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Determining the Range of Acceptable Forest Road Erosion

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Abstract. *In recent years there has been increased awareness and societal pressure concerning environmental impacts and aesthetics of forest operations such as road management. Forest roads continue to be attributed to account for the majority of erosion from forestlands. Previous research over the past 70 years has presented many questions concerning the impact of roads on forest systems. Research has presented some information on the effect of forest road erosion on forests and the benefit of BMPs in controlling erosion. However, one question that needs to be addressed in designing acceptable road systems is what is the range of acceptable forest road erosion losses? This paper presents a summary of forest road erosion losses and their effects on forest systems from various geographical regions considering road design, climatic factors and management regimes. This paper also provides information to aid in the understanding of the range of erosion losses that are or have been acceptable based on previous work.*

Keywords. Soil Erosion, Forest Roads, Review, Water Quality, Sediment Delivery

Introduction

Soil erosion is an inevitable natural process that occurs when energized water comes in contact with the soil surface. Numerous investigations have reported on this process of soil detachment and transport. Since the beginning of time soil erosion has been forming and reshaping the world as precipitation falls to and water flows across the soil surface. The soil erosion process will continue to occur as long as the first law of thermodynamics holds (conservation of energy). Based on this fact, some level of geologic erosion is expected and considered normal. Previous investigations have suggested a geologic erosion rate of 0.3 t/ha/yr (Smith and Stamey, 1964) and that this rate is so slow that it is likely not harmful (Bennett et al., 1951). However, erosion rates greater than the geologic erosion rate can be detrimental and negatively impact environmental resources (Binkley and Brown, 1993; Reid and Dunne, 1984; Rienhart et al., 1963; van Lear et al., 1997).

It is recognized, as presented by numerous research reports, that undisturbed forest watersheds are valuable in protecting or improving water quality. Forest streams are critical for aquatic sustainability and water supply. This is apparent when we consider that as much as 70 percent of river flow in the nation is initiated by storm runoff from precipitation onto forest watersheds (USEPA, 2000). In the last couple of decades, the quality of surface and subsurface water has received increased attention and concern primarily due to questions of sustainability. The degradation of the water supplies was documented during the period of environmental awakening of the 1960’s and 70’s. During this period, the influence of land use patterns on surface water quality became evident through requirements instituted by the Clean Water Act. In the past decade, the effects of land use changes have refocused attention on impacts of management activities on water quality. Increased land development / land use change can threaten the quality of water that flows through watersheds in the U.S. However, waters that flow from forested watersheds historically (and continue to) constitute some of the most pristine surface waters in the nation.

Accelerated soil erosion resulting from human disturbances and/or land use practices challenges the sustainability of these practices. Accelerated erosion losses may not promote soil conservation (Smith and Stamey, 1964), decrease productivity, and result in degraded water quality (Grace, 2005a) by transporting nutrients directly to streams (Patric, 1976), alter light penetration in aquatic systems (Kirk, 1994), and affect the behavior of visual predators in aquatic ecosystems (Davies-Colley and Smith, 2001). Previous research presents gaps in the understanding of the sustainability of forest road management practices and raises a critical question, What level of erosion losses are acceptable or sustainable? Erosion tolerances have been proposed in previous research for agricultural lands that are in the order of 3 to 15 t/ha/yr for various regions of the U.S. (Smith and Stamey, 1964). However, Smith and Stamey (1964) concluded that the acceptability of these tolerances from a soil quality standpoint depends greatly on rates of soil renewal and depth of reserve soil in the profile. These soil erosion rate tolerances maybe acceptable from a soil quality standpoint but not necessarily indicate acceptability from an environmental and water quality standpoint. The objective of this paper is to explore the issues and challenges associated with accelerated erosion rates and sediment delivery from forest roads in the context of sustainable erosion from a water quality standpoint.

Road Erosion

Unpaved and native surfaced roads are critical in forest management for recreation, wildlife, and timber production. These forest roads have the potential for greatly accelerated erosion rates

(Authur et al., 1998; Bilby et al., 1989; Megahan and Ketcheson, 1996; Grace, 2002b; Patric, 1976). In the studies evaluated in this work, the influence of roads and road operations on soil erosion varies and is influenced by many factors such as soils, climate, region, and management practices (Table 1). Forest roads typically contain several aspects that influence the energy of stormwater runoff. Grace (2005a) presented eight factors that impact stormwater hydrology and increase the potential for accelerated erosion losses. These factors can be lumped into three primary categories for increased erosion potential which include (1) altered watershed hydrology; (2) altered surface soil conditions; and (3) continual surface disturbance. The altered soil surface conditions that contribute to the increased potential for erosion losses include a soil surface without vegetative cover and altered soil structure as a function of the construction process (Grace, 1999). The soil surface is typically devoid of vegetation to reduce the energy of raindrop impact to dislodge soil particles. Watershed hydrology modifications, in conjunction with an altered soil surface, perhaps has the greatest influence on soil erosion losses from unpaved roads due to the increased soil detachment and transport energy associated with runoff concentrated in ditches which often intercept natural drainage patterns. Roads often increase the runoff velocity within sections of a watershed. This increase generally shifts and changes the shape of the watershed hydrograph (Wemple et al., 1996), i.e. decreasing the time of concentration and increasing the peak discharge of streams.

Accelerated erosion losses can be attributed to each component of the road corridor, i.e. sideslopes, ditch, and the traveledway (Burroughs and King, 1989; Clinton and Vose, 2003, Grace, 2002a; 2002b; 2005b; Grace et al., 1998; Luce and Black, 1999, 2001; Swift, 1984a; 1988). The combination of the characteristics from each of these components can result in greatly accelerated road corridor erosion losses. Swift (1984a) suggested a partitioning of erosion from the road prism in the Southern Appalachians in which cutslopes, fillslopes, and the road bed accounted for 54, 25, and 21 percent of total road prism erosion losses, respectively. This work suggests that road sideslopes account for as much as 80 percent of the total soil loss from the road prism, the majority of which occurs during the establishment period for vegetation. Similarly, Cline and others (1981) reported a soil erosion partitioning of 75 percent from road sideslopes and 25 percent from the roadbed. In contrast, road sideslopes and ditches accounted for less than 5 percent of sediment yield from active roads in the Olympic Mountains of Washington State (Reid and Dunne, 1984).

Consistent with Swift's (1984a) investigation, Grace (2002a) reported accelerated erosion losses during the vegetation establishment period on cut and fillslopes, but erosion rates decreased significantly following establishment (>2 years). This investigation reported that erosion losses from the untreated sideslopes decreased during the last 4 years of the 8-year data collection period. The reduction in the erosion losses with time for the cutslopes was primarily attributed to removal of the easily transported sediment from the surface and not to ground cover (Grace, 2007). However, the combination of surface armoring and erosion control treatments were provided in previous research as the mechanisms for soil erosion reductions (Burroughs and King, 1989). This research found an exponential decrease in sediment yield from treated and untreated fillslopes with subsequent rainfall applications. The effect of vegetation on sediment export from forest roads was also emphasized in an investigation in western Oregon (Luce and Black, 1999). The investigators concluded that clearing vegetation from road cutslopes and ditch cleaning resulted in a seven-fold increase in sediment production from the road prism.

In a study of total road prism erosion, Grace (2005c) measured sediment deposition areas contributed by 235 forest road sections on the National Forests of Alabama and the Chattahoochee National Forest in Georgia. The mean distance that sediment extended into the forest was 30 meters. The investigation revealed that the factors influencing the distance sediment traveled downslope of the sections were the road section characteristics of length, width, and the product of the two factors (road area). In a similar investigation, sediment deposition was quantified for a total of 16 road sections in the Coastal Plain of Alabama (Grace and Elliot 2008). Average soil erosion was estimated as the quantity of deposited sediment on the forest floor adjacent to road sections under evaluation. This quantification neglected the portion of suspended sediments moving past the most remote point of visible sediment deposition. However, average quantity of sediment deposited on the forest floor represented 276 t/ha of soil loss from the forest road sections. The soil loss estimates ranged from 48 to 480 t/ha for the 16 forest road sections.

Numerous investigations have reported sediment yield reductions from erosion control treatments on each component of the road corridor (Table 1), (Burroughs and King, 1989). Sediment yield reductions as great as 90 percent have been achieved using aggressive erosion control treatments. Mitigation practices utilized on a given component directly influence the overall erosion losses and sediment delivery from the road corridor. For example, King and Gonsior (1980) reported a 100 percent trap efficiency for filter windrows below road fillslopes which translates to a total reduction in sediment transport below windrows. In the Nez Perce National Forest, as much as 47 percent of the road sediment entering a stream was transported across the fillslope side of the road over a 4-year period following construction (Burroughs and King, 1989). These results suggest that aggressive treatment of the fillslope with erosion control techniques consistent with those mentioned above likely influences sediment delivery.

Sediment Delivery

The primary objective of road stormwater management is to remove the water from the road corridor with reduced erosion energy which minimizes sediment delivery to stream systems. Disconnecting forest roads from stream systems requires that stormwater runoff have two primary characteristics: small volumes and non-erosive velocities. Minimizing stormwater runoff volumes requires frequent dispersion onto areas with high infiltration rates or trap efficiencies. High infiltration rates reduce the quantity of stormwater from the road corridor. Reduced stormwater runoff volumes have reduced capacity to transport sediment detached from the road corridor (Swift and Burns, 1999). Small volumes of stormwater runoff are controlled with less effort and minimize the distance that stormwater travels toward downlope streams by maximizing the distance of (disconnecting) roads from stream systems. The forest floor or alternative stormwater control structures are beneficial in satisfying this objective of road stormwater management.

In the Idaho batholith, an investigation by King and Gonsior (1980) seems to support the beneficial aspects of stormwater control. The investigators found that road construction had no effect on annual stream discharge during the first year after construction. However, a net aggradation in stream channel transects was detected during this period indicating that road sediment was stored in the stream channels. Accelerated erosion losses were reported for both the cut and fillslopes during the two-year period following road construction. The investigators hypothesized that the magnitude of local erosion was in the order of 100 times greater than stream sedimentation that could be attributed to roads and that fillslope erosion was greatly accelerated during the first few storms following construction. Bilby (1985) in contrast reported no significant increase of fine sediment in gravels below a heavily used forest road in western Washington. The investigator included that the reason for the lack of deposition was due to the fine nature (80 percent < 0.004 mm) of the road sediments. Bilby reported that 21 percent of the suspended sediment in the stream was contributed by the forest road corridor.

In Oklahoma's Ouachita Mountains, sediment yields ranged from 20 to 190 t/ha/yr from secondary access road segments based on measurements of sediment deposited and suspended in sluice boxes located in ditch outlets and culverts (Vowell, 1985). However, a significant increase in mean and maximum turbidity and TSS was detected in the stream for only one of eleven storms sampled in the investigation. In another Ouachita Mountain road study in Arkansas, sediment delivery was projected as 1 percent of the observed erosion rates (132 t/km/yr) which translated to approximately 0.10 t/ha/yr distributed over the entire basin. These investigations, as with many other erosion and sedimentation investigations i.e. (Beschta, 1978; Grace, 2005a, 2005c; Megahan and Ketcheson, 1996; Sugden and Woods, 2007; Swift, 1986, 1988; Trimble and Sartz, 1957) emphasized the significance of road location or road proximity to streams in sediment delivery.

Discussion and Implications

Soil and water are two of the critical and valuable renewable natural resources that will likely become more valuable in the near future. It is recognized that the characteristics found in undisturbed forest watersheds are often optimal for minimal soil erosion and maintaining or improving water quality. Accelerated erosion losses have been observed in forest watersheds following disturbance (or management practices) but the effects of the disturbing activities are most often short lived (<1 year) with the exception of road activities. Consequently, roads in forest watersheds are clearly presented as an area of concern in forest management. Roads are cited as the major source of soil erosion and eventual stream sedimentation in forest watersheds. The frequency of traffic and road activities such as maintenance grading, ditching, and mowing can result in continual soil erosion losses (Grace and Clinton, 2007).

It is also recognized and supported by disciplined research that forest roads have greatly accelerated soil erosion from each component of the road corridor. Previous investigations linked to WEPP (X-DRAIN; ROAD) development have provided some understanding of soil erosion and sediment deposition within buffer zones below forest roads (Elliot, 2004; Elliot and Tysdal, 1999; Elliot et al., 1998; Grace and Elliot, 2008). However, the linkage has not yet been made between accelerated erosion losses from the road corridor and road sediment introduction (or sedimentation) to forest streams. Rates of soil erosion, sediment delivery to streams, and the linkage between the two components are essential in development, refinement, and application of soil erosion and water quality models to be used as watershed planning tools. Previous investigations have not clearly related road erosion rates to sediment delivered to stream systems (Grace, 2005a) due to the complexity of identifying and quantifying each source of sediment within a watershed unit. The failure to clearly link erosion rates and sediment delivery is primarily attributed to the approaches utilized to estimate sediment delivery. Traditional approaches to quantifying sediment delivery to stream systems have been presented and discussed in detail by Croke and Hairsine (2006). These approaches have assumptions and limitations that can influence the sediment delivery determinations. Additional research is required on the error associated with assumptions and limitations inherent to sediment delivery estimates in order for these estimates to benefit in sustainable road and sediment control designs.

The critical nature of proper road location in relation to forest streams is emphasized in forest management based on conclusions drawn from previous investigations in forested watersheds during the past four decades. The question, "How far from streams should roads be located?" was originally posed more than 50 years ago by leading scientists. Scientific investigations have been conducted to determine the quantity and distance sediment that moves downslope from forest roads (Clinton and Vose, 2003; Elliot et al., 1994; Grace, 2005c; Megahan and Ketcheson, 1996; Packer, 1967; Swift, 1986, 1988; van Lear et al., 1997). As a result, minimum buffer strip and filter strip distances have been recommended for various geographical regions of the U.S. in an attempt to minimize the influence of roads on stream systems based on limited data. Consequently, the question posed 50 years ago has yet to be answered by the scientific community as is evident by the lack of road sediment delivery information in the literature. Answering this question is elemental in defining and designing sustainable road systems. However, the lack of data to support road location decisions has resulted in standards and practices that may not be sustainable. Additional research is needed to relate observed road erosion losses to sediment delivery to forest streams. These investigations need to consider the influence of downslope characteristics and sediment control practices on sediment movement from the road corridor. This sediment delivery data and the influence of downslope characteristics on soil erosion are ultimately required to define the range of tolerable forest road erosion.

Conclusions

Based on the reviewed research studies, the range of tolerable erosion is a sliding scale. Road erosion and eventual sediment delivery to streams largely depends on the soils, climate, region, traffic intensity and topography. Study results are highly variable and range from negligible to hundreds of t/ha/yr. The review indicates the need for proper road location to reduce the potential for sediment delivery to forest streams. In addition, the effects of sediment control practices have been found to influence sediment delivery based on this previous work. These practices can be effectively designed to trap eroded road sediments and isolate or essentially disconnect roads from stream systems. The trapping characteristics of sediment control practices act as a surrogate to extend the distance between the road and stream systems. This supports the classical view of maximizing the distance of forest roads from streams to minimize the quantity of sediment delivered.

Soil erosion estimates between 3 and 15 t/ha/yr have been deemed as tolerable on agricultural lands from a soil quality standpoint for various regions of the United States based on previous investigations. However, soil erosion rates greater than 100 t/ha/yr are commonly observed from the forest road prism. This accelerated soil erosion loss is contributed by each component of the road prism and can be influenced by environmental factors such as precipitation, climate, region, and soils. Despite the high erosion rates from the forest road corridor, previous research has seldom linked observed erosion rates to water system degradation. This fact could lead to generalizations that the accelerated erosion losses from roads are acceptable or tolerable. However, the lack of supporting experiments and data makes these types of generalizations unfounded from a scientific standpoint. The effect of forest floor and streamside management zones on negating the influence of roads on environmental parameters is not yet defined but is likely more critical to the design and maintenance of sustainable road systems than a blanket erosion tolerance for water systems. It is due to this conclusion that the range of acceptable erosion lies somewhere between the agricultural land upper limit estimate of 3 to 15 t/ha/yr proposed previously and the erosion rate range reported by the investigations reviewed here for forested roads of 1.0 to 250 t/ha/yr. A more precise definition of the acceptable range of forest road erosion first requires linkages between upslope soil erosion rates and sediment delivery, secondly to determine the influence of sediment and runoff control practices on sediment delivery, and finally answering the question related to sustainable road erosion rates.

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Table 1. Soil erosion and sediment delivery associated with different forest road management strategies in various regions of the United States.

Region	Soils	Road Design	Traffic Level	Annual Precipitation, mm	Management	Quantity	Reference
Southern Appalachians	--	--	Light	1520	Construction (low-water road crossing)	+2800 mg/L	Thompson et al., 1996
Southern Appalachians	--	--	Light	1520	Low-water road crossing	+260 mg/L @ 20 m downstream +110 mg/L @ 45 m downstream +45 mg/L @ 92 m downstream	Thompson et al., 1996
	Belt Supergroup (Parent)		Light	600-1000	General access	5.47 Mg/ha/yr	Sugden and Woods, 2007
	Glacial Till Soils		Light	600-1000	General access	5.27 Mg/ha/yr	Sugden and Woods, 2007
Oregon Coast Range	Jory, Bellpine, and Bohannon soils	Insloped w/ aggregate surfacing	Light	1800-3000	Untreated	50 kg	Luce and Black, 1999
Oregon Coast Range	Jory, Bellpine, and Bohannon soils	Insloped w/ aggregate surfacing	Light	1800-3000	Surface Grading	57 kg	Luce and Black, 1999
Oregon Coast Range	Jory, Bellpine, and Bohannon soils	Insloped w/ aggregate surfacing	Light	1800-3000	Surface grading, ditch cleaned, and cutslope vegetation removal	377 kg	Luce and Black, 1999
Southern Appalachians	Chandler series soils	Outsloped, drained by broad-based dips	Light	1870	Construction / Establishment	90 t/ha/yr Roadbed accounted for 21 % Cutslope accounted for 54 % Fillslope accounted for 25 %	Swift, 1984a
Southern Appalachians	Tatum series soils	Mid-slope half-bench crowned road	Light	1400	Construction / Establishment	6.0 t/ha/yr on bare cutslopes 10.0 t/ha/yr on bare fillslopes 0.8 t/ha/yr on grassed cutslopes 1.1 t/ha/yr on grassed fillslopes > 40 % of losses observed during the first year of the 8 year study	Grace et al. 1998; Grace, 2002; 2007

Table 1 (continued). Soil erosion and sediment delivery associated with different forest road management strategies in various regions of the United States.

Region	Soils	Road Design	Traffic Level	Annual Precipitation, mm	Management	Quantity	Reference
Coastal Plain	Florala, Orangeburg, and Dothan series soils	Crowned, unsurfaced, drained by lead-off ditch	Light to High	1520	General Access	276 t/ha/yr	Grace and Elliot, 2008
Southern Appalachians	Fannin Series	Outsloped w/o inside ditch	Heavy	2000	Construction	144 t/ha over 6 months for unsurfaced roadbed 30 t/ha over 6 months for 15 mm crushed rock surface roadbed	Swift, 1984b
Southern Appalachians	Fannin Series	Outsloped w/o inside ditch	Light	2000	General Access	60 t/ha over 6 months for unsurfaced roadbed 20 t/ha over 6 months for 15 mm crushed rock surface roadbed	Swift, 1984b
Southern Appalachians	Fannin Series	Outsloped w/o inside ditch	Heavy	2000	Logging Traffic	200 t/ha over 6 months for unsurfaced roadbed 20 t/ha over 6 months for 15 mm crushed rock surface roadbed	Swift, 1984b
Olympic Mountains of Washington	--	Insloped drained by culverts	Light to Heavy	3900	General Access	3.8 for light traffic to 500 t/km/yr for heavy traffic	Reid and Dunne, 1984
Ouachita Mountains	--	Insloped w/ cross-drain culverts	Light		General Access	55 t/ha/yr (58 % suspended and 42% deposited)	Miller et al., 1985
Ouachita Mountains	Goldston-Carnasaw-Sacul Association	Insloped w/ cross-drain culverts and crowned with lead-off ditches	Light	1300	Construction	90 t/ha/yr (ranged from 18 to 170 t/ha/yr)	Vowell, 1985
Central Appalachians	--	Minimum-standard w/broad-based dip to drain	Light	1300 - 1500	Construction	Unsurfaced - 120 t/ha/yr 3 in. gravel – 15 t/ha/yr 1 in. crusher run – 25 t/ha/yr	Kochenderfer and Helvey, 1987
Central Appalachians	--	Ditched with culverts	Light	1300 - 1500	General Access	1 in. crusher run – 15 t/ha/yr	Kochenderfer and Helvey, 1987