

**Improving Road Erosion Modeling for the Lake Tahoe Basin and
Evaluating BMP Strategies for Fine Sediment Reduction at Watershed Scales
(P010) – Final Report**

Parameterizing WEPP for Lake Tahoe
Improving WEPP:Road for Lake Tahoe
Validating WEPP Model for Lake Tahoe

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Lake Tahoe is well known for its beauty and exceptionally clear waters. However, there has been a decreasing trend in water clarity of the lake caused by an increased influx of fine sediments and nutrients into the lake (TRPA; Tahoe Regional Planning Agency, 2004). A key strategy for protecting water quality in the Lake Tahoe Basin is to reduce pollutants entering stream channels (Tallac Applied Ecology & Design, 2006). Proper implementation of this strategy has been challenging because it requires accurately identifying the non-point pollution sources (e.g., erosional “hot spots”), and the adequate BMPs (Best Management Practices) that reduce sediment and nutrient transport to stream channels.

Roads, especially with native surfaces, can be the greatest single source of sediment delivered to stream systems (Megahan, 1972; King and Gonsior, 1980). The Forest Service Lake Tahoe Basin Management Unit (LTBMU) evaluated 134 miles of road decommissioning and BMP upgrades between 2003 and 2005 (USDA Forest Service LTBMU, 2006), focusing on the road segments that were hydrologically connected to streams (USDA Forest Service LTBMU, 2005). Their road BMP upgrades were to protect soil and water resources and included upgrades of surfacing (e.g., pavement), drainage (e.g., rocked ditch), and slope stabilization (e.g., rocked fillslope and revegetation).

One of the evaluation methods used by LTBMU was WEPP: Road, an interface developed by the Rocky Mountain Research Station (RMRS) using the Water Erosion Prediction Project (WEPP) model (Elliot et. al, 1999). WEPP: Road allows the users to quantify the sediment load and assess the effectiveness of BMPs on soil erosion. For this reason, WEPP: Road will be used as a future planning and designing tool in the basin (USDA Forest Service LTBMU, 2006). WEPP estimates usually range between -50% and +50% of observed values (Elliot et. al, 1999). In order for WEPP: Road to produce more accurate results, the model parameters need to be refined for a specific region. For the current version of WEPP:Road, the decomposed granite parent material simulation was performed in the Zena Creek watershed in Idaho. The volcanic parent material simulation was performed in the Tee Meadow watershed in Idaho. While these sites provide reasonable WEPP estimates, an improvement in the mean sediment production estimate would result from parameterization on Lake Tahoe soils. Additionally, the WEPP:Road model interface was not able to simulate erosion under some road conditions (e.g., armored/rocked fillslopes and non-forested buffers, i.e. the area between the road and the stream channel). The WEPP: Road validation and limitations have been well-known issues for the applications within LTBMU (USDA Forest Service LTBMU, 2005). Such improvements will ensure that the WEPP model serves as a reliable tool that helps to 1) better understand the non-point pollution sources and accurately identify them, and 2) select the adequate BMPs and properly assess their effectiveness.

A Geographic Information System (GIS)-based quantitative approach was developed to effectively estimate sediment loading not only from hydrologically connected road segments, but also from the entire road network within the basin. This approach combined WEPP:Road and simulated annealing optimization, in order to analyze the economic and sediment reduction trade-offs of implementing alternative BMPs.

We proposed to fill this critical need by 1) parameterizing the WEPP model specifically for the Lake Tahoe Basin, 2) improving the current WEPP: Road interface, 3) validating the WEPP model for the Lake Tahoe Basin and 4) developing a quantitative approach to identify erosional “hot spots” and the adequate BMPs to efficiently reduce the sediment transport to stream channels.

Erosion models are powerful tools for land managers in their efforts to protect and manage resources. Models allow the simulation of current conditions to gain a better understanding of system processes and also allow forecasting future conditions. Erosion from undisturbed forest lands is typically low and unpaved roads are often the greatest single source of sediment in forest environments (Megahan and King, 2004; McNulty et al., 1995; Wemple et al., 1996; Ziegler and Giambelluca, 1997; Ziegler et al., 2004). With unpaved road networks covering over 600,000 km of U. S. Forest Service land in the United States, roadway contributions to runoff and sediment budgets have become evident (Jones and Grant, 2001; Gucinski et al., 2001; McNulty et al., 1995; USFS, 2002). However, erosion responses are not the

same from all roads, but rather typically depend on a combination of physical site-specific characteristics (Gucinski et al., 2001; Megahan and King, 2004). At the same time, roads are important for recreation opportunities, timber access, fire suppression activities, and general forest management (Gucinski et al., 2001; USFS, 2002). A model that accurately predicts erosion from unpaved forest roads can be used to identify erosional “hot spots,” compare long-term erosion impacts of proposed roadway projects, and forecast the efficacy of proposed roadway best management practices (BMPs) (McNulty et al., 1995).

Process based soil erosion models explicitly simulate hillslope and watershed processes. These models typically use numerical solutions of governing equations that mathematically represent the hydrological processes that govern long term soil erosion. Among these are rainfall, runoff, infiltration, evapotranspiration, plant growth, and soil water changes.

Numerous process-based erosion models are available. The Water Erosion Prediction Project (WEPP) and Kinematic Erosion Model (KINEROS2) are two that have been adapted to model erosion on forest roads (Elliot et al, 1995, Laflen et al., 1997, Ziegler et al., 2001). The WEPP model includes components for weather generation, frozen soils, snow accumulation and melt, irrigation, infiltration, overland flow hydraulics, water balance, plant growth, residue decomposition, soil disturbance, consolidation, and erosion and deposition (Flanagan and Nearing, 1995). WEPP has been parameterized for land-use and management conditions, including crop-, range-, and forest lands, roads, and prescribed and natural fires.

Sediment production from roads is dominated by five factors: climate, infiltration; raindrop splash; concentrated flow; and cover. Climate concerns the timing of precipitation events during the year, whether they occur as rain or snow, and how accumulated snow melts. The climate component of WEPP generates mean daily precipitation, daily maximum and minimum temperature, mean daily solar radiation, and mean daily wind direction and speed.

Infiltration is a measure of the rate at which water soaks into the road surface. WEPP uses the Green-Ampt Mein-Larson equation for infiltration as presented by Chu (1978).

$$f = K_e \left(1 + \frac{(\phi - \theta_i) \Psi}{F} \right) \quad \text{Eqn. 1}$$

where f is the infiltration rate (mm h^{-1}), K_e is the effective hydraulic conductivity (mm h^{-1}), ϕ_e is the effective soil porosity ($\text{mm}^3 \text{mm}^{-3}$), θ_i is the initial soil water content (mm mm^{-1}), Ψ is the average wetting front capillary potential (mm), and F is the cumulative infiltration depth (mm). The average wetting front capillary potential is calculated in WEPP as a function of soil type, soil water content, and soil bulk density (Alberts et al., 1995). Rainfall simulation is used to determine effective hydraulic conductivity (Foltz et al., 2007).

Raindrop splash is the result of rain impacting the road surface and dislodging soil particles. These dislodged soil particles are transported off the road surface by shallow overland flow. The WEPP model describes raindrop splash erosion as

$$D_i = K_i \times I \times q \quad \text{Eqn. 2}$$

where D_i is the interrill detachment rate ($\text{kg s}^{-1} \text{m}^{-2}$), K_i is the interrill erodibility coefficient (kg s m^{-4}), I is the rainfall intensity (m s^{-1}), and q is the interrill runoff rate (m s^{-1}). Rainfall simulation is also used to determine the interrill erodibility coefficient (Foltz et al., 2007).

Concentrated flow frequently occurs on roads in wheel ruts and in the adjacent ditches. This type of flow causes several times greater erosion than raindrop splash and should be minimized in a well designed and maintained road. A rill erosion model based on Foster et al. (1977) is used in WEPP.

$$D_r = D_c \times \left(1 - \frac{G}{T_c}\right) \quad \text{Eqn 3.}$$

where D_r is the rill detachment rate ($\text{kg m}^{-2} \text{s}^{-1}$), D_c is the detachment capacity of the flow ($\text{kg m}^{-2} \text{s}^{-1}$), G is the sediment load per unit width ($\text{kg m}^{-2} \text{s}^{-1}$), and T_c is the transport capacity of the flow ($\text{kg m}^{-2} \text{s}^{-1}$). The sediment load G ranges from zero for water without sediment to one at transport capacity at which point the rill detachment rate (D_r) is zero. Detachment capacity (D_c) is represented by the following excess shear erosion equation (Foster et al., 1995):

$$D_c = K_r \times (\tau - \tau_c) \quad \text{Eqn 4.}$$

where K_r is the rill erodibility coefficient (s m^{-1}), τ is hydraulic shear stress in the rill (Pa), and τ_c is the critical shear stress required for detachment to occur (Pa). Concentrated flow simulations on roads is used to determine the rill erodibility coefficient (Foltz et al., 2008).

Cover is the fourth of the factors influencing road erosion. The undisturbed forest floor typically has greater than 80% ground cover due to duff and forbs which protects the bare soil from raindrop splash and reduces the velocity of concentrated flow. Roads that are open to traffic have little to no cover to protect the surface. Roads that are closed to traffic for several years often have cover from plants and litter. Ones that have been closed for decades often have 3 to 5 m tall trees growing on the road surface. Cover is usually measured directly using line intercept or grid count methods (Booth et al., 2005).

The overall objective of this study was to reduce sediment entering Lake Tahoe by improving and validating the WEPP model applications for road management in the Lake Tahoe Basin. Specifically, we proposed to:

1. Parameterize the WEPP model for the Lake Tahoe Basin;
2. Improve WEPP: Road interface for the Lake Tahoe Basin;
3. Validate the WEPP model for the Lake Tahoe Basin;
4. Develop a GIS-based quantitative approach to (a) predict the sediment loading using WEPP: Road, (b) identify erosional “hot spots” from a watershed-scale road network and (c) determine the optimal road network design that minimizes sediment production through BMP application.

METHODS

This section details the methodology to determine WEPP infiltration and interrill erosion parameters, the model validation efforts, and the improvement to the Road:WEPP interfaces. The GIS methodology can be found in the Final Report by Chung and Efta (2010).

RAINFALL SIMULATION

The rainfall simulation sites were four native surface roads in the Lake Tahoe basin (Figure 1). The Spooner Summit and Ward Creek roads were composed of soils derived from volcanic parent material and the Secret Harbor and Mt. Rose road were composed of soils derived from granitic parent material. Soil texture was determined by wet sieving road surface samples. Six rainfall simulation plots were

installed on each road for a total of 24 plots. Plot locations were randomly chosen on each road and were typically spread within a one mile section of road. One-meter-square bounded plots were constructed from three sheet metal borders with a collection tray and runoff apron at the downhill edge of the plot. The borders were driven 50 mm into the soil surface. The runoff apron was sealed with bentonite to prevent seepage. Plots were installed in the tire tracks of the running surface. Slopes ranged from 2 to 10% with an average of 5.6%.

A properly designed rainfall simulator needs to have the same characteristics as natural rainfall in order to ensure that the physical processes that occur during natural rainfall also occur during simulated rainfall (Meyer and McCune, 1958; Meyer and Harmon, 1979). Two of the major characteristics of natural rainfall are drop size and drop velocity. Together these determine the kinetic energy of rainfall. Surface sealing and aggregate stability are two kinetic energy dependent processes.

Nozzle selection and water pressure at the nozzle largely determine drop size. A backpackable rainfall simulator was used by the Rocky Mountain Research Station (Foltz et al., 2007). This simulator uses a single VeeJet 80100 nozzle in a spray-down configuration. The manufacturer reports that this nozzle, when supplied with 41 kPa (6 psi) water, forms drops with a size distribution similar to natural rainfall.

Raindrops in natural rainfall fall at terminal velocity. For the VeeJet 80100 nozzle operating at 41 kPa, the larger drops exit the nozzle above terminal velocity and smaller ones exit at below terminal velocity. In a fall of 3 m, the height of the backpackable simulator, most of the drops are at terminal velocity. The combination of drop size and terminal velocity ensures that the simulator closely approaches the kinetic energy of natural rainfall (Laws and Parsons, 1943)

A storm with an intensity of 86 mm hr⁻¹ and a duration of 50 minutes was delivered to each plot. The rainfall rate measured during a series of calibration runs prior to rainfall simulations. Simulations were conducted under antecedent moisture conditions which ranged from 0.1 to 2.5% gravimetric water content. The goal of the simulations was to achieve steady-state runoff and not intended to be representative of any particular design storm. The duration was chosen to ensure that the entire plot contributed runoff and to exceed the steady state infiltration rate. Both of these conditions are necessary to calculate infiltration from equation 1 and interrill erosion from equation 2. Timed grab samples were taken during every minute of the runoff period and used to calculate runoff rates and sediment concentrations.

HYDRAULIC CONDUCTIVITY

Hydraulic conductivity can be calculated in two different ways. One is to calculate the difference between the rainfall rate and the steady state runoff (Foltz et al., 2009). A second way is to use the WEPP model to determine effective hydraulic conductivity (Foltz et al, 2007). Since the focus of the study was the WEPP model, we chose to use WEPP to determine effective hydraulic conductivity by comparing predicted values from the WEPP model and measured values from the rainfall simulations. The optimized fit for effective hydraulic conductivity was found by changing the assumed saturated hydraulic conductivity value until the differences between the corresponding predicted and observed runoff volumes, and between the predicted and observed peak runoff rates, were minimized; i.e., minimizing the objective function value (eq. 5):

$$OBJ = (RO_{obs} - RO_{WEPP})^2 + (Peak_{obs} - Peak_{WEPP})^2 \quad \text{Equ. 5}$$

where RO_{obs} is the observed runoff (mm), RO_{WEPP} is the WEPP predicted runoff (mm), $Peak_{obs}$ is the observed peak runoff (mm sec⁻¹), and $Peak_{WEPP}$ is the WEPP predicted peak runoff (mm sec⁻¹).

The objective function (equation 5) was used to match both the runoff volume and the peak runoff rate. When WEPP model predictions match closely, there is little conflict between the two portions of the objective function. In those cases when the model does not closely approximate the observed hydrograph, it is not possible to simultaneously match both runoff volume and peak runoff rate resulting in neither being predicted well. The Nash-Sutcliffe model efficiency coefficient has been as a measure of how well a model predicts observed conditions (Moriassi et al., 2007). Values range from negative infinity to 1 with a value of one representing perfect agreement between observed and predicted data. A value of zero indicates there is no difference between using the mean of the observed data and the model predictions. Values less than zero indicate that the mean of the observed data is a better estimate than the model data.

INTERRILL ERODIBILITY COEFFICIENT

The interrill erodibility coefficient in equation 2 can also be determined either by direct solution or by using the WEPP model. Similar to the selection of the WEPP model for effective hydraulic conductivity, the WEPP model was used to determine the interrill erodibility coefficient, K_i . Once the effective hydraulic conductivity was found, another trial and error solution was employed until the WEPP predicted erosion matched the observed erosion.

IMPROVE WEPP:ROAD INTERFACE

The WEPP:Road interface was improved by implementing a Lake Tahoe only interface. This interface serves as a front end to the WEPP model. It contains climate stations in the basin and infiltration and interrill erosion parameters determined in this report.

MODEL VALIDATION

Model validation was attempted by installing ditch flow collection boxes at Spooner Summit and in the Blackwood watershed during the summer months of 2007, 2008, and 2009. Ditch flow was conveyed in a 8 inch diameter plastic pipe to a sediment collection box set on concrete piers. Each box was designed to collect and measure ditch runoff from summer thunderstorms. They consisted of a 0.32 m³ settling tank which overflowed into a second settling tank of 0.15 m³ with a modified 22 1/2° V-notch weir at the outlet. The weir was modified by adding a 6 mm wide by 13 mm long slot at the base of the 'V' to overcome problems with maintaining a reliable zero reading at the base of the 'V'. An ISCO 3230 flow meter was used to measure and record water levels at five minute intervals. The flow meters were connected to ISCO 3700 samplers with their intake tubes located in the 0.15 m³ settling box. The samplers were programmed to sample when the water level exceeded 3 mm above the base of the weir.

RESULTS AND-DISCUSSION

The soil characteristics of the two parent materials are shown in table 1. Elliot and Hall (1997) recommend using a soil texture of sandy loam for granitic soils. They do not have a recommendation for volcanic soils. Prior to the results from the current study, Elliot (personal communication, 2008) suggested using silt loam for the volcanic soil at Tahoe. Inspection of the Tahoe granitic and the generic granitic soil characteristics show a reasonable match. However, the Tahoe volcanic and generic volcanic match poorly. For both Tahoe soils, the generic sandy loam would be a better match based on the soil textures.

EFFECTIVE HYDRAULIC CONDUCTIVITY

The composite runoff hydrograph for each location is shown in figure 2. Each of the locations displayed runoff within three minutes from initiation of rainfall followed by a steep rising limb to steady state runoff within 50 minutes. Following cessation of rainfall, runoff declined to zero within a minute.

These hydrograph characteristics are typical of small plot rainfall simulations on native surface roads (Foltz et al., 2009, Sheridan et al., 2008) and reflect a small depression storage, vegetation free, and shallow soil depth surface typical of a road.

Total runoff for each individual rainfall simulation are presented in table 2. The maximum runoff volume for the granitic soils was 53.77 mm while the minimum was 39.43 mm. Compared to the average for all twelve granitics, the range represented 13% above and 17% below the average. Comparable ranges for the volcanic soils were 13% above and 12% below the average. Similarly, the coefficient of variation for runoff volume was 10% for the granitic soils and 8% for the volcanic soils. Both the range and the coefficient of variation are indicators of the spatial variability of native surface road runoff under controlled conditions.

All 24 of the rainfall simulations resulted in effective hydraulic conductivity values ranging from 2.5 to 12.1 mm hr⁻¹. The average and coefficient of variation for both of the geologic parent materials are shown in table 3. Note that the coefficient of variation increased from 8 to 10 for runoff to 37 to 40 for effective hydraulic conductivity.

The Nash-Sutcliffe model efficiency coefficient ranged from 0.994 to 0.790 indicating good fits between the WEPP predicted and the observed hydrograph. Figure 3 shows the observed and WEPP predicted hydrographs with the highest and lowest Nash-Sutcliffe coefficients. There was no apparent difference in Nash-Sutcliffe coefficients between parent materials. We concluded that using the objective function to determine effective hydraulic conductivity in the WEPP model was well suited to modeling the runoff from these native surface road plots.

Inspection of table 3 shows that the Lake Tahoe basin derived effective hydraulic conductivity was nearly 2.5 times larger than the generic WEPP values for the granitics (9.3 vs. 3.8 mm hr⁻¹) and nearly 30 times larger for the volcanics (7.5 vs. 0.27 mm hr⁻¹). Based on soil texture rather than parent material, the volcanics were nearly 2 times larger than the WEPP recommended value for a sandy loam soil (7.5 vs. 3.8 mm hr⁻¹). In any case, the Lake Tahoe basin derived effective hydraulic conductivities were larger than the generic WEPP recommended values by at least two times.

WEPP values are based on Elliot et al. (1993) where they used the cropland soil relationship to predict effective hydraulic conductivity for five native surface roads with soil textures of loamy sand, sandy loam, loam, and gravelly loamy sand. The cropland soil relationship predicted effective hydraulic conductivities ranging from 0.002 for a sandy loam to 0.24 mm hr⁻¹ for a loam. They compared the WEPP predicted total runoff to observed total runoff and concluded that gravelly loamy sand predicted value of 0.029 needed to be increased to 2.87 mm hr⁻¹ in order to achieve differences in predicted and observed total runoff of “seldom greater than 10%.” No optimization of effective hydraulic conductivity was performed in their study.

Luce and Cundy (1994) used the Philip’s infiltration equation coupled to a kinematic wave overland flow equation to determine four parameters to model the processes of infiltration, depression storage, and overland flow. One of the parameters, Philip’s A, was hydraulic conductivity. Using an optimization routine they determined the best combination of the four parameters for six native surface roads with soil textures of sandy silt, sandy loam, and silt loam. They reported hydraulic conductivities ranging from 5 x 10⁻⁵ to 8.82 mm hr⁻¹. While this range includes both the current study and Elliot et al. (1993), the Philip’s equation for infiltration and Green-Ampt equations are parameterized differently. Philip’s uses time as the independent variable while Green-Ampt uses cumulative infiltration as the independent variable making direct comparison of “hydraulic conductivity” difficult.

Foltz et al. (2009) reported that a sandy loam soil texture native surface forest road that had been allowed to revegetate for 30 years then reopened for a small timber sale had an effective hydraulic conductivity averaging 11 mm hr⁻¹. In this study the same effective hydraulic conductivity optimization routine was used and is, therefore, directly comparable to the current study.

INTERRILL ERODIBILITY COEFFICIENT

The composite sediment concentration graphs for each location are shown in figure 4. The two volcanic soil locations (Spooner Summit and Ward Creek) exhibited initial peaks in sediment concentration followed by a decreasing trend to reach steady-state sediment concentrations between minutes five and ten. Previous studies have reported similar trends in sediment concentrations (Foltz et al., 2009; Ziegler et al., 2001). In contrast, the two granitic soil locations (Mt. Rose and Secret Harbor) had relatively low initial sediment concentrations followed by increases to steady-state levels. Both parent materials reached a steady-state sediment concentration approaching 15 g L^{-1} and did not decrease with time as described in other studies (Foltz et al., 2009; Ziegler et al., 2001).

A possible explanation for the sustained sediment concentrations is the moderate to strong water repellency measured at three of the four locations as shown in table 4. There was a high degree of spatial variability in the water drop test with the exception of Mt. Rose which showed no water repellency. During the rainfall simulations we observed hydrophobic conditions characterized by “beading” of runoff from the plot. DeBano (2000) reported on the mechanisms for increased erosion via raindrop splash under hydrophobic conditions. Hydrophobicity limits surface sealing during a rainfall event as hydrophobic soil particles tend to remain dry, non-cohesive, and thus, susceptible to detachment by raindrop splash (DeBano 2000).

Total sediment for each individual rainfall simulation are presented in table 2. The maximum sediment mass for the granitic soils was 1.943 while the minimum was 0.582 kg. Compared to the average for all twelve granitics, the range represented 75% above and 48% below the average. Comparable ranges for the volcanic soils were 46% above and 36% below the average. Similarly, the coefficient of variation for sediment mass was 36% for the granitic soils and 20% for the volcanic soils. Both the range and the coefficient of variation for sediment mass are higher than those for runoff. Sediment mass variability includes both variability in runoff and inherent variability due to sediment alone.

The 24 rainfall simulations yielded interrill erodibility values ranging from 1.11×10^6 to $7.82 \times 10^6 \text{ kg s m}^{-4}$. The average and coefficient of variation for both of the geologic parent materials are shown in table 5. Basin derived interrill erodibility coefficients for granitics were essentially unchanged (2.2 compared to 2.0) while basin derived volcanics were 1.6 times larger than the generic WEPP ones (3.1 compared to 2.0). Note that the coefficient of variation increased from 20 to 36 for sediment mass to 40 to 62 for interrill erodibility coefficient. Derived parameters, such as effective hydraulic conductivity and interrill erodibility, have a larger coefficient of variation than directly measured field values, such as runoff and sediment mass.

Foltz et al. (2009) reported an interrill erosion coefficient range of 1.0×10^6 to $1.8 \times 10^6 \text{ kg s m}^{-4}$ on a re-opened sandy loam texture native surface road. In an obliterated road study, Foltz et al. (Foltz et al., 2007) found interrill erodibility coefficients ranging from 1.2×10^6 to $6.1 \times 10^6 \text{ kg s m}^{-4}$. Cropland interrill erodibilities (Elliot et al., 1989) ranged from 0.77×10^6 to $4.32 \times 10^6 \text{ kg s m}^{-4}$.

IMPROVE WEPP:ROAD INTERFACE

At the request of the SNPLMA, the interface development aspects of this project were merged with those of another round 7 project (Brooks et al., 2010), resulting in the online Tahoe Basin Sediment Model (<http://forest.moscowfsl.wsu.edu/cgi-bin/fswcpp/tahoe/tahoe.pl>). In the context of this project, the interface contains soil and vegetation files describing high and low traffic graveled, and paved roads, treated and untreated cutslopes, and the option to select from ten different vegetation and soil conditions downslope of the road. The attached worksheet that was developed for the June, 2010 Basin Workshop contains instructions for describing rutted, insloped, outsloped, graveled or paved roads, and for evaluating the benefits of adding waterbars. The worksheet also contains instructions for using the

interface to evaluate the benefits of mulching and mulch incorporation on reducing runoff and erosion from road cut or fill slopes, or other highly disturbed construction areas.

The soil files for the road options were developed from numerous sources. The hydraulic conductivity and interrill erodibility were based on research that was part of this proposal. The rill erodibility values were from recent complimentary research that was not funded by this proposal (Foltz et al., 2008), including some unpublished results. The soil files used to evaluate cutslope management were from published data that was collected in the basin (Grismer and Hogan, 2005; Grismer et al., 2008).

The approach to vegetation modeling is different than the other online interfaces (Disturbed WEPP, WEPP FuME and ERMiT). The plants are modeled with a fixed ground cover, an input from the user, and a fixed canopy that is equal to the ground cover. This means that users no longer need to calibrate the model to ensure the correct ground cover as was required in Disturbed WEPP (Elliot et al., 2000), but it does allow the model to account for canopy effects on snow melt rates, a feature missing in the WEPP FuME and ERMiT interfaces (Elliot, 2005; Robichaud et al., 2007).

The interface also contains seven new climate files for the basin built from the SNOTEL stations located within the basin (Brooks et al., 2010). As with the other online interfaces, the interface has the ability to modify the SNOTEL or other NOAA stations in the area with monthly precipitation records from the PRISM climate database and to vary the temperatures with elevation using the adiabatic lapse rate (Scheele et. al., 2001).

A Tahoe Basin Sediment Model workshop was held at Incline Village, NV on June 16 and 17, 2010. There were fifteen attendees from USDA Forest Service and other federal, state, and local agencies. As of October 1, 2010 there had been 500 hits on the web based interface.

MODEL VALIDATION

The proposal offered installing the sediment collection boxes for a single summer thunderstorm season on both a paved and unpaved road. Both road sections at Spooner Summit and in the Blackwood watershed were paved because we could not find suitable unpaved road sections.

Table 6 details the installation and removal dates and the precipitation during the collection interval for each of the three years. Precipitation data for Spooner Summit was taken from the Marlette Lake Snotel Site at a distance of 5 miles and at an elevation 793 feet higher. For the Blackwood Creek site precipitation from the Rubicon #2 Snotel Site located 8 miles and 1093 higher in elevation was used. Although the expectation was to collect runoff in a single year, no ditch runoff from the two road sections was collected during the three summer thunderstorm intervals. Based on the precipitation one can conclude that 0.3 inches of rainfall in a day was not sufficient to produce ditch flow from a paved road section.

Based on the three years experience in this study, collection of snowmelt season runoff would be a better option for model validation. Local knowledge and the WEPP Tahoe interface predictions agree that the majority of runoff and sediment are produced from snowmelt events. Such a study would be able to validate the WEPP Tahoe interface.

FURTHER WORK

The erosion parameterization aspect of this study would be complimented by additional work to determine the rill erodibility parameters of rill erodibility coefficient and critical shear as defined in Equation 4. These two additional parameters would complete a Lake Tahoe, basin specific, erosion parameter set for the WEPP suite of models. Rill erosion studies usually consist of taking water and sediment samples from a series of concentrated flows in a well defined rill. From the flow rates, rill dimensions, and sediment concentrations, the rill erodibility coefficient and critical shear can be calculated. Full details can be found in Foltz et al. (2008).

CONCLUSION

There were four objectives of the study. The first was to parameterize the WEPP model for the Lake Tahoe Basin. Using rainfall simulation the study determined that Lake Tahoe basin hydraulic conductivities were 9.3 and 7.5 for granitic soils and volcanic soils, respectively. Similarly, the interrill erodibility coefficients were 2.2×10^6 and 3.1×10^6 for granitic soils and volcanic soils, respectively.

The second objective was to improve WEPP: Road interface for the Lake Tahoe Basin. An improved WEPP:Road-like interface was developed specifically for the Lake Tahoe Basin incorporating the erosion parameter values determined from rainfall simulation. The interface, called Tahoe Basin Sediment Model, is available at <http://forest.moscowfsl.wsu.edu/cgi-bin/fswepp/tahoe/tahoe.pl>.

The third objective was to validate the WEPP model for the Lake Tahoe Basin. In three years, two years more than the original proposal, there were insufficient rainfall events to validate the model. This suggests that winter snowmelt runoff validation attempts could be more successful.

The final objective was to develop a GIS-based quantitative approach to (a) predict the sediment loading using WEPP: Road, (b) identify erosional “hot spots” from a watershed-scale road network and (c) determine the optimal road network design that minimizes sediment production through BMP application. A methodology using WEPP:Road and simulated annealing was demonstrated for 7.6 miles of roads in or adjacent to the Glenbrook Creek watershed. Over a 30 year prediction time frame, 4.4 miles produced no sediment with only 0.8 miles in a “High Risk” category. An optimal BMP application strategy was found that minimized sediment from the existing network subject to a variety of road budget constraints. This optimum application of BMPs resulted in a 64% reduction in sediment over the 30 year planning horizon. (A complete discussion of the GIS-based quantitative approach can be found in Chung and Efta (2010).

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Table 1 – Soil characteristics for Lake Tahoe Basin specific locations and for generic WEPP recommendations.

Parent Material	Soil Texture	Rock (%)	Sand (%)	Very Fine Sand (%)	Clay (%)
Tahoe granitic	Sand	9	89	17	0.4
Generic granitic	Sandy loam	20	60		5
Tahoe volcanic	Sand to gravelly loamy sand	18	85	24	0.7
Generic volcanic	Silt loam	10	30		15

Generic granitic and generic volcanic taken from Elliot and Hall, 1997.
Very fine sand is 0.10 to 0.05 mm

Table 2 – Rainfall simulation summary for four Lake Tahoe basin specific locations.

Parent Material	Site	Replication	Rainfall Duration (min)	Volume Runoff (mm)	Mass Sediment (kg)	Average Concentration (g/mm)	Runoff Coefficient (%)
Granitic	SH	1	50	44.27	1.501	33.9	61
		2	50	47.62	1.375	28.9	66
		3	60	50.17	0.851	17.0	57
		4	50	47.38	0.880	18.6	64
		5	50	53.48	1.103	20.6	73
		6	50	53.77	1.045	19.4	73
		AVG	51.7	49.40	1.126	23.1	66
	CV	8	8	23	29	10	
	MR	1	50	45.90	0.987	21.5	63
		2	50	46.67	0.582	12.5	63
		3	50	52.44	1.523	29.0	71
		4	50	46.14	1.943	42.1	63
		5	50	39.43	0.581	14.7	54
		6	50	41.11	0.980	23.8	56
AVG		50	45.3	1.099	23.9	61	
CV	0	10	49	45	10		
Volcanic	AVG		50.8	47.4	1.110	23.5	64
		CV	6	10	36	36	10
	SS	1	50	48.2	1.152	23.9	69
		2	60	54.3	0.995	18.3	62
		3	50	53.9	1.475	27.3	74
		4	50	52.1	1.424	27.3	71
		5	50	58.5	1.973	33.7	80
		6	50	56.3	1.254	22.3	77
		AVG	51.7	53.9	1.379	25.5	72
	CV	8	7	25	21	9	
	WC	1	50	47.48	1.209	25.5	65
		2	50	45.52	1.089	23.9	62
		3	50	47.94	1.303	27.2	65
		4	50	46.90	1.280	27.3	64
5		50	53.12	1.419	26.7	73	
6		50	55.85	1.702	30.5	79	
AVG		50	49.5	1.334	26.8	72	
CV	0	8	16	8	10		
AVG		50.8	51.7	1.356	26.16	70	
CV		6	8	20	15	9	

SH – Secret Harbor
MR – Mount Rose
SS – Spooner Summit
WC – Ward Creek

Table 3 – Effective hydraulic conductivity for Lake Tahoe Basin specific locations and for generic WEPP recommendations.

Parent Material	n	Effective Hydraulic Conductivity (mm hr ⁻¹)	CV (%)	Nash-Sutcliff Range
Granitic-Lake Tahoe	12	9.3	40	0.994 to 0.790
Granitic-Generic	-	3.8	-	-
Volcanic-Tahoe	12	7.5	37	0.994 to 0.888
Volcanic-Generic	-	0.27	-	-

Table 4 – Water drop penetration time (WDTP) test results measured at four native surface road locations in the Lake Tahoe basin.

Parent Material	Location	WDPT (sec)	Water Repellency Class
Granitic	Mt. Rose	0 – 1	Wettable
	Secret Harbor	0 – 63	Wettable-strongly repellent
Volcanic	Spooner Summit	0-420	Wettable-strongly repellent
	Ward Creek	0-140	Wettable-strongly repellent

Table 5 – Interrill erodibility coefficient for Lake Tahoe Basin specific locations and for generic WEPP recommendations.

Parent Material	n	Interrill Erodibility Coefficient (kg s m ⁻⁴)	CV (%)	Range of percent error between observed and WEPP predicted (%)
Tahoe Granitic	12	2.2 x 10 ⁶	40	0.12 to -0.07
Generic Granitics	-	2.0 x 10 ⁶	-	-
Tahoe Volcanic	12	3.1 x 10 ⁶	62	0.66 to -0.16
Generic Volcanic	-	2.0 x 10 ⁶	-	-

Table 6 – Installation dates and precipitation for sediment boxes located at Spooner Summit and Blackwood Creek.

Location	Year	Installed	Removed	Precipitation	
				Total (in)	Max. Daily (in)
Spooner Summit	2007	July 14	Sept 19	0.9	0.3
	2008	June 8	Sept 23	0.1	0.1
	2009	June 9	Sept 25	0.1	0.1
Blackwood Creek	2007	July 15	Sept 20	2.1	0.4
	2008	June 9	Sept 24	0	0
	2009	June 10	Sept 26	0.7	0.4

Precipitation data for Spooner Summit taken from Marlette Lake Snotel site

Precipitation data for Blackwood Creek taken from Rubicon #2 Snotel site

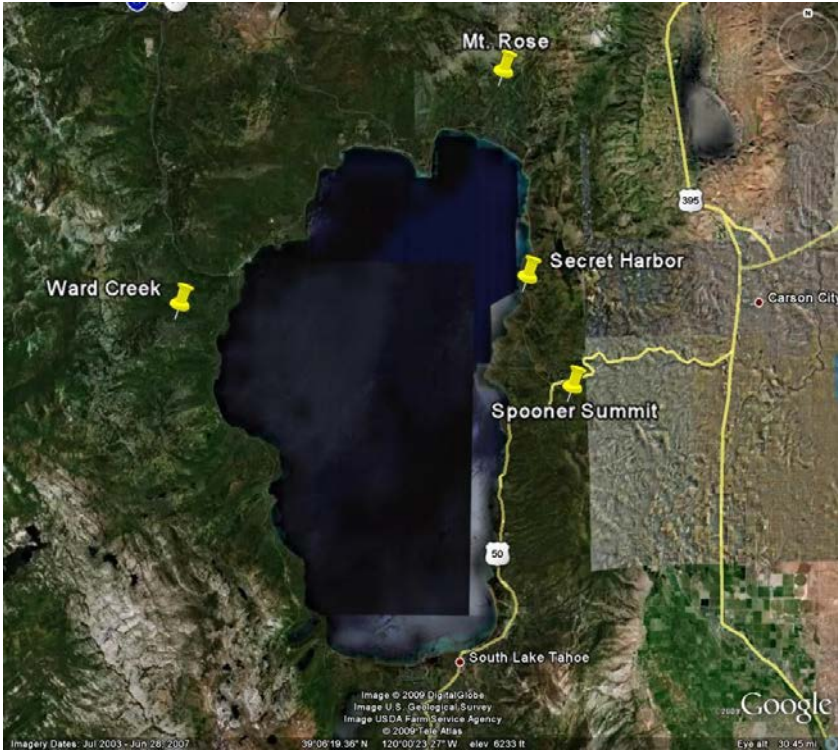


Figure 1. Location of four rainfall simulation sites in Lake Tahoe basin.

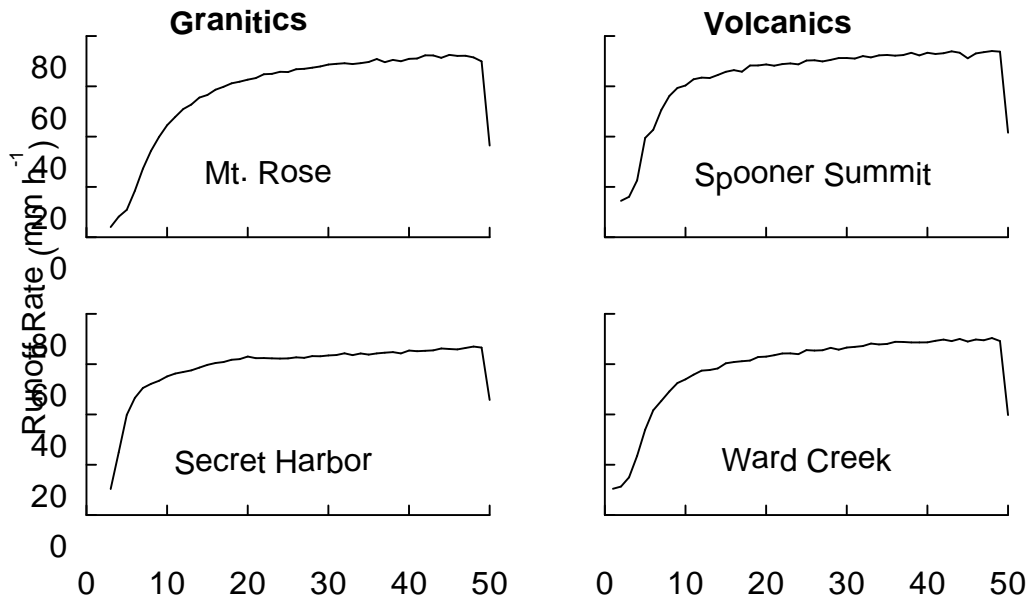


Figure 2. Composite hydrographs (n=6) during rainfall simulations at four Lake Tahoe locations.

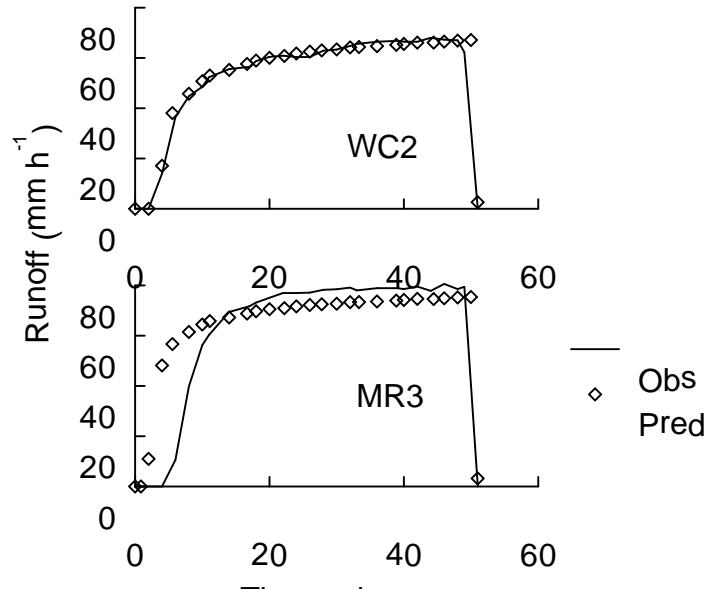


Figure 3. Observed and WEPP predicted hydrographs for highest Nash-Sutcliffe coefficient, 0.994 for Ward Creek 2 (WC2) and lowest Nash-Sutcliffe coefficient, 0.790 for Mt. Rose 3 (MR3).

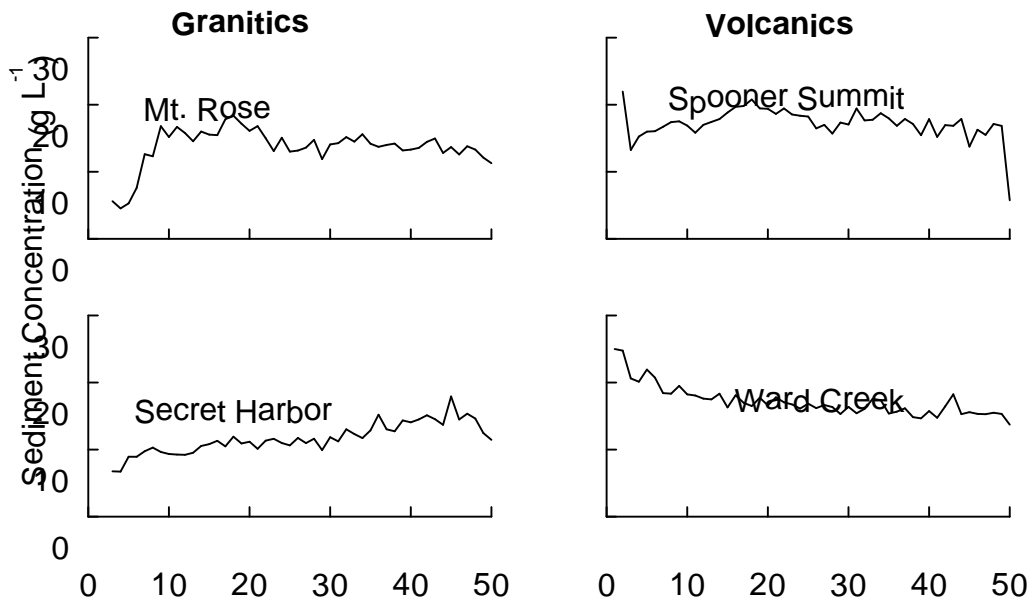


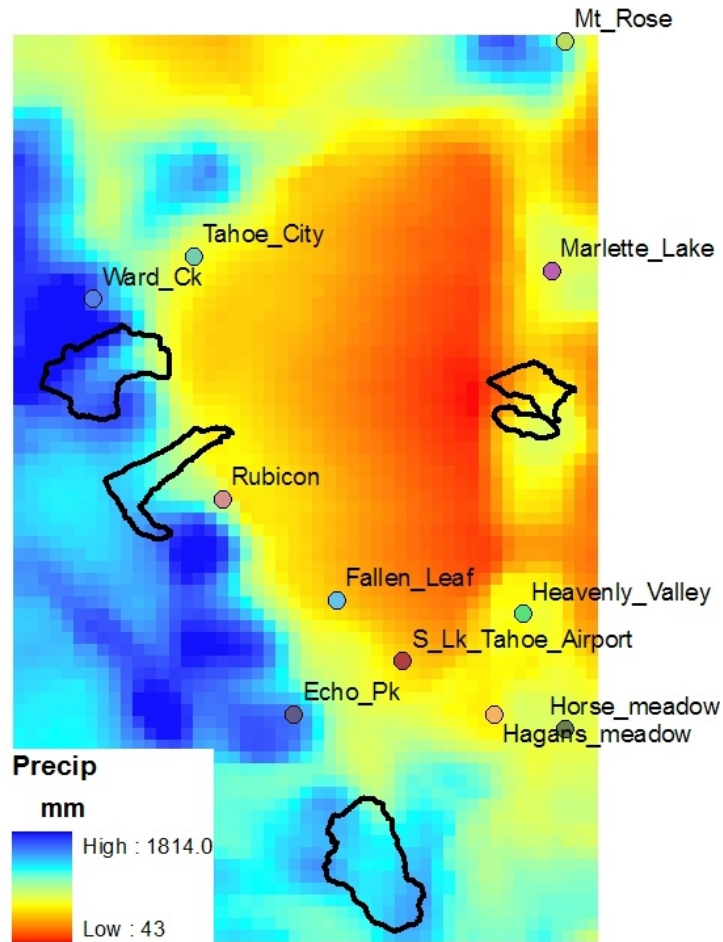
Figure 4. Sediment concentrations during rainfall simulations at four Lake Tahoe locations.

<h1>Tahoe Basin Sediment Model</h1>	
Air Water and Aquatic Environments Rocky Mountain Research Station, Moscow, Idaho 83843	& Department of Biological and Agricultural Engineering University of Idaho June, 2010

**Worksheet Developed for the Lake Tahoe Basin Sediment Model
Workshop**

June 16 – 17, 2010

**Tahoe Center for Environmental Sciences
Sierra Nevada College, Incline Village, Nevada**



Distribution of Precipitation and location of Snotel and weather station in Tahoe Basin
(Courtesy E. Brooks, Univ. of Idaho, Moscow)

W. Elliot, PE, PhdD, Research Engineer
Rocky Mountain Research Station
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Workshop supported with funding from the Southern Nevada Public Land Management Act, Rounds 7 and 10, U.S. Dept. of Agriculture Pacific Southwest and Rocky Mountain Research Stations, the University of Idaho and Em Consulting, Reno.

Online Interface Workshop

I. Find the Web Site: <http://forest.moscowfs1.wsu.edu/fswepp/>.

1. Select U.S. Customary units and enter your “personality” code.
2. Select the .
3. Ponder the interface.

II. Select the Desired Climate

1. Click .
2. Scroll to the bottom of the Region, select and Click .
3. Select and click .
4. Note the Rubicon Climate (seems a bit on the dry side), and in the upper right corner click the box.
5. Select the PRISM grid cell 2.5 miles north and click .
6. Click Adjust Temperature for Elevation by Lapse Rate.
7. Name the Climate “” and click .
8. Click .
9. Select from Climate List.
10. Specify years to simulate as (workshop only) and click .
11. At the bottom of the output screen, click .

III. Tahoe Interface for Roads

Basic Approach: Model likely current condition and compare to benefits from reducing traffic, outsloping the road, or paving.

A. Most Common surfaces, high traffic and rutted, insloped, or flat.

1. In Soil Texture Box, select .
2. For the upper element, select and for the lower element .
3. Specify the topography:

4%	200 ft
4%	
20%	50 ft
15%	

4. Click and fill in the first line in Table 1 on the next page.
- B. Low Traffic: Change to and
- C. Outsloped Road: Select , change upper length to , and (total area remains unchanged).

- D. Paved Road: Select **Rock/Pavement** in soil box, Change upper length to **200 ft**, **High Traffic Road** in Treatment and **Run WEPP** .
- E. Add Waterbar: Select **High Traffic Road**, **granitic** Soil, Upper length is **100 ft**, (Assume area remains unchanged).

Table 1. Results of Road Erosion Runs

Climate Station: _____ Annual Precip: _____ in.
 Road Length: _____ ft Road Width: 14 ft Area: _____ Acres
 Buffer Length: _____ ft Buffer Width: 14 ft Area: _____ Acres
 (43,560 Square feet = 1 Acre)
 Road + Buffer Area: _____ Acres

Road Surface	Runoff (inches)			Road Erosion Rate	Road + Buffer Delivery Rate	Delivery from buffer
	Rain	Snow	Total	(tons/acre)	(Tons/acre)	Tons

Questions?

IV. Tahoe Interface for Fuel Management

Basic Approach: Estimate “background” sediment from undisturbed forest and wildfire; Compare background to erosion associated with thinning and prescribed fire.

A. Undisturbed Forest Erosion:

1. Select climate **N of Rubicon** and soil **granitic** .
2. Specify upper and lower treatments to be **Mature Forest** .
3. Specify Slope to be:

20%	300 ft
30%	100 ft

4. **Run WEPP** and enter sediment delivery into Table 2 (Columns (1) and (5)).

B. Wildfire before treatment:

1. Change upper treatment to **High severity fire** **30** percent cover and lower treatment to **Low severity fire** **50** percent cover.

2. Run WEPP and enter sediment delivery into Table 2 (column (1)).
- C. Calculate “background” sediment budget:
1. Divide the erosion in column (1) by the return interval in column (2) and enter the results in column (3).
 2. Sum up the two average annual values in column (3) to get the background sediment delivery rate.
- D. Estimate the sediment generated by thinning and prescribed fire:
1. For thinning, Upper treatment: select **Thin or young forest** and set the cover to **85** percent and the Lower treatment to **Mature forest** leaving the default cover at **100** percent.
 2. Run WEPP and enter the sediment delivery in Table 2, column 5.
 3. For prescribed fire, Upper tmt: select **Low severity fire** and leave the default cover at **85** percent and the Lower treatment as **Mature forest** with **100** percent cover.
 4. Run WEPP and enter the sediment delivery in Table 2, column (5).
- E. Estimate the sediment generated by wildfire following fuel treatment:
1. Set the upper treatment to **High severity fire**, **40** percent cover and the Lower treatment to **Low severity fire**, **70** percent cover.
 2. Run WEPP and enter the sediment delivery in Table 2, column (5).
- F. Calculate the “Treated” sediment budget:
1. Divide the erosion in column (5) by the return interval in column (6) and enter the results in column (7).
 2. Sum up the four average annual values in column (7) to get the average annual treated sediment delivery rate.
 3. Discuss the background versus the treated sediment delivery. The extra sediment from roads, if any, may also need to be considered (low traffic roads become high?)

Table 2. Summary of Erosion Analysis for Fuel Management

<i>Column:</i>	(1)	(2)	(3)	(4)	(5)	(6)	(7)
No Treatment	Sed Delivery (t/a)	Return Interval (years)	Annual Average (t/a/yr)	Treated	Sed Delivery (t/a)	Return Interval (years)	Annual Average (t/a/yr)
Forest		1		Forest		1	
				Thinning		20	
				Rx Fire		20	
Wildfire		40		Wildfire		50	
Background sediment delivery rate:				Treated sediment delivery rate:			

Questions?

V. Tahoe Interface for Mitigating Bare Areas (Ski Slopes, road cuts, etc.)

Basic Approach: Estimate “untreated” sediment from site with no or low cover.

Compare untreated to treatment scenarios (mulching, incorporate residue (tillage), and shortening slope with a water bar). For ski slopes, generally use “sod grass” rather than “bare.”

A. Current condition:

1. Select climate and soil .
2. Specify upper and lower treatments to be , percent rock.
3. Specify Slope to be

30%	50 ft
30%	50 ft
30%	50 ft
20%	50 ft

4. and enter average runoff, erosion and sediment delivery, and 10-year return period sediment delivery into table 3.

B. Mulching treatment:

1. Change upper and lower treatments to percent cover.
2. and enter average runoff, erosion and sediment delivery, and 10-year return period sediment delivery into table 3.

C. Mulch and tillage treatment:

1. Change upper and lower treatments to percent cover.
2. and enter average runoff, erosion and sediment delivery, and 10-year return period sediment delivery into table 3.

D. Waterbar only, no mulch:

1. Change upper treatment to percent rock, and lower treatment to percent cover.
2. and enter average runoff, erosion and sediment delivery, and 10-year return period sediment delivery into table 3.

E. Discuss results: costs, life of treatment, feasibility of treatment, local considerations...

Table 3. Erosion associated with mitigation bare areas

Treatment	Runoff (in.)	Erosion Rate (t/a)	Sed Delivery (t/a)	10-yr Sediment Deliver	Cost (\$) and/or Life of Tmt
Bare					
Surface Mulched					
Incorporate Mulch					

Water Bar					
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Questions?

VI. Estimating the amount of fine sediment delivered from a hillslope

Basic Approach: At the end of the run, look at the end of the annual detailed output file to calculate the amount of clay (or clay plus part of the silt) in the runoff. Clay size particles and aggregates are assumed to be less than 4 microns in diameter. Silt is generally between 4 and 62.5 microns diameter. (1,000 microns = 1 mm)

1. Rerun the previous run of Bare + buffer.
2. Enter the delivered sediment into Table 4, line 9.
3. At the bottom of the output page, click annual detailed.
4. At the bottom of the annual detailed summary file, study the **Sediment Characteristics and Enrichment** table.
5. Enter the information requested from the **Sediment Characteristics and Enrichment** output into Table 4, columns (1) and (2).

Table 4. Fraction of Delivered Sediment that is clay (less than 4 micron dia)

Column:	(1)	(2)	(3)
Class	Percent Clay	Fraction in Flow Exiting	Percent Clay in Class
1			
2	0.0		
3			
4			
5	0.0		
Total Clay in delivered sediment:			Percent
Sediment Delivered:			Tons/acre
Total Clay Delivered (Percent Clay x delivered sediment)			Tons/acre Lbs./acre

6. Multiply columns (1) and (2) to get the total percent of clay in each class.
7. Add up the clay percentage in the 5 classes and enter the total in Table 4.
8. Multiply the percent clay in the delivered sediment by the amount of sediment delivered and enter the value in the last box in both tons/acre and pounds per acre (1 ton has 2000 lbs).
9. The same can be done for the fraction of silt of interest, for example, if interested in silt between 4 microns and 10 microns, this is $(10-4)/(62.5-4)$ or about a tenth of the delivered silt fraction. Additional data about the fraction of silt in this

category may be available from previous studies. (Beyond the scope of this project.)

Questions?
