map Unit	Surface Erodibility	Substrate Erodibility	Landform Sediment Delivery Efficiency	Landslide Potential
10UA	Moderate	Low	High	Low
13UA	Low	Low	High (escarpment), Low (surface)	Moderate
30QA	Low	Low	Low	Low
30QB	Low	Low	Low	Low
30QG	Moderate	Low	Low	Low
32QA	Moderate	Low	Low	Low
60QA	Low	Low	High	Low
60QB	Low	Low	High	Low
60QC	Low-moderate	Low	High	Low
64QA	Low	Low	Moderate	Low
64QB	Low	Low	Moderate	Low
64QC	Low-Moderate	Low	Moderate	Low
64QD	Moderate	Low	Moderate	Low
64QE	Moderate	Low	Moderate	Low

APPENDIX F

Seed mixes used for the obliteration project at O'Brien Creek Watershed

Lolo Seed Mix #2A (Current seed mix)

Variety and Species		Pure	Germ	Origin
Annual Ryegrass –	Gulf	24.74%	95%	OR
Crested Wheatgrass –	Nordan	14.88%	87%	Canada
Pubescent Wheatgrass –	Mandan759	23.86%	95%	SD
Mountain Bromegrass –	Bromar	14.90%	95%	WA
Tall Fescue –	Forager	9.92%	92%	OR
Hard Fescue -	VNS	9.87%	87%	OR

Crop Seed = 0.32% Inert = 1.31% Weeds = 0.20%

Lolo Seed Mix #2C (Future seed mix)

Variety and Species		Pure	Viable	% Mix	Origin
Annual Ryegrass -	VNS	98.57%	97	22.38	OR
Mountian Bromegrass -	Bromar	99.59%	96	12.55	WA
Tall Fescue -	Fawn	99.35%	92.5	13.51	OR
Hard Fescue -	Brigade	98.15%	95	13.35	WA
Sheep Fescue -	MX-86	96.09%	92	13.07	ID
Timothy -	Climax	99.99%	99	10.30	CN
Canada Bluegrass -	Talon	94.40%	91TZ	12.84	WA

Crop Seed = 0.30% Inert = 1.71% Weeds = 0.00%

Table F.1. General plot details

Plot	Geologic Formation	Slope Category	Land Treatment	Replications
A-CS	Bonner	n/a	Existing Road-Cutslope	5
A-FS	Bonner	n/a	Existing Road-Fillslope	5
A-RT	Bonner	n/a	Existing Road-Road Tread	5
A-RC	Bonner	n/a	Existing Road-Road Center	5
B	Bonner	<45%	Recontoured Road-(0 months)	5
C	Bonner	<45%	Natural Slope-Control	5
D-CS	Mount Shields	n/a	Existing Road-Cutslope	5
D-FS	Mount Shields	n/a	Existing Road-Fillslope	5
D-RT	Mount Shields	n/a	Existing Road-Road Tread	5
D-RC	Mount Shields	n/a	Existing Road-Road Center	5
E	Mount Shields	<45%	Recontoured Road-(0 months)	5
F	Mount Shields	<45%	Natural Slope-Control	5
G	Bonner	>45%	Recontoured Road-(0 months)	5
H	Bonner	>45%	Natural Slope-Control	5
I	Bonner	<45%	Recontoured Road-(12 months)	5
J	Mount Shields	>45%	Natural Slope-Control	5
K	Mount Shields	>45%	Recontoured Road-(0 months)	5
L	Mount Shields	<45%	Recontoured Road-(12 months)	5
M	Bonner	>45%	Recontoured Road-(12 months)	5
N	Mount Shields	>45%	Recontoured Road-(12 months)	5

Table F.2. Specific plot details

Plot	Actual Slopes	Aspects	Rocks	Vegetation
A-cutslope	50 - 88%	SW	20-60% cobble 20-70% gravel	5 - 35% (knapweed, sticks, grass in bunches, twigs)
A-fillslope	60 - 90%	SW	50-80% cobble 30-40% gravel	20 - 100% (tall, dead grass, knapweed, plants, wood, sticks)
A-road tread	5 - 12%	SW	60-80% cobble 40-95% gravel	0 - 5% (small tufts of grass)
A-road center	6 - 15%	SW	10-70% cobble 30-50% gravel	40 - 75% (tall green and yellow grass, knapweed, short tufts of grass)
B	13 - 35%	NE	1-30% cobble 5-10% gravel	0%
C-(control)	20 - 40%	NE	0%	100% (grass, plants, pine needles, sticks, baby trees, wood)
D-cutslope	95 - 100%	S	0-10% cobble 10-90% gravel	5 - 80% (tiny plants, sticks, dead grass, knapweed)
D-fillslope	72 - 92%	S	0-20% cobble 5-35% gravel	70 - 100% (tall grass, wood, knapweed)
D-road tread	0 - 2%	S	0-20% cobble 50-85% gravel	0 - 5% (small tufts of grass)
D-road center	0 - 1%	S	0% cobble 30-75% gravel	40 - 100% (tall grass, knapweed, sticks, tufts of grass)
E	27 - 39%	SE	40-60% cobble 20-30% gravel	0 - 5% (some dead grass, sticks, twigs)
F-(control)	30 - 3%	S	0-10% cobble 10-30 gravel	30 – 80% (sticks, dead grass, knapweed)

G	50 - 80%	E	10-70% cobble 10-30% gravel	0%
H-(control)	53 - 68%	E	5-30% cobble	100% (dead pine needles, grass, wood branches, pine cones)
I	10 - 42%	NE	30-80% cobble 10-40% gravel	20 - 90% (tall green ad yellow grass (in bunches or clumps), knapweed, tumbleweed, bark)
J-(control)	50 - 100%	NE-E	0-10%cobble 0-5% gravel	100% (grass, pine cones, pine needles, leaves, plants, sticks, moss, bark)
K	66 - 95%	NE	20-60% cobble 20-40% gravel	0 - 1% (twigs, dead grass)
L	25 - 45%	S	5-40% cobble 60-85% gravel	20 – 90% (tall, dead grass, some knapweed)
M	55 - 100%	NE	70-90% cobble 10-40% gravel	70 – 90% (tall green and yellow grass, knapweed, bark, wood, tiny green plants)
N	90 – 100%	S	10-50% cobble 60-90% gravel	70 – 90% Tall dead grass and knapweed, sticks, some wood)

Table F.3. Raw data plot summary

Plot	Total Sediment Erosion Collected (grams)	Rank	Average Water Runoff Collected (liters)	Average Percent Water Runoff (%)
A-RT	269.856	4	24.232	87.30
A-RC	199.696	6	20.702	74.73
A-CS	333.300	2	17.674	63.68
A-FS	89.247	10	6.069	21.86
B	307.690	3	9.123	32.87
C	7.376	15	2.837	10.22
D-RT	167.698	8	15.503	55.85
D-RC	66.811	12	12.392	44.64
D-CS	209.208	5	9.551	64.41
D-FS	3.478	19	0.871	3.14
E	168.194	7	8.781	31.64
F	28.102	14	7.542	27.17
G	711.121	1	12.736	45.88
H	5.099	16	2.445	8.79
I	35.919	13	2.290	8.25
J	4.788	17	1.499	5.40
K	113.818	9	5.478	19.74
L	0.964	20	0.150	0.54
M	68.024	11	4.467	16.10
N	3.503	18	0.694	2.50

Table F.4. Raw data for sediment erosion collected (grams)

REP.	Plot-A Road Tread	Plot-A Road Center	Plot-A Cutslope	Plot-A Fillslope	Plot-B
1	329.815	287.568	267.281	95.953	247.615
2	304.263	238.265	293.389	93.175	347.621
3	245.975	134.452	504.165	46.169	409.917
4	326.680	114.424	327.264	127.851	314.115
5	142.547	223.773	274.399	83.085	219.183
Average	**269.856**	**199.696**	**333.300**	**89.247**	**307.690**

REP.	Plot-C Control	Plot-D Road Tread	Plot-D Road Center	Plot-D Cutslope	Plot-D Fillslope
1	6.682	51.022	36.618	336.522	7.699
2	9.495	172.945	31.212	278.306	4.698
3	2.877	26.838	117.988	322.755	1.370
4	6.893	213.235	78.033	20.513	1.071
5	10.934	374.450	70.203	87.946	2.550
Average	**7.376**	**167.698**	**66.811**	**209.208**	**3.478**

REP.	Plot-E	Plot-F Control	Plot-G	Plot-H Control	Plot-I
1	241.223	48.092	498.384	2.700	68.594
2	100.249	20.411	982.720	5.504	24.484
3	150.103	10.443	647.717	1.997	8.976
4	173.699	20.825	529.506	4.807	11.310
5	175.694	40.741	897.276	10.487	66.229
Average	**168.194**	**28.102**	**711.121**	**5.099**	**35.919**

REP.	Plot-J Control	Plot-K	Plot-L	Plot-M	Plot-N
1	4.814	46.697	1.760	90.414	5.739
2	7.606	147.976	0.180	120.189	1.980
3	2.742	114.451	0.420	26.910	3.488
4	4.909	181.561	0.971	33.161	2.720
5	3.867	78.403	1.490	69.444	3.590
Average	**4.788**	**113.818**	**0.964**	**68.024**	**3.503**

Table F.5. Raw data for water runoff collected (liters)

REP.	Plot-A Road Tread	Plot-A Road Center	Plot-A Cutslope	Plot-A Fillslope	Plot-B
1	26.265	21.980	17.104	4.308	7.583
2	22.758	20.513	19.937	4.925	9.348
3	18.949	21.473	15.582	4.692	10.467
4	26.520	17.885	18.644	11.315	11.380
5	26.666	21.659	17.103	5.105	6.836
Average	**24.232**	**20.702**	**17.674**	**6.069**	**9.123**

REP.	Plot-C Control	Plot-D Road Tread	Plot-D Road Center	Plot-D Cutslope	Plot-D Fillslope
1	1.340	15.800	9.192	10.330	1.594
2	3.818	17.014	5.976	11.975	1.146
3	2.475	10.578	14.314	7.295	0.355
4	2.718	15.660	17.368	7.804	0.593
5	3.836	18.465	15.109	10.353	0.667
Average	**2.837**	**15.503**	**12.392**	**9.551**	**0.871**

REP.	Plot-E	Plot-F Control	Plot-G	Plot-H Control	Plot-I
1	9.494	7.627	10.173	2.175	2.800
2	7.455	7.648	14.917	3.822	0.964
3	7.364	7.661	13.844	1.298	1.051
4	10.299	7.646	11.228	3.162	2.861
5	9.291	7.128	13.518	1.768	3.775
Average	**8.781**	**7.542**	**12.736**	**2.445**	**2.290**

REP.	Plot-J Control	Plot-K	Plot-L	Plot-M	Plot-N
1	1.648	6.325	0.199	6.035	1.642
2	1.590	4.820	0.040	6.261	0.256
3	1.172	6.086	0.072	1.149	0.848
4	1.378	4.169	0.192	3.097	0.312
5	1.707	5.990	0.249	5.795	0.413
Average	**1.499**	**5.478**	**0.150**	**4.467**	**0.694**

Table F.6. Percentage data for control plots

Plot	% Sediment	% Water Runoff	% Water Runoff	% Water Infiltration
	(from ave. total runoff collected)	(from ave. total runoff collected)	(from ave. total water used)	(from ave. total water used)
C	0.26	99.74	10.22	89.78
F	0.37	99.63	27.17	72.83
H	0.21	99.79	8.81	91.19
J	0.32	99.68	5.40	94.60

Table F.7. Percentage data for recontoured road (0 months) plots

Plot	% Sediment	% Water Runoff	% Water Runoff	% Water Infiltration
	(from ave. total runoff collected)	(from ave. total runoff collected)	(from ave. total water used)	(from ave. total water used)
B	3.26	99.74	32.87	67.13
E	1.88	98.12	31.64	68.36
G	5.29	94.71	45.88	54.12
K	2.04	97.96	19.74	80.26

Table F.8. Percentage data for recontoured road (12 months) plots

Plot	% Sediment	% Water Runoff	% Water Runoff	% Water Infiltration
	(from ave. total runoff collected)	(from ave. total runoff collected)	(from ave. total water used)	(from ave. total water used)
I	1.54	98.46	8.25	91.75
L	0.64	99.36	0.54	99.46
M	1.50	98.50	16.09	83.91
N	0.50	99.50	2.50	97.50

Table F.9. Percentage data for road segment plots

Plot	% Sediment	% Water Runoff	% Water Runoff	% Water Infiltration
	(from ave. total runoff collected)	(from ave. total runoff collected)	(from ave. total water used)	(from ave. total water used)
A-RT	1.10	98.90	87.30	12.70
A-RC	0.96	99.04	74.58	25.42
A-CS	1.85	98.15	63.67	36.33
A-FS	1.45	98.55	21.86	78.14
D-RT	1.07	98.93	55.85	44.15
D-RC	0.54	99.46	44.64	55.36
D-CS	2.14	97.86	34.41	65.59
D-FS	0.40	99.60	3.14	96.86

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