Soil Transport on a Forested Hillslope: Quantifying Baseline Rates of Surface Erosion, Jim's Creek, Willamette National Forest, Oregon

by

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A RESEARCH PAPER

submitted to

The Geosciences Department
Oregon State University

in partial fulfillment of the
requirements for the
degree of

Master of Science

Geography Program

December 2008

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ACKNOWLEDGEMENTS

I would like to thank Julia Jones for her continuous support and encouragement over the course of this work. Her ability to motivate and create a sense of achievement during times of uncertainty was greatly appreciated. I would like to thank Fred Swanson for providing guidance and expertise during this project. The time spent in the field discussing opportunities for this project, the thorough manuscript reviews, and provision of comments and suggestions that greatly helped to improve this writing were sincerely appreciated. I would like to thank Tim Bailey of the Willamette National Forest for his expertise on the Jim's Creek Savanna restoration project and insight during field trips. I would like to thank David Murdough of the Willamette National Forest for securing materials and constructing equipment used during this study.

I owe a deep respect and appreciation to my parents, for without I would not be the person I am. I would like to express sincere thanks to John and Jeanne for their continual support and encouragement. Lastly, I owe a tremendous gratitude to my wife Karlie, for her wisdom, encouragement, laughter, patience and motivation over the course of my program and this project.

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Soil Transport on a Forested Hillslope: Quantifying Baseline Rates of Surface Erosion, Jim's Creek, Willamette National Forest, Oregon

Abstract

Surface erosion is a low magnitude, highly variable process that transports organic and mineral debris by force of overland flow, rain drop impact and ravel. Surface erosion operates continuously across catchments and can accelerate following disturbance from land management activities and natural events such as wildfire. To evaluate the impact of forest management activities on rates of soil erosion and test erosion modeling predictions, an erosion monitoring program was implemented prior to initiation of the Jim's Creek savanna restoration project on the Middle Fork Ranger District of the Willamette National Forest, Oregon. This study monitored soil and organic debris accumulation prior to logging and prescribed burning to quantify baseline rates of soil transport. Soil transport was monitored using 1.15 m wide erosion traps located at 12 sites for periods ranging from 292 to 454 days. Soil erosion measurements ranged between a trace (2.1 g) and 478 g and averaged 90.1 g per erosion trap over the study period. Rates of soil transport ranged between 1.1 g m^{-1} mo^{-1} and 351.4 g m^{-1} mo^{-1} with an average soil transport rate of 54.3 g m^{-1} mo^{-1} per erosion trap. Sites where vegetative ground cover was less than 40% consistently yielded the highest rates of soil transport. No evidence of overland flow was observed. A greater mass of fine mineral soil (< 2mm) was eroded than coarse mineral soil (> 2mm) suggesting raindrop splash erosion is the dominant soil transport process. The Disturbed WEPP soil erosion model was used to simulate soil erosion at each erosion trap. The predicted soil transport rates

were compared against field measurements to evaluate model accuracy. The Disturbed WEPP model consistently over-estimated upland erosion rates and sediment production for 10 of the 12 simulated hillslope elements by 380 – 1900 %. This study suggests the Disturbed WEPP model may be unsuitable for simulating erosion processes and predicting rates of soil transport within the Jim's Creek project area.

1. Introduction

The detachment and transport of mineral soil is a common and continuous process that operates across a range of landscape types. The physical transport of both organic and inorganic material within forested watersheds operates through a set of naturally occurring, interconnected and highly variable processes that operate over various scales of magnitude in both space and time. Although naturally occurring, material transport processes can be accelerated or altered by natural events such as wildfire or land management activities that disturb and alter site characteristics which moderate material transport processes.

The erosion of mineral soil from forested catchments is a significant issue facing land use managers today, especially where land use practices have the potential to accelerate the rate and magnitude at which this process naturally operates. Disturbance from forest management activities has the potential to modify erosion source areas and transport processes, resulting in altered rates of soil transport. Because surface erosion transports fine mineral soil, concern for water quality and aquatic resources is often linked to discussions on soil transport.

Soil erosion models have been developed to simulate erosion processes and quantify rates of soil erosion to evaluate soil erosion potential following management disturbance to forest catchments. Soil erosion models provide resource managers a tool for evaluating and planning land management activities.

To evaluate the impact of forest management activities on rates of soil erosion and test erosion modeling predictions, an erosion monitoring program was implemented prior to initiation of the Jim's Creek savanna restoration project on the Middle Fork Ranger District of the Willamette National Forest, Oregon. An environmental assessment was completed to evaluate the potential impacts of management operations on natural resources surrounding the Jim's Creek area. Soil erosion modeling was completed using the Disturbed WEPP soil erosion model to simulate soil erosion following timber harvest and prescribed burning. Erosion predictions from the Disturbed WEPP model, as completed by the Willamette National Forest, indicated a mean annual average potential erosion amount of 2,250 tons/acre[1] in response to timber harvest and slash burning treatments (USDA, 2006). Model results did not indicate whether eroded soil would be transported to the stream network or deposited locally.

Given uncertainty in erosion model predictions and the presence of two federally designated threatened fish species within the Middle Fork Willamette River, interest was expressed by the Willamette National Forest to document the background extent of surface erosion and the potential for soil delivery to the channel network.

[1] The Disturbed WEPP soil erosion model simulates soil erosion for a user defined period of time and calculates a mean annual erosion rate based on erosion values for weather events with various return cycle periods. The modeling completed by the WNF was based on a 30 year simulation period and the mean annual average erosion rate was calculated by averaging erosion values calculated for weather events with return cycles of 30, 15, 6, 3 and 1.5 years. Model runs were completed for 23 random transects located within the Jim's Creek area to calculate an average erosion potential for each treatment alternative (David Murdough, Personal communication, November 21, 2008).

This study evaluates the erosion regime of a forested basin, with the specific objectives to include:

- Measurement and quantification of background rates of surface erosion prior to thinning and prescribed burning of a 100 year old Douglas-fir forest (160 stems/acre) to 20 stems/acre;
- Identification of the dominant surface erosion transport processes;
- Evaluation of the extent of surface erosion within the Jim's Creek project area and assessment for potential soil delivery to the channel network; and,
- Evaluation of erosion model predictions.

The scope of this study was restricted to a period ranging between 292 to 454 days and represents a snapshot in time of the erosion regime within the Jim's Creek area. Surface erosion was monitored during and between seasonal transitions and allowed documentation of erosion rates during the fall, winter, spring and summer seasons.

2. Literature Review

2.1. Material transport processes

Surface erosion is one in an array of material transport processes that operate throughout a catchment. Surface erosion is the particle-by-particle transport of material over the ground surface by various processes, including overland flow, raindrop impact and dry ravel (Swanson et al., 1982). The process is continuous, highly variable and generally operates at low magnitude (Swanson et al., 1982).

The rate of surface erosion can vary both spatially and temporally due to changes in a number of site characteristics. Selby (1993) identified four dominant factors that influence the magnitude of surface erosion including: bedrock geology, climate, soil character and vegetation. The relationship between these factors controls the magnitude of erosion. For example, a well vegetated catchment with permeable soil absorbs incoming precipitation, reducing the potential for surface runoff and minimizing surface erosion (Selby, 1993). In contrast, a disturbed watershed with reduced vegetative ground cover and impermeable soil maximizes the potential for surface runoff and surface erosion.

Vegetation is regarded as a primary factor that influences surface erosion. Vegetation regulates erosion by protecting the soil surface from eroding processes (Swanson et al., 1982). Vegetative ground cover intercepts rainfall, decreases runoff velocity and increases soil strength, granulation and porosity (Selby, 1993). These combined effects reduce the erosive power of precipitation by increasing infiltration capacities and preventing rill formation (Selby, 1993) and concentrated flow. Clayton and Megahan (1997) studied surface erosion in forested soils in Idaho and evaluated the influence of various site characteristics on erosion rates. Study results indicated that ground cover was the single dominant factor that influenced the majority of the variance in erosion rates. Mersereau and Dyrness (1972) monitored soil erosion following logging activities in the western Cascades of Oregon and indicated that a combination of factors, including slope steepness, aspect and vegetative ground cover, operate together to influence erosion rates.

The degree to which the soil surface is protected from eroding forces will influence the erodibility of a soil surface. The erosive force of rain, for example, is a function of raindrop size, shape and kinetic energy (Terry, 1998). The mass and velocity of a falling raindrop determines the kinetic energy and the degree of compression and shear experienced at the soil surface upon raindrop impact (Terry, 1998). The erosive force of rain is reduced where ground cover, consisting of living and dead vegetation and fine organic litter, protects the soil surface and prevents contact between raindrops and soil (Selby, 1993). Vegetation often offsets the effects of other site characteristics on erosion (Selby, 1993), such as aspect, gradient and slope length.

Precipitation characteristics, including amount, duration and intensity, are also regarded as a significant control on the rate of surface erosion (Selby, 1993). Spigel and Robichaud (2007) monitored rates of erosion following wildfire in the Bitterroot National Forest, Montana, and determined rainfall intensity was the single factor influencing erosion rates. Rainfall intensities that exceeded 75 mm h^{-1} produced the most erosion and often masked the influence of other site variables such as ground cover and slope steepness (Spigel and Robichaud, 2007). Where the soil surface is exposed, the intensity and duration of rainfall will influence the magnitude of surface erosion.

Topography, including slope steepness and length, affects the rate of erosion (Selby, 1993). Slopes with high gradients enable soil to be transported over greater distances (Selby, 1993). The relationship between the rate of erosion and the steepness of a slope suggests rates of erosion increase rapidly with increases in slope (Selby, 1993). Roering et al. (1999) confirmed this relationship through a non-linear soil transport law that emphasizes slope-dependent transport processes, such that small changes in gradient produce large changes in rates of erosion. Field research has documented the relationship between rates of erosion and hillslope gradient. Mersereau and Dyrness

(1972) monitored erosion rates on 60 % slopes and 80 % slopes and captured over 400 % more soil from the steeper slopes.

In addition to slope gradient, slope aspect has been shown to influence the rate of erosion. Mersereau and Dyrness (1972) monitored soil erosion on north and south facing slopes and observed significantly higher rates of soil transport on south facing slopes. South facing slopes may dry more quickly, reducing soil cohesion and promoting accelerated rates of soil transport (Mersereau and Dyrness, 1972).

The potential for surface erosion and soil transport has been quantified as a function of the erodibility of a given surface and the erosive power of erosion processes (Selby, 1993). As the eroding power magnifies and the vulnerability of a soil to erosion increases, the rate of erosion increases and the volume of soil mobilized is enhanced. Erosion then becomes a function relating vegetation, precipitation, soil characteristics and hillslope topography.

Other material transport processes operate within forested landscapes. Swanson et al. (1982) examined physical transport processes within a forested watershed in western Oregon and distinguished hillslope and channel transport processes. Hillslope transport processes include solution transport, litterfall, creep, root throw, debris avalanches, and slump and earthflows in addition to surface erosion (Swanson et al., 1982). These processes vary both spatially and temporally in the rate and extent at which they operate. Because surface erosion involves the transport of fine soil particles, concern for water quality is especially linked with surface erosion.

2.2. Water quality

Federal and state water quality laws and regulations require management of soil erosion during land management activities to protect aquatic resources and preserve water quality. Excessive sedimentation from land management activities has been linked to both aquatic habitat degradation and injury to aquatic organisms. Cordone and Kelley (1961) presented a literature review of research on the detrimental effects of sediment on trout and salmon within streams. Their review indicated that prolonged turbidity within streams is harmful, as sediment deposition within aquatic habitats leads to a reduction in aquatic insect fauna, reduced survival rates of eggs and alevins, and degradation of habitat (Cordone and Kelley, 1961). Reiser and White (1988) investigated egg survival for steelhead and chinook salmon following exposure to two sediment size-classes and observed a progressive decline in egg survival following exposure to increased fine sediment concentrations. Fine sediment accumulation has been shown to inhibit salmon egg incubation success by reducing gravel permeability and oxygen exchange (Greig et al., 2005). Considering some stream networks provide habitat for threatened and endangered aquatic species, the imperative for water quality and habitat preservation is foremost.

2.3. Land management and surface erosion

Land management activities, such as logging and road building, often disturb the soil mantle and increase the potential for accelerated surface erosion. Surface erosion has drawn the interest of land managers due to its highly variable nature and potential detrimental effect on water quality and aquatic resources. Studies were conducted across the Pacific Northwest to investigate the impact of land management activities such as logging on soil transport. The use of paired watersheds enabled responses within treated watersheds to be compared with control watersheds to document changes in soil erosion following management activities. Most studies identified a significant correlation between increased soil erosion and forest disturbance by management activities. Brown and Krygier (1971) investigated sediment production within the Oregon Coast Range following clear-cut logging and burning. Sediment yield doubled within one watershed following clear-cut logging, and tripled within another watershed following logging and burning. Grant and Wolff (1991) examined long term sediment yield data following timber harvest within the western Cascade Mountains of Oregon and reported a doubling of sediment export following logging operations. The disturbance of the soil surface through land management activities accelerates the displacement and transport of soil by removing litter and vegetation that stabilize the soil surface (Mersereau and Dyrness, 1972).

2.4. Forest disturbance and soil transport processes

Land management activities such as logging can produce feedbacks that alter forest conditions and hydrological processes. Croke and Hairsine (2006) reviewed the sequence of responses following forest harvest activities that modify sediment sources and sediment delivery pathways. Forest harvest activities including tree removal and road construction can often influence soil conditions, such as bulk density, through compaction of the soil mantle. This type of disturbance can alter hydrological processes that influence the magnitude of surface runoff and surface erosion. Variation in intensity and impact of harvest operations in addition to climatic variability can moderate the magnitude of response of surface runoff and erosion (Croke and Hairsine, 2006).

For example, Croke et al. (1999) monitored runoff and sediment production from compacted skid trails and general harvest areas within forested areas of Australia. Rates of runoff were significantly less within the general harvest area and resulted in reduced sediment transport rates and sediment yields (Croke et al., 1999). Management activities have the potential to accelerate surface runoff and erosion processes by modifying sediment and runoff source areas and altering sediment delivery pathways (Croke and Hairsine, 2005).

2.5. Modeling surface erosion – USLE, RUSLE and WEPP

Quantitative models have been developed to simulate soil erosion from cropland and forest land using empirical relationships among erosion factors that control the erodibility of a soil surface. Empirical studies documented the various factors that effect soil erosion and regression analysis was used to compute the mathematical relationship between each factor and soil loss (Renard et al., 1997). The Universal Soil Loss Equation (USLE) was developed using the empirical relationships between erosion factors and soil loss. The USLE uses the product of rainfall erosivity, soil erodibility, slope length, slope gradient, cropping management, and erosion control practices to calculate soil loss (Selby, 1993). Other erosion prediction models have been developed following the inception of USLE. A revised version of USLE (RUSLE) was developed by incorporating updated data relationships (Renard et al., 1997). The Water Erosion Prediction Project (WEPP) was developed after RUSLE and models soil erosion by simulating the physical processes that generate erosion (Elliott, 2004).

Each erosion prediction model was developed to provide resource managers with a tool for evaluating the effects of management activities on soil disturbance and erosion. The USLE and RUSLE are empirically based models that were developed primarily using agricultural erosion data from the central and eastern United States (Larsen and

MacDonald, 2007). In contrast, the WEPP model simulates erosion through use of stochastic weather generation and physical processes such as infiltration, plant growth and vegetative ground cover, sediment detachment, transport and deposition (Flanagan and Nearing, 1995). The WEPP model has the capability to simulate spatial and temporal distributions of soil loss and can be extrapolated to a range of site conditions (Flanagan and Nearing, 1995).

3. Background

3.1. The study area

The study area is approximately 278 hectares located within the Middle Fork Ranger District of the Willamette National Forest in the central western Cascades of Oregon, USA and is associated with the Jim's Creek Savanna Restoration project (43.508°N, 122.415°W) (Figure 3.1). The project area occupies a predominately south – southwest facing slope, with slopes ranging from nearly horizontal to greater than 50 %. Elevation ranges from approximately 600 to 1000 meters. Vegetation within the project area is dominated by 100 year old Douglas-fir, with some older ponderosa pine, sugar pine, incense cedar, Oregon white oak, bunchgrass and fern (USDA, 2006). An extensive moss mat is present throughout much of the Jim's Creek project area and protects much of the mineral soil surface. The extensive moss mat and the rather dense canopy cover resulting from conifer establishment and growth may reflect fire suppression within the area. Soils are classified as fine textured, relatively shallow with depths ranging from a few centimeters to one meter (USDA, 2006). Surface soils in undisturbed forests of western Oregon exhibit hydraulic conductivities of 150 centimeters per hour (cm/h) (Dyrness 1969, Ranken 1974, Yee 1975, Harr 1976). Soil infiltration

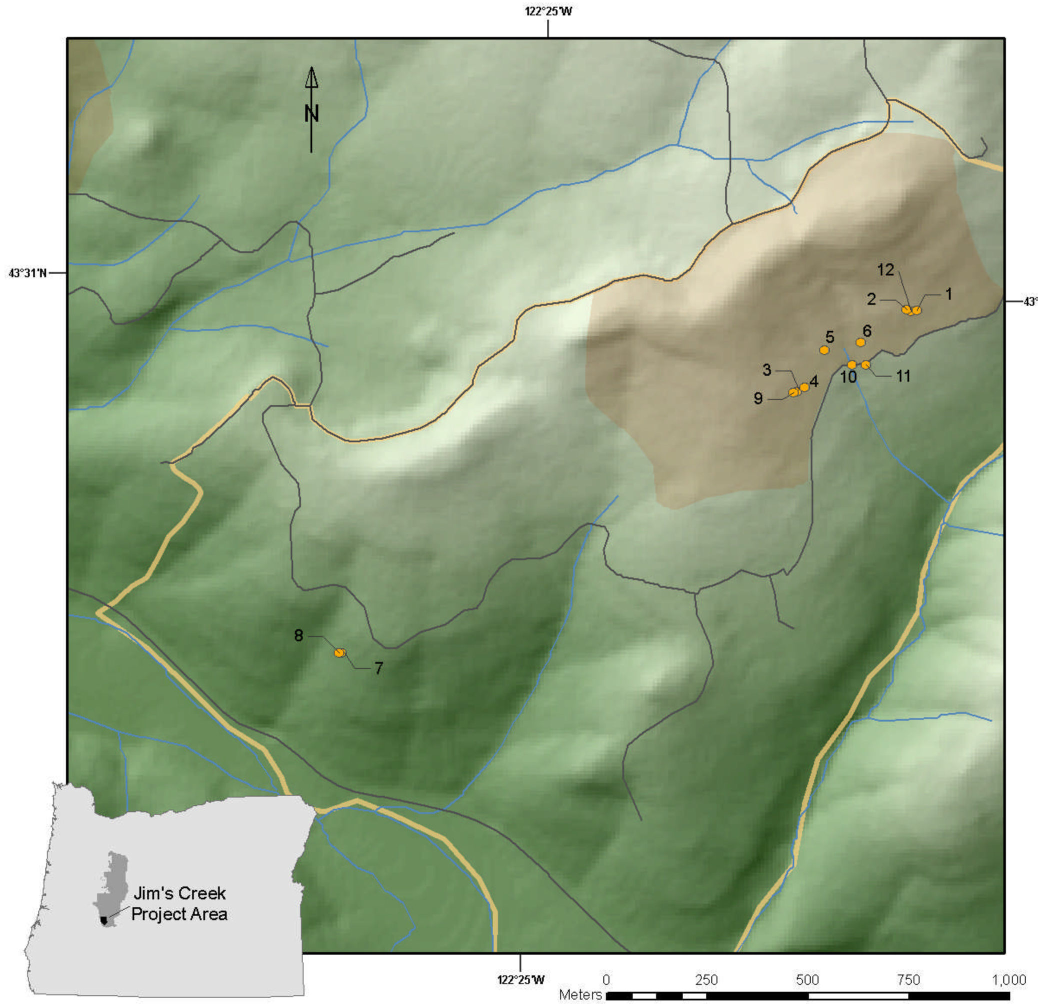

Figure 3.1. Map of the study area. The filled circles show locations of erosion traps and are identified by number. The bold line shows the extent of the Jim's Creek savanna restoration project area and the shaded region located within the north east corner identifies the extent of the 1996 South Zone Complex fire.

capacities generally exceed maximum rainfall rates, such that all rainfall enters the soil profile (Harr, 1976). The geology is Holocene and Pleistocene landslide deposits and 17 to 25 m.y. Tertiary andesitic rocks (Sherrod and Smith, 2000). Climate is moderate with warm dry summers and cool wet winters. The mean annual rainfall is 1162 mm, with the majority falling during the winter months of November, December and January (OCS, 2008). The physical characteristics of the Jim's Creek project area including hillslope gradient, southerly aspect and ground cover are highly relevant to the current erosion regime.

3.2. The Jim's Creek Savanna Restoration Stewardship Project

The Jim's Creek Savanna Restoration Project is a USDA Forest Service Stewardship project being implemented by the Willamette National forest within the Middle Fork Ranger District, Oregon. The Jim's Creek project was developed for the purpose of restoring and developing an open, low density forest dominated by ponderosa pine, Douglas-fir and Oregon white oak (USDA, 2006). The restoration project recommends removal of 100 year old Douglas-fir, grand-fir and incense cedar trees (USDA, 2006) over the project area using skyline and aerial logging systems. The largest younger aged class Douglas-fir, grand-fir and incense cedar trees will be retained, in addition to all ponderosa pine and sugar pine trees within the project area (USDA, 2006).

Slash generated from logging operations will be hand piled and burned following completion of all logging activities to reduce fuel loads. Riparian buffers 15 m either side of ephemeral channels and full tree height on permanent streams will be maintained within the project area (USDA, 2006). Native ground vegetation including bunchgrass and Oregon white oak saplings will be planted within all treated areas following fuels reduction (USDA, 2006). The project goal for developing and maintaining an open forest requires application of periodic maintenance burning that is scheduled to occur following reestablishment of the native grass layer.

3.3. Erosion prediction modeling – Disturbed WEPP

The National Environment Policy Act (NEPA) and relevant Federal and State laws and regulations require the Forest Service prepare an environmental assessment to evaluate environmental impacts that may arise from proposed management actions (USDA 2006). Potential soil erosion and stream sedimentation arising from management activities were evaluated within the Jim's Creek Savanna Restoration Project Environmental Assessment.

To evaluate the potential for surface erosion following logging and prescribed fire activities, the Disturbed WEPP model was used by the Willamette National Forest. The Disturbed WEPP model is a web based interface to the Water Erosion Prediction Project soil erosion model (WEPP) that evaluates the risk of surface erosion following disturbance, such as thinning and harvesting operations, prescribed burns and wildfire (Elliot et al., 2000). WEPP is a physically based, process oriented model developed to simulate sediment transport and deposition using a stochastic weather generator, infiltration modeling, hydrology, soil physics, plant science, hydraulics and erosion mechanics (Flanagan and Nearing, 1995).

The WEPP model simulates overland flow routing and interrill and rill erosion processes along a hillslope profile to predict soil loss, sediment transport and sediment yield (Flanagan and Nearing, 1995). Interrill erosion simulates soil detachment by raindrop impact and sediment transport and delivery to rills by shallow sheet flow (Flanagan and Nearing, 1995). Overland flow routing allows for calculation of peak runoff rates and duration of runoff that are used to calculate flow shear stress and sediment detachment, transport and deposition (Flanagan and Nearing, 1995).

The Disturbed WEPP model results for the Jim's Creek project indicated a potential mean annual erosion amount of 2,250 tons/acre due to timber harvest and slash burning treatments (USDA, 2006). The prescribed burning used for fuels reduction and site preparation was identified as the primary driver for excessive erosion (Tim Bailey, personal communication, August 7, 2006). Model results do not indicate whether mobilized sediment would be transported to the stream channel network or deposited locally (Tim Bailey, personal communication, August 7, 2006).

Multiple studies have been pursued to validate the WEPP model against field observations following forest management activities and incidents of wildfire. Within western Oregon, Geren and Jones (2006) evaluated the Disturbed WEPP model against long-term suspended sediment yields from the H.J. Andrews (HJA) Experimental Forest. Results indicated the Disturbed WEPP model tended to over-estimate sediment yields in comparison to long-term data by as much as two to three orders of magnitude (Geren and Jones, 2006).

Larsen and MacDonald (2007) tested Disturbed WEPP on the Colorado Front Range following wildfire and reported that Disturbed WEPP tended to over-predict lower erosion yields by as much as two orders of magnitude. Higher erosion yields were under-predicted by as much as an order of magnitude. Larsen and MacDonald's (2007) results indicated that the WEPP model fails to simulate the complexity of site characteristics and plot-scale variability that influence postfire soil transport rates and processes. The WEPP model assumes too high of an effective hydraulic conductivity and simulates rapid vegetation regrowth resulting in under-predictions of soil erosion (Larsen and MacDonald, 2007).

Spigel and Robichaud (2007) evaluated the Disturbed WEPP model following a wildfire in Montana. Results indicated the model over-predicted at lower erosion yields and under-predicted at higher erosion yields (Spigel and Robichaud, 2007). The WEPP model fails to accurately reflect the spatial variability of site characteristics, such as ground cover and water repellency, which influence soil transport processes and rates (Spigel and Robichaud, 2007). Erosion model accuracy may be limited by data availability and resolution, resulting in simulation of soil erosion for average site conditions (Larsen and MacDonald, 2007).

3.4. GIS analysis of landslide distribution

Deep-seated landslides create landforms characterized by a distinctive morphology that can be identified in the field. The morphology is recognizable by (1) the presence of a headscarp left where soil and possibly bedrock detached and moved downslope, (2) low-gradient, hummocky benches on the surface of transported material, and (3) steep lower slope at the downslope end of the deposit of transported material (Roering et al., 2005). In some terrains the morphology can be distinguished by defining a topographic signature through a relationship between topographic curvature and gradient.

Roering et al. (2005) developed a simple algorithm based on the relationship between hillslope curvature and gradient to map the spatial extent of large deep-seated landslides in the Oregon Coast Range, using a Digital Elevation Model (DEM). Roering et al. (2005) plotted the distribution of field-delineated landforms against the calculated topographic gradient and curvature and defined a topographic envelope, or range of gradient and curvature values, that most accurately distinguished the distribution of large deep-seated landslides from landforms uninfluenced by that process. Near-zero values of curvature (-0.008 m^{-1} to +0.008 m^{-1}) and gradient values between 0.16 and 0.44 were identified as most accurately distinguishing the morphology of known landslides (Roering et al., 2005). Spatial averaging was used to calculate the fraction of points within a search radius that fell within the topographic envelope (Roering et al., 2005). Roering et al. (2005) termed the spatial averaged calculation β values, with a range between 0 and 1.0. A β value of 0 indicates that adjacent terrain does not exhibit landslide morphology and a β value of 1.0 indicates that all adjacent terrain exhibits landslide morphology. Roering et al. (2005) identified a β value of greater than 0.33 to accurately delineate the boundaries of deep-seated landslides within their study site in the Oregon Coast Range.

The spatial distribution of deep-seated landslides within the Jim's Creek project area was analyzed by modeling the distribution of topographic gradient and curvature. Field observations within the Jim's Creek project area revealed small scale features (less than 50 m in width) with topography indicating landslide activity. Topographic gradient and curvature were calculated for the Jim's Creek project area in ArcGIS 9.2 using a 10m DEM. Roering et al. (2005) utilized a DEM with a grid spacing of ~26.5 m and deemed it sufficient for calculating the topographic components of large deep-seated landslides (250 m planform dimension). Grid cells with a gradient between 16 and 44 % and a value of curvature between – 0.008 and + 0.008 m were selected from the gradient and curvature calculations for the Jim's Creek area (Figure 3.2).

A binary grid displaying locations of grid cells located within the topographic envelope was produced for the Jim's Creek project area. To refine the analysis, the binary grid was spatially averaged. Roering et al. (2005) used a 250 m radius to smooth their selection because it represented the width of several deep-seated landslides identified in the Oregon Coast Range. The lack of aggregated cells within the spatial selection from the Jim's Creek area suggested large scale features were not delineated by the analysis. A search radius of 250 m was initially used to average the spatial selection and returned a grid with no points. Subsequent spatial averaging was completed using a smaller radius of 30, 20 and 10m to search for small shallow landslides. Only the 10m radius identified areas with greater than 33 % of the adjacent cells falling within the topographic envelope (Figure 3.3), suggesting only small-scale, shallow landslides may be active within the Jim's Creek area. Using the output from the 10 m spatially averaged grid, 74 distinct areas with morphology suggestive of a landslide were identified (Figure 3.4).

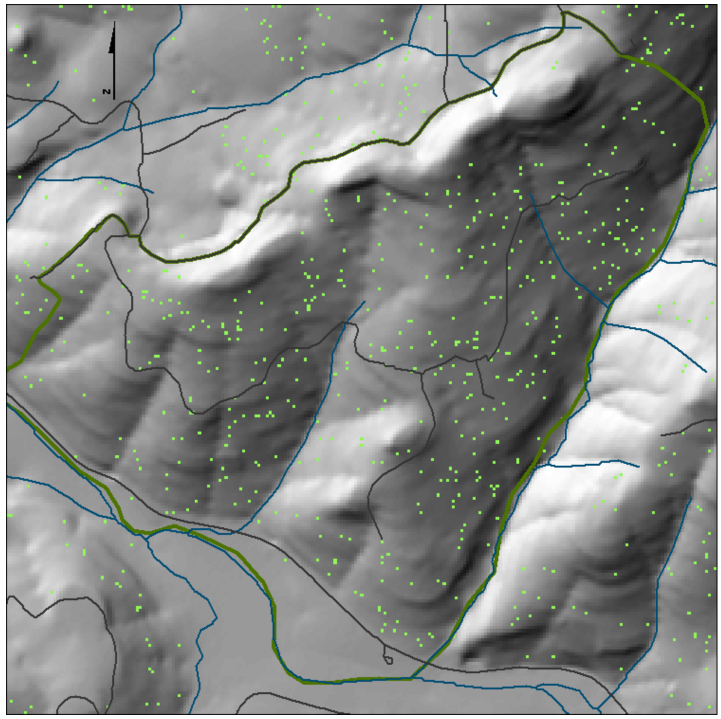

Figure 3.2. Spatial selection of grid cells that fall within the topographic envelope of landslide prone terrain within the Jim's Creek project area. The locations of green pixels indicate regions with a curvature value between -0.008 and +0.008 m and a topographic gradient value between 16 and 44%.

Roering et al. (2005) reported that their topographic envelope encompassed more than 92% of field delineated landslides in their Coast Range study area. Given a potential error of 8%, this analysis suggests roughly 68 discrete landslide-produced landforms are present within the Jim's Creek project area. The area of predicted landslide-produced landforms ranged between 100 m^2 and 500 m^2 and represented a total area of 11,400 m^2.

The estimated distribution of cells identified as landslides cover a total area of approximately 1.14 hectares. Of the 278 hectares within the project area, the identified points cover a spatial extent of approximately 0.41% of the land surface.

Swanson et al. (1982) studied the distribution of debris avalanches and slumps and earthflows within another forested watershed in western Oregon and reported the spatial extent to be 1%-2% and 5%-8%, respectively. The predicted spatial extent of landslides within the Jim's Creek area falls below the distribution observed within terrain comprised of steep hillslopes and underlain by hydrothermally altered volcanic rocks (Swanson and James, 1975). The difference in topography and geology between the two sites may account for different styles and extent of mass movement processes and landforms. The predominant distribution of widely spaced grid cells identified as landslide-prone terrain suggests large deep-seated landslides may not be present within the Jim's Creek project area.

The absence of extensive aggregated patches of cells identified as landslide-prone terrain would suggest only small scale landforms (50 m width) are present within the Jim's Creek area. It is possible that the relationship between

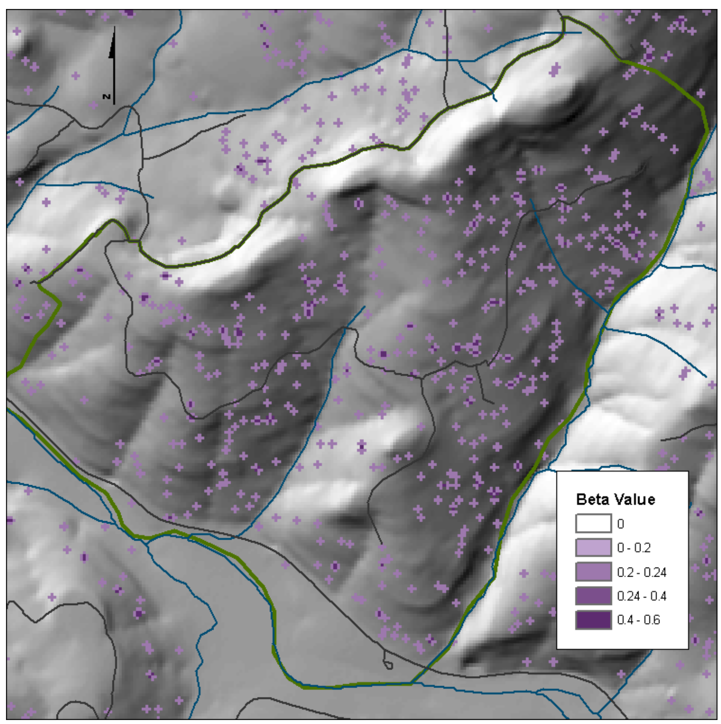

Figure 3.3. Spatially averaged grid displaying β values. A β value of 0 indicates none of the adjacent terrain is located within the topographic envelope and a β of 0.6 indicates 60% of the adjacent terrain is located within the topographic envelope.

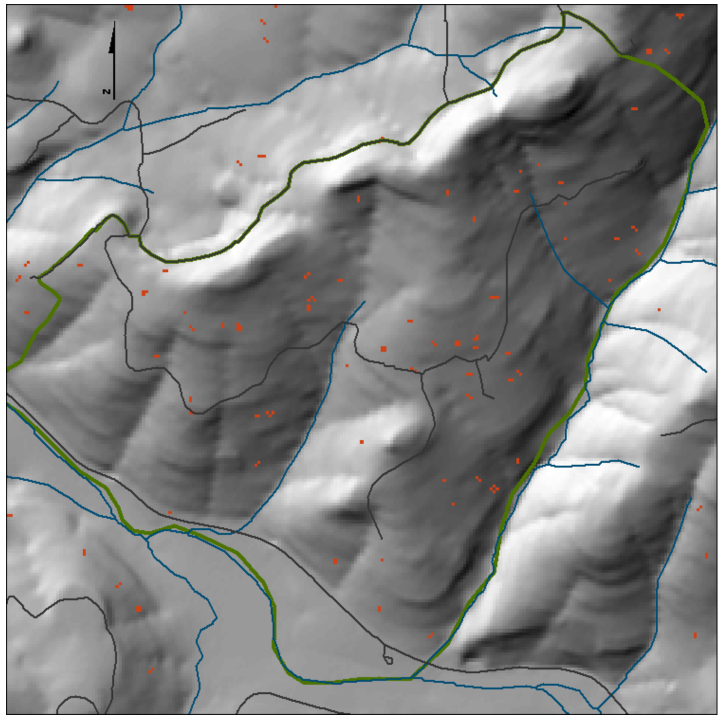

Figure 3.4. Projected locations of shallow landslides within the Jim's Creek project area. The zones marked in red indicate regions where greater than 33% of the surrounding terrain fell within the topographic envelope for landslide prone terrain.

topographic gradient and curvature for landforms formed within the Jim’s Creek project area is different than the relationship observed for deep-seated landslides within the Oregon Coast Range. If such differences exist, the algorithm presented by Roering et al. (2005) may not be appropriate for the type of terrain, geology and geomorphic regime found within the Jim’s Creek area.

Roering et al. (2005) analyzed contrasting terrain composed of highly dissected and steep drainage networks and dormant landslide terrain expressed by much less steep, hummocky bench-like morphology. The significant topographic contrast between landforms facilitated delineation of deep-seated landslides using topographic criteria. Within the Jim’s Creek project area, the contrast in terrain morphology is less distinct and geomorphic processes may be restricted to small spatial scales. Field observations within the Jim’s Creek area identified only smaller scale, shallow landslides less than 50 m in width. The coarse spatial resolution of the DEM used for this analysis may not be appropriate for detecting the type of landforms within the Jim’s Creek area. For example, features smaller than 10 m would not be detected using a 10 m DEM. A higher resolution DEM, such as 1 m LiDAR, would be useful for analyzing and detecting small scale mass movements and other landforms within the Jim's Creek area.

3.5. Endangered species

The Middle Fork Willamette River flows adjacent to the Jim's Creek project area and receives runoff directly from ephemeral and perennial streams that originate within the project area. The Middle Fork River provides forage and refuge habitat for Spring Chinook salmon (*Oncorhynchus tshawytscha*) and bull trout (*Salvelinus* confluentus) (USDA, 2006). Both species have been designated as threatened under the Endangered Species Act by the National Marine Fisheries Service (USDA, 2006). Due to the proximity and connectivity of the project area to the Middle Fork River and the potential for accelerated erosion following land management, there is concern for degradation of aquatic habitat within the Middle Fork River.

4. Methods

4.1. Measuring surface erosion

To quantify the background rate of surface erosion, 12 erosion traps (122 x 46 x 10 cm) constructed from wood were installed within the Jim's Creek project area (Figure 4.1). All traps were designed with a removable cover to reduce the input of fine organic litter. Drainage holes were located along the upper perimeter to drain potential standing water and/or overland flow. Installation sites were selected to sample surface erosion across a range of slope steepness and ground cover conditions within the Jim's Creek area, and were located to maintain accessibility from the road system.

Two hillslope gradient categories were selected for sampling including gentle (gradient less than 28 degrees) and moderate to steep (gradient greater than 28 degrees). An initial qualitative assessment of ground cover was made to identify sites with either a continuous and dense ground cover consisting of living vegetation, moss mat and forest litter, or a discontinuous ground cover consisting of some exposed soil surface.

Figure 4.1. An example of an erosion trap with accumulated debris. The cover was removed to collect the accumulated material and to photograph debris accumulation within an erosion trap.

Some erosion traps were located within an area that experienced wild fire in 1996 to monitor soil erosion on sites with disturbed ground cover and exposed mineral soil surface. The slopes within this area were protected by a shallow layer of needle litter and minimal vegetative ground cover and presented an opportunity to monitor soil transport rates on previously disturbed slopes. Most other slopes within the Jim's Creek area were covered by an extensive mat moss, living vegetation, fine organic litter and coarse woody debris and were assumed to have very low erosion rates. Thus, the distribution of erosion traps represents a range of site conditions within the Jim's Creek project area.

A quantitative estimate of ground cover was made using the canopy-coverage method (Daubenmire, 1959) and a ground cover classification and sampling technique presented by Robichaud & Brown (2002). Ground cover was assigned a cover class from a list of types including: bare soil, litter, duff, gravel, rock or live vegetation (Robichaud and Brown, 2002). A 40 cm^2 wood frame was constructed and lined using a metal grid with intersecting wires every 10 cm. Two sets of ground cover measurements were taken near each erosion trap. The area immediately upslope from each erosion trap opening was sampled in addition to three random observations made within the contributing area above each trap. Each sample point within the upper contributing area was randomly selected by blindly throwing the gridded frame upslope approximately 1 – 2 m. An estimate of coverage (Daubenmire, 1959) was made by assigning one of six coverage classes (0 to 5, 5 to 25, 25 to 50, 50 to 75, 75 to 95, 95 to 100). A mid-point value (0 to 5 : 2.5, 5 to 25 : 15, 25 to 50 : 37.5, 50 to 75 : 62.5, 75 to 95 : 85, 95 to 100 : 97.5) was assigned to each coverage measurement (Daubenmire, 1959). Three samples were taken in front of each erosion trap to sample the possible source area along the full length of each trap opening. Each sample point was assigned a cover class, an estimate of coverage and a corresponding mid-point value. The three mid-point values were averaged for each erosion trap to derive an estimated percent cover for the area above each trap.

Erosion traps were secured to the hillslope using wooden stakes inserted into the soil surface along the trap perimeter. A piece of aluminum sheeting was used to connect each trap to the hillslope surface. The section of aluminum sheeting was cut to the length of the trap opening and was attached directly to the trap opening. A slit was made into the hillslope parallel to the trap opening and the aluminum sheeting was inserted. The aluminum sheeting was used to join the trap opening to the hillslope surface and minimize any discontinuity between the hillslope surface and the trap surface. An attempt was made to collect the accumulated contents of each trap on a monthly basis, except when site access was prohibited by snow. Table 4.1 identifies the site characteristics for each trap.

4.2. Soil sample analysis

All accumulated material was passed through a 2mm sieve to determine percent organic content, percent coarse mineral content (> 2mm) and percent fine mineral content (< 2mm). Each sample was allowed to air dry and an initial weight, in grams, was taken. A Rotap Testing Sieve Shaker was used to separate each sample. An initial shaking time of nine minutes (Whalley, 1990) was enforced, however, due to the physical characteristics of each sample, it was determined that a shaking time of 5 minutes would be adequate to separate each sample.

The initial separation isolated a fine mineral fraction containing some fine organic material and a coarse mineral and coarse organic fraction. Following initial separation, the fine mineral fraction and the coarse mineral and coarse organic fraction were weighed. The coarse mineral and coarse organic fraction was further processed by identifying coarse organic particles by eye and removing by hand. Any remaining coarse organic particles were removed by adding water to the coarse sample and floating off the residual coarse organic particles. The remaining coarse mineral fraction was air dried and weighed one final time to derive the coarse mineral fraction weight. The difference in weight between the initial coarse mineral and coarse organic fraction and the final coarse mineral fraction was assumed to be the weight of removed coarse organic particles. The fine mineral and fine organic fraction was carefully passed through a 2mm sieve multiple times by hand to remove fine organic particles. The fine organic particles consisted primarily of needles and careful agitation of the sample allowed the needles to be isolated above the sieve openings and removed by hand. The remaining fine mineral fraction was weighed to derive the fine mineral fraction weight. The difference in weight between the initial fine mineral and fine organic fraction and the final fine mineral fraction was assumed to be the weight of removed fine organic particles. The weight of hand removed and floated off coarse organic particles was added to the weight of the sieved fine organic particles to derive the organic fraction weight.

Table 4.1. Summary of erosion trap site characteristics.

Trap ID	Hillslope Gradient (%)	Aspect	Estimated Cover (%)	Trap Opening (m)	Date of Installation	Total Days
1	51	180 ° S	61.67	1.15	3/30/2007	454
2	65	125 ° E/SE	22.50	1.15	9/8/2007	292
3	49	140 ° E	77.50	1.15	5/19/2007	404
4	41	106 ° E	85.00	1.15	5/19/2007	404
5	44	110° E	38.33	1.15	5/19/2007	404
6	42	146 ° E/SE	30.83	1.16	5/19/2007	404
7	60	225 ° W	97.50	1.16	7/8/2007	354
8	65	233 ° W	93.33	1.15	7/8/2007	354
9	60	110 ° E	38.33	1.16	7/8/2007	354
10	53	169 ° S	77.50	1.15	7/8/2007	354
11	56	126 ° E/SE	89.17	1.16	7/8/2007	354
12	53	156 ° S	54.17	1.16	9/8/2007	292

4.3. Calculation of soil transport rates

The accumulated mass of fine mineral soil (< 2mm), coarse mineral soil (>2mm), total soil and organic debris was converted to a rate to express mass of material transported across a 1 m length of hillslope parallel to contour per month (g m^{-1} mo^{-1}). This unit calculation was made to compare transport rates between erosion traps with different number of days of accumulation. In addition, a rate calculation provides a useful metric for estimating soil delivery to downslope areas, including streams, by multiplying the rate by stream perimeter (Swanson et al., 1982). It was not possible to express mass accumulation per unit area due to uncertainty in upslope contributing areas. To convert each period mass into a rate, a time conversion factor and a length of hillslope contour conversion factor was multiplied to each fraction accumulation. The time conversion factor represents the ratio of days in one month to total days in a sample period and the hillslope contour factor was calculated as the ratio of 1 m of hillslope contour to the length of each trap opening to correct for lengths greater than 1 m.

4.4. Precipitation data

A precipitation record was retrieved from the Railroad Overpass SNOTEL site (NRSC, 2008) to represent the weather history for the Jim's Creek area over the course of this study (Table 4.2). The Railroad Overpass SNOTEL station was selected as an adequate representation of the weather for the Jim's Creek area due to its location within the western Cascades and the similar elevation. Railroad Overpass is located to the north east of the Jim's Creek project area and sits at an elevation of 820 meters. The amount of precipitation recorded for the sample period ending September 8, 2007 varies between erosion traps because traps were installed at different dates and thus have different total days of accumulation.

Table 4.2. Precipitation record from Railroad Overpass SNOTEL station (NRCS 2008).

Precip. Period	Total precip., cm	Long term average precip., cm	Days, precip. > 1cm	Days, precip. > 2cm	Days, precip. > 3cm	Trap
3/30/07 - 9/8/07	30.7	36.5	14	2	0	1
5/19/07 - 9/8/07	5.8	17.3	7	2	0	3,4,5,6
7/8/07 - 9/8/07	5.3	5.4	4	1	0	7,8,9
7/8/07 - 10/14/07	14.5	12.8	8	3	0	10,11
9/8/07 - 10/14/07	9.1	7.4	4	2	0	1-9, 12
10/14/07 - 11/17/07	18.5	18.2	6	5	2	All
11/17/07 - 12/14/07	16.8	23.2	5	2	1	All
12/14/07 - 4/5/08	70.9	59	33	9	3	All
4/5/08 - 5/9/08	14.2	13.5	7	1	0	All
5/9/08 - 6/26/08	11.4	13.6	4	2	1	All

4.5. Erosion simulation – Disturbed WEPP

The Disturbed WEPP soil erosion model was used to simulate rates of soil erosion for each erosion trap. The Disturbed WEPP model requires users to identify eight parameters that describe the site characteristics for erosion simulation. The parameters include: climate, soil texture, treatment, gradient, horizontal length of the simulated hillslope element, percent cover, percent rock within the soil and years of simulation. The erosion simulation calculates a mean annual average upland erosion rate per unit area and the rate of sediment production across a one meter length of hillslope parallel to contour. The average upland erosion rate and rate of sediment production values are calculated by averaging erosion rates predicted for weather events with various return cycles. For example, a 30 year simulation will calculate average erosion rates for weather events with 1.5 year, 3 year, 6 year, 15 year and 30 year return periods. As such, the mean annual average erosion rate reflects extreme transport rates associated with high magnitude weather events.

A long term climate record was obtained for the Railroad Overpass SNOTEL site and was used to customize the simulation climate. To customize the simulation climate, mean monthly maximum and minimum temperatures, mean monthly precipitation and average number of wet days within a month were calculated using data from the Railroad Overpass SNOTEL site. Treatment type defines the forest conditions, such as canopy cover and groundcover, for an erosion simulation. The twenty year old forest treatment was selected to most accurately represent the canopy cover and ground cover conditions at each site during this study. Elliot et al. (2000) indicate this forest condition represents the maximum erosion protection that can be achieved from vegetation. Considering the majority of the Jim's Creek area was undisturbed, established forest, this treatment type most accurately reflected the site conditions. To simulate the discontinuous ground cover observed within the previously burned area, the percent cover parameter was lowered in comparison to the undisturbed, forested sites.

The simulation calculates erosion for an upper and lower hillslope element and requires the user to define a gradient value for an upper, middle and lower position and a horizontal length for the upper and lower elements. For each erosion trap, it was assumed that the entire hillslope length above each trap could contribute material. For each site, the upper gradient value was defined as 0 to represent the gradient at either a road surface or a ridge top. The middle and lower gradient values were acquired from a percent slope grid calculated from a 10 m DEM in a GIS. In a GIS, a horizontal line was drawn beginning at each erosion trap and ending at either a road or a ridge top. An attempt was made to draw each line perpendicular to the hillslope contour. Each line was split exactly in half and a midpoint was created. The midpoint was intersected with the percent slope grid to identify the middle gradient value. The lower gradient value was identified by intersecting the location of each erosion trap with the percent slope grid.

The length of each horizontal line segment was divided in half to define the horizontal length for the upper and lower hillslope elements. Percent cover was distinguished for traps located on undisturbed forested hillslopes and for traps located within the previously burned area. An average estimated percent ground cover was calculated using ground cover values from traps located on undisturbed, forested sites and from traps located within the previously burned area. Rock percent defines the percent of rock fragments within the soil profile and WEPP reduces the hydraulic conductivity of the soil in direct proportion to the rock content (Elliott et al., 2000). Thorough soil surveys have not been completed within the Jim's Creek area and the percent of rock fragments within the soil is unknown. The default rock percent value of 20% was used for these simulations due to uncertainty in actual rock fragment content within the soil. The default simulation period of 30 years was used for each erosion simulation. Table 4.3 lists the model parameters used for erosion simulations at each trap.

The Disturbed WEPP model algorithm calculates an upland erosion rate that represents the mass of soil eroded from a unit area and extrapolates this value throughout a hillslope profile to determine sediment leaving the hillslope profile. The model simulates soil detachment within a unit area and routes the eroded soil to the bottom of the hillslope element. The routing of sediment resembles a 'snow-ball' traveling down a slope, where a core forms and material is added to the core along the profile resulting in net accumulation of material at the downslope area (Appendix A). Soil is detached from a unit area and contributed to the next downslope area, resulting in a downslope net accumulation of soil in transport.

Table 4.3. Model parameters for Disturbed WEPP erosion simulations.

Trap	Treatment	Upper Gradient (%)	Middle Gradient (%)	Lower Gradient (%)	Horizontal Length (ft)	Vegetative Cover (%)	Rock (%)
1	Twenty year old forest	0	55	42	914	51	20
2	Twenty year old forest	0	59	39	910	51	20
3	Twenty year old forest	0	38	33	910	51	20
4	Twenty year old forest	0	47	33	933	51	20
5	Twenty year old forest	0	41	29	905	51	20
6	Twenty year old forest	0	44	31	965	51	20
7	Twenty year old forest	0	49	43	328	89	20
8	Twenty year old forest	0	54	43	359	89	20
9	Twenty year old forest	0	37	34	907	51	20
10	Twenty year old forest	0	36	33	46	89	20
11	Twenty year old forest	0	32	38	54	89	20
12	Twenty year old forest	0	58	41	880	51	20

5. Results

5.1. Soil erosion and seasonality

Soil erosion was detected at each erosion trap, with high variability between the traps and over time (Appendix B and C). Figures 5.1a and 5.1b display the rates of accumulation of fine and coarse mineral soil and organic debris for each erosion trap over time. Rates of soil transport were generally consistent over time and across all erosion traps. Each trap initially produced low soil transport rates during the summer and early fall, followed by generally high winter rates and low spring rates. Rates of soil production declined significantly leading into the summer period.

5.2. Soil transport rates

Rates of soil transport ranged between 1.2 g m^{-1} mo^{-1} (trap 7, 6/26/2008) and 351.4 g m^{-1} mo^{-1} (trap 1, 10/14/2007) with an average soil transport rate of 54.3 g m^{-1} mo^{-1} (Table 5.1). The maximum soil transport rate of 351.4 g m^{-1} mo^{-1} was observed for a trap that became detached from the hillslope, possibly due to animal activity, and mobilized soil that was in direct contact with the aluminum sheeting attached to the hillslope.

Table 5.1. Cumulative soil transport rates (g m^{-1} mo^{-1}) per trap per sample period.

Trap	9/8/07	10/14/07	11/17/07	12/14/07	4/5/08	5/9/08	6/26/08	Avg.	Min.	Max
1	14.9	351.4	216.3	123.8	40.6	7.6	7.6	108.9	7.6	351.4
2	----	64.8	117.8	109.0	33.2	29.3	19.9	62.3	19.9	117.8
3	15.5	75.1	153.0	126.7	31.1	31.7	10.3	63.3	10.3	153.0
4	12.6	11.8	35.3	23.3	8.9	6.8	21.2	17.1	6.8	35.3
5	17.8	39.0	208.2	112.9	46.8	37.8	33.0	70.8	17.8	208.2
6	36.6	59.8	126.4	195.6	39.5	48.9	46.2	79.0	36.6	195.6
7	7.5	3.9	6.0	4.2	5.8	6.5	1.1	5.0	1.1	7.5
8	7.5	10.8	6.7	4.7	9.4	11.2	3.4	7.7	3.4	11.2
9	62.8	158.1	175.6	144.5	59.4	62.5	38.5	100.2	38.5	175.6
10	----	20.6	90.0	51.4	13.0	16.2	9.2	33.4	9.2	90.0
11	----	16.1	42.7	106.3	18.1	19.7	25.6	38.1	16.1	106.3
12	----	67.5	55.5	71.0	46.8	10.7	122.6	62.4	10.7	122.6
Avg.	21.9	73.2	102.8	89.5	29.4	24.1	28.2	54.0	21.9	102.8

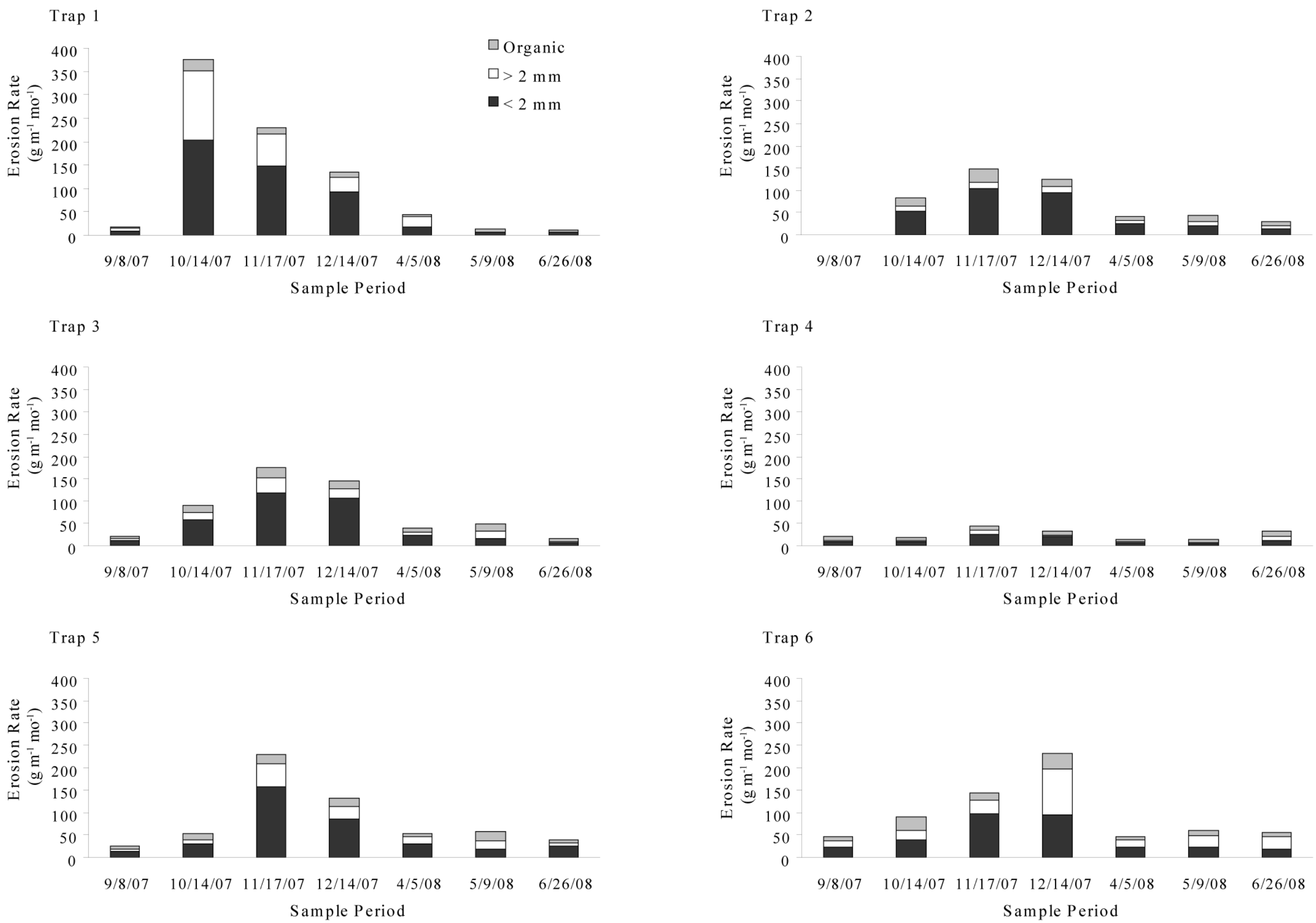

Figure 5.1a. Mineral soil and organic debris transport rates for erosion traps 1– 6. Date indicates the day the trap was emptied. The mineral soil and organic accumulations for sample period ending 9/8/2007 reflect different days of accumulation. Note erosion trap 2 was not collected during the first sample period.

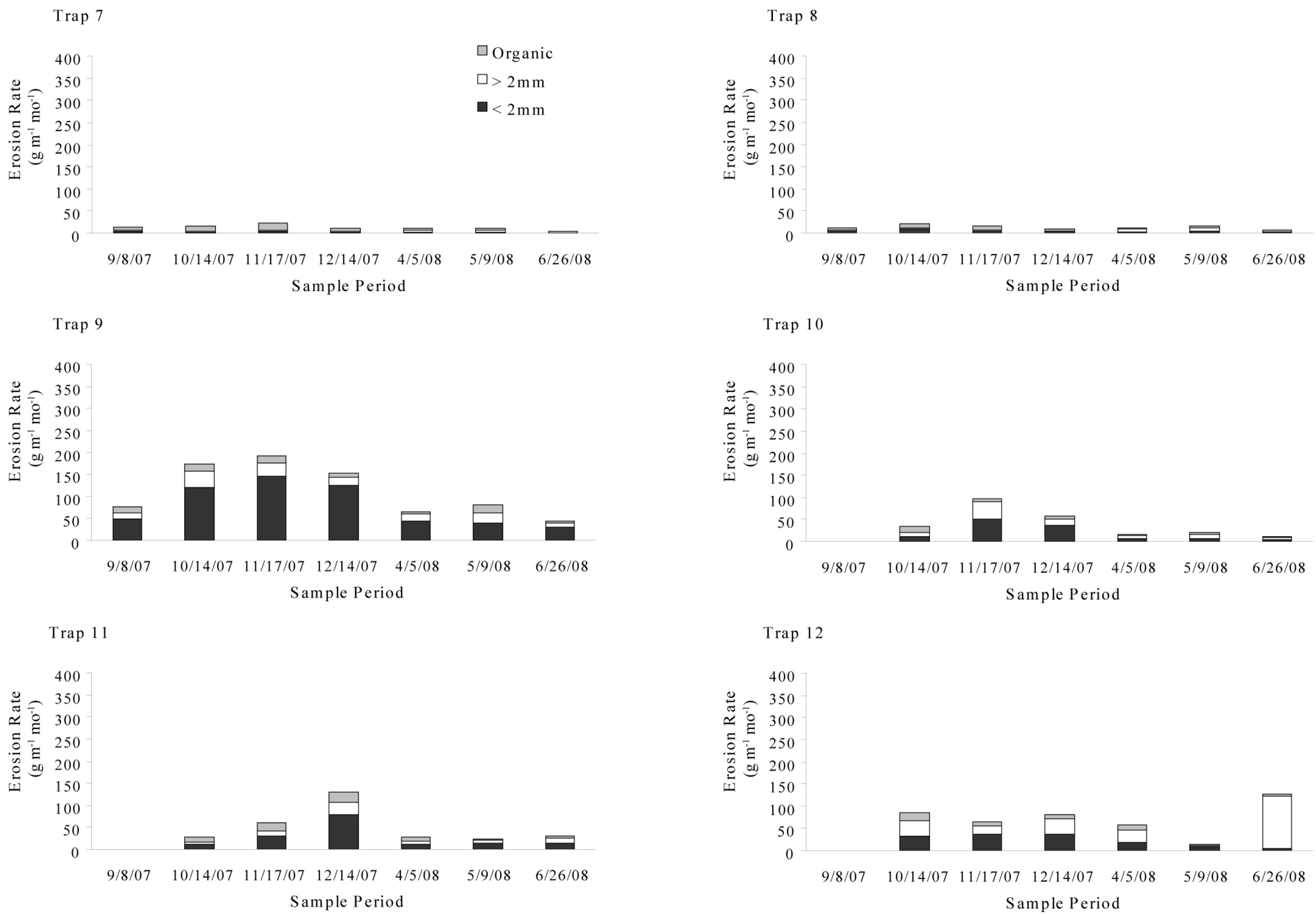

Figure 5.1b. Mineral soil and organic debris transport rates for erosion traps 7– 12. Date indicates the day the trap was emptied. The mineral soil and organic accumulations for sample period ending 9/8/2007 reflect different days of accumulation. Note erosion traps 10, 11 and 12 were not collected during the first sample period.

Average rates of soil transport per sample period ranged between 21.9 g m^{-1} mo^{-1} (9/8/2007) and 102.8 g m^{-1} mo^{-1} (11/17/2007).

The frequency distribution of soil transport rates indicates the data are strongly skewed to the right (Figure 5.2). Of the observed soil transport rates, 78% were less than 75 g m^{-1} mo^{-1}. The lowest soil transport rates were consistently recorded for erosion traps 7 and 8 ($\overline{\chi}$ = 5, $\overline{\chi}$ = 7.7 g m^{-1} mo^{-1}) and the highest average soil transport rate was recorded for erosion trap 1 ($\overline{\chi}$ = 108.9 g m^{-1} mo^{-1}). Most traps measured similar proportions of soil erosion during each sample period and no individual trap accounted for a dominant proportion of soil transport during any sample period (Table 5.2). Erosion trap 9 had the highest average proportion of soil accumulation (17 %) per sample period (Table 5.2). Trap 9 is located on a locally steep hillslope with 38% vegetative ground cover.

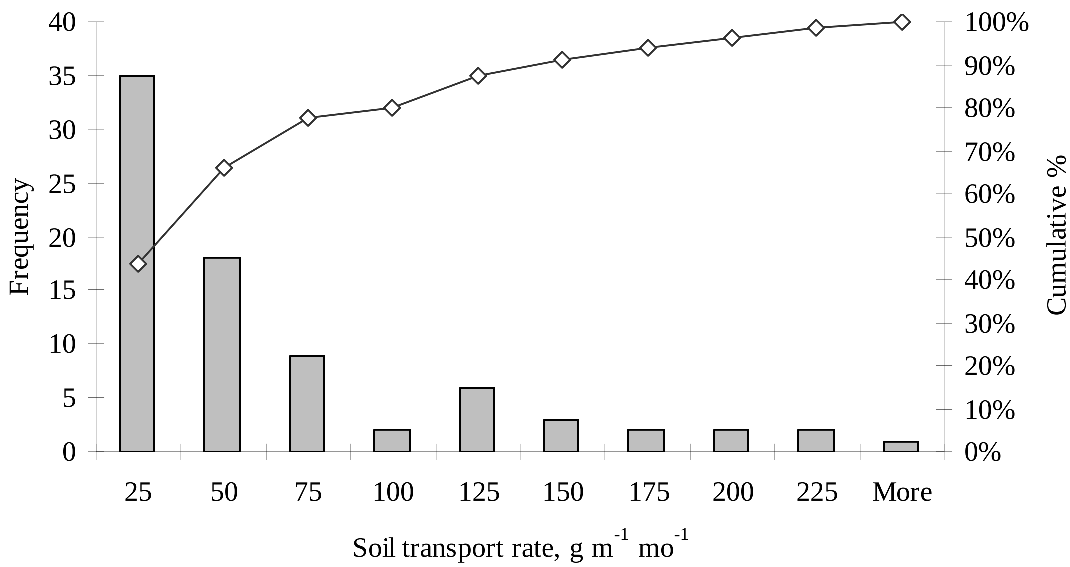

Figure 5.2. Cumulative soil transport rate frequency distribution across sample periods and traps.

The observed rates of soil transport appear to trend with the precipitation record from Railroad Overpass (Figure 5.3). High soil transport rates corresponded well with

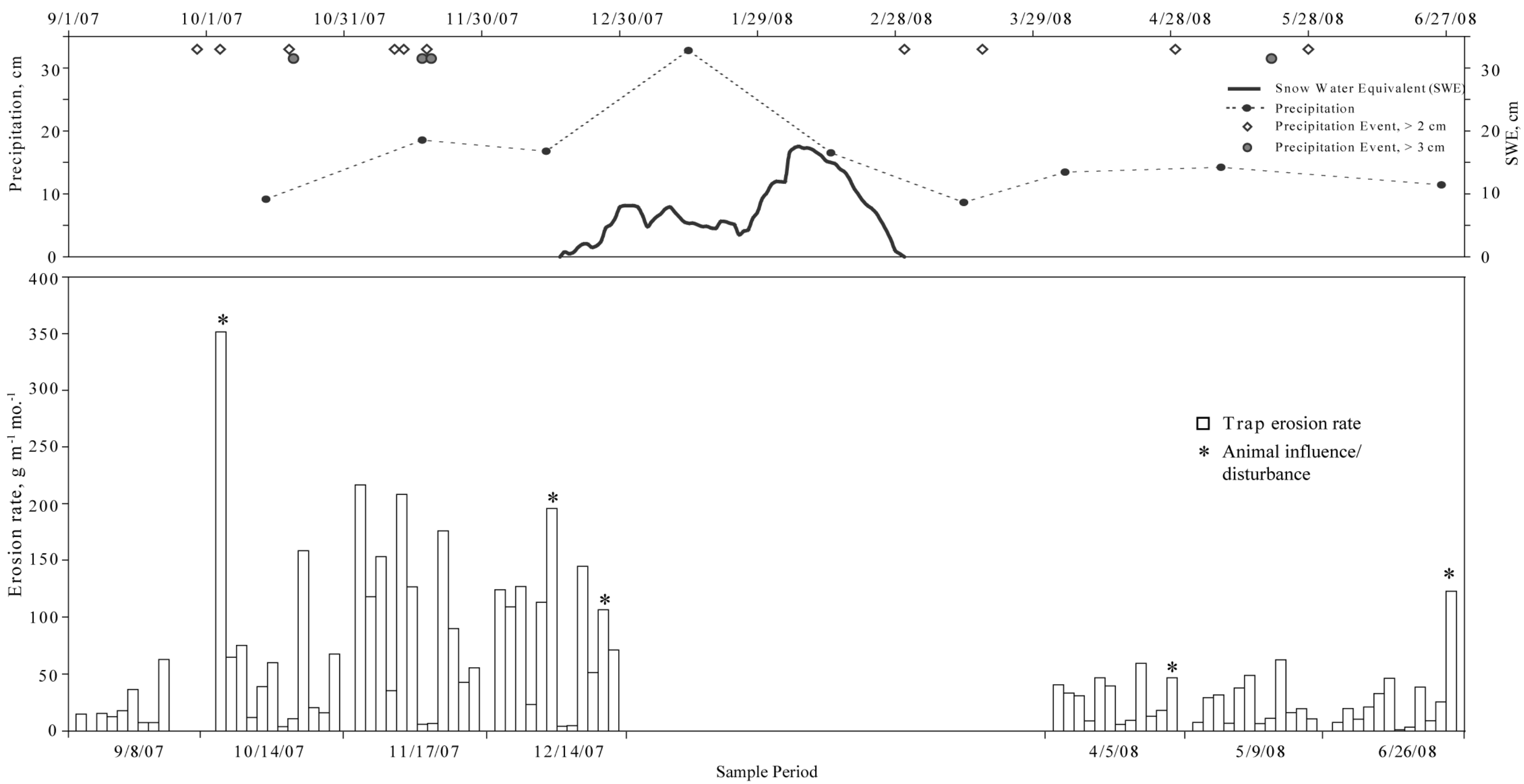

Figure 5.3. Erosion rates versus time. For each sample period, the vertical bar represents the erosion rate for each trap, with traps 1 – 12 arrayed left to right. Erosion rates for traps 2 and 10 - 12 were not plotted for the first sample period because the traps had been recently installed and had not yet accumulated sufficient debris. The observed transport rates varied seasonally, with low rates during the fall, followed by high rates during the winter and low rates again during the spring and early summer. The precipitation record indicates the total amount of precipitation recorded for a sample period and was plotted on a monthly basis for the sample period ending 4/5/08. The precipitation record for sample period 9/8/07 was not plotted due to variability in precipitation accumulation between erosion traps as the result of different installation dates. The duration of snowpack at Railroad Overpass is plotted using the snow water equivalent record. * indicates a disturbance or animal activity may have modified the observed soil transport rate. During sample period 10/14/07, trap 1 became dislodged from the hillslope probably because of animal activity; during sample period 12/14/07, trap 6 was disturbed by a fallen tree upslope of the trap and trap 11 received material from an animal disturbance; during sample period 4/5/08, trap 12 showed signs of animal disturbance; and during sample period 6/26/08, trap 12 registered an anomalous rate due to the accumulation of one coarse gravel particle.

Table 5.2. Percent soil accumulation per trap per sample period.

	Erosion Trap											
Sample Period	1	2	3	4	5	6	7	8	9	10	11	12
09/08/2007	0.15	----	0.10	0.09	0.12	0.25	0.03	0.03	0.24	----	----	----
10/14/2007	0.37	0.07	0.08	0.01	0.04	0.06	0.00	0.01	0.17	0.06	0.05	0.07
11/17/2007	0.17	0.10	0.12	0.03	0.17	0.10	0.00	0.01	0.14	0.07	0.03	0.05
12/14/2007	0.11	0.10	0.12	0.02	0.10	0.18	0.00	0.00	0.14	0.05	0.10	0.07
04/05/2007	0.11	0.09	0.09	0.03	0.13	0.11	0.02	0.03	0.17	0.04	0.05	0.13
05/09/2007	0.03	0.10	0.11	0.02	0.13	0.17	0.02	0.04	0.22	0.06	0.07	0.04
06/26/2007	0.02	0.06	0.03	0.06	0.10	0.14	0.01	0.01	0.11	0.03	0.08	0.36
Average	0.14	0.07	0.09	0.04	0.11	0.15	0.01	0.02	0.17	0.04	0.05	0.10

high precipitation, except for the period between 12/15/2007 and 4/5/2008. For the sample period ending 4/5/2008, snowpack was consistently present between 12/25/2007 and 2/29/2008 at the Railroad Overpass SNOTEL site, and snow cover was observed at the Jim's Creek area on 1/2/2008. The presence of snowpack would have protected the soil surface from impact by liquid precipitation and minimized soil erosion by raindrop splash and ravel. Raindrop splash would have occurred only during periods of time when the soil surface was exposed. During this 112 day period, only 37 days were without snowpack at the Railroad Overpass SNOTEL site. Precipitation when snow cover was absent amounted to 20 cm and included two days with precipitation exceeding 2 cm each. The erosive potential of precipitation during this period may have been dampened by the presence of snowpack, and the observed rates of soil transport reflect the weather conditions and transient snow cover during this period of time.

5.3. Soil erosion by fine and coarse fractions

Overall, soil transport rates of fine mineral soil (< 2mm) exceeded transport rates of coarse mineral soil (> 2mm) (Figure 5.4). For all samples collected (n = 81), 82 % accumulated more fine mineral soil than coarse mineral soil. The average transport rate of fine mineral soil was 36.5 g m^{-1} mo^{-1} and ranged between a trace (0.2 g m^{-1} mo^{-1}) and 202.8 g m^{-1} mo^{-1}, with 81% of samples less than 75 g m^{-1} mo^{-1}. The average transport

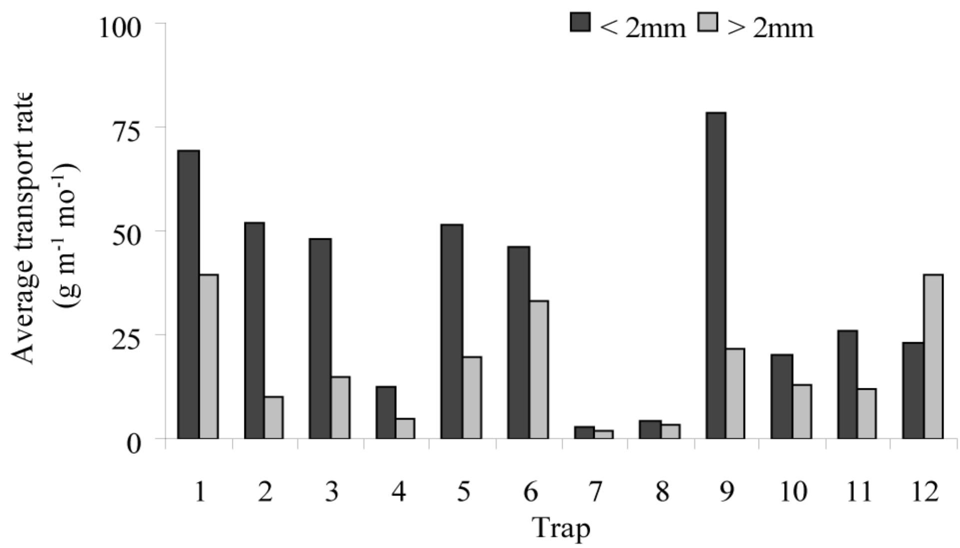

Figure 5.4. Average transport rate per trap for fine and coarse mineral soil fractions.

rate of coarse mineral soil was 17.7 g m^{-1} mo^{-1} and ranged between a trace (0.02 g m^{-1} mo^{-1}) and 148.6 g m^{-1} mo^{-1}, with 77% of samples less than 25 g m^{-1} mo^{-1}. Between the period of 10/14/2007 and 11/17/2007, 7 of 12 traps produced the highest soil transport rates for fine mineral soil (Figures 5.1a, 5.1b). During this period, 18.5 cm of precipitation was recorded at the Railroad Overpass SNOTEL weather station and five days registered precipitation amounts greater than 2 cm (NRCS, 2008). The highest transport rates for course mineral soil were rather inconsistent and were not consistently observed for a single sample period.

5.4. Soil transport rates and site characteristics

Average soil transport rates per trap were related to site characteristics including percent ground cover, slope, and aspect using Spearman's rank order correlation coefficient. A significant negative correlation was detected between the average soil transport rate for each trap and percent ground cover (r = - 0.72, Figure 5.5). A significant relationship was not detected between average soil transport rate and gradient (r = -0.33) or aspect (r = -0.28). The small range of sampled hillslope gradient values (41 – 65%) and the predominant southerly aspect limited assessment of the effects of gradient and aspect on soil transport rates within the Jim's Creek area.

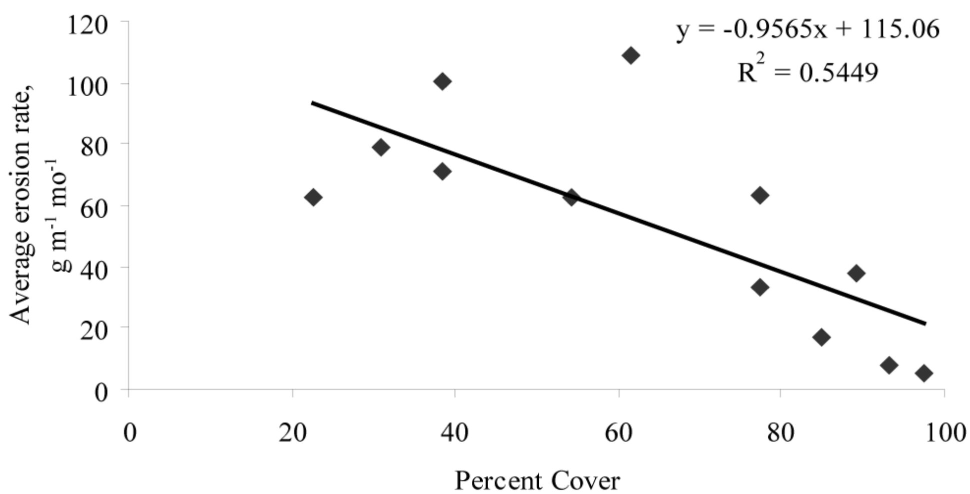

Figure 5.5. Scatterplot of average erosion rate per erosion trap against estimated percent vegetative ground cover.

5.5. Soil transport rates and precipitation

Cumulative soil transport rates and transport rates of fine and coarse mineral fractions were related to total precipitation during a sample period and daily precipitation accumulations within a sample period, using Spearman's rank order correlation coefficient. Transport rates for each sample period were related to the number of days within the sample period that experienced daily precipitation amounts greater than 1 cm, 2 cm and 3 cm.

The relationship between soil transport rates and precipitation was generally insignificant. Cumulative soil transport rates per sample period per trap were not significantly correlated to total precipitation during a sample period (Figure 5.6) except for erosion trap 5 (r = 0.78). No significant relationships were detected between cumulative soil transport rates and number of days within a sample period with precipitation greater than 1, 2, or 3 cm for any of the traps. The average soil transport rate per sample period was not significantly correlated to total precipitation during a sample period, or to the number of days within a sample period with greater than 1, 2, or 3 cm of precipitation. Transport rates for fine mineral soil and coarse mineral soil were not related to precipitation amount during the sample period or the number of days within a sample period with greater than 1, 2, and 3 cm of precipitation.

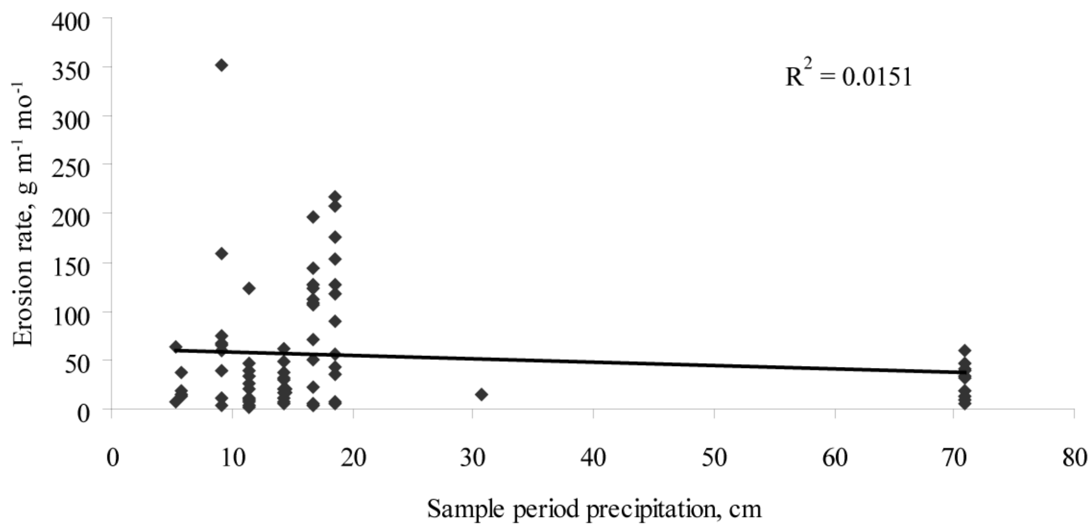

Figure 5.6. Erosion rate versus total precipitation per sample period.

5.6. Soil erosion transport processes

Observations made during this study suggest mineral soil particles were transported predominately by raindrop splash and to a lesser extent by ravel and biogenic activity. Soil particles were observed adhering to the interior walls and underside of multiple erosion traps (Figure 5.7). The presence of soil particles adhering to interior walls suggests particles were dislodged by raindrop impact and displaced vertically and laterally into the erosion trap. The aluminum sheeting attached between the hillslope surface and the trap was typically bare, suggesting accumulated debris was continually displaced. Soil particles were not observed adhering to the interior perimeter walls or underside of covers of traps 7 and 8. The extensive ground cover, consisting of moss mat, living vegetation and fine organic litter, within their contributing areas essentially blanketed the entire mineral soil surface and prevented raindrops from impacting the mineral soil surface.

The presence of coarse mineral particles within numerous erosion traps suggests ravel and possibly animal activity were occurring at some slope positions. Larger diameter particles (> 1 cm) accumulated within multiple erosion traps. Animal footprints were observed directly above two trap openings and debris within one of the traps indicated animal activity mobilized the soil. Animal activity is considered to be one mechanism for mobilizing soil, however, the disruption of an erosion trap by animal activity should disqualify the sample from the affected sample period, due to the inaccurate representation of soil transport rates. Trap 1 would be considered for disqualification from sample period 10/14/07, as the trap was dislodged, resulting in an abnormally high transport rate. No features associated with overland flow were observed

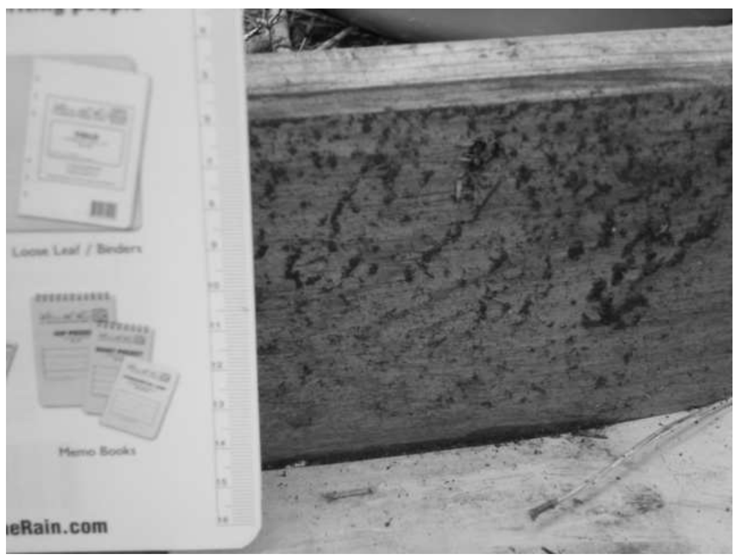

Figure 5.7. An image of mineral soil particles observed adhering to an erosion trap wall.

near any of the traps. Overland flow was observed on forest roads within the project area, but not on the undisturbed forest floor.

5.6.1. Operative geomorphic processes

The predominant geomorphic processes observed within the Jim's Creek project area include surface erosion and root throw. It is assumed that soil creep and solution transport operate within the project area, although these processes have not been quantified here. Evidence for both recent and historic root throw was observed within the Jim's Creek project area. The presence of freshly uprooted trees, soil mounds and pit and mound topography indicate this process is operative across the landscape. The occurrence of root throw is spatially limited, and in general soil that is mobilized by the displacement of root wads appears to be transported locally. This soil will not reach the stream network unless the tree was rooted adjacent to a channel.

One recent shallow mass movement was observed within the project area and is estimated to have occurred during the fall of 2006. The shallow mass movement occurred within a zone of topographic convergence in a first order stream channel tributary to Dead Horse Creek. A second shallow mass movement was observed within the Jim's Creek channel, 20 m below the intersection of Jim's Creek with forest road 2129.371. This landform is estimated to have occurred within the past decade based on the growth of Douglas-fir saplings on the downslope lobate form. Other features observed within the Jim's Creek project area include small slumps identified by steep head scarps, bench-like topography and 2 m high faces on the lobate form marking their downslope extent. These features are generally small scale and may range in width and length by up to a few tens of meters. The majority of small slumps observed within the area are estimated to be over a century old based on the presence of large diameter, straight-grown, old coniferous trees growing on and around them. Field observations made during this study suggest mass movement landforms within the Jim's Creek project area are typically small (5 x 5 m), widespread and limited in their downslope displacement.

5.7. Surface erosion extent

The spatial extent of surface erosion within the Jim's Creek project area appears to be limited to areas with exposed mineral soil. An area that experienced wildfire in 1996 within the Jim's Creek project area was specifically targeted for monitoring due to the presence of disturbed forest floor and the assumption that well protected soil surfaces have very low erosion rates. Outside this area, the mineral soil surface is covered by an extensive moss blanket, living vegetation, fine organic litter and coarse woody debris, protecting the soil surface from erosion processes. The area that experienced wildfire covers 52 hectares and represents 18 % of the Jim's Creek area.

Four of the 12 erosion traps (7, 8, 10, 11) were located on undisturbed forested slopes outside of the burned area. These traps produced four of the five lowest average soil transport rates, regardless of precipitation amount and hillslope gradient. The four erosion traps located on undisturbed forested hillslopes had an average soil transport rate of 19.9 g m^{-1} mo^{-1} versus 69.4 g m^{-1} mo^{-1} for traps located within the burned area. The average ground cover, including living vegetation and litter, for the traps located on undisturbed forested slopes was 89% versus 51% for traps located within the burned area and slope averaged 59% versus 46%. Only erosion trap 4, within the perimeter of the burned area, produced soil transport rates similar to those observed for traps 7, 8, 10, and 11.

A limited number of erosion traps sampled undisturbed forested slopes within the Jim's Creek area. A large portion of the mineral soil surface within the Jim's Creek project area is protected by extensive moss mat, living vegetation, fine litter and coarse woody debris, minimizing soil transport rates. The difference between soil transport rates for traps located on undisturbed slopes and traps located on previously disturbed slopes indicates rates of soil transport are sensitive to ground cover. The limited number of traps located outside the burned area prevents thorough assessment of the extent of surface erosion within the Jim's Creek project area. However, the higher soil transport rates observed within the previously burned area reflects the effect of vegetative ground cover on rates of soil transport.

5.8. Disturbed WEPP simulated erosion rates

Mean annual average erosion rates calculated using the Disturbed WEPP erosion model were compared against mean observed soil transport rates to evaluate the accuracy of the Disturbed WEPP model and test the suitability for application within the Jim's Creek area (Appendix D). The rates reported for the Disturbed WEPP model represent the simulated mass of soil transported across one meter of hilllslope, paralle to contour, at the end of each hillslope profile. Each hillslope profile that was simulated represents the length of hillslope beginning at each erosion trap and continuing upslope to either a road or ridgetop. The Disturbed WEPP erosion simulations over-predicted rates of soil transport for 10 of the 12 erosion traps by 380 – 1900% (Figure 5.8.). Simulations for erosion traps 10 and 11 were below the observed mean soil transport rates.

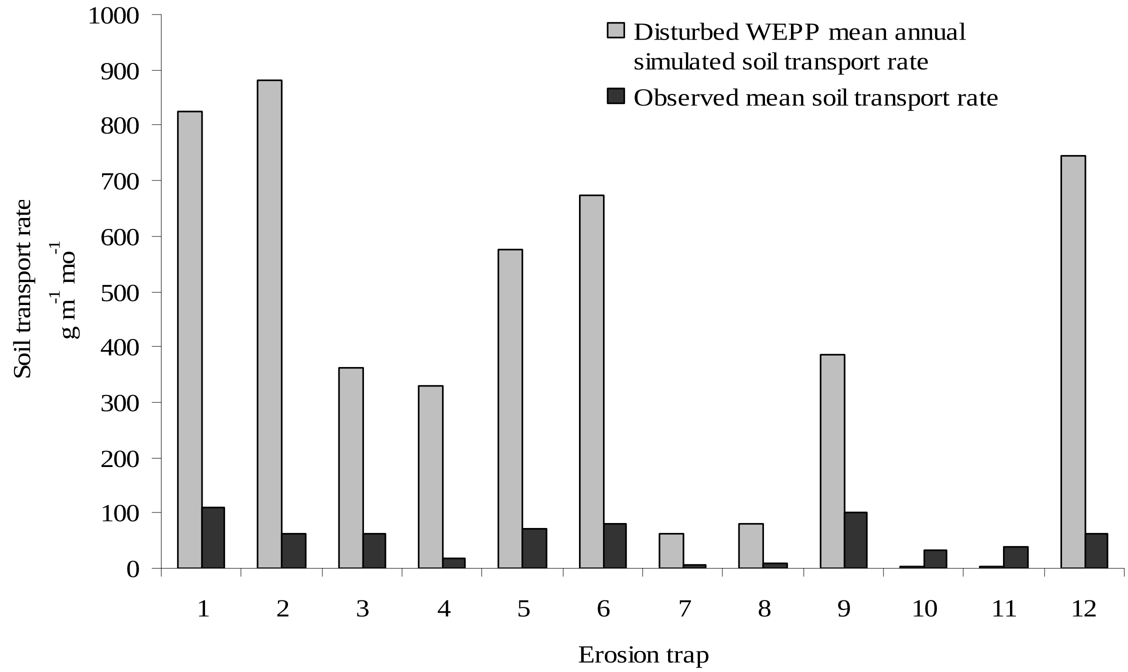

Figure 5.8. Disturbed WEPP mean annual simulated soil transport rates versus observed mean soil transport rates.

6. Discussion

6.1. The Jim's Creek erosion regime

The erosion regime within the Jim's Creek project area is characterized by low magnitude and highly variable soil transport rates. The majority of soil erosion sampled over this study was minor, and reflects the dominance of low magnitude and seasonal transport processes. The extensive ground cover consisting of moss mat, other living vegetation, fine litter and coarse woody debris throughout most of the project area significantly minimizes surface erosion. Erosion rates were rather seasonal and reflect the importance of seasonal variation of raindrop splash, dry ravel, and animal activity. These processes appear to be the dominant soil transport processes operating within the Jim's Creek study area.

The highest average soil transport rates occurred between 10/15/2007 and 11/17/2007 and may suggest early wet season rates of soil transport can be high, potentially owing to decreased soil cohesion following the summer dry season. This period experienced the first significant precipitation for the wet season. The precipitation record at the Railroad Overpass Snotel site for this time period was similar to the long-term mean and suggests the observed rates may represent rates of soil transport for average weather conditions.

Soil erosion measurements collected during this study were largely composed of fine mineral particles, suggesting raindrop splash is dominant in mobilizing mineral soil particles. The presence of soil particles adhering to the interior perimeter and underside of erosion trap covers indicates particles were dislodged by raindrop impact and displaced both vertically and laterally. Pedestals observed upslope and nearby erosion traps further suggest raindrop splash is active. The absence of rills suggests soil transport by sheet wash and overland flow was not occurring.

Dry ravel does not appear to be a significant soil transport process within the Jim’s Creek project area. Almost 100 % more fine mineral soil was eroded than coarse mineral soil, indicating raindrop splash is more dominant. Seasonality appears to be important for the mobilization of fine mineral soil. The majority of fine mineral soil was transported during the wet season. The smallest soil accumulation occurred during the spring and fall. Mersereau and Dyrness (1972) observed 600% more soil movement during periods with little rain at steep study sites in the H.J. Andrews Experiment Forest. The minor soil transport rates observed at Jim’s Creek during early summer suggest dry ravel is an insignificant transport process. The highest rates of coarse soil transport occurred during the wet season and suggest dry ravel is a minor soil transport process.

The range of slope gradients sampled at Jim's Creek (41 – 65 %) was minor. Slopes with gradients greater than 50 % are isolated to small patches within the study area. A simple GIS analysis of slope distributions indicated slopes with gradients greater than 50 % account for only 7 % of the total area. Significant transport rates of ravel are restricted to high gradient slopes. Mersereau and Dyrness (1972) collected 400% more mineral soil on 80 % slopes than on 60 % slopes and observed larger yields during the dry season as soils dried out and became less cohesive. Considering coarse mineral soil was a minor portion of overall soil accumulations and less soil was collected during drier periods overall, the contribution of ravel to the erosion regime appears to be very minor.

A significant negative correlation was detected between soil erosion and percent vegetative ground cover (Figure 5.5). For surface erosion by raindrop splash, soil detachment can occur only where soil is exposed to the force of raindrops (Selby, 1993). Erosion traps with more exposed soil within the source area tended to accumulate more soil and have higher soil transport rates.

Previous research has emphasized the importance of vegetative ground cover on rates of surface erosion. Miura et al. (2002) monitored soil transport and splash erosion on steep forested slopes in Japan and emphasized the importance of forest floor conditions for controlling rates of soil transport. Miura et al. (2002) found that forest type had a significant effect on soil transport rates. Ground cover, as influenced by forest type, regulates the area of exposed mineral soil that may be impacted by raindrops (Miura et al., 2002). Miura et al. (2002) observed the highest transport rates of fine mineral soil within forest stands having the lowest vegetative ground cover. The observations of Miura et al. (2002) indicate soil transport rates by raindrop splash are sensitive to variation in forest cover. Within the Jim's Creek project area, an extensive mat of moss was present, in addition to a thick organic litter layer and coarse woody debris. The presence of intact ground cover increases surface roughness, protects the soil surface from raindrop impact, and acts as depositional sites for displaced soil particles.

The exposure of the mineral soil surface to erosion processes by land disturbance appears to be a major control on soil transport rates. The observed relationship between erosion rates and ground cover suggest disturbance of ground cover can increase rates of erosion. For this study, variation of ground cover between 55 and 78% resulted in variation in soil transport by roughly 100 % (Figure 5.5). Erosion traps located within a previously burned area produced average soil transport rates that were 350% higher than average rates observed for traps located on undisturbed forested slopes.

The relationship between soil transport rates and precipitation per sample period was not correlated and suggests other site characteristics moderate rates of soil transport. The climate in the western Cascades of Oregon is typified by low intensity, long duration storms. Precipitation intensities are generally low and soil infiltration capacities are high, preventing development of surface runoff on undisturbed slopes. Low intensity precipitation minimizes the potential for raindrop splash erosion; however, throughfall drops are larger and more erosive.

Soil erosion and soil transport rates did not correlate positively or negatively with hillslope gradient. This may be due to the limited number of sample locations and the small range of slope values sampled. In general, slopes within the Jim's Creek project area are gentle, with only isolated areas with a gradient greater than 50 %. Both Bennett (1982) and Mersereau and Dyrness (1972) observed appreciably higher rates of soil transport on slopes greater than 60%. The minor distribution of slopes with a gradient greater than 50% within the Jim's Creek project area appears to limit the potential for erosion by dry ravel.

The rates of surface erosion observed in this study compare well with rates observed within other undisturbed forested sites. Morris and Moses (1987) observed soil transport rates between 1 and 228 g m^{-1} mo^{-1} on forested hillslopes in the Colorado Front Range. Swanson et al. (1982) monitored soil transport rates along a stream perimeter within a steep, undisturbed, forested watershed in the western Cascades of Oregon and calculated an average transport rate of 16 g m^{-1} mo^{-1}. Within the western Cascades of Oregon, Mersereau and Dyrness (1972) observed soil transport rates between 27 and 307 kg m^{-1} mo^{-1} from bare and vegetated sites on 60 % slopes, following logging and hot slash burning. The average soil transport rate observed within the Jim's Creek project area was 54 g m^{-1} mo^{-1}.

The high variance of soil erosion indicates the importance of microscale controls on rates of erosion (Morris and Moses, 1987). Swanson and Grant (1982) noted that the placement of soil collection devices near local hillslope source areas, such as soil mounds produced by root throw, influenced soil accumulations. Localized hillslope source areas are rare and isolated landforms within the Jim's Creek project area and do not represent a significant source for soil transport.

The distance over which particles were transported was not documented in this study. Bennett (1982) monitored the movement of glass beads placed on burned plots in the Oregon Coast Range and reported an average distance of movement of 1.1 m on slopes less than 60 %. Minor rates of soil transport observed in the Jim's Creek site and spatially isolated source areas minimizes the potential for increased erosion and soil transport to the channel network. Soil erosion processes observed during this study suggest soil is transported locally over short distances by raindrop splash and ravel. The potential for soil transport to the stream network by surface erosion processes appears to be very limited under an erosion regime dominated by raindrop splash.

6.2. Precipitation patterns and soil transport

The pattern of daily precipitation during each sample period appeared to correspond with the observed rates of soil transport. For example, the highest average soil transport rates for a sample period were observed for the period ending 11/17/2007. During this period, sevens days received greater than 2 cm of precipitation, and the total precipitation for the period was the second highest of all sample periods, with the exception of the sample period ending 4/5/2008.

The precipitation record during this study period did not differ significantly from the long-term mean conditions at the Railroad Overpass Snotel site. Precipitation amounts during each sample period were quite similar to the long-term mean values (Table 4.2). Only sample periods 12/14/07 and 4/5/08 differed significantly from the long-term mean. The precipitation amount during sample period 12/14/07 was 27% below average and the precipitation amount during sample period 4/5/08 was 20% above average, although a significant portion of the precipitation fell as snow. The similarity in precipitation patterns between this study period and the long-term mean suggests the observed rates of soil transport represent rates of soil transport under average weather conditions.

During this study, snow cover was present at the Jim's Creek area for several months, which included four days with precipitation greater than 2 cm each and three days with greater than 3 cm of precipitation each. The presence of snow cover would have protected the soil surface from impact by liquid precipitation and minimized the potential for soil detachment and transport. The form of precipitation during this time period may have been snow, further limiting the erosive potential of the precipitation events. The Jim's Creek area lies within a range of elevation that is below the elevation that typically develops an annual snowpack. Given that the snowpack accumulation may be anomalous, the rates observed during the sample period ending 4/5/2008 may be less than what would have occurred under normal weather conditions.

6.3. Forest structure, ground cover and soil transport

This study did not evaluate the influence of forest structure characteristics, such as canopy cover, on rates of soil transport. Canopy structure above each erosion trap may have influenced the observed rates of soil transport by modifying precipitation intensity and size of raindrops interacting with the forest floor. Throughfall drops, formed by coalescing raindrops on foliage and limbs, have been shown to generate more kinetic energy than direct rainfall (Mosley, 1982). Mosley (1982) investigated kinetic energy of throughfall drops and direct rainfall at the Maimai experimental area of New Zealand and found throughfall drops had 1.5 times more kinetic energy than that of direct rainfall, resulting in increased soil detachment under the forest canopy than in the open. If this relationship holds true, it is possible the observed rates of soil transport within the Jim's

Creek area may have been enhanced by the generation of throughfall drops from the forest canopy. Under savanna conditions, the development of throughfall drops will be minimized and the potential interaction between throughfall drops and the soil mantle will be reduced, potentially resulting in minimized rates of soil detachment and transport.

The forest structure and ground surface characteristics observed within the Jim’s Creek area during this study developed under conditions of fire suppression. The observed rates of soil transport represent rates of soil transport for forest conditions that experienced wildfire a decade earlier and for undisturbed forested conditions. Given the Jim’s Creek area will be transformed into a savanna, the future erosion regime will most likely differ drastically in comparison to the observed erosion regime. Under savanna conditions, the spatial extent of moss mat will most likely break down and give way to a grass understory. The accumulation of fine organic litter and coarse woody debris will also most likely decline under savanna conditions.

The implications of the findings in this study for soil erosion under savannah conditions before fire suppression and under the future conditions of restored savannah vegetation, if they are successful, are difficult to interpret. This study sampled sites with rather complete forest cover and sites burned about a decade earlier, but without an effort to restore native understory vegetation after the wildfire. Past and possible future savannah vegetation may have effects relative to current vegetation such as lower canopy interception of precipitation, lower throughfall, that may result in large drop sizes with more erosive potential than rainfall, lower extent of the moss mat that may suppress surface erosion under forest cover, and lower extent and thickness of the litter layer on the soil surface. The extent of ground cover and understory vegetation under savannah conditions is not well known. So, although it would be highly speculative to suggest how erosion rates will change with savannah restoration, it does seem likely that the erosion rate will be more like the pre-fire suppression rate than is the case before inception of the Jim's Creek project. Sampling in this study pre-dates the forest management treatments of the Jim's Creek project, so the data of this study serve as reference rates for assessing effects of the treatments themselves (i.e., logging, prescribed fire, understory retoration, etc.).

6.4. Jim's Creek erosion regime and Disturbed WEPP

The Disturbed WEPP model results presented by the Willamette National Forest in the Jim's Creek Environmental Assessment indicated a potential mean annual erosion amount of 2,250 tons/acre within the Jim's Creek project area as the result of timber harvest and slash burning treatments. If we assume delivery to the downslope project perimeter, as delineated by sections of Deadhorse Creek and forest road 21 within the stream and transportation GIS layers, this amounts to 16 kg m^{-1} yr^{-1} (per meter of stream/road perimeter along the base of the Jim's Creek project area), based on a 30 year simulation period. The mean estimate soil movement rate observed in this study is 0.65 kg m^{-1} yr^{-1}, which is 3.9 % of the above interpretation of the Willamette National Forest erosion prediction value.

The Disturbed WEPP model may significantly overestimate the potential for enhanced soil erosion following management activities within the Jim's Creek project area. The WEPP model simulates erosion processes that were not observed within the Jim's Creek area and that have not been observed, in general, on undisturbed, forested sites within the western Cascades of Oregon. WEPP simulates soil detachment by raindrop impact and models sediment transport from interrill areas by broad sheet flow to rill channels, where sediment is either deposited or transported by concentrated flow (Flanagan and Nearing, 1995). Overland flow was not observed during this study and soil was primarily mobilized by raindrop impact, animal activity and ravel. The potential for development of overland flow following harvest activities is considered to be minor. Because the WEPP model simulates soil erosion by overland flow, the calculation of high soil transport rates is feasible. Larsen and Macdonald (2007) indicate that WEPP model errors may occur due to the inability of physically-based equations in the model to represent key erosion processes that operate on the land. The physical processes that are simulated with the WEPP model may fail to represent the observed processes that operate on the ground. Based on the observed soil erosion transport processes within the Jim's Creek area, it appears the Disturbed WEPP model may be inappropriate for simulating soil erosion within the Jim's Creek project area.

Elliot et al. (2000) indicate simulated rates of erosion from any prediction model will only be within 50% of the true value, emphasizing the spatial variability of surface erosion processes and the limits of physically-based models. Other factors of the WEPP model can result in inaccurate predictions of soil erosion. Zhang and Garbrecht (2003) found that inaccurate storm pattern simulations by WEPP led to over-prediction errors as high as 47% for annual sediment yields; and Covert et al. (2005) found that WEPP over-predicted runoff from small harvested and burned forested watersheds, which could lead to inaccurate prediction of erosion processes and transport rates.

6.4.1. Disturbed WEPP model simulations

The Disturbed WEPP model reports a mean annual average rate of erosion for a simulation period as an upland erosion rate per unit area and as sediment transported over a meter length of hillslope parallel to contour. Under a 30 year simulation, the model simulates erosion for weather events with return periods of 30, 15, 6, 3 and 1.5 years and calculates the mean annual average rate of erosion by averaging the simulated erosion rates for each return period. Consequently, the reported mean annual average rate of potential soil erosion reflects the rates of erosion for high intensity weather events where storm runoff is simulated. Consideration should be given to weather conditions that are associated with observations of soil erosion to account for departures from mean weather conditions that would potentially modify soil transport rates.

The style of soil detachment and routing simulated by the Disturbed WEPP model does not match the style of soil detachment and transport observed within the Jim's Creek area. Given the dominant soil transport processes of raindrop splash and ravel, soil is transported out of an element and deposited downslope with no net accumulation in the volume of soil in transit. In contrast, Disturbed WEPP simulates soil detachment and net accumulation in the volume of soil in transport. The WEPP model implements physically-based equations that simulate process which are not observed within the Jim's Creek area, resulting in inaccurate erosion predictions. The inability of the model to accurately account for observed soil transport processes and local variability in hillslope characteristics such as slope and ground cover results in inaccurate erosion predictions.

6.5. GIS analysis of landslide distribution

Field observations and the landslide modeling results suggest predominately small-scale, landslide-produced landforms are distributed within the Jim's Creek project area over a small spatial extent. Field observations generally confirm this result, although predicted landforms were not confirmed in the field. Observed slumpy ground indicated landslide activity was widespread and small in spatial scale. Individual slump landforms range up to a few tens of meters in width and length. The downslope lobate form of observed shallow landslides appeared to be displaced locally, within a few tens of meters from the landform headscarp. Compared to landslide inventories conducted in other watersheds of western Oregon, such as the H.J. Andrews Experimental Forest, the distribution of predicted shallow landslides within the Jim's Creek area is minor, representing only 0.41% of the land surface within the Jim's Creek area.

The algorithm used to predict the location of shallow landslides within the Jim's Creek area (Roering et al., 2005) may be inappropriate for the terrain and style of landforms and processes found within the Jim's Creek project area. The algorithm was based on the topographic contrast between large scale (250 m planform width), deep-seated landslides within the Oregon Coast Range and steep, highly dissected terrain. A critical feature of the Coast Range study area is the strong contrast between landslide and non-landslide topography which both occur at readily detectable scales. Differences in landform morphology within the Jim's Creek project area are much more subdued and occur at fine spatial scales, which may prevent accurate delineation of shallow landslides using the algorithm presented by Roering et al. (2005). Only a single range of topographic gradient values and curvature values was used to analyze landslide-prone terrain within the Jim’s Creek project area. Subsequent analysis was not pursued to evaluate other combinations of gradient and curvature that might identify landslide-prone terrain within the Jim’s Creek project area. Further field analysis of landslide distribution is necessary to document the distribution and magnitude of shallow landslides within the Jim’s Creek project area. Access to 1 m resolution LiDAR topographic data may greatly assist this analysis.

7. Conclusions

This study documented background rates of surface erosion for a range of site conditions within the Jim’s Creek project area. Rates of surface erosion are generally insignificant, averaging 54.3 g m^{-1} mo^{-1}, are characterized by predominately low rates of transport and reflect the seasonal variation of soil transport processes including raindrop splash, dry ravel, and animal activity. The extensive distribution of moss mat, living vegetation, fine litter and coarse woody debris throughout a majority of the Jim’s Creek area protects the soil surface from erosion processes and minimizes soil erosion potential.

Ground cover appears to be a significant control on soil transport rates. A significant negative correlation was detected between rates of soil transport and ground cover percent. This relationship emphasizes the sensitivity of soil transport rates to ground cover. The future erosion regime within the Jim’s Creek area will depend on ground cover characteristics that develop under savanna conditions.

Surface erosion transport processes appear to be dominated by raindrop splash, indicated by the predominant erosion of fine mineral soil and the presence of soil particles attached to erosion trap walls. Erosion of fine mineral soil appears to be enhanced where ground cover has been disturbed resulting in exposed soil surface.

Average rates of soil transport were 350% higher within an area that experienced wildfire than rates observed on undisturbed forested slopes.

The Disturbed WEPP model may inaccurately estimate rates of soil erosion by simulating erosion processes that are not operative within the Jim's Creek area or the western Cascades of Oregon. Ten of the 12 erosion simulations over-predicted soil transport rates by 380 – 1900 % and two erosion simulations under-predicted soil transport rates by 5% in comparison to the observed mean estimate rate of soil transport. The Disturbed WEPP model simulation of transport processes that are not active within the Jim's Creek project area and the inability of the model to represent plot level variability in site characteristics such as surface roughness and gradient, renders the model inappropriate. Overland flow was not observed on undisturbed slopes and indicates the WEPP model may not be appropriate for estimating surface erosion within the Jim's Creek area.

The extent of surface erosion within the Jim's Creek project area is minor and reflects variability of site characteristics such as percent ground cover and slope, and the extensive distribution of moss mat, living vegetation, fine organic litter and coarse woody debris. The complexity of hillslopes within the Jim's Creek area have the potential to mitigate the effects of management activities on accelerated erosion and soil transport to the channel network. This study provided baseline rates of soil transport for undisturbed forested slopes within the Jim's Creek project area. Future monitoring of soil erosion within the Jim's Creek area will be beneficial for assessing the effects of low impact harvest and prescribed burning on soil transport processes and rates.

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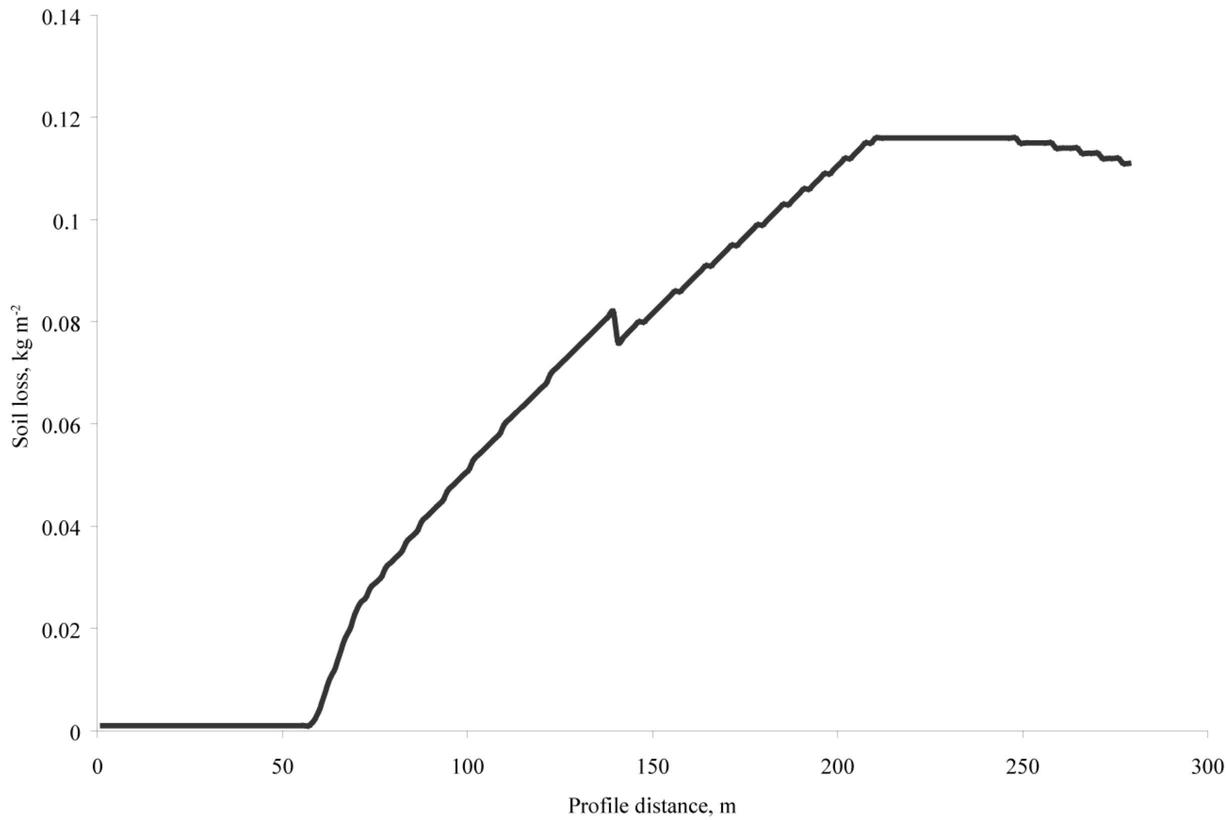
Appendix A: Example of soil routing from the Disturbed WEPP soil erosion model.
Note: The graph represents the Disturbed WEPP model simulation of soil detachment and routing down a hillslope profile for the trap 1 transect. This specific example represents the 10th year from a 30 year simulation, with yearly simulated rainfall amounting to 1162 mm and simulated storm runoff amounting to 12.59 mm. The decline near 150 m represents soil deposition associated with the transition from hillslope element 1 to hillslope element 2. Note how soil loss gradually accumulates along the profile due to the continuous simulation of detachment and transport. At the end of the profile, soil loss levels off as the profile gradient declines. This profile represents simulation from one year within a 30 year simulation, in which some years simulate no soil erosion and other years simulate greater soil erosion.



Appendix B: Cumulative debris (g) caught in erosion traps for sample periods September 8, 2007 thru June 26, 2008.

Note: The mineral soil (<2mm and >2mm fractions) and organic debris accumulations for sample period 9/8/2007 reflect different periods of time. Erosion trap 1 collected material from 3/30/2007, erosion traps 3,4,5,6 collected material from 5/19/2007, erosion traps 7,8,9,10,11 collected material from 7/8/2007 and erosion traps 2 and 12 collected material from 9/8/2007.

	9/8/2007			10/14/2007			11/17/2007			12/14/2007		
Trap	< 2mm	> 2mm	Organic	< 2mm	> 2mm	Organic	< 2mm	> 2mm	Organic	< 2mm	> 2mm	Organic
1	59.2	32.3	21.2	275.9	202.1	31.8	190.1	87.8	16	95.3	31	10.6
2	----	----	----	73.7	14.4	24.4	133.6	17.7	38.7	96.7	14.5	16
3	46	19.4	19.9	77.5	24.7	20	152	44.5	28.3	108.2	21.1	19.1
4	36.3	17.2	31.6	12.4	3.7	8.9	33.9	11.5	11.6	20.6	3.2	8.1
5	55.9	19.6	29.3	40.1	13	20.3	202.1	65.3	26.3	86.9	28.3	18.8
6	97.6	58.6	37.7	54.5	27.6	40.7	126.3	37.5	23.1	98.6	102.7	37.4
7	12	5.8	12.7	3.9	1.4	16.3	6	1.8	23	3.2	1.1	7.3
8	12.8	4.8	8.8	11.3	3.4	12.1	7	1.6	12	4.2	0.6	4
9	113.4	35.1	32.4	163.5	53.4	21.1	188.4	39.1	22.6	129.3	19.4	8.5
10	----	----	----	45	31.3	51	66.7	48.9	10.6	37.4	15	5.9
11	----	----	----	39.5	20.2	40.9	37.5	17.8	22.6	81.4	28	23.5
12	----	----	----	43.6	49	25.5	47.4	24.5	13.2	38.8	34.3	10.7

	4/5/2008			5/9/2008			6/26/2008			Total		
Trap	< 2mm	> 2mm	Organic	< 2mm	> 2mm	Organic	< 2mm	> 2mm	Organic	Mineral	Organic	All
1	80.1	93.2	19	8.9	0.9	6.8	11.6	2.1	5.8	1170.5	111.2	1281.7
2	111.9	29.9	40.2	26.1	11.6	18.5	24.2	11.8	16.6	764.1	185.9	950
3	93.9	38.7	31.4	22.2	18.5	20.8	10.9	7.8	11.5	685.4	151	836.4
4	27.1	10.9	20.7	6.9	1.8	8.1	19.3	19.1	21.9	223.9	110.9	334.8
5	128.5	71.3	24.3	22.5	26	25.2	47.3	12.6	13.3	819.4	157.5	976.9
6	100.3	70	24.7	29.7	33.6	13.4	35.8	48.7	15.8	921.5	192.8	1114.3
7	11.8	13.2	20.8	2.6	5.8	6.9	1.9	0.2	8.3	70.7	95.3	166
8	7.5	32.6	8.9	5.5	8.9	5.6	3.3	2.9	4.5	106.4	55.9	162.3
9	185.3	70.7	22.7	49.9	31.1	23.2	55.2	15.3	10.1	1149.1	140.6	1289.7
10	34.2	21.1	15.8	10	10.8	7	9.8	6.8	5.6	337	95.9	432.9
11	47.4	30.6	36.8	18.2	7.3	5.6	23.6	23.2	6.5	374.7	135.9	510.6
12	83	118.6	45.3	10.8	3.1	5.3	8.9	215.4	8	677.4	108	785.4

Appendix C: Calculated transport rates (g m^{-1} mo^{-1}) for sample periods September 8, 2007 thru June 26, 2008.

Note: Accumulated mineral soil (<2mm and >2mm fractions) and organic debris was converted into a mass per unit hillslope contour length per unit time (g m^{-1} mo^{-1}) to allow comparisons between erosion traps. The unit time conversion was calculated as the ratio between numbers of days in one month to number of days in the sample period. The unit hillslope contour conversion was calculated as the ratio between 1 m of hillslope contour to the length of erosion trap opening.

	9/8/2007			10/14/2007			11/17/2007			12/14/2007		
Trap	< 2mm	> 2mm	Organic	< 2mm	> 2mm	Organic	< 2mm	> 2mm	Organic	< 2mm	> 2mm	Organic
1	9.7	5.3	3.5	202.8	148.6	23.4	148.0	68.3	12.5	93.4	30.4	10.4
2	----	----	----	54.2	10.6	17.9	104.0	13.8	30.1	94.8	14.2	15.7
3	10.9	4.6	4.7	57.0	18.2	14.7	118.3	34.6	22.0	106.1	20.7	18.7
4	8.6	4.1	7.5	9.1	2.7	6.5	26.4	9.0	9.0	20.2	3.1	7.9
5	13.2	4.6	6.9	29.5	9.6	14.9	157.3	50.8	20.5	85.2	27.7	18.4
6	22.9	13.7	8.8	39.7	20.1	29.7	97.5	28.9	17.8	95.8	99.8	36.3
7	5.1	2.5	5.4	2.8	1.0	12.0	4.6	1.4	17.7	3.1	1.1	7.1
8	5.5	2.0	3.8	8.3	2.5	8.9	5.4	1.2	9.3	4.1	0.6	3.9
9	48.0	14.9	13.7	119.2	38.9	15.4	145.4	30.2	17.4	125.7	18.9	8.3
10	----	----	----	12.2	8.5	13.8	51.9	38.1	8.3	36.7	14.7	5.8
11	----	----	----	10.7	5.4	10.9	28.9	13.7	17.4	79.1	27.2	22.8
12	----	----	----	31.8	35.7	18.6	36.6	18.9	10.2	37.7	33.3	10.4

	4/5/2008			5/9/2008			6/26/2008			Average		
Trap	< 2mm	> 2mm	Organic	< 2mm	> 2mm	Organic	< 2mm	> 2mm	Organic	< 2mm	> 2mm	Organic
1	18.8	21.8	4.5	6.9	0.7	5.3	6.4	1.2	3.2	69.4	39.5	8.9
2	26.2	7.0	9.4	20.3	9.0	14.4	13.3	6.5	9.2	52.1	10.2	16.1
3	22.0	9.1	7.4	17.3	14.4	16.2	6.0	4.3	6.3	48.2	15.1	12.9
4	6.3	2.6	4.8	5.4	1.4	6.3	10.6	10.5	12.1	12.4	4.8	7.7
5	30.1	16.7	5.7	17.5	20.2	19.6	26.1	6.9	7.3	51.3	19.5	13.3
6	23.3	16.3	5.7	22.9	25.9	10.3	19.6	26.6	8.6	46.0	33.1	16.8
7	2.7	3.1	4.8	2.0	4.5	5.3	1.0	0.1	4.5	3.1	1.9	8.1
8	1.8	7.6	2.1	4.3	6.9	4.4	1.8	1.6	2.5	4.5	3.2	5.0
9	43.0	16.4	5.3	38.5	24.0	17.9	30.2	8.4	5.5	78.6	21.7	11.9
10	8.0	4.9	3.7	7.8	8.4	5.4	5.4	3.7	3.1	20.3	13.1	6.7
11	11.0	7.1	8.5	14.0	5.6	4.3	12.9	12.7	3.6	26.1	12.0	11.3
12	19.3	27.5	10.5	8.3	2.4	4.1	4.9	117.7	4.4	23.1	39.3	9.7

Appendix D: Disturbed WEPP simulated soil transport rates (g m^{-1} mo^{-1}).

Note: 'Sediment leaving profile' describes the mass of soil transported across a meter length of hillslope parallel to contour and is comparable to the observed average soil transport rates. 'Upland erosion rate' describes the mass of soil eroded from a unit area. The return period analysis indicates the rates of erosion for years with weather events of a given return period – note the mean annual average is calculated using the return period rates of erosion and consequently reflects the extreme soil transport rates associated with a weather event with a return period of 30 years.

	Disturbed WEPP Simulation, mean annual average for 30 year simulation		Observed	Return period analysis based on 30 years of climate, sediment leaving profile, g m^{-1} mo^{-1}				
Trap	Sediment leaving profile, g m^{-1} mo^{-1}	Upland erosion rate, g m^{-2} mo^{-1}	Average soil transport, g m^{-1} mo^{-1}	30 year	15 year	6 year	3 year	1.5 year
1	826.3	3.0	108.9	20045.3	2552.2	26.0	15.6	0.0
2	879.8	3.2	62.3	21400.3	2659.8	45.1	1.6	0.0
3	362.8	1.3	63.3	10155.5	501.7	3.1	0.5	0.0
4	329.1	1.2	17.1	9240.5	455.8	2.7	0.5	0.0
5	574.2	2.1	70.8	16055.9	812.4	5.2	1.0	0.0
6	672.1	2.3	79.0	18820.1	988.4	2.7	0.0	0.0
7	63.6	0.7	5.0	1397.7	302.5	3.0	0.0	0.0
8	79.0	0.8	7.7	1710.9	385.9	4.5	0.0	0.0
9	384.4	1.4	100.2	11202.8	260.3	1.5	0.0	0.0
10	1.6	0.1	33.4	31.7	4.7	1.3	0.8	0.0
11	1.9	0.1	38.1	40.8	5.2	1.4	0.8	0.0
12	744.7	2.3	62.4	20146.6	1613.8	3.5	0.0	0.0