RISK ASSESSMENT OF FUEL MANAGEMENT PRACTICES ON HILLSLOPE EROSION PROCESSES

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ABSTRACT

Fuel and land management activities in the past century have placed wildland values such as soil and water quality at greater risk due to increased soil erosion. Eroded sediment can lead to decreased long-term soil productivity and adversely impact aquatic ecosystems. Higher runoff rates from severely burned landscapes can lead to flooding and increased risk to human life and property. Over the past ten years, we have completed studies on eight sites in the Northwest and Southeast U. S. measuring erosion impacts associated with prescribed burning. We are now carrying out field and laboratory studies addressing knowledge gaps in our understanding of fuel management practices on soil erosion, and developing a user-friendly computer interface to be able to evaluate the risk and consequences of erosion hazards following wildfires, mitigation treatments, and prescribed burns. Specific tasks that we are addressing include: determining hillslope characteristics that govern dry ravel processes such as slope steepness, vegetation density, soil texture and disturbance impacts; determining the spatial and temporal variability in infiltration and erosion parameters needed to predict overland flow and soil detachment after wildfire; quantifying effectiveness of three mitigation practices in reducing sediment production for specified design storms following wildfires; and evaluating measured erosion rates and estimates of sediment production after wildfires at the upland watershed/catchment scale. Data collection has begun from a burned over catchment and preliminary results will be presented. Additional discussion will address methodologies and approaches to evaluate and model erosion risk and hazard.

Keywords: erosion, fire severity, risk assessment, modeling

INTRODUCTION

Fire is a natural and important part of the disturbance regime of many ecosystems. However, fuel management practices have altered fire size and intensity in the past century, which have in turn affected the runoff response and pushed erosion rates beyond natural levels. Fire suppression efforts have increased fuel loading over historical amounts, and altered wildland species composition. The larger fuel loads and thicker ground cover material contribute to higher severity fires. Such fires remove more of the ground cover material protecting the mineral soil, which leads to downstream flooding and sedimentation. This sediment adversely affects spawning and rearing sites for anadromous fish species, mobilizes in-stream sediment, destroys aquatic habitat, may adversely affect downstream water supply systems and lead to a decrease in soil productivity of sensitive forest soils. Additionally, higher runoff rates from severely burned landscapes can lead to flooding and increased risk to human life and property. For a given watershed if several low severity fires occur over a century as opposed to a single or few high severity fires on much of the area, the damage from erosion, debris flows, mass wasting and floods following fires will likely be lower.

Background

Many important site characteristics that regulate the hydrologic function of a watershed can be affected by fire (McNabb and Swanson 1990). Vegetation, litter and duff may be consumed, leaving soils vulnerable to raindrop impact and overland flow (Robichaud 1996). Reduced evapotranspiration following fires, when the vegetation has been killed, causes higher soil water contents which may lead to greater overland flow. If the organic layers are consumed and mineral soil is exposed, soil infiltration rate and water storage capacity are reduced. Such impacts may last for weeks or decades, depending on the fire's severity and intensity, remedial measures, and the rate of recovery of the vegetation. With increased overland flows, the occurrence of surface erosion and dry ravel, debris torrents, mass wasting, and downstream flooding may increase.

Our past research on prescribed burns indicates that differences in overland flow and surface erosion reflect differences in fire severity. On areas burned at low severity, negligible increases in erosion rates were measured (Robichaud et al. 1994), whereas areas that burned with high severity showed a three-fold to an order of magnitude increase in erosion rates (Robichaud and Waldrop 1994). On an Oregon forest, Robichaud and Brown (1999) measured first year erosion rates of 38 Mg ha^{-1}, decreasing to 2.3 Mg ha^{-1} the second year, and negligible amounts the third year. Many of these sites had mosaic patterns of high and low severity conditions and thus they can not be treated as a single homogenous unit. Methods have been developed to address these various patterns of fire severity for prescribed fires and can provide reasonable estimates on the effects of a prescribed burn on erosion (Elliot and Hall 1997; Robichaud and Monroe 1997).

In the arid and semiarid Southwest, dry ravel is a common form of hillslope erosion following wildfire. Dry ravel is the gravity-induced downslope surface movement of soil grains, aggregates, and rocks. It is a ubiquitous process in semiarid steepland ecosystems (Anderson et al. 1959). Triggered by animal activity, earthquakes, wind, and perhaps thermal grain expansion, ravel may best be described as a type of dry grain flow (Wells 1981). Fires greatly alter the physical characteristics of hillside slopes, stripping them of their protective cover of vegetation and organic litter, and removing barriers that would otherwise trap moving sediment. Consequently, during and immediately following fires, large quantities of surface material are liberated and move downslope as dry ravel (Krammes 1960; Rice 1974). Sediment from dry ravel is deposited in upland channels, providing a ready source of material for subsequent fluvial transport and/or debris flows. Previous work has quantified dry ravel on southern California steeplands for unburned, prescribed fire, and wildfire conditions. However, the hillslope characteristics that govern dry ravel are poorly understood. Knowledge of these controlling factors is necessary for modeling this hillslope erosion process.

Rainfall simulation is a proven technique to provide infiltration and erosion rates of forest and rangeland soils on steep terrain. Rainfall simulators (Elliot et al. 1989; Robichaud 1996; Robichaud and Waldrop 1994; Robichaud et al. 1993) have been used to measure infiltration and erosion rates across the United Stated related to timber harvest operations, prescribed burns (Robichaud 1996; Robichaud et al. 1993), range management practices (Franks et al. 1998; Pierson and Blackburn 1994), and other conditions (Elliot et al. 1989). Much of this information is used to parameterize and validate the Water Erosion Prediction Project (WEPP) (Laflen et al. 1997) and Simulation of Production and Utilization of Rangelands (SPUR) (Carlson and Thurow 1992) models.

WEPP has been applied to a broad range of conditions varying from agriculture to rangelands and forests, in the U. S., and elsewhere (Laflen et al. 1997). WEPP allows users to vary inputs to describe site-specific soils, topographic, vegetation, and climate conditions. Outputs from WEPP include not only erosion rates, but also sediment yield, and soil water contents for every day of simulation. A windows-based interface for a WEPP-based road erosion prediction tool was recently completed and is receiving widespread national interest because of its simplicity in addressing a complex problem (Elliot et al. 1998).

Although there is a considerable wealth of research information available on erosion following fire, there are some areas that are still not adequately understood to suitably predict erosion risks after wildfire. These

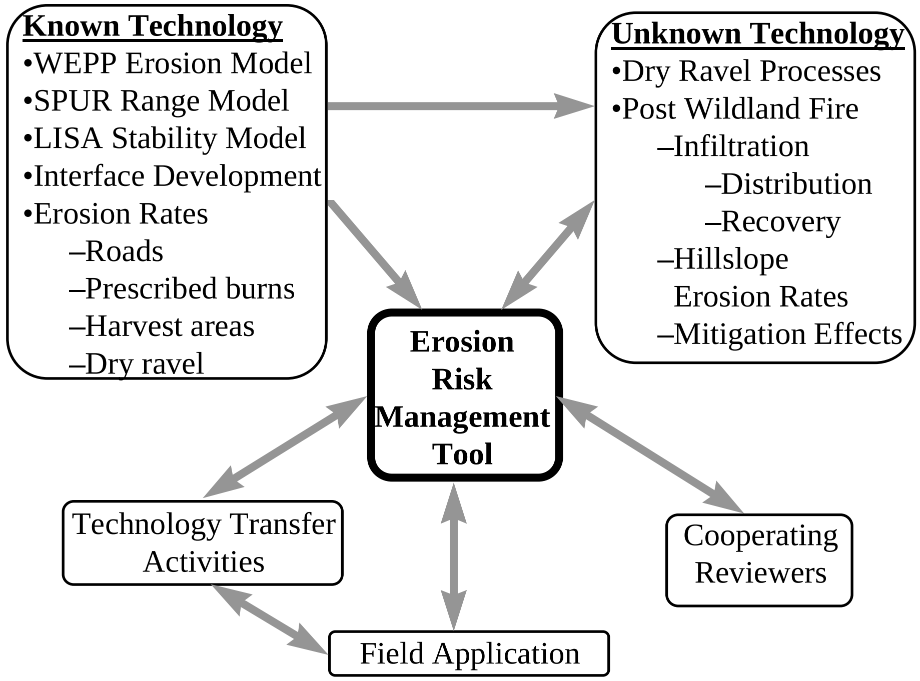

Figure 1. Relationships of the known, the unknown, and the transfer of technology.

include the dry ravel process; post-wildland fire infiltration, recovery and distribution; hillslope erosion rates; and mitigation effects (Figure 1).

Based on this literature review, our objectives address knowledge gaps and our ability to predict both the consequence of wildfires, and the effectiveness of various mitigation practices and prescribed fires on sediment production for rangelands, brushlands, chaparral, and forests. Specific objectives are: 1) to adapt existing technology and incorporate new information into an integrated management tool for predicting erosion risk from fire and fuel management practices; 2) To determine hillslope characteristics that govern dry ravel processes; 3) To determine the spatial and temporal variability in infiltration and erosion parameters needed to predict overland flow and soil detachment after wildfire; 4) To quantify effectiveness of three mitigation practices in reducing sediment production for specified design storms following wildfires; 5) To evaluate measured erosion rates and sediment production after wildfires at the upland watershed/catchment scale.

MATERIALS AND METHODS

The erosion risk management tool relates several components of our known technology with the new technology we are obtaining (Figure 2). Input files are being developed for the interface, and sensitivity analyses will be conducted. The input files are based on past research results, and results from ongoing studies. The main engine for predicting soil erosion is the WEPP model (Laflen et al. 1997), with an interface specifically tailored to address the sedimentation needs for land/fuel managers desiring to evaluate relative risks from sedimentation for varying soils, topographies, and climates within their area. In addition to WEPP, the LISA stability model (Hammond et al. 1992) and a dry ravel model (Objective 2) will be integrated by the same common interface. Results from objectives 2 through 5 provide information to populate the tool's database, to develop or modify conceptual models of the processes, and to provide validation data.

In the interface, the local climate or a design storm, topography, soils, vegetation, and burned condition is selected. The model predicts the likelihood of sediment delivery from surface erosion, mass wastage, and dry ravel from a given hillslope. There are linkages between the hydrology outputs from WEPP and the hillside stability and dry ravel components. Additionally, there is a feedback loop from potential unstable or raveling hillslopes to the ephemeral channel erodibility prediction from the WEPP model.

Dry ravel occurs when the driving forces of gravity plus a trigger event overcome the frictional resistances on a marginally stable hillslope. In order to effectively

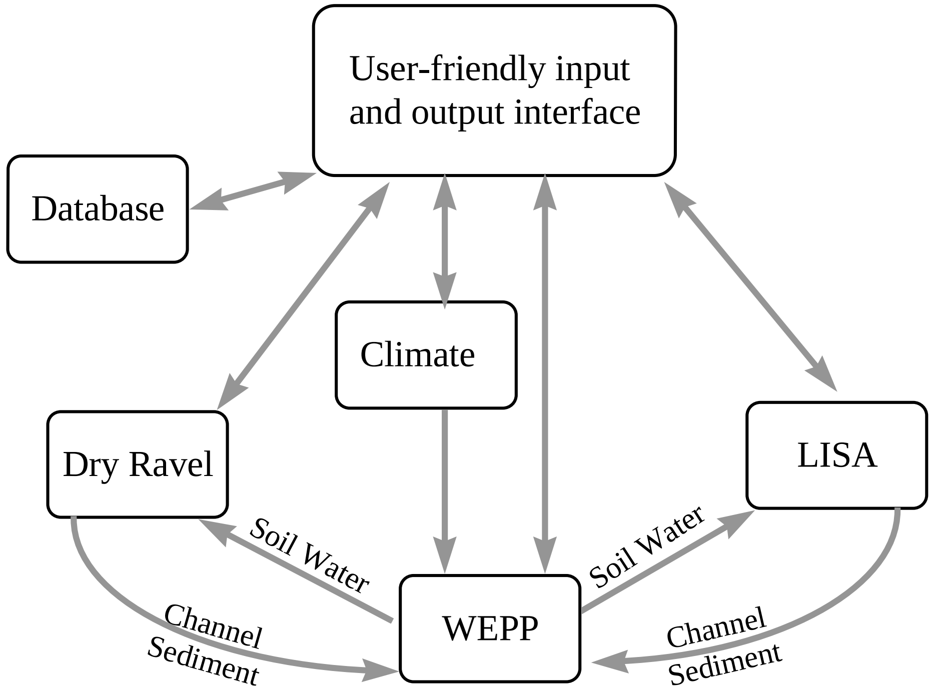

Figure 2. Diagram of erosion risk management tool.

model dry ravel, the nature of both the hillslope characteristics and the triggering forces must be determined. A controlled laboratory experiment will assess the range and thresholds of the initial conditions and triggers that govern dry ravel. Laboratory trials are being conducted a 1 m^2 hinged platform, designed to hold a 30-mm thick layer of soil material. Each platform tilts at five different slope angles. The soils have a range of textures found across southern California. Wooden sticks inserted into the platform through the soil bed at three different densities simulate shrub stems and root systems. The three factors are combined in a factorial design to yield 75 different combinations of slope angle, soils, and vegetation density. Each combination is replicated three times. In all cases, the soil material will be wetted to approximate field capacity, then the platform tilted and the soil allowed to air dry. If the soil mass experiences ravel during the drying period, the moisture content of the surface material at that time is determined. If the soil mass dries completely without raveling, it is subjected to a series of trigger forces. First, a controlled impact is applied to the platform frame, gradually increasing in intensity. Second, direct contact with the soil surface is made with a standardized object under a gradually increasing height. Third, objects of increasing weight are dropped from a set height. The first occurrence of ravel is noted for each of these trigger events and, if ravel occurs, the run is reset before the next trigger is applied.

After wildfire, hydrophobic conditions can create both a spatial and temporal variability in infiltration capacity. The spatial component can be addressed by point sampling, whereas the temporal component must be addressed by repeated measures over time. Therefore, to properly determine the effect of wildfire on reducing infiltration we must measure infiltration rates immediately following a fire and then measure the rate of recovery, which is estimated to be one to three years. To accomplish this, we have four rainfall simulators ready to mobilize on short notice.

The study will consist of sampling two vegetation types each replicated three times under both severely burned and unburned conditions (12 sites). Vegetation types will consist of a dense forest and a rangeland shrub community on slopes of about 40 percent. On each site, infiltration will be measured immediately following the fire and for two to three years following the fire with ten 0.5 m^2 replicated plots per site for a total of 120 plots. Simulated rainfall will be applied to each plot at a rate of approximately 75 mm hr^{-1} for a 60-minute duration. Sub-samples of both runoff and sediment will be collected throughout the rain event. Surface soil and vegetation parameters such as hydrophobicity, bulk density, particle size, aggregate stability, ground cover, and vegetative biomass will be sampled for each plot. Standard statistical analyses of variance and covariance for repeated measures will be applied to the data.

After wildfires, land managers often rely on local expertise to determine which mitigation practice may work best, although the effectiveness of most common practices has not been documented. We summarized past mitigation techniques and documented observations on their performances (Robichaud et al. 1999). There are conflicting results on how well three common techniques [contoured felled logs (log erosion barriers), hand trenching, and straw waddles] are at reducing erosion immediately following wildfires. Large plot rainfall simulation techniques provide a method for direct comparison of these mitigation techniques by comparing treatments on similar soils, slopes and fire severity conditions. A suitable field site will be located after a wildfire. Similar areas will be selected based on: soil type, habitat, high severity burn condition, slopes (40 to 60 percent), and equipment access.

Plots (5 m width by 10 m length) will be delineated with metal borders and a collection trough will be installed at the base of each plot. Three BAER operational treatments will be applied. For the first treatment, felled logs approximately 3 m in length and 16 to 25 cm diameter, will be placed on the contour near the bottom of the plot with continuous ground contact. They will be staked at each end. The second treatment will have 20 cm diameter straw waddles installed in a similar manner. Hand trenches will be excavated with a pulaski for the third treatment to create small areas for a mini-reservoirs. A control plots will have no activities. Each treatment will be replicated four times. Replications are limited due to the time consuming nature of large plot rainfall simulation experiments.
Rainfall will be applied with a CSU-type simulator capable of providing uniform rainfall at 25 mm/hr for a 30-minute duration. Sub-samples of both runoff and sediment will be collected throughout the rain event. Samples will be processed in our soils laboratory to determine runoff rate, sediment concentration and total sediment yields. Trap efficiency of the erosion barriers will be determined by measuring sediment stored behind each and comparing sediment yields leaving the treated plots to the control. Results will be analyzed by standard statistical procedures. These results will be used to make comparisons between treatments and provide information for modeling each mitigation practice.

Detailed measurements of increased runoff and sediment after wildfires is often limited and lacks detail for use in validating erosion prediction models such as WEPP. Past erosion research has focused on timber harvest operations and prescribed burn areas. These observations have been and are being used to validate erosion predictions for these conditions (Elliot et al. 1996). These validation sites, however, are not valid for wildfire conditions. With prescribed fire, the fire severity is generally low with only short hillslope lengths under high severity conditions. Wildfire sites for various habitat conditions such as forested, rangeland and chaparral are needed to provide a means to verify estimates derived from erosion prediction models.

To achieve this objective, small catchments or upland watersheds are located after wildfires in forest, rangeland and chaparral habitats. The first site was located in the fall of 1998 on the Wenatchee National Forest after the 4000 ha Twenty Five Mile Creek fire. The site is to be monitored continuously for approximately three years until sediment yields due to the fire are no longer measurable. Runoff and sediment yields are measured with flumes and sediment boxes.

At Twenty Five Mile Creek, two watersheds are instrumented for year-round collection of runoff and sediment data. The first has only the fire treatment and the second has the fire treatment and the mitigation practice of contour felled logs. Metal headwalls direct runoff though a 1-foot H-flume with attached sediment traps which measures runoff flow and collect sediment. Weather stations at each site monitor precipitation, wind speed, wind direction, temperature, relative humidity and solar radiation. The weather stations' dataloggers collect runoff data electronically and are transmitted via a cellular phone daily to our web page. Sediment traps are emptied after each storm event. Sites have been characterized by surface conditions, soil type, and topography for use in model validation.

On adjacent burned-over hillslopes, silt fences are installed to measure natural hillslope erosion rates to validate sediment production predicted by hillslope erosion models. Silt fences are cost-effective and efficient methods to determine sediment yields because they have a greater than 95 percent trap efficiency. Four sites were located in the burn area. Sediment trapped behind the silt fences are sampled and weighed to determine sediment yield amounts. Measurements are made after each storm event.

RESULTS (In Progress)

Much of this work is just getting started or is ongoing. For example, computer interfaces are being integrated into web pages and have similar look and feel as our road erosion prediction interfaces. Input files are being developed and sensitivity analysis is just getting started.

The dry ravel study has been designed and equipment fabrication has begun. Soil samples are collected and are ready to be processed.

Rainfall simulation work will be conducted upon finding a suitable location after a wildfire and the mitigation study is planned for summer, 2000.

Since one watershed study (forest condition) was installed last year, some preliminary results indicate that erosion can be easily triggered by small rain events. Two rainfall events (June and July), produced only 7 mm of rain each but caused 0.3 Mg ha^{-1} and 0.7 Mg ha^{-1} of sediment to leave the watersheds.

Work is continuing to complete the objectives. The erosion risk management tool is expected to be available in 2002.

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