Forest Road Sediment Production and its Implications

FRST 497 Graduating Essay

Kyle Hansen

2009-24-04

Abstract

Preventing forest road erosion requires an in-depth understanding of how road design, construction, weather, maintenance and deactivation affect sediment production. Four road components that are potential problem areas are: road surfaces, fillslopes, cutslopes, and roadside ditches. In order to assess and compare origins of sediment production and the effectiveness of each proposed treatment, GIS is used to analyze sediment production from forests roads and its impact on streams. In order to evaluate terrain stability, a SINMAP method is used to calculate the relative wetness of the site based on input including: slope, area, and parameters of steady state hydrology. To prevent fillslope erosion, the treatments in order of increasing effectiveness include: straw with asphalt tack, straw with a net or mat, straw alone, erosion control mats, wood chips or rock, and hydromulch. Similar treatments were applied to cutslopes with the exception of those too difficult to apply to the typically steeper gradients. Road surfaces were treated with layers of crushed rock which proved to mitigate the effects of surface erosion. Roadside ditches were also treated with surfacing in an attempt to either reduce the velocity of runoff water or cover the ditch bottoms thus preventing scouring. Ultimately, the prevention of sediment production, erosion and negative effects on slope stability and stream contamination requires proper planning, design and research by the Forest Professional.

Keywords: forest road, sediment production, erosion, slope stability.

Table of Contents

Table of Figures

Introduction

Sediment production from forest roads originates on road surfaces, fillslopes, cutslopes and drainage structures and results in the movement of 35 times the volume of soil than on adjacent unlogged terrain (Rood, 1984). Sediment is any particulate material that can be transported by water which is eventually deposited. Sediment production is the primary cause of erosion which is the removal of solid material (sediment, rock, soil, and other particles) in the environment. The road surface is the road component on which logging equipment drives and is the most crucial component when attempting to prevent erosion. Fillslopes have the worst track record as far as slope stability and require extensive measures to maintain stability prevent erosion. Cutslopes are often extremely steep and are required in order to create a bench for the road prism requiring earth to be blasted or excavated, and also have a high risk of sediment production. Roadside ditches intercept runoff water produced by the road surfaces and cutslopes and transport it to water crossings that discharge the collected runoff into drainage points. The drainage points are locations in the forest basin where water runoff transporting sediment is deposited by drainage structures. Drainage structures change the natural drainage pathways and drainage points thus having large implications on erosion. The sediment stripped from these four road components are transported via natural and man-made waterways to a site of deposition which could negatively impact fish stream water quality. The site of drainage points is also at risk of developing decreased slope stability due to soil unusually high soil saturation. Estimates of erosion reduction have been based on the standard road building procedures seen throughout the industry and the viable treatments for each road component that is at risk of erosion. This essay describes in detail the sources of forest road sediment production; sediment production calculations, the implications of sediment in fish streams, methods to reduce forest road based sediment production, proper road deactivation; and ways to design a road and apply treatments to minimize sediment production.

Problem Areas

Road Surfaces

Road surfaces include all road and skid trail surfaces that are at risk of erosion. The extent of road surface erosion varies greatly based on factors including: road design, surfacing, machinery in use and precipitation levels. Forest roads are often designed for cost-effectiveness and operatability as the Forest Engineer's main objectives. Unfortunately, safety and road’s resistance to erosion are often secondary to the thought put into the costing of the operation. Haul roads are often built to parallel and constantly cross streams, and use inadequate drainage structures. Haul roads as well as skid trails are often designed to be excessively steep and follow the drainage patterns of the area to be logged posing serious hydrology-induced erosion risks. These designs, subsequently, are the root of stream sediment contamination and its complications. Such complications include measurable impacts on streams and their fish populations, adjacent stands of timber, cutblock regeneration and decreased slope stability (Burroughs & King, 1989).

Fillslope

Fillslopes exhibit the highest erosion rates of all the road components. Fillslopes are areas where earth has been relocated in order to fill a segment of the road to continuously maintain the desired grade. Fill slopes result in some sidecasting of material which involves moving the fill material to the downslope side during forest road construction. Sidecasting is undesirable, although not completely avoidable, and has long been known to be a major source of sediment production. Fill may be sourced from proximal road cutslopes or from a more costly and remote source known as a quarry, and is highly variable in composition. The main factors affecting fillslope sediment production are: fill soil composition, steepness, and exposure to runoff water. Fill soils that have finer grain properties is more likely to be transported by runoff water. The steeper the fillslope and the more runoff water it is subject to also increase the rate of erosion. There are many treatments for fillslope erosion depending on the local precipitation rates, soil characteristics, slope gradient, and the time between road construction and the treatment. Erosion mitigation on fillslopes is based on six different treatments. The most important factor in preventing erosion on fillslopes is to apply the treatment as soon as possible because nearly half of the total sediment production occurs during the first month following construction. Control measures for erosion that are applied immediately after fillslope construction in order to increase the probability of reduced sediment production compared to measures implemented later (Burroughs & King, 1989).

Cutslope

Many factors affecting fillslope sediment production are similar for cutslopes. Sediment production on cutslopes is affected by: the type of erosion control treatments, the application rates for different treatments, the timing of the treatments, the local slope gradient and length of cutslope, and the inherent erodibility of the soil. However, the treatments used to control erosion on cutslopes vary slightly from fillslopes because cutslopes generally have much steeper slopes. Cutslopes are much more prone to dry raveling (crumbling) during the dry summer months of the year. Sediment production is especially high in areas composed mainly of coarse sandy soils which one would expect of a non cohesive soil (Burroughs & King, 1989). It was found that coarse sand cutslopes exhibit two to five times the erosion during the summer than during the rest of the year (Boise State University 1984). Another study estimated that 80% of the year's erosion occurs during the winter when saturated soils are more prone to sloughing and especially during the spring snow melt (King and Gonsior 1980).

Roadside Ditch

Roadside ditches are one of the most crucial road components in areas of high precipitation. Scouring of soil in roadside ditches is a common source of sediment production. Rerouting the natural drainage pathways of small streams with ditches increases the water runoff volumes in the ditch at any given time. An increased volume of water leads to increased flow rates which in turn increases the amount of sediment that may reach fish streams and other waterways. The importance of reducing sediment production by fillslopes, road surfaces and cutslopes becomes crucial when attempting to keep the water runoff entering the ditches clean. Mitigating sediment production within ditches requires the reduction of drainage water flow rates to prevent the scouring of the ditch bottoms. Numerous treatment methods may be used to line the ditch bottoms. Lining ditch bottoms decreases the runoff flow rates. Reducing runoff flow rates reduces the sediment transported to drainage points by runoff water. Once roads are no longer in use proper deactivation of ditches and road surfaces is required. Without proper deactivation, roadside ditches can often spill over onto the road surface and begin to gradually erode fillslopes and cutslopes. Extensive water damage and sediment build up may lead to slope instability which, in the case of a landslide, would have major implications on nearby waterways, timber supply and the safety of crews. Stream-crossing culverts may inhibit the flow of water downstream and lead to extensive erosion and landslides resulting from increased water discharge levels at drainage points. Excessive water discharge on soil at drainage points saturates the soil increasing its weight and decreasing its resistance to the shear forces caused by this weight (Flanagan et al. 1998).

Estimating Sediment Production

In order to assess the sediment production of each road segment, methods for quantifying sediment production rates must be established. From these rates, risk of sediment production of each road construction method may be compared. Once the risk of sediment production has been assessed, the company may choose to focus their road building budget on the areas with the highest risk of erosion within the bounds of the local road building and deactivation regulations. Models for estimating erosion are highly variable. Below is an example of a model that uses GIS as a tool to analyze sediment production from forests roads and its impact on streams and slope stability (Prasad, Tarboton, Luce, & Black, 2004). Local knowledge and studies on the effectiveness of past models will allow the professional to tailor a model suitable for the area at hand.

Studies by the US Forest service in Boise, Idaho, outline the importance of linear and point data at a fine scale in order to establish an understanding of impacts over larger areas requiring an inventory of the roads and their effect on their studied drainage points (Luce and Black 2002). Luce and Black also noticed that competing models did not take into account the characteristics of drains and their specific locations. Their improved model includes a database to upload data collected in the field which would later be used in a GIS program producing an assessment of the coincidence of road and terrain characteristics (Prasad, Tarboton, Luce, & Black, 2004). From this, the model can be used to determine the potential risks imposed on adjacent aquatic ecosystems.

Road Sediment Analysis Model

This model was developed to provide three functions:

- An estimation of erosion (sediment production) from stream sediment inputs and forest roads.
- An assessment of the impacts of road drainage on terrain stability.
- An analysis of drainage systems and how crossing affects fish habitat and possible habitat segmentation.

Terrain Stability and Road Drainage

The following diagram outlines the conceptual framework of the GIS system used to evaluate sediment production from roads and stream sediment input.

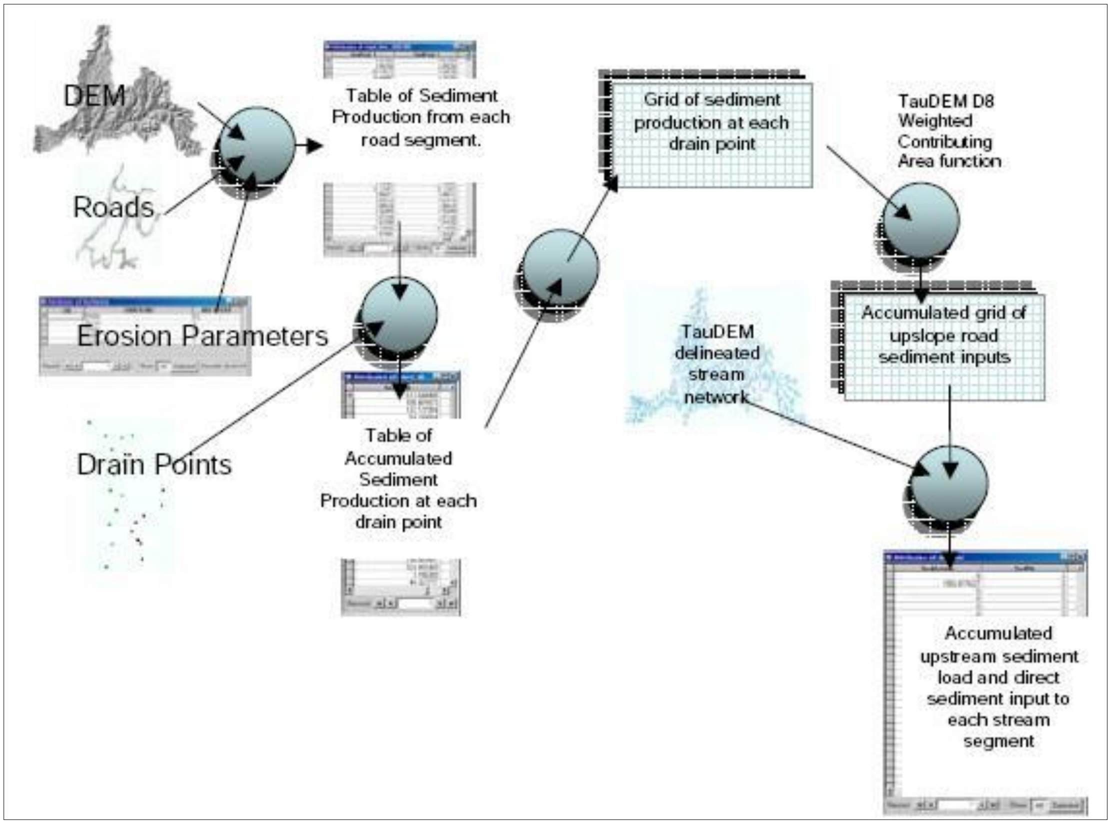

Figure 1: A GIS based system evaluating sediment production from forest roads (Prasad, Tarboton, Luce, & Black, 2004).

The first step in this model analysis is to evaluate the sediment production of each segment of forest road. Sediment production is calculated based on a base road sediment production rate which is then adjusted by multipliers in order to account for ditch vegetation and the condition of the road surface for the given slope and length of the road segment (Prasad, Tarboton, Luce, & Black, 2004). The following formula calculates the erosion for a given segment of road,

$$E_i = \frac{aLSrv}{2}$$

Equation 1: Calculates the erosion for a segment of the road (one side) (Prasad, Tarboton, Luce, & Black, 2004).

where “a” is the base erosion rate (default: 79 kg/m(elevation)), “L” is the length of the road segment, “S” is slope, “r” is the road surface multiplier, “v” is the multiplier used to adjust for ditch vegetation, and the subscript “i” denotes the side of the road being studied. Road sides are calculated separately in order to account for not only their different attributes but also for their different drain points.

Drain points are monitored for accumulated sediment load resulting from sediment produced on the road surface and transported via roadside ditches. Accumulated sediment load is calculated at each drain point by adding up all the values calculated with Equation 1 and adding it to the road attribute table under a given “DrainID”. Naturally, each road segment is represented by a DrainID for each side of the road (Prasad, Tarboton, Luce, & Black, 2004).

The drain points where data are collected are points where runoff water from the road surface and ditches is diverted to the forest basin. The forest basin includes adjacent timber or streams. The input of sediment into the streams is evaluated by a TauDEM (Tarboton and Ames 2001) delineated stream network. The contributing area grid, denoted by “D8,” creates a grid of accumulated sediment load at each drain point and is used as a weight grid. The accumulated sediment input into the stream can then be determined by overlaying the stream network diagram over the D8 and then finding number of grid cells beneath the stream segment downstream from the drain point (Prasad, Tarboton, Luce, & Black, 2004).

Terrain Stability and Road Drainage

Drain points collect sediment transported downhill by roadside ditches and as a result diverted sediment deposits can accumulate on adjacent slopes and cutblocks to the point where there is a high risk of pore water pressure induced slope instability. In order to assess the risk of erosion and slope instability, the slope at each drain point is first recorded on the drain point table. Next, the SINMAP model is used in order to quantify the risk of slope instability using both the infinite plane slope stability model and steady state hydrology outlined by Montgomery and Dietrich (1994). By overlaying the stability index grid from SINMAP and the drain points, the terrain stability at each drain point can be recorded; however, to account for the impact of the quantity of road runoff at each drain point the SINMAP approach must be altered to replace road drainage for the steady state recharge used by SINMAP as shown in Figure 2 below (Prasad, Tarboton, Luce, & Black, 2004).

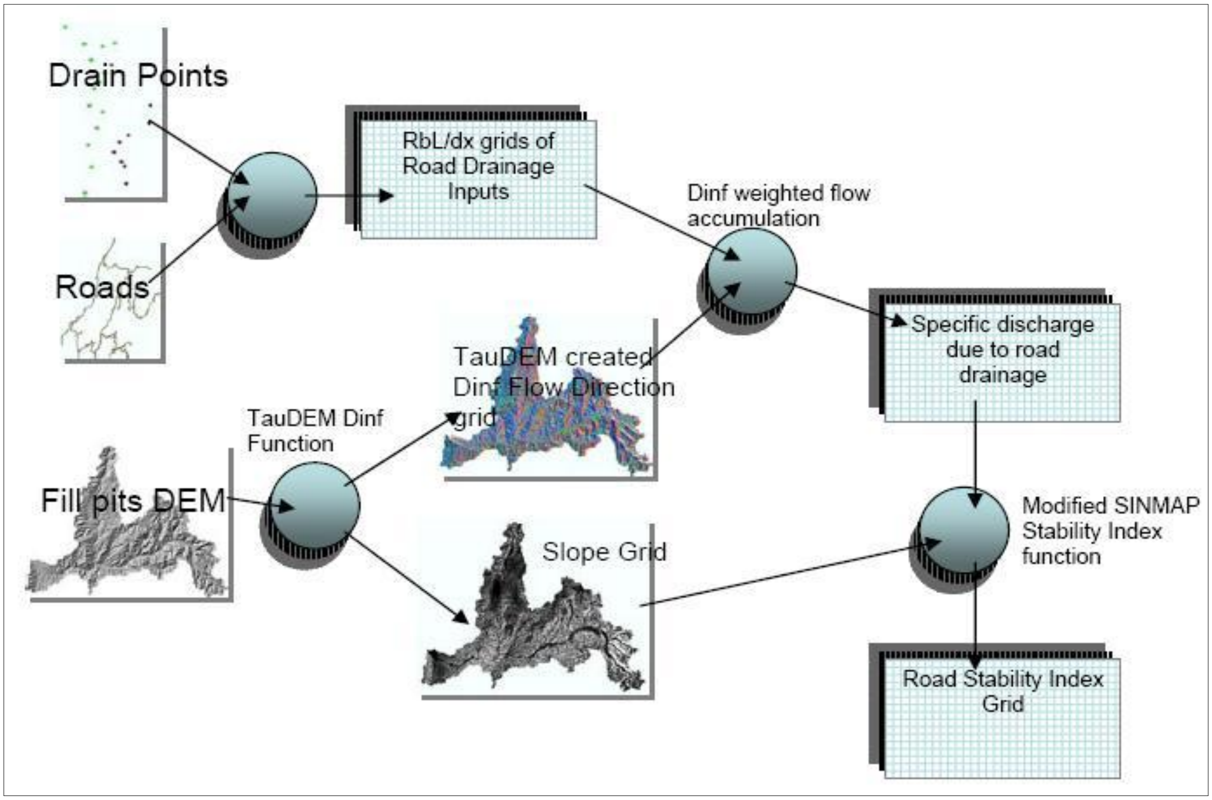

Figure 2: SINMAP method calculating terrain stability (Prasad, Tarboton, Luce, & Black, 2004).

Terrain stability calculated using the SINMAP method calculates the relative wetness of the site based on input including: slope, area, and parameters of steady state hydrology. Relative wetness is calculated using Equation 2 below.

$$w = Min(\frac{Ra}{TS}, 1)$$

Equation 2: Relative soil wetness (Prasad, Tarboton, Luce, & Black, 2004).

Equation 2 is constructed by combining “R” which is the steady state recharge that provides soil moisture, “T” the transmissivity of the soil, “a” the catchment area, and “S” the slope. From this base equation for SINMAP is modified to equate to road drainage. First, the numerator is replaced by “RbL/dx,” the specific discharge due to road drainage, where “R” is the steady state runoff water from the forest roads, and “b” denotes the road width. Finally, the new formula for wetness in relation to road drainage is shown below as Equation 3 below. From this equation terrain stability can be quantified after calculating RminbL/dx and RmaxbL/dx for each drain point. These maximums and minimums are then used to construct a weigh grid for the area to be used with SINMAP to find the road stability index grid (Prasad, Tarboton, Luce, & Black, 2004).

$$w = Min(\frac{RbL/dx}{TS}, 1)$$

Equation 3: Modified wetness formula to equate to road drainage (Prasad, Tarboton, Luce, & Black, 2004).

Implications

The introduction of sediment into streams as a result of logging and forest road building has been recognized as a risk to fisheries and other aquatic organisms. It was concluded that in total, sediment reaching streams is 23 times more likely in clearcut areas than untouched sites (Rood 1984). Forest management has variable impacts on stream ecosystems that vary with impact, duration, logging activity, extent of road building, and the fish species that inhabit the stream (Chatwin & Smith, 1992). Extensive research at Carnation Creek studied the implications of logging and the effects it has on slope stability and streams. During moderate rainfall intensities it was concluded that the volume of landslide material had increased by 12 times as a result of adjacent logging (Hartman and Scrivener 1990). The frequency of landslides is increased by forestry activities because of elevated water yields and more direct water runoff pathways down steep slopes.

Sediment addition in fish streams can cause dewatering of some areas, disturbance of incubating fish eggs, and the transportation of fine sediment into spawning gravel (Scrivener and Brownlee 1989). Multiple source problems arise during watershed restoration projects because a lot of sediment is often trapped in channels abandoned by the stream or stored above large woody debris jams. This material is then released at times of high runoff flow and has cumulative effects on fish habitat (Chatwin & Smith, 1992).

Both high levels of sediment and turbidity can reduce the biological productivity of various aquatic habitats. One way that these factors affect aquatic populations is by potentially decreasing the stream plant growth which may have indirect effects on those organisms that feed on those plants. The organisms that feed on stream plants are the food source for other organisms such as fish. Some examples of lethal and sublethal effects that sediment in streams has on fish include: its effect on feeding and growth, displacement caused by avoidance, egg survival and development, and the effect on cover and increased risk of predation. Factors affecting the list above include but are not limited to:

changes in water temperature, duration of exposure, particle size and the angularity of the particles (Birtwell, 2001).

Sediment in the water may be measured in parts per million (ppm). To maintain an acceptable fish population, a sediment level of no more than 25-80ppm is required in the stream. As the amount of suspended solids increases above 25ppm, the health of fish declines until the concentration of sediment reaches 400ppm in which case there is a very low chance that the stream will be able to support an acceptable fish population. Table 1 outlines the risk to the fish population with increasing sediment concentrations; keep in mind that 1ppm = 1 mg/L (Birtwell, 2001).

Table 1: Outline of risk to fish and their habitat at increasing stream sediment levels (Birtwell, 2001).

Sediment increase ($mg \cdot L^{-1}$)	Risk to fish and their habitat
0	No risk
<25	Very low risk
25 - 100	Low risk
100 - 200	Moderate risk
200 - 400	High risk
>400	Unacceptable risk

The shape of the suspended sediment particles has also been determined to cause physiological stress to fish leading to increased mortality rates. Angular sediment particles suspended in the stream have been shown to cause mortality at much lower concentrations than smooth particles. For example, when Mount St. Helens erupted in Washington State, very angular volcanic ash entered nearby fish streams and ultimately wiped out the fishery resources (Birtwell, 2001).

Mitigation

Road Surfaces

The control of sediment production on road surfaces relies on choosing the proper surfacing materials, construction, and proper planning for when hauling will take place. By measuring sediment production in tones per hectare per millimeter of precipitation before and during timber harvesting, studies have shown that logging traffic on unsurfaced roads potentially increase sediment production by 1.9 times. In the case that the road surface has become rutted by heavy trucks, the sediment production will increase to 2.08 times that of a smooth road surface (Burroughs et al. 1984). Rutting can be reduced by using lower air pressures in the hauling truck's tires which will increase the surface area of the tire and reduce the pressure by spreading out the applied force. Studies have shown that the addition of a 6-inch layer of 1.5-inch minus crushed rock manages to reduce sediment production by 70% over a five month period compared to an unsurfaced road (Swift, 1983). After 13 months, the same road showed grass growth along the edges that helped to reduce sediment production to 84% compared to an unsurfaced road. As expected, the thickness of the surfacing layer is important to the layer's performance. A 2-inch layer was found to have little to no effect on stopping sediment production while an 8-inch layer of larger stones (3-inch D_{50}) was 97% effective. The mitigation of sediment production by adding gravel layers is a function of the erodibility of both the surfacing material and the original soil used to build the road. The best results were seen when surfacing used crushed rock over a very erodible subgrade material (Burroughs & King, 1989).

Fillslope

Minimizing erosion on fillslopes depends on numerous conditions including: timing of application of the control measure, type of the control measure, amount (if at all) by which the road is insloped, the slope gradient, and the inherent erodibility of the soil used to construct the fillslope. Many studies have shown that erosion is especially high initially after construction but decreases exponentially over time as the fillslope material consolidates as shown in Figure 3 below. Figure 4 outlines and compares the effectiveness of six different fillslope treatments. In order of increasing effectiveness the six treatments are: straw with asphalt tack, straw with a net or mat, straw alone, erosion control mats, wood chips or rock, and hydromulch (Burroughs & King, 1989).

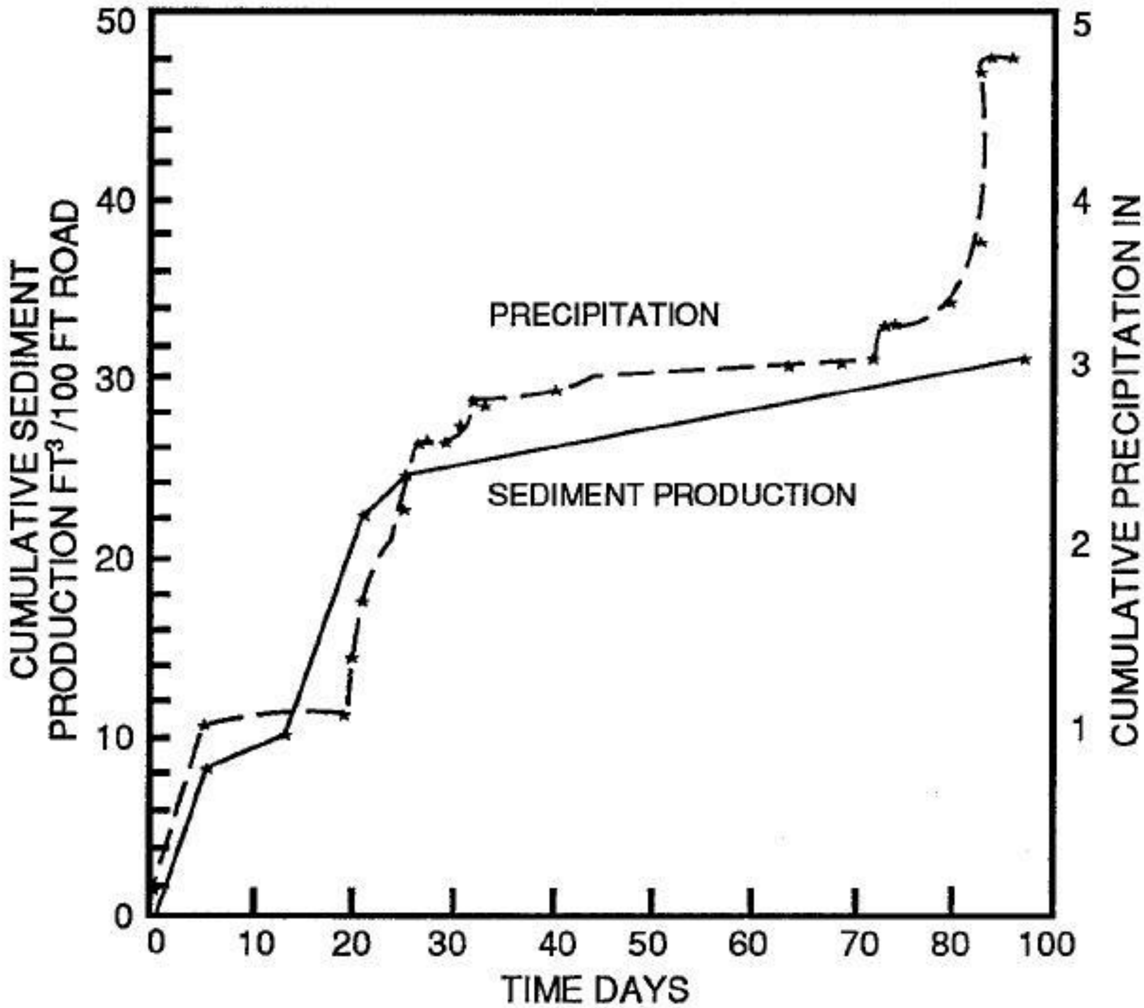

Figure 3: Illustrates sediment production as a function of time (Burroughs & King, 1989).

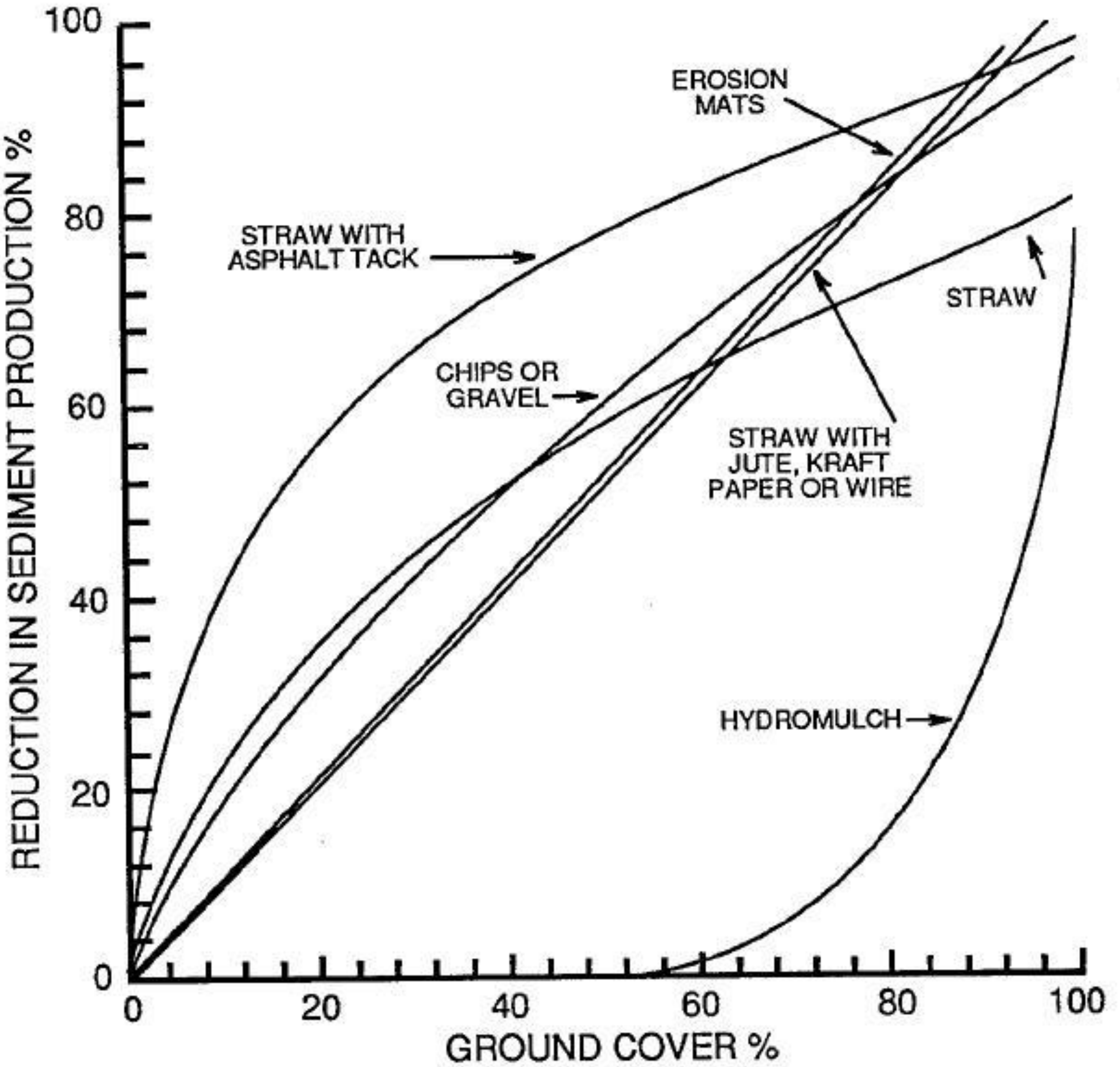

Figure 4: Illustrates the effectiveness of the six different fillslope treatments (Burroughs & King, 1989).

In all cases, as the soil became siltier, and the slope became steeper the effectiveness of the treatment decreased. It is also important to note that the effectiveness relies on the percentage of ground cover in which case the evenness of the ground is important since it is difficult to lay mats down on uneven surfaces for example. Ground ice and regular frost heave also affect the ability of the treatment to cover the ground sufficiently. The use of hydromulch is especially sensitive to the evenness of the ground due to its short strand lengths. The commonly used treatment of applying grass seed is much less effective than the treatments mentioned above because the most erosion happens in the first month or two before grass seed germination. Another treatment omitted from the study above is the creation of filter windrows which are barriers constructed of logging debris (Burroughs & King, 1989). They can be constructed along the bottom of the fillslope using an excavator and have been shown to reduce fillslope erosion my 75 to 85 percent (Cook and King 1983). It should also be noted that this is the most cost-effective treatment since logging slash is abundant and easily accessible with an excavator; however, rapid decay of the woody debris reduces its longevity.

Cutslope

Variables affecting the success of fillslope erosion treatments also apply to cutslope erosion treatments. These variables are: the timing of treatment, the slope length and gradient, the type of control treatment, and the erodibility of the soil. Some control treatments such as rock mulches, hydromulch, and wood chips may not be suitable depending on the steepness of the cutslope. Many of the fillslopes studied were between gradients of 80-100 percent. It is assumed that the same treatments will work for cutslopes of similar gradients. Dry raveling and sloughing, the main erosion mechanisms in effect on cutslopes, take place in the driest and wettest times of the year; therefore, planning the time of year for construction and treatment is extremely important (Burroughs & King, 1989). Table 2 shows a qualitative analysis of numerous erosion control treatments on a 1:1 slope. It is important to note that as the cutslope becomes steeper the ability to properly apply the treatment becomes increasingly difficult; in consequence, the effectiveness decreases.

Table 2: The effectiveness of various control measures on a 1:1 slope (Goss et al., 1970).

Erosion type	Effectiveness rating[1]						
	Jute net	Excelsior mat	Straw	Straw and asphalt[2]	Asphalt	Wood fiber (hydromulch)[3]	Sod
Sheet	9	10	8	10	6	3	10
Rill	6	10	8	10	6	3	10
Slump	10	8	6	7	3	3	8

[1]10 = most effective; 1 = not effective.
[2]Application rate for asphalt is 968 gal/acre for asphalt alone and 400 gal/acre when applied with straw.
[3]Application rate of 1,200 lb/acre.

Roadside Ditch

By using the treatments above to reduce the erosion on road surfaces, fillslopes, and cutslopes, the water entering the roadside ditches is relatively clean; however, it has the capacity to strip soil out of the ditch bottoms and banks. There are numerous methods used to prevent ditch erosion ranging from plastic mats, paving, jute, combinations of natural and artificial materials, and flumes. Mats and flumes can reduce water velocity by 56-78% by protecting loose soil and grass seed. Building flumes and paving ditches is extremely costly; therefore, the most common erosion control treatment in ditches is rip rap or rock blankets. Choosing the proper D_{50} is a function of ditch slope, shape, and the average flow rate of the water. There are graphical solutions provided to determine the proper design of rip rap, but because they are very inconvenient to use, design is more commonly based on the professional experience of the road builder. This report recommends that as a rule of thumb, the size of rock in the riprap should be 1.5 times D_{50} and that the thickness should be 1.5 times the maximum rock size used and never fall below 6 inches(Burroughs & King, 1989).

Road Design to Reduce Sediment Production

When designing a forest road, understanding erosion and its implications and designing the road accordingly can help minimize the risk of erosion thus saving money, adjacent timber, and fish streams. The U.S. Forest Service, the USDA Natural Resources Conservation Service, California Department of Forestry and Fire Protection, the National Park Service, and many forest and ranch landowners have all began to promote the idea of road design that is referred to as "Low Impact on Hydrology" (LITH). The main objective of the LITH is to reduce sediment production that has negative effects on fish streams and slope stability. In order to design a road that is less disruptive to the watershed runoff, roads are constructed as "outsloping road" that eliminate the need for inboard ditches. Granted, this does not eliminate the sediment production of the road surface; however, this can be reduced by the methods previously explained involving proper road surfacing. Secondly, LITH road designs suggest the installation of "rolling dips" to replace ditch relief culverts. Because water runoff is now allowed to pass over the road surface, proper maintenance of the road surface becomes crucial. In the event that the road surfacing becomes rutted from vehicles, the water will be diverted straight down the road and will surely produce high sediment levels. The idea is to eliminate traditional roadside ditching that concentrates water flow to such a small area that flow rates are magnified and as a result scour the banks of the ditches (Dashiell & Lancaster, 2001). The use of LITH roads would require strict use restrictions in wet weather along with the installation of a hardened surface to minimize rutting during times of the year when water is flowing over the road.

The American Association of State Highway and Transportation (AASHTO) states that LITH road designs are only applicable to "Very Low-Volume Local Roads"; therefore, it is not suggested that roads with heavy use, such as mainlines, use the LITH design. Spur roads that have a short life span and see much less traffic are a prime candidates for the LITH design as long as the surface is built to withstand the rigors of the equipment to be used to harvest, yard, and haul logs from the block. Another benefit of this design is the fact that LITH roads do not need to be deactivated and save the cost of removing culverts and digging water bars. Forest roads designed to LITH guidelines to include the following design limitations:

- Allowing for the use of a larger horizontal curve radius in order to accommodate outsloping.
- Lower design speeds for hauling.
- Steeper profile grades within safe reason.
- The length of LITH designed segments must also be reduced to accommodate safety considerations such as steep terrain. With their lack of roadside ditches, the likelihood of ice, snow on the driving surface increases (Dashiell & Lancaster, 2001).

Current Road Regulations

Current road building regulations outlined under the Forest and Range Practices Act (FRPA) is founded upon a result-based legislation which, rather than apply cookie-cutter regulations to operations such as road building, utilizes the term "Professional Reliance" to ensure proper road building. Professional Reliance implies that the Registered Professional Forester (RPF) is responsible to not only recognize potential risks to resource values where roads are proposed, but to properly address them. Complicated legislature and heavy control of road building displayed during the NDP reign in British Columbia entrained inflated costs and company incentive loss. If this were ongoing today, government officials with little to no road building experience would be assigned the evaluation of road construction by strictly following a checklist based on set regulations overlooking many realities of building a forest road. Guidelines from the NDP’s over-complicated Forest Practice Code may be used as guideline to help RPFs make the best decision to address the problem at hand. It is the professional’s obligation to approach situations that are outside his or her field of expertise with what is known as “due diligence”. This involves seeking out professionals that have experience in the situation. For example, in order to properly address FRPA’s goal to protect biodiversity, a Registered Professional Biologist (R.P.Bio) must be consulted. Similarly, when slope stability is questioned, it is important to hire a Geotechnical Engineer to assess the terrain in question (BC Ministry of Forest and Range, 2009). There are flaws in this system. Not all professionals are reliable and it is helpful to consult with Forest Practice Code books related to road construction. Of these books, the Forest Road Engineering volume is especially helpful and is still one of the best references today.

Deactivation

Not only is road deactivation a statutory obligation outlined under the Forest and Range Practices Act, but it is vital to uphold the forestry company's obligation to the public to manage public tenures in an environmentally conscious fashion. Scars from landslides mark cutblocks and roads dating from a time when accepted knowledge and regulations permitted subpar deactivation methods that lead to extensive erosion and slope instability. Methods of deactivation are based on not only years of trial and error, but studies on the effects of hydrology on terrain stability and their cost-effectiveness. The key objectives of road deactivation include:

- minimizing the maintenance costs for inactive roads
- improving aesthetics of landscape
- enhancing the productive growing sites (where practicable)
- using safe, proven and practical methods to minimize the risk of road-related erosion and slope instability
- returning forest hydrology as close to its original state as possible at both surface and sub-surface levels
- maintaining required access

The deactivation of forest roads has become a specialized trade where forest professionals and operators must continually adapt to highly-variable site conditions. It is important for land managers to constantly monitor precipitation levels and understand how they relate to slope stability.

Once all guidelines, objectives, hazards, and other safety concerns are fully understood, crews may begin to deactivate the road as necessary under given circumstances. The most common procedure used to attempt the restoration of natural waterways by preventing ditches from spilling over onto the road surface is to dig diagonal cross-ditches. Waterbars may also be dug across the road surfacing in an effort to reduce the amount of water flowing down the road surface. In areas where seepage from large cutslopes is evident, the use of blanket drains may be effective. Construction of a blanket drain involves laying a layer of cobbles or shot rock down in the road bench and then covering it over with soil to hide the road cut. This improves the visual aesthetics and allows seepage to freely drain through the layer of rock. A similar method known as French drains uses the same buried rock but uses more rock that is laid down along an entire road segment because of extensive seepage until water can reach a gully or cross ditch. If this seepage is not widely spread but more concentrated to one part of the cutslope trench, drains may be installed. In cases where seepage is evident from both the surface and sub-surface of a cutslope, a trench-drain may be the most appropriate deactivation method. Trench drains involve the removal of road side ditches, filling the road cut with earth and then creating mounds of rock that run across the road surface from the road surface up to the top of the fill used to cover the road cut. Another way to maintain the natural surface drainage pattern or stream is to build a ford which is essentially a depression in the road profile allowing water to flow freely across but not down the road and still allowing vehicles to pass through. Fords may be built through non-fish streams if approved by the B.C. Ministry of Environment, Department of Fisheries and Oceans, and the B.C. Ministry of Forests. Fords must be armoured to above the high watermark with rock the same size or larger than those found in the original stream bed to prevent erosion (BC Government, 1999).

The majority of road side failures occur as a result of fillslope instability. Some deactivation methods involve partial or full “sidecast pullback”. Even though sidecasting is not a widely used road building method anymore, some fill and loose soil is still present along most road edges that have a high likelihood of eroding. Sidecast pullback would occur in the case of permanent deactivation of the road. For roads that will still see limited use, insloping or outsloping may be used. This involves moving the road surfacing around causing the road to either slope inward toward the cutslope or to slope to the downhill side. Partial sidecast pullback is mandatory in the event of outsloping where all the water will run over the surface of the road. It is very important that this be done in areas where the fillslopes do not show any signs of slope instability and be constructed to be erosion-resistant (BC Government, 1999).

Forest roads undoubtedly have one of the largest environmental impacts out of all logging operations. Not only are they the root of most sediment production but the severe compaction caused by roads have long-lasting effects on the site. Some researchers will go as far as to say that forest roads will never return to their former state. The compaction or hardness of soil is usually expressed by its bulk density which is measured at various depths and various points on and around road during studies. Although not as severe, rubber tire skidders and other logging equipment used to move logs from the block to the trucks compact the soil with each pass. In this case the bulk density increased markedly and the greatest increase in bulk density was seen at a depth of 0–5 cm. In this case the soil hardness tended to show recovery within 9 years after logging, though not completely. Growth and root penetration of seedlings decreased with the increase of soil hardness. Because compaction has such a large impact on stand regeneration, some roads are actually dug up during deactivation. This procedure is designated by several different terms including: scarification, silviculture fluffing, or simply decompaction. It is important to do this in a way that will not impede streams or cause sediment production or terrain instability. At this time all culverts and wood material should be removed from crossings to restore natural drainage routes and disturbed areas should be seeded with grass to further prevent sediment production (Matangaran & Kobayashi, 1998).

Conclusion

Forest road components have a huge impact on sediment production and its effects on streams and runoff water flow characteristics. Increased runoff flow rates and discharge quantities at drainage points are detrimental to slope stability. Once sediment production has been evaluated with a GIS based system and slope stability has been evaluated with a SINMAP based system, each road component may be assessed individually and then realistically as an interactive system. It was found that 47% of all materials displaced by erosion in areas clearcut eventually end up in streams. This is important to the well-being of fisheries because 100-200 ppm of sediment in streams poses a moderate risk to fish health, 200-400 ppm poses a high risk and a concentration greater than 400ppm poses an unacceptable risk. Angular sediment was found to put fish at an even higher risk and may cause concern at even lower concentrations. In order to reduce the risk to fish and compromised slope stability, treatments to each road component were compared. Adding a 6-inch crushed rock layer to road surfaces decreased sediment production by 70%. After 13 months, seeded grass had started to grow around the edges of the surfacing and this method proved to be 84% effective against erosion. Other noteworthy precautions include proper surface maintenance to prevent rutting as well as reduced tire pressure in logging equipment. Fillslopes are subject to the highest erosion concerns and showed the majority of their erosion taking place within the first 2-3 months after road construction making quick treatment application imperative. The best treatment proved to be the straw with asphalt tack while the worst was hydromulch due to difficulties in effective application. The best treatments for cutslopes were sod and excelsior mats which helped cover any soil at risk of being carried away by runoff water. Although costly and difficult to maintain, ditch mats decreased runoff water velocity by 78% reducing the concern of runoff scouring ditch bottoms. The most cost effective low maintenance treatment was a properly designed layer of rip rap rock. Possible solutions to failing road components are to use a road that is designed to have “Low Impact on Hydrology” (LITH). LITH designs exclude the use of roadside ditches and by utilizing an outsloping grade. With proper surfacing and maintenance, water from uphill and cutslopes runs across the road and is evenly deposited along the fillslopes which must first be treated to ensure runoff does not cause erosion or slope stability issues. For roads that have served their purpose and require little to no access, proper deactivation is key in reducing the long term effects of rerouted drainages. It is the main objective in properly deactivating a road that the original hydrology will be restored by using various deactivation techniques. In closing, the prevention of sediment production, erosion and negative effects on slope stability and stream contamination requires proper planning, design and research by the Forest Professional.

Works Cited

BC Government. (1999). *Technical Standards and Guidelines for Forest Road Deactivation/ Restoration Activities.* Victoria: BC Government.

BC Ministry of Forest and Range. (2009). *FOREST PLANNING AND PRACTICES REGULATION.* Victoria: BC Government.

Birtwell, I. (2001). *Effects of sediment on fish and their habitat.* Vancouver: Canada Fisheries and Oceans.

Black, T., & Luce, C. (2002). *Road Inventory Strategy for Watershed Analysis.* Rocky Mountain Research Station, Boisie, Idaho: USFS .

Boise State University. (1984). *Project completion report: sediment yield from cut and fill slopes.* Boise, Idaho: Boise State University.

Burroughs, E., & King, J. (1989). *Reduction of Sil Erosion on Forest Roads.* Boise, Idaho: United States Forest Service.

Burroughs, E., & Watts, F. (1984). *Surfacing to reduce erosion of forest roads built in granitic soils.* Honolulu: University of Hawaii.

Chatwin, S., & Smith, R. (1992). *Reducing soil erosion associated with forestry operations through integrated research: an example from coastal British Columbia, Canada.* Victoria: IAHS.

Clarkin, K., & Conner, M. (2003). *National inventory and assessment procedure for identifying barriers to aquatic.* San Dimas, CA: USFS San Dimas Technology and Development Center.

Cook, M., & King, J. (1983). *Construction cost and erosion control effectiveness of filter windrows on fillslopes.* . Intermountain Forest and Range Experiment Station: US Department of Agriculture.

Dashiell, H., & Lancaster, M. (2001). *Road Design Guidelines for Low Impact on Hydrology.* California: Five Counties Salmonid Conservation Program.

Flanagan, S., & Furniss, J. (1998). *Methods for Inventory and Environmental Risk Assessment of Road Drainage Crossings.* San Dimas, CA.: USDA Forest Service, Technology and Development Program.

Goss, R., & Blanchard, M. (1970). *The establishment of vegetation on non- topsoiled highway slopes in Washington.* Washington State University: Washington State Highway Commission.

King, J., & Gonsior, M. (1980). *Effects of forest Roads on stream sediment.* Moscow, ID.

Matangaran, J., & Kobayashi, H. (1998). The effect of tractor logging on forest soil compaction and growth of Shorea selanica seedlings in Indonesia . *Journal of Forest Research* , 13-15.

Montgomery, D., & Dietrich, W. (1994). *A Physically Based Model for the Topographic.* Water Resources Research.

Prasad, A., Tarboton, J., Luce, C., & Black, T. (2004). *A GIS Tool to Analyze Forest Road Sediment Production and.* Boise Idaho: United States Forest Service .

Roberts, R. (1987). *Stream channel morphology: major fluvial disturbances in logged watersheds on the Queen Charlotte Islands.* Victoria, BC: BC Ministry of Forests.

Rood, K. (1984). *An aerial photograph inventory of the frequency and yield of mass wasting on the Queen Charlotte Islands.* Victoria, BC: BC Ministry of Forests.

Swift, L. (1984). *Soil losses from roadbeds and cut and fill slopes in the southern Appalachian Mountains.* Southern Journal of Applied Forestry.

Tarboton, D., & Ames, D. (2001). *Terrain Analysis Using Digital Elevation Models.* Salt Lake City: Presentation at Forest Service 2001 Geospatial Conference.