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EROSION PROCESSES AND PREDICTION IN NW U.S. FORESTS

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ABSTRACT

The greatest amounts of forest erosion usually follow infrequent wildfires. Sediment from these fires is gradually routed through the stream system. The forest road network is usually the second greatest source of sediment, generating sediment annually. Erosion rates associated with timber harvest, biomass removal, and prescribed fire are generally minimal with current management practices. Landslides and debris flows can contribute significant amounts of sediment during infrequent wet years, or following wildfire. A relatively new source of sediment in forested watersheds is from recreation, particularly all-terrain vehicle trails. Stream channels store and route sediment, but in the absence of channel disturbance, tend to reach an equilibrium condition where sediment entering a given reach is balanced by sediment carried on downstream. At times this sediment from roads, wildfire or landslides may accumulate in channels until higher flow rates, often associated with rainfall on melting snow, flush it downstream. Predictive tools to aid in estimating long term, low level sedimentation from undisturbed forests, and erosion from sediment delivery from roads, and short term, event driven sediment from disturbed forests have been developed. The Water Erosion Prediction Project (WEPP) model has been parameterized for these surface erosion processes, and soil and vegetation databases for these conditions are distributed with the WEPP Windows interface, and our online and GIS interfaces. The internet interfaces were developed to allow users to more easily predict soil erosion for a wide range of climatic and forest conditions, including roads, fires, and timber harvest. The interfaces have been designed to allow users to compare the effects of the most common management practices for each application.

KEYWORDS. Forest fire, Forest roads, Slope stability, WEPP.

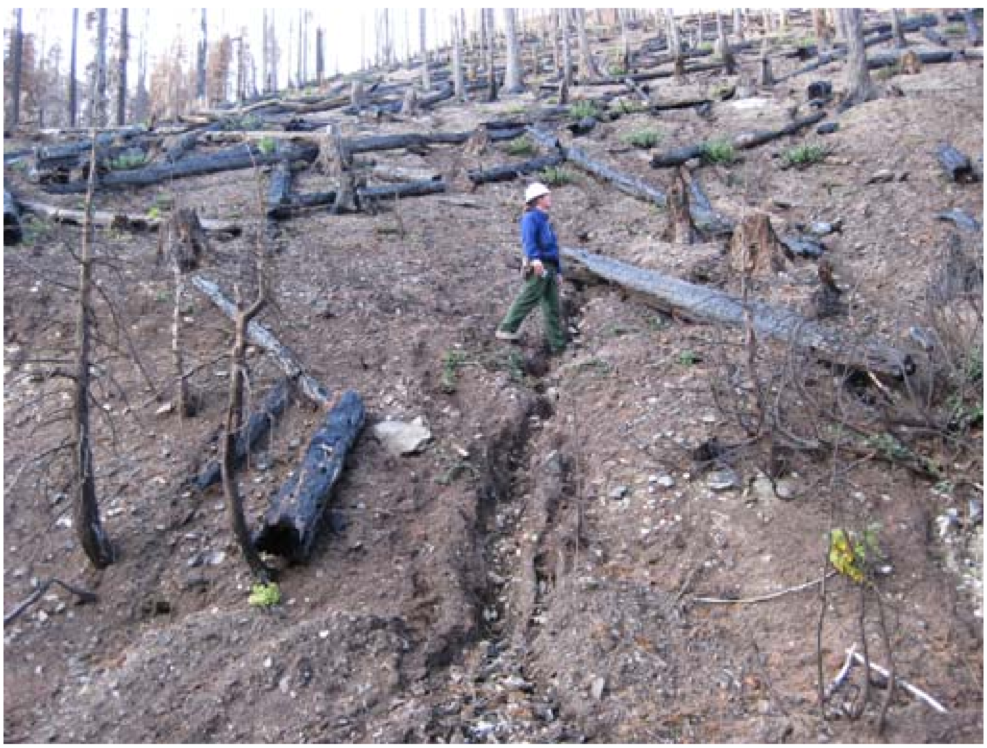

Figure 1. Severe rill erosion following wildfire (Source: N. Wagenbrenner).

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INTRODUCTION

Sediment from forest watersheds is generated by three main processes; surface erosion, mass wasting, and stream channel erosion. The three processes can often overlap or complement each other. For example, following a wildfire, surface erosion may exceed the ability of a channel to transport the eroded sediments, so sediment accumulates in flood plains. In the decades that follow, deposited sediments are gradually entrained and transported further downstream. A landslide may expose bare mineral soil, aggravating surface erosion. Stream bank erosion may undercut a steep bank at the toe of a marginally stable hill, resulting in a landslide (Elliot et al., 2010).

Surface erosion is generally minimal unless a hill slope is disturbed (Megahan and King, 2004, Elliot et al., 2010). The two main disturbances in forests are wildfire and the road network. Other disturbances are associated with timber harvest, prescribed fire, recreation access, and animal activity. Superimposed on these surface disturbances are climatic factors that lead to major runoff events, like heavy rainfall, rapid warming resulting in high snow melt rates, or heavy rain falling on a snow pack ("rain-on-snow"). Weather events that result in most of the erosion only occur about one year in ten. Times when a disturbance is followed by severe weather are when the greatest erosion occurs (Megahan and King, 2004, Elliot et al., 2010). Recent studies over several decades have suggested that in forests, sediment yields range from 2 to 10 Mg/sq km/yr, whereas cosmogenic studies indicate that true long term (thousands of years) erosion rates are likely to be 100 to 500 Mg/sq km/yr (Kirchner et al., 2001).

SURFACE EROSION

In forests, surface erosion is generally found on disturbed forested hillslopes and on the forest road networks. Roads and other forest access tend to erode every year that they are used, and are considered a chronic source of sediment, whereas forested hillslopes generally experience erosion in the year or years following a disturbance.

Disturbed Forested Hillslopes

Undisturbed forest hillslopes have zero, or very little surface erosion. Natural disturbances can sometimes generate small amounts of sediment. The greatest natural disturbance is wildfire. Human disturbances like logging, thinning, and other fuel reduction activities can also generate sediment

Wildfire

NW forest ecosystems are fire adapted, with plant communities that are able to thrive in spite of wildfires with frequencies varying from 50 to 300 years (Agee and Skinner, 2005; McDonald et al., 2000). The greatest surface erosion rates in forested watersheds usually follow wildfire (Figure 1). Erosion rates following wildfire are dependent on the weather the following year (Megahan and King, 2004, Robichaud et al., 2007), and typically range from 1 to 20 Mg/ha.

Forest Management

In the last half of the twentieth century, timber harvest was the dominant forest management practice to provide building materials for the post world war II building boom (Megahan and King, 2004). In addition to timber harvest, a proactive fire suppression strategy was followed. These two practices have resulted in forests with an over abundance of even age timber with a considerable amount of understory. This type of stand is highly susceptible to wildfire, and the frequency and severity of wildfire has been increasing in recent decades (Agee and Skinner, 2005).

In the past decade, management of federal forests has focused on fuel management to reduce the risk of high severity wildfire (Agee and Skinner, 2005). State and privately owned forests, and some federal forests still continue to harvest timber for sale, but in all cases, much greater consideration is given to forest and watershed health (Karwan et al., 2007). The most common fuel management practices are thinning, particularly to remove the understory, and the use of prescribed fire (Figure 2). Recent studies have shown that these practices do not necessarily reduce the likelihood of a wildfire occurring, but they tend to reduce the severity of the fire (Reinhardt et al., 2008). Erosion from thinning will be similar to the undisturbed forest, whereas erosion from the prescribed fire is typically increased by a factor of 10 in the year following the treatment.

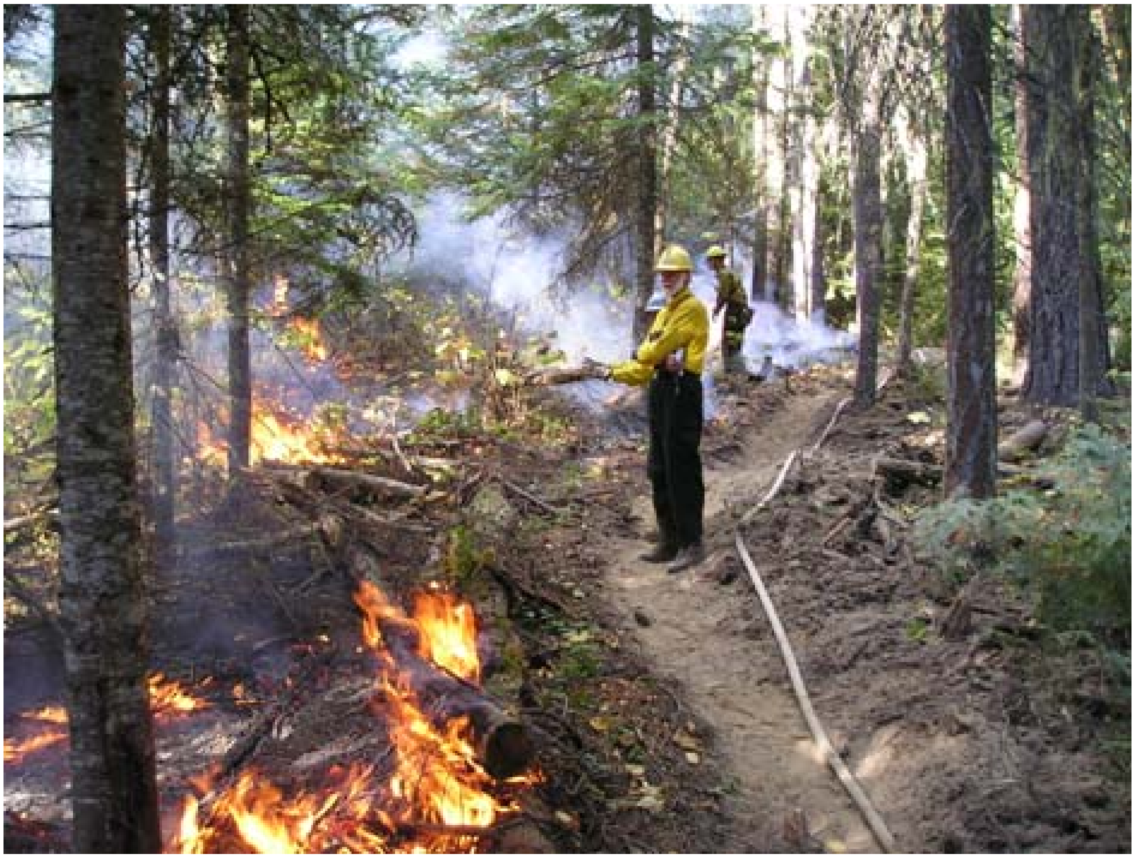

Figure 2. Fire line around a prescribed burn to reduce ground fuel loads (Source: J. Sandquist).

In recent years, interest in using forests as a source of biomass for fuels has increased (Rummer et al., 2003). They reported that erosion rates predicted for fuel management ranged from 0 to 0.4 Mg/ha, depending on climate and topography. The analysis included consideration of increased road erosion as well as erosion from the harvested areas.

Even though the increase in erosion on forested hillslopes due to timber harvest, fuel reduction or biomass removal will likely be minimal, the increased use of roads and skid trails can increase overall sediment yields (Elliot et al., 2010). Foltz et al. (2009) observed that roads become overgrown if not used, but should a road be cleared and used for logging traffic, the erosion rates will likely increase by a factor of 100.

Forest Access

Forest roads serve a multitude of uses including fiber production, grazing, and recreation. All of these uses require some form of access, as do fire suppression activities. These access networks are further extended with temporary or long term trails that can be made by logging skidders, all-terrain vehicles (ATVs), bicycles, wild and domestic animals and humans. In the absence of wildfire, it is these access corridors that are generally recognized as the greatest generator of sediment within our forests (Megahan and King, 2004).

Forest Roads

Forest roads have long been identified as a significant source of sediment in forested watersheds (Megahan and King, 2004). Road erosion rates range from less than 1 to 100 Mg/ha, compared to forests with erosion rates of only a few kilograms per hectare. Sediment delivery from roads depends on the road surface conditions, road location, topography, soil properties, design, use and management.

Newly-constructed or reconstructed roads generate much more sediment than older roads (Megahan and King, 2004). Even older roads will tend to generate some sediment unless they become fully vegetated, including all fill slopes and cut slopes (Foltz et al., 2009; Megahan and King, 2004). Older roads are also a perpetual risk of significant sediment generation from blocked culverts (Gucinski et al., 2001).

The road running surface has a much lower hydraulic conductivity than the surrounding forest, with measured values from less than 1 mm/h to about 10 mm/h. In contrast, the hydraulic conductivity of the surrounding forest ranges from 20 to more than 100 mm/h. The net result of these differences is that the road is generally a source of surface runoff and erosion, whereas the forest can serve as a buffer area of runoff infiltration and sediment deposition (Elliot et al., 2010).

Figure 3. Ruts forming on a well maintained road from heavy logging traffic (Source: W. Elliot).

Road erosion can be minimized by preventing rut formation (Figure 3) and diverting runoff either directly to the fill slope with an outsloped road, or to an inside ditch with a insloped road, if the inside ditch is non erodible. Gravel increases the ability of the road to carry traffic without rut formation. The gravel itself can be a source of fine sediment, however (Foltz and Truebe, 2003). Another factor that influences road erosion is traffic. Roads with heavy traffic generate 4 to 5 times the sediment of roads with light traffic (Foltz, 1996; Elliot et al., 2010).

Once the sediment leaves the road, the buffer area between the road and a channel can be a source of sediment. Outsloped roads seldom generate any sediment in the buffer, although there may be some evidence of erosion on the fill slope. On rutted and insloped roads, however, sediment collected in the ruts and/or the inside ditch can be transported down the slope in a channel if the cross drain delivers the runoff to a swale or ditch. In these cases, there is a risk for offsite erosion that may generate more sediment than was generated from the road itself (Elliot and Tysdal, 1999). Ketcheson and Megahan (1996) noted that the amount of surface debris on the buffer influenced sediment deposition and delivery.

Skid Trails

Logs are generally collected from forests with tracked or rubber-tired skidders on slopes less than about 25 percent and with overhead cables on steeper slopes, and moved from where they were cut to a road or landing. Erosion rates of skid trails are dependent on how many passes of the skidder they have experienced, and, like roads, where they are located on the landscape. The further a skid trail is from concentrated flow, the less likely it is to delivery sediment to the stream system. Cable operations tend to cause fewer disturbances than skidders, although the steepness of the cable corridor is usually greater than with ground-based skidders.

Recreation

One of the growing uses of forested areas is for recreation. Recreation impacts include camp grounds, increased traffic on forest roads, erosion associated with All Terrain Vehicles (ATVs), and other trails. Since camp grounds are generally on flat areas and tend to be grassy, most erosion is limited to roads or parking areas. The effect of increased traffic on road erosion was discussed previously. Erosion from human or animal trails is likely to be limited as trails are small, but could be significant where steep trails segments cross streams. ATV trails are a growing risk for sediment generation in forests. Research has shown that the erosion risk from unmanaged ATV trails may equal that of a road network in a forest (Meadows et al., 2008).

Mass Wasting

Mass wasting is most often associated with weather patterns that lead to saturated soils on steep slopes. One element stabilizing slopes is tree roots. If the trees are harvested, or killed by wildfire, the roots will decompose, and several years following the removal/death of trees, steep slopes are the most susceptible to failure (Hammond et al., 1992). Stream erosion at the base of steep slopes, and road cuts on steep lands can also lead to instability. In developed forests, roads are often associated with landslide initiation due to over steepening of both the cut and fill slopes (McClelland et al., 1997).

Channel Erosion and Sediment Delivery

In forested watersheds, channels tend to be dynamic as they receive, route, store, and entrain sediment generated by disturbed hillslopes and roads. Sediment detachment processes are frequently divided into channel bed scour, channel bank scour, and bank mass erosion.

Channel bed erosion is generally a function of the size of material on the bed and the ability of the stream flow to entrain that material. In the absence of disturbance, upland beds tend to be coarse. Roads, wildfire and upstream erosion can generate fine sediment in excess of the sediment transport capability of some stream segments, and the bed can become covered with fines (Elliot, 2006). These fines tend to accumulate during low runoff events, but can be flushed downstream during bank full flows, which occur about once every two years. During larger events, the material may be mobilized and deposited on adjacent flood plains.

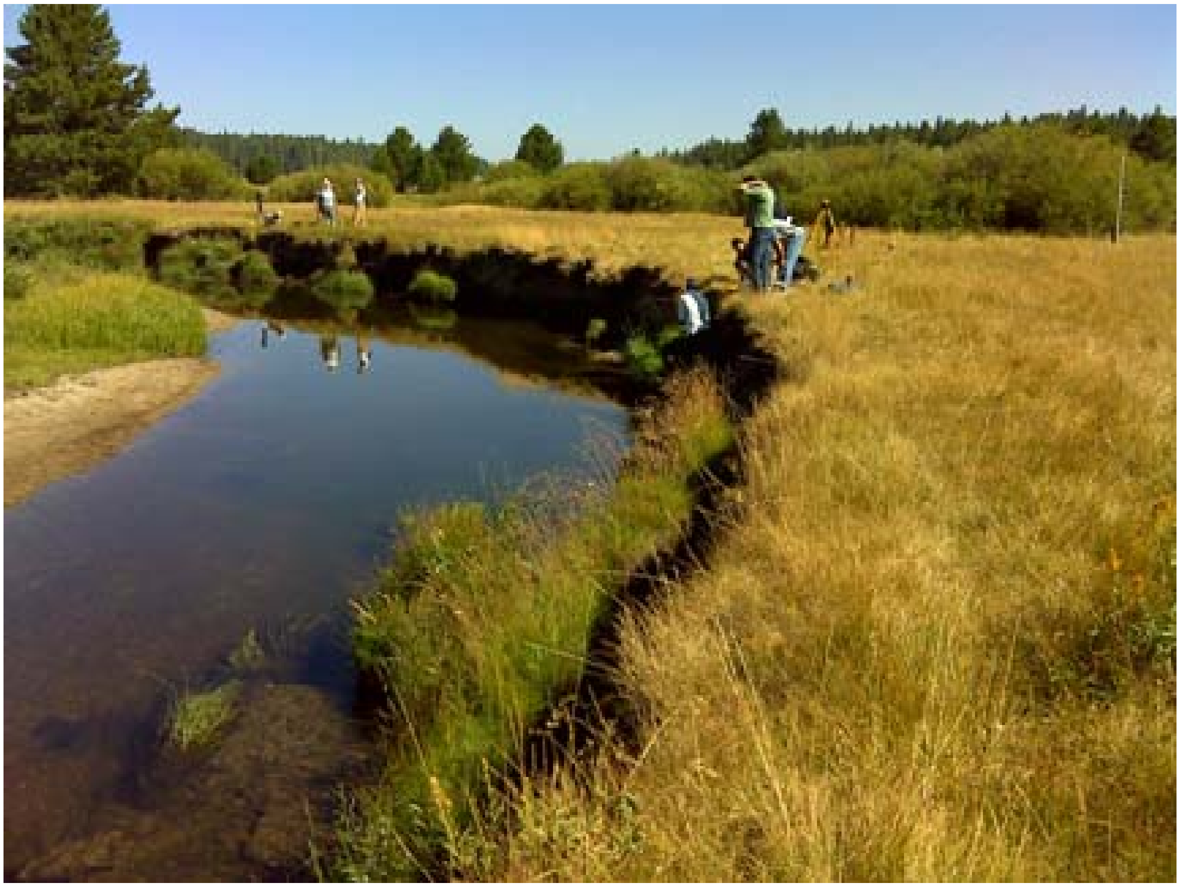

Figure 4. Toppled banks along a forest meadow stream (Source: W. Elliot).

Stream bank erosion is also driven by larger flow events. Bank erosion is frequently much greater from mass failure when the toe of a bank is undercut by channel erosion, followed by a period of high flow which can saturate the bank, and then a drop in flow, leaving the bank weakened by saturation and unstable from undercutting (Elliot et al., 2010). The bank will then topple into the stream (Figure 4), and gradually the blocks will be eroded and the sediment transported downstream during high flows. When channels or banks are not disturbed, channels will reach an equilibrium condition. This process may take years following many of the above disturbances. Until it reaches equilibrium, the channel will tend to be a source of additional sediment.

Predictive Tools

There are a number of predictive tools have been developed for estimating soil detachment, transport and deposition in forests including USLE, Curve Number, and WEPP-based technologies as well as a number of region-specific and GIS customized tools (Elliot et al., 2010). A suite of tools developed by the authors are based on the Water Erosion Prediction Project (WEPP) model (Laflen et al., 1997), and are accessible through the internet on public servers. One set, FSWEPP, is for running disturbed forest hillslopes (Elliot, 2004), and includes interfaces targeting managed hillslopes, burned hillslopes, and road segments. The most recent tool is an online watershed interface (Frankenberger et al., 2011) developed specifically for forested watersheds.

SUMMARY AND CONCLUSIONS

The greatest amounts of erosion are associated with infrequent wildfires. Sediment from these fires is gradually routed through the stream system, with the greatest amounts of sediment transport associated with infrequent periods of stream flows. The forest road network is the second greatest source of sediment, generating sediment annually. Recreation may be an increasing source of sediment in forest watersheds. At times eroded sediment may accumulate in channels until higher flow rates flush it downstream. Landslides and debris flows can contribute significant amounts of sediment during infrequent wet years, or following wildfire. Stream channels store and route sediment, but in the absence of channel disturbance, tend to reach an equilibrium condition where sediment entering a given reach is balanced by sediment carried on downstream.

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