Modeling Report: Lake Tahoe Fuels Reduction Strategy

Internal Review Draft for Phase I & II
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Prepared for:

Lahontan Regional
Water Quality Control Board
2501 Lake Tahoe Blvd.
South Lake Tahoe, CA 96150

U.S. Environmental Protection Agency
Region 9
75 Hawthorne St.
San Francisco, CA 94105

Prepared by:

Tetra Tech, Inc.
10306 Eaton Place, Suite 340
Fairfax, VA 22031

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1. Introduction

Lake Tahoe is a designated Outstanding National Resource Waterbody; however, the lake has lost about 30 feet of clarity depth since the late 1960s, with fine sediment- and nutrient-driven algae production as the primary stressors. In response, a detailed watershed model (Lake Tahoe Watershed Model) was developed to represent the unique orography and hydrology of the Lake Tahoe Basin, predict sediment loads by land use source, and calculate total maximum daily load (TMDL) allocations (Tetra Tech 2007). The Lake TahoeTMDL identifies the major factors driving increased sediment loads to the lake including land disturbance, an increasing resident and tourist population, habitat destruction, air pollution, soil erosion, roads and road maintenance, and loss of the natural landscape's ability to detain and infiltrate rainfall runoff (LRWQCB & NDEP 2010).

Since the Lake Tahoe TMDL development, the Lake Tahoe Basin Multi-Jurisdictional Fuel Reduction and Wildfire Prevention Strategy (Fuel Reduction Strategy) has been developed to mitigate potential future damage from extreme forest fires like the Angora fire of 2007. The Fuel Reduction Strategy proposes 49,000 acres of first-entry vegetative fuels treatments and 19,000 acres of maintenance treatments across multiple jurisdictions to create Community Defensible Space (USDA 2007). Those fuel reduction treatments would be in lands managed by the United States Forest Service (USFS), Lake Tahoe Basin Management Unit (LTBMU), and other land management agencies in California and Nevada. In addition, the USFS plans to construct new roads that would provide easier access through key segments of its managed lands. While actions associated with fuel reduction represent new disturbances in the Tahoe Basin that might cause increased erosional sediment loading, they also serve as insurance against a catastrophic forest fire.

In consideration of the existing Lake Tahoe TMDL, the Fuel Reduction Strategy's possible effects were evaluated to determine the potential implications on the established TMDL baseline sediment load to the lake (LRWQCB & NDEP 2010). That evaluation used an extensive set of analytical tools and scaled sediment erosion and transport modeling and included the following:

- Geographic information system (GIS) analysis to locate existing and planned fuel reduction treatments and new forest roads
- A set of *management categories* (or potential impact categories) that spatially represent the physical land characteristics (slope and soil type) governing the potential impact of fuel reduction treatments on annual sediment erosion around the basin
- Site-scale modeling using the Tahoe Basin Sediment Model (TBSM), an online version of the Water Erosion Prediction Project (WEPP) customized for the Lake Tahoe Basin, to quantify the relative change in annual sediment loading from application of fuel reduction treatments and roads
- A basinwide extrapolation of site-scale modeling scenarios to the Lake Tahoe Watershed Model to estimate the relative change in both total and fine sediment loading to Lake Tahoe from the 2004 TMDL baseline. This extrapolation makes the following general assumptions:
    - Predicted changes in loading are relative to the 2004 TMDL baseline established using the Lake Tahoe Watershed Model (Tetra Tech 2007, LRWQCB & NDEP 2010)
    - All fuel reduction treatments proposed in the Fuel Reduction Strategy occur at a single point in time, the effects of which are modeled over the same time period (i.e. meteorological conditions) as the TMDL baseline model run.

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2. Fuel Reduction Projects

GIS shapefiles of proposed fuel reduction projects in the Lake Tahoe Basin that were made available by the USFS LTBMU were developed as part of the Fuel Reduction Strategy. The data represent a collaborative effort of multiple agencies working in the basin, including the LTBMU, Tahoe Regional Planning Agency, California Department of Forestry and Fire Protection, Nevada Division of Forestry, California Tahoe Conservancy, California State Parks, local fire protection districts, and the city of South Lake Tahoe (USDA 2007). Available GIS data sets include the basinwide Fuel Reduction Strategy and two related projects planned for the South Shore and Carnelian areas of the basin.

2.1. Summary of Fuel Reduction Treatments

The Fuel Reduction Strategy proposes project areas for implementing fuel reduction treatments to mitigate potential future damage from forest fires in the Lake Tahoe Basin. It lays out general fuel reduction project areas on a basinwide scale, while the South Shore and Carnelian projects represent implementation of the strategy at the jurisdictional level. Collaboration with EPA and the Lahontan Regional Water Quality Control Board (Regional Board) identified the following three fuel reduction treatments that will be applied as part of the Fuel Reduction Strategy.

- *Whole tree skidding* (WTS)—Trees are felled and dragged from the butt end to a landing for processing, sorting, and removal. This treatment requires a road or skid trail network and has the greatest potential to cause disturbance. Landings for this prescription are large enough for log decks, residual slash, processing equipment, and log truck operations. Residual biomass from WTS is either burned in very large piles or chipped and removed,
- *Cut-to-length* (CTL)—Machinery on tracks or balloon tires uses mechanical arms to cut trees and remove limbs. Limbed material is left in place and provides a surface upon which the equipment operates, further lessening ground disturbance related to equipment impacts. Tree boles are then cut to a specified length and placed on a pile. A forwarder picks up the stacked trees and limbs, which are then removed. This treatment increases ground cover, reduces soil compaction during the removal process, and lessens the number of equipment trips to remove the tree boles to a landing location. It does not require skid trails and can be done on up to 30 percent slopes.
- *Hand crew/hand thinning* (HC)—Trees and limbs are cut by hand with chainsaws, usually generating pieces that can be handled by one or two people, generally less than 10–15 feet long. Typically the material spills on the floor, which is then piled and allowed to cure prior to being burned in place. The greatest impact of this treatment is caused by burning the cured piles.

Chipping and mastication typically follow other treatments like WTS and CTL. Both tend to leave a lot of chipped material behind, which increases ground cover without creating much disturbance on the ground. Tahoe Basin fire districts have used low ground pressure chippers in conjunction with hand crew operations to treat areas that have excessive fuel loading issues.

2.2. Fuel Reduction Strategy

The Fuel Reduction Strategy proposes 49,000 acres of first-entry fuel reduction treatments and 19,000 acres of maintenance treatments across multiple jurisdictions in the Lake Tahoe Basin. The proposed projects in this plan provide a 10-year strategy to reduce the risk of uncharacteristic, extreme wildfire.

The plan's purpose is to propose projects to create Community Defensible Space, to comprehensively display all proposed fuel reduction treatments, and to facilitate communication and cooperation among those responsible for plan implementation (USDA 2007).

Though the Fuel Reduction Strategy plans fuel reduction projects throughout the basin, it does not specify what type of fuel reduction treatments will be used in those areas. Treatments are planned and implemented at the project level, as is the case for the South Shore and Carnelian projects. A map of the Fuel Reduction Strategy-proposed project areas is presented in Figure 2-1. Note that some of the treatment areas fall outside the extent of the Lake Tahoe Watershed Model boundaries and are therefore not represented in the watershed-scale simulation results.

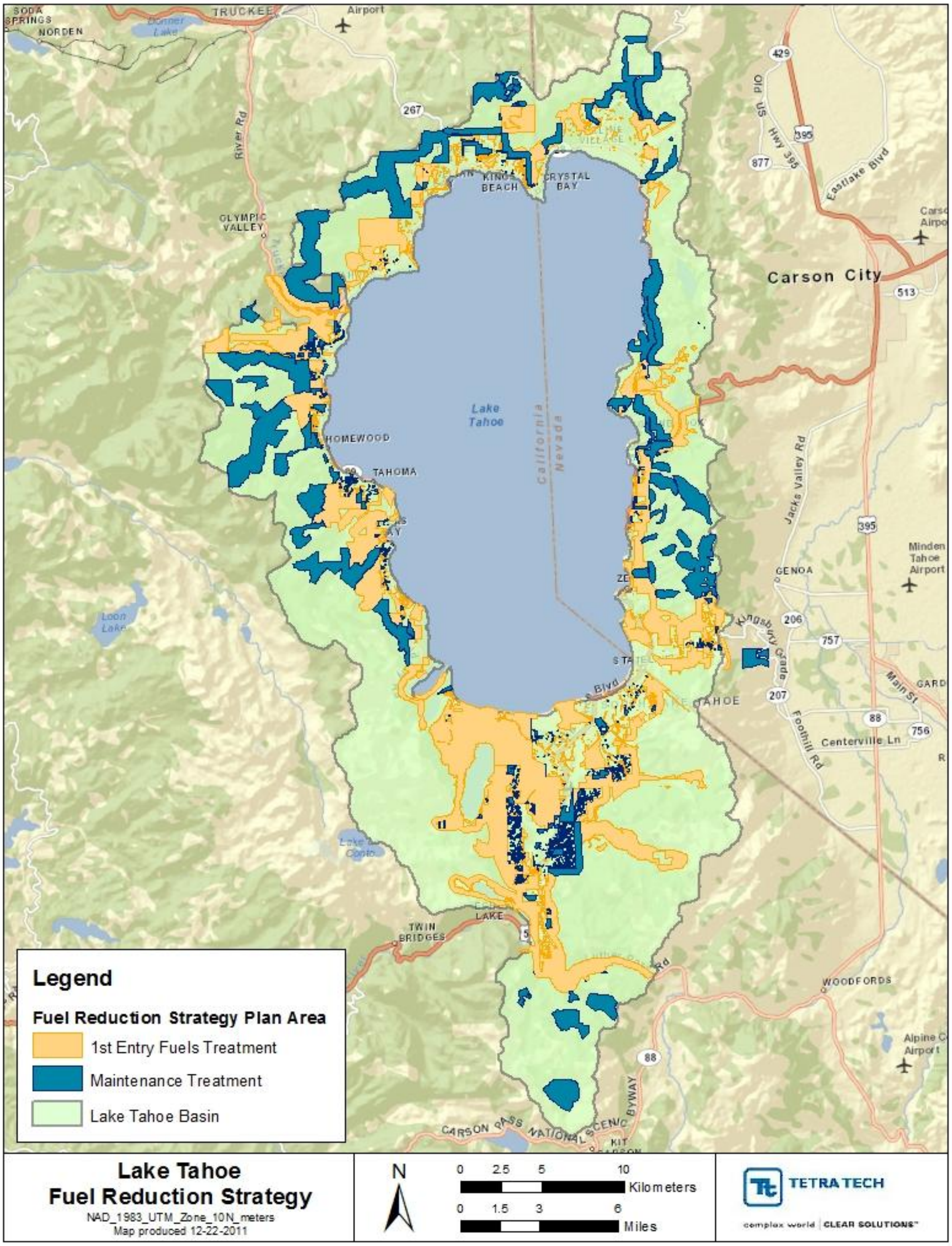

Figure 2-1. Lake Tahoe Fuel Reduction Strategy.

2.3. South Shore and Carnelian Fuel Management Projects

Fuel reduction projects are planned to create defensible space around developed areas in the wild land-urban interface. The South Shore and Carnelian projects represent jurisdiction-level implementation of the Fuel Reduction Strategy by the USFS LTBMU. These projects are generally representative of USFS fuel reduction projects that account for roughly 85 percent of all projects planned for the Lake Tahoe Basin (USDA 2007) (Figure 2-2).

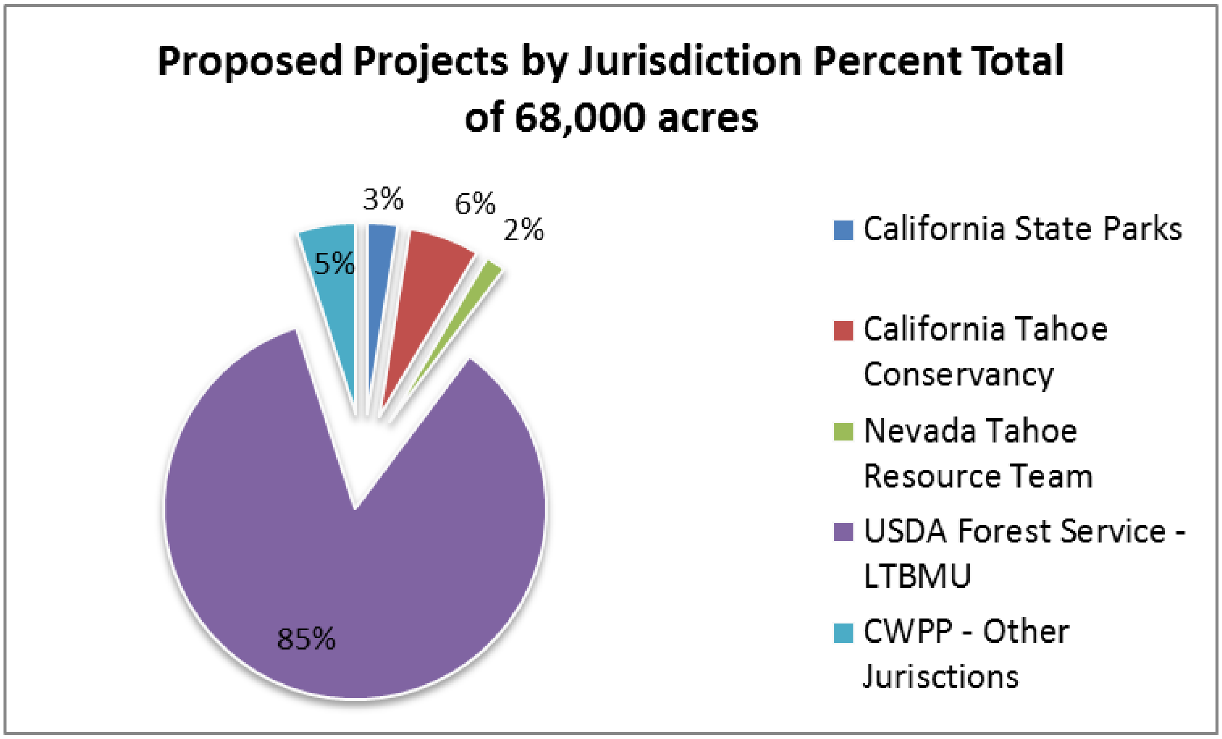

Figure 2-2. Percent of fuel reduction projects by jurisdiction.

The South Shore fuel reduction project is one of the first, and likely the largest, project pending in the basin as part of the Fuel Reduction Strategy. It includes just over 10,000 acres of planned fuel reduction treatments. Similarly, the Carnelian project is one of the larger in the basin, targeting approximately 3,300 acres of forest for fuel reduction treatment. At the current stage of planning, the South Shore project specifies fuel reduction treatments in more detail than the Carnelian. Treatments in the South Shore area have been defined as WTS, CTL, or HC. Treatments in the Carnelian area are defined more generally and include hand thinning and mechanical treatment, which can include both CTL and WTS. Figure 2-3 maps the spatial extent of fuel reduction treatments proposed as part of these projects.

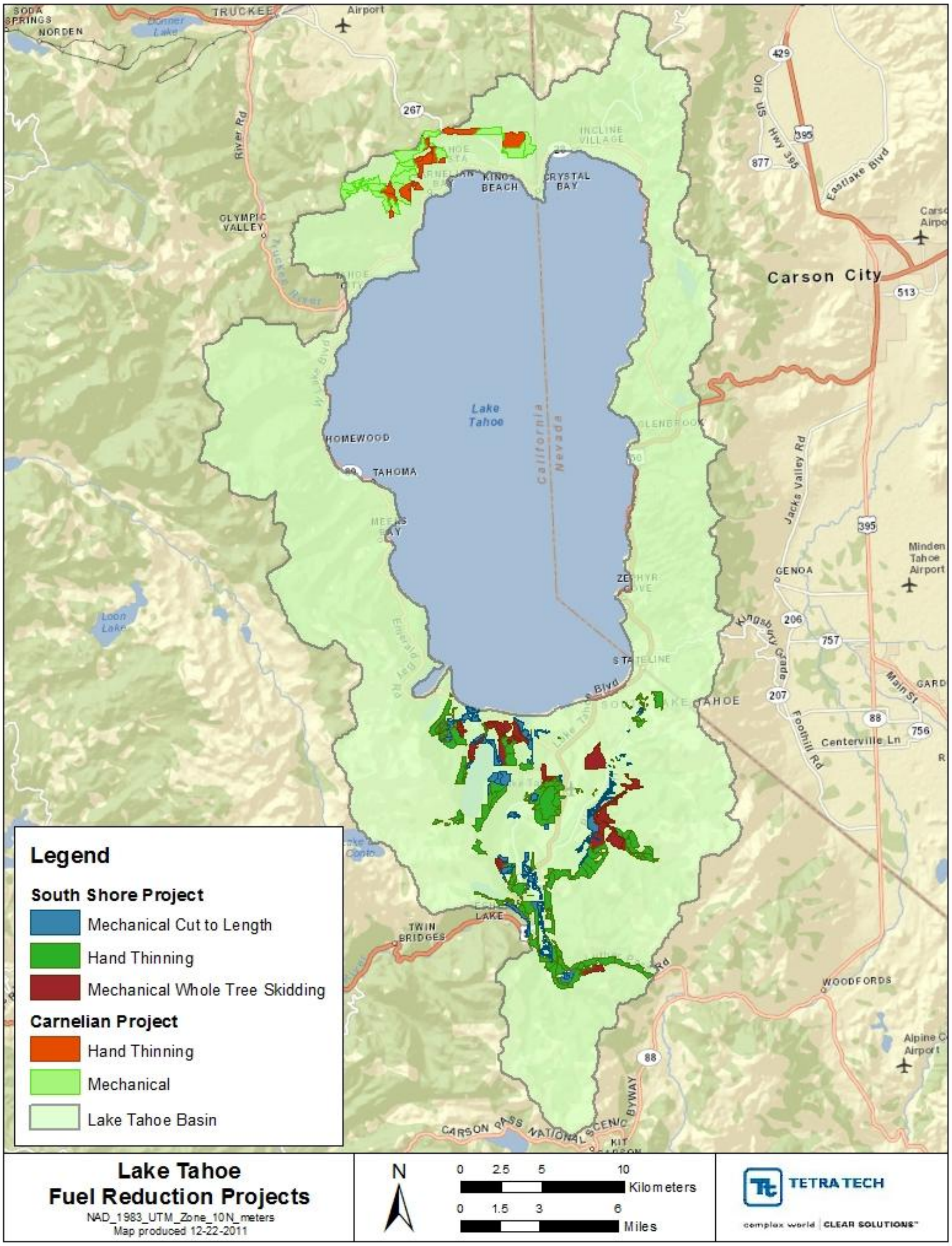

Figure 2-3. Proposed fuel reduction treatments for the South Shore and Carnelian projects.

2.4. Project Forest Roads

USFS roads are used to gain access to forest lands for fuel reduction treatments. These types of roads are typically unpaved and might support some grass or shrub cover, especially during periods of inactivity. Even so, the creation or maintenance of these roads has the potential to contribute additional sediment loading by reducing ground cover, compacting soils, and creating preferential flow paths for rainfall runoff.

In support of the proposed fuel reduction treatments, additional USFS roads will need to be established or reactivated. As discussed in Section 4.5, the impact of USFS roads will be considered when evaluating the impacts of fuel reduction treatments. GIS data of USFS roads are available for the South Shore project as presented in Figure 2-4. Approximately 24 miles of road are associated with the project area, with lengths of 15 and 4 miles defined as maintenance and reconstruction, respectively. These data were used to characterize the road densities associated with fuel reduction treatments as discussed in Section 5.

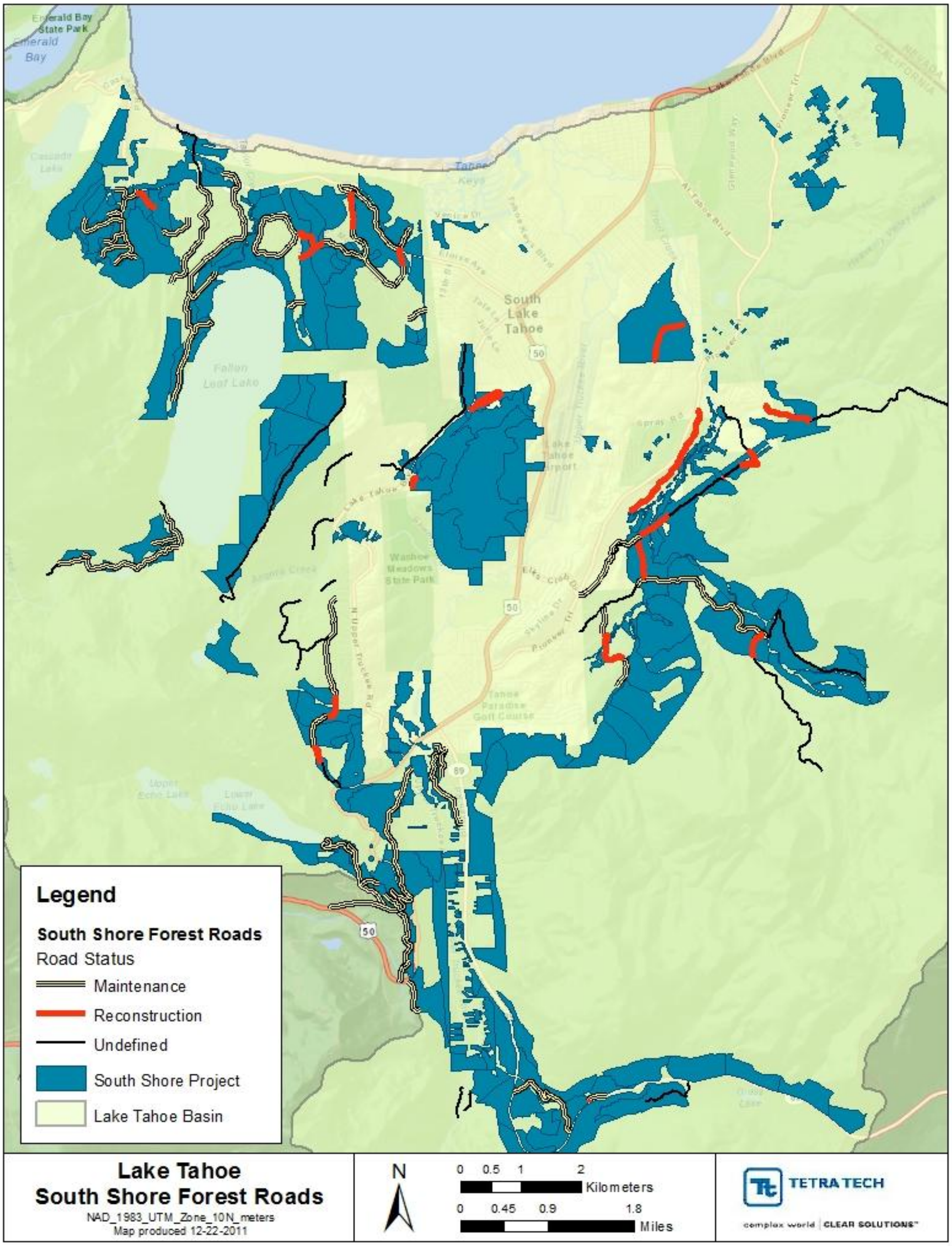

Figure 2-4. South Shore project forest roads.

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3. Development of Management Categories

Many factors influence the way land responds to a fuel reduction treatment, including geological characteristics of the landscape, weather, and ground cover. Some factors are more influential than others and can be spatially mapped in the watershed. Those influential factors can be used as a basis for disaggregating and categorizing the watershed into areas that respond similarly to similar actions (i.e. Management Categories) to better understand the degrees to which they influence hydrology and sediment loading response. For example, fuel reduction treatments on steep slopes in high precipitation areas would be expected to exhibit a markedly different response than the exact same treatments performed on either steep or moderate sloped areas in low precipitation areas. Likewise, soil erodibility, which also varies spatially, would influence how the land responds to treatment.

In addition, management categories will be mapped to spatial features of the existing Lake Tahoe Watershed Model used to develop the TMDL. Besides land cover and precipitation, soil type and slope are two of the most sensitive variables that affect the potential erodibility of an area. Rainfall, soil type, and slope considerations make up four of the six factors of the Revised Universal Soil Loss Equation (Renard et al. 1997). Because climate variability (i.e., precipitation) is already represented in the watershed model, management categories were developed to capture the variability of physiographic factors of soil type and slope. That analysis used readily available GIS data sets to derive the management categories for easy integration with subsequent efforts, including site-scale modeling and basinwide extrapolation.

3.1. Slope

Slope values were grouped into three ranges representing low (0–9 percent), medium (10–29 percent), and high (> 30 percent) erosion potential. The thresholds for separating slope categories were based on typical intervals associated with zoning and land management. To determine slopes throughout the Tahoe Basin, 30-meter digital elevation model (DEM) layer developed by USGS (2009) was transformed into percent slope values. The 30-meter DEM layer was used to maintain consistency with the Lake Tahoe Watershed Model. Figure 3-1 shows slopes throughout the basin.

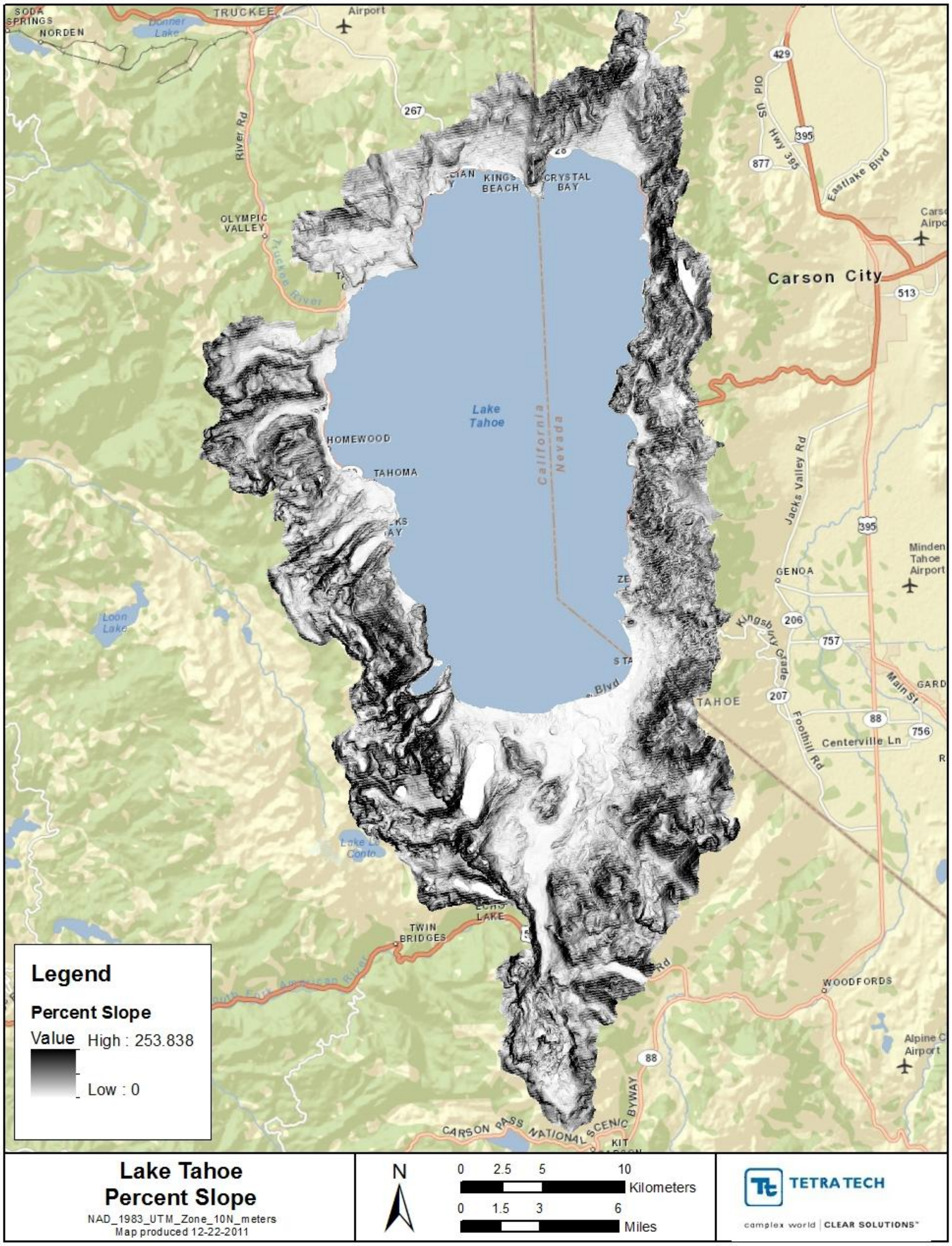

Figure 3-1. Lake Tahoe Basin percent slope (data from USGS 2009).

3.2. Soil

The management soil types were selected on the basis of soils included in the TBSM (discussed in Section 4.2), which include granitic, volcanic, and alluvial soils (Elliot and Hall 2010). Soils data available through the Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) database were used to categorize the parent material of soils in the basin according to the categories included in the TBSM. NRCS has established three soil geographic databases, with the SSURGO database providing the most detailed level of information. Data available in SSURGO were designed primarily for site-scale natural resource planning and management.

The parent material of soils was determined by comparing the soil map unit IDs to associated soil descriptions in a soil survey report for the Tahoe Basin (NRCS 2007). Soil types grouped according to the TBSM classifications are presented in Figure 3-2. Granitic and volcanic soil types dominate the basin. Alluvial soils make up a much smaller fraction, but areas of organic and beach sand soils are so small they are considered negligible and are generally outside the management domain. The till-mixed soils are analogous to alluvial-mixed soils.

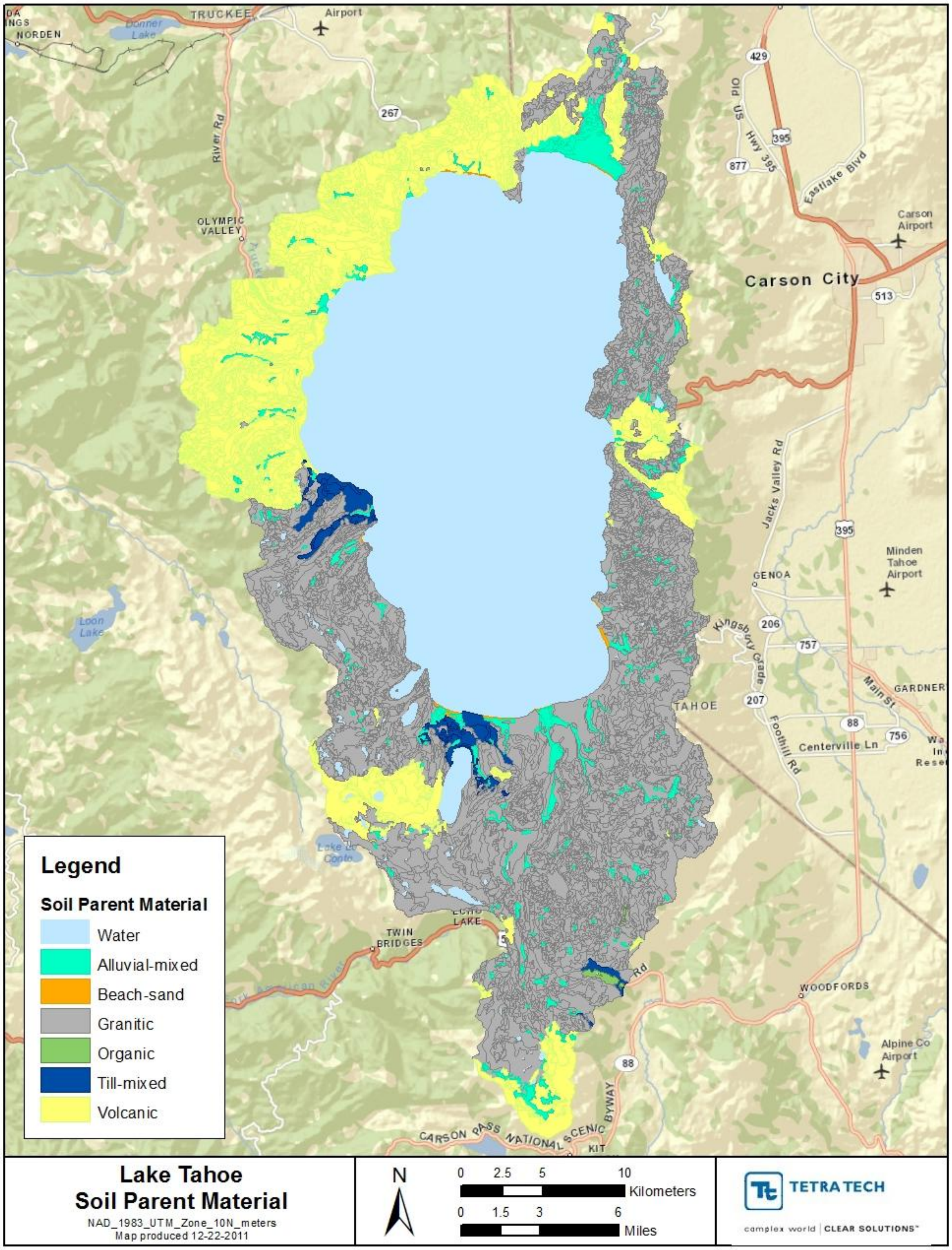

Figure 3-2. Lake Tahoe Basin soil parent materials (data from NRCS 2007).

3.3. Management Categories

Precipitation varies spatially throughout the Lake Tahoe Basin. Annual average precipitation totals on the western side of the lake are often double those on the eastern side, and the influence of elevation affects the volume of precipitation and the distribution of form (rain versus snow).

Within the context of this modeling effort, the effects of climate (i.e., precipitation) are represented by 12 climate stations in the Lake Tahoe Watershed Model. Because the model is configured to account for spatially variable climate trends, precipitation was intentionally excluded from the final set of management categories. Table 3-1 presents a nine management category matrix of soil type and slope. The way an area of the same management category manifests its sediment load will vary spatially in the model as precipitation varies.

Table 3-1. Matrix of management categories

Management matrix		Soil type		
		Granitic	Volcanic	Alluvial
Slope	Low (0%–9%)	Granitic Low Slope	Volcanic Low Slope	Alluvial Low Slope
	Med (10%–29%)	Granitic Medium Slope	Volcanic Medium Slope	Alluvial Medium Slope
	High (> 30%)	Granitic High Slope	Volcanic High Slope	Alluvial High Slope

The management categories provide a spatially organized framework through which modeling results can be consistently evaluated. The categories are also based on physical attributes that are common to both the site-scale model and the watershed model, which is integral for basinwide extrapolation. These include soil types consistent with the TBSM and elements of the Erosion Potential classification developed as part of the *Lake Tahoe Basin Framework Implementation Study* used in the Lake Tahoe Watershed Model (Simon et al. 2003).

The GIS data sets for slope and soil type presented in Figure 3-1 and Figure 3-2 were merged to produce a new dataset representing the spatial distribution of the management categories proposed in Table 3-1. Table 3-2 is a summary of area distribution by management category, with other soil types including beach-sand and organic. A map showing the final soil-slope combinations, representing the management categories, is shown in Figure 3-3.

Table 3-2. Area distribution by management category

Management category		Area (acres)	Percent (%)
Soil type	Slope		
Granitic	Low (0%–9%)	15,767	7.8%
	Med (10%–29%)	51,453	25.5%
	High (> 30%)	59,356	29.4%
Volcanic	Low (0%–9%)	7,844	3.9%
	Med (10%–29%)	28,426	14.1%
	High (> 30%)	24,511	12.1%
Alluvial	Low (0%–9%)	10,513	5.2%
	Med (10%–29%)	3,143	1.6%
	High (> 30%)	416	0.2%
Other		530	0.3%

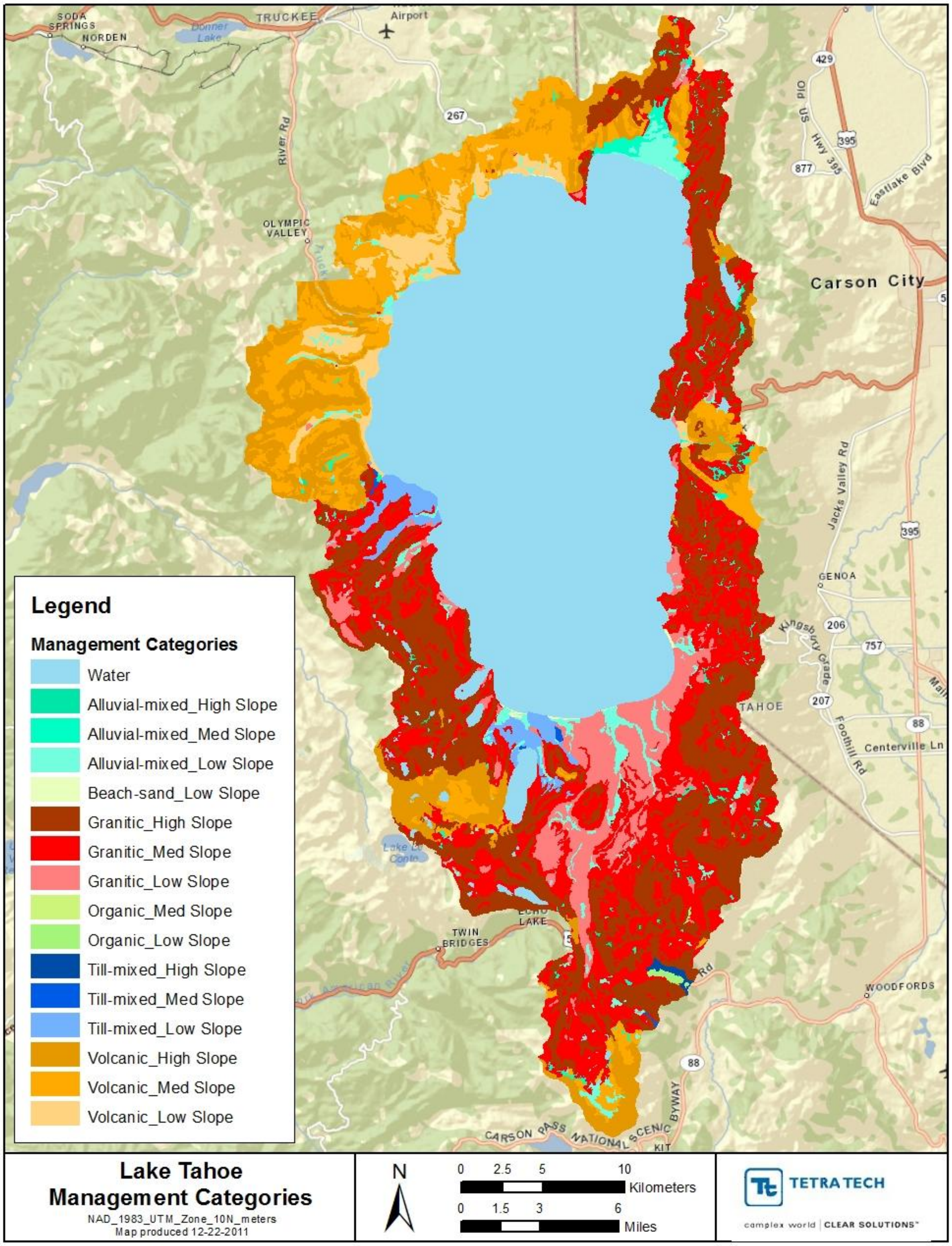

Figure 3-3. Lake Tahoe Basin fuel reduction plan management categories.

4. Site-Scale Modeling

Site-scale modeling allows for the simulation of sediment loading impacts from fuel reduction projects at the treatment level. Site-scale model results can then be extrapolated to assess impacts on a larger scale. Existing site-scale modeling reports were reviewed to determine if available simulation results could be used to represent the impact of fuel reduction treatments around the Lake Tahoe Basin. LTBMU completed three site-scale modeling reports for the Heavenly Creek, Ward Unit 5, and Roundhill fuel reduction projects, which were available at the time this report was written. To bolster the weight of evidence of the modeling results, those reports were used to inform the parameterization of additional site-scale models developed using the USFS online WEPP interface tools. Both the TBSM and WEPP FuME tools were evaluated as potential platforms for site-scale model development.

The TBSM online WEPP interface was selected as the modeling platform because of its direct applicability to the Lake Tahoe Basin and consistent representation with physical features such as soils. Full documentation of the model selection process is in Appendix A. Site-scale WEPP models were developed using the TBSM for each combination of fuel reduction treatment and management category. That approach provided a basis for mapping the management categories to the existing land cover categories included in the Lake Tahoe Watershed Model, thus linking them. In this way, the site-scale simulated impacts of fuel reduction treatments on each management category give a numerical basis to investigate the potential implications on Lake Tahoe Watershed Model baseline loads.

4.1. Local WEPP Modeling Reports

The Ward Unit 5, Heavenly Creek fuel, and Roundhill fuel reduction projects each assessed the implementation of fuel reductions treatments on forested lands. All three projects used site monitoring data to inform the development of site-scale WEPP models to examine the impact of the treatments being implemented.

The Ward Unit 5 fuel reduction project implemented the CTL treatment with low ground pressure machinery to minimize disturbance of surround vegetation and soils. The project involved pre- and post-disturbance monitoring at 67 locations throughout the project area measuring (1) percent canopy cover, (2) percent ground cover, and (3) saturated hydraulic conductivity (Elliot and Hall 2010). The sample locations were selected to capture a representative range of conditions from undisturbed forest, roads, landings and disturbed areas where the CTL treatment was used.

The Heavenly Creek modeling report included similar monitoring activities at 143 pre-project sites and 69 post-project sites identified by visible equipment tracks (LTBMU 2008). The actual treatments used at the post-project sites were not documented, however. A wildfire in December 2002 also allowed monitoring at sites with both burned and unburned conditions.

The Roundhill Fuels Reduction Project again included a field monitoring plan that detailed the collection of soil and cover characteristics for two project areas using whole-tree forwarding fuel reduction treatment. Whole-tree forwarding uses equipment comparable to the CTL treatment (LTBMU 2011). It should be noted that whole-tree forwarding does not operate on the slash mat that is the norm for CTL treatments, and the number of equipment passes to remove cut trees is greater than what would be expected under a conventional CTL prescription.

Site-scale WEPP models were developed for several hillslopes at each project site. The WEPP models were set up using a mature coniferous forest cover type, sandy loam soil, and default model parameter in conjunction with the field verified values. The three tables below present key parameters of interest used for the Ward Unit 5 (Table 4-1), Heavenly Creek (Table 4-2), and Roundhill Fuel Reduction (Table 4-3) WEPP modeling.

Table 4-1. Parameters used in the Ward Unit 5 site-scale WEPP model application

Site description	Treatment condition	Canopy cover (%)	Ground cover (%)	Keff (in/hr)
Forest	Pre-Project	75%	100%	6.33
	Post-Project	50%	100%	4.74
Road	Pre-Project	75%	85%	3.12
	Post-Project	50%	43%	2.94

Source: LTBMU 2007

Table 4-2. Parameters used in the Heavenly Creek site-scale WEPP model application

Site description	Treatment condition	Canopy cover (%)	Ground cover (%)	Keff (in/hr)
Burned	Pre-Project	40%	100%	5.55
	Post-Project	40%	85%	2.4
Unburned	Pre-Project	25%	100%	5.55
	Post-Project	10%	85%	2.4

Source: LTBMU 2008

Table 4-3. Parameters used in the Roundhill site-scale WEPP model application

Site description	Treatment condition	Canopy cover (%)	Ground cover (%)	Keff (in/hr)
Forest	Pre-Project	60%	100%	5.43
	Post-Project	30%	95%	2.08

Source: LTBMU 2011

Evaluation of results for the Ward Unit 5 models shows an increase in average annual sediment yield of 0.1 ton/acre (LTBMU 2007). Conversely, the Heavenly Creek and Roundhill models predicted no impact on the annual average sediment yield from pre-project to post-project conditions and indicated that the estimated sediment yield from project areas was less than 0.001 ton/acre (LTBMU 2008, 2011). The values in Table 4-1 through Table 4-3 were used to derive a set of parameters for site-scale TBSM of the three fuel reduction treatments applicable to the Fuel Reduction Strategy as described in the following sections.

4.2. Tahoe Basin Sediment Model

The TBSM is a publicly available, customized Web application interface for the WEPP model designed specifically for applications in the Lake Tahoe Basin. The functional unit used for modeling hillslopes in the TBSM is an overland flow element (OFE). While the WEPP Windows application allows the user to define the exact number of OFEs, the TBSM divides a hillslope into exactly 2 elements. A schematic representation of the TBSM hillslope is presented in Figure 4-1. Each element can be used to represent an area of specific land cover, such as forest cover or road, from which upland erosion can occur. Upland erosion can occur on both elements, but eroded sediment can be stranded on either element, preventing it from leaving the hillslope profile.

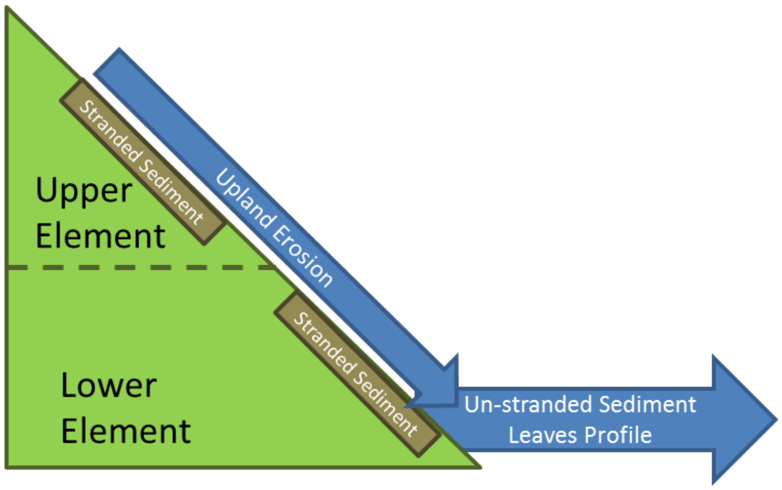

Figure 4-1. Schematic of hillslope configuration in the TBSM.

The TBSM further streamlines the modeling process by incorporating a set of soil parameters, land cover, and climate files specific for the Lake Tahoe Basin. Users are only asked to specify (1) soil type, (2) land cover, (3) slope, (4) horizontal length, (5) percent cover (6) percent rock, and (7) number of simulation years. Based on these parameters, the interface will create of a series of input files used by a back-end system to run the WEPP executable file.

The TBSM performs WEPP simulation based on user input from the interface for a variable timeframe which is also set by the user. Model results are presented as average annual upland erosion and sediment yield leaving the profile. Reported values also include mean annual average precipitation, depth of storm runoff, erosion, and sediment yield leaving the hillslope profile. Examples of simulation results for annual average statistics are presented in Figure 4-2, while examples of the TBSM user interface are presented in Figure 4-3. The following subsections describe in further detail each user-specified parameter of the TBSM.

Mean annual averages for 50 years

			Total in 50 years	
62.66	in.	precipitation from	4841	storms
0.34	in.	runoff from rainfall from	137	events
0.14	in.	runoff from snowmelt or winter rainstorm from	24	events
0.071	t ac^{-1}	upland erosion rate (0.016 kg m^{-2})		
0.036	t ac^{-1}	sediment leaving profile (0.242 kg m^{-1} width)		

Figure 4-2. Example of annual average statistics for a 50-year simulation.

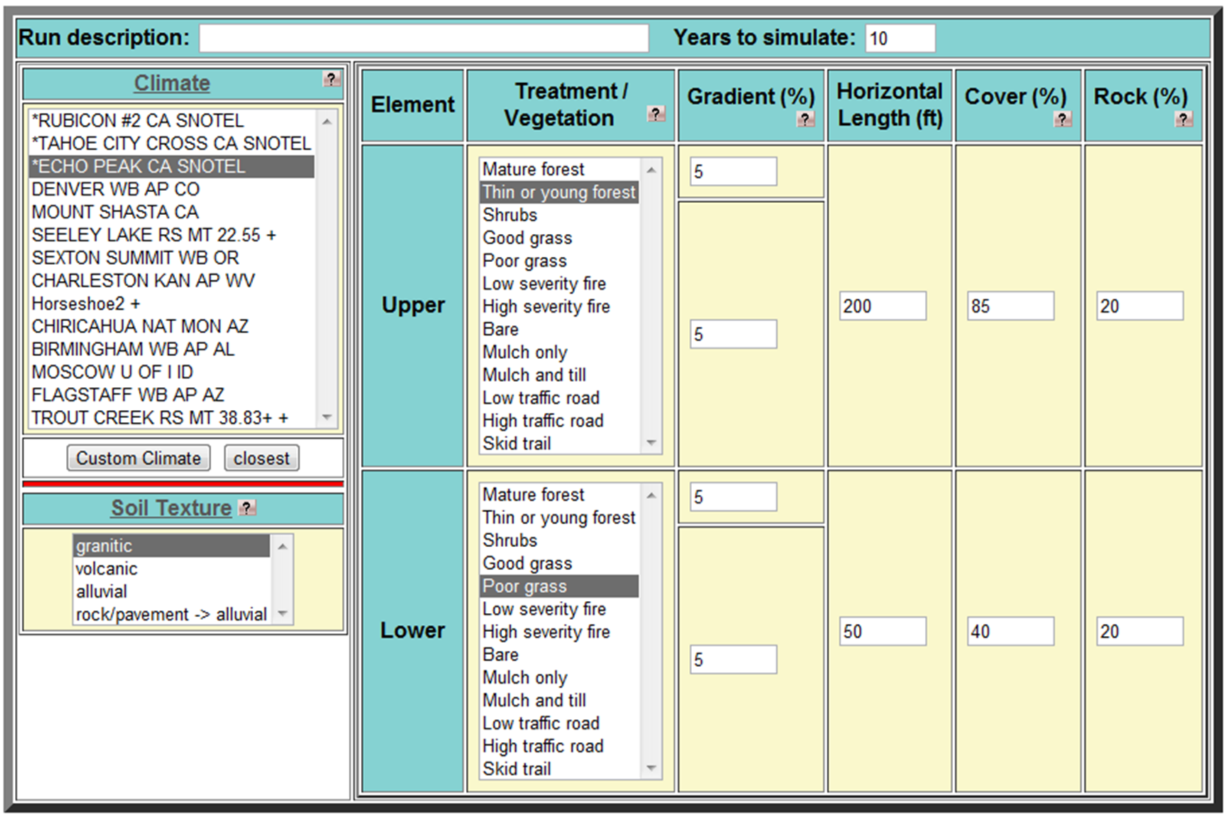

Figure 4-3. TBSM online interface.

Soils

Users are able to specify three different soils types including (1) volcanic (2) granitic, and (3) alluvial. An additional option of rock/pavement is available for representing impervious surfaces such as paved roads or bedrock. The soil type is set once and applies to both the upper and lower flow elements of the modeled hillslope. The TBSM creates a WEPP soil input file with parameter values representative of typical conditions in the Lake Tahoe Basin for the selected soil type. The specific parameters used for each soil type is available through the TBSM Web interface.

Climate

Users are asked to select a custom climate station local to their area of interest. A list of custom climate stations for the Lake Tahoe Basin is available that include SNOTEL locations. Any of the available custom climates can be modified using PRISM data to adjust for differences in location and elevation.

Treatment/Vegetation Type

The TBSM provides thirteen categories representing types of hillslope vegetative cover allowing the user to model several combinations of natural and treatment-altered site conditions. These treatment types provide different parameterizations of plant height, plant spacing, root depth, soil rill and interrill erodibility, saturated hydraulic conductivity, and several other parameters (Elliot and Hall 2010). Parameters are set by the TBSM to reflect general conditions of the Lake Tahoe Basin and are not set by the user.

Horizontal Length

The horizontal length represents the length of each overland flow element along the hillslope profile. Horizontal length is used in conjunction with the percent gradient to calculate a surface slope for the hillslope profile.

Percent Gradient

Percent gradient is parameterized at two points for each overland flow element. For the Upper OFE the user specifies a percent gradient value at the top of the element and midway down the length. For the Lower OFE the user specified a percent gradient value midway down the length and at the toe.

Percent Cover

Percent cover will vary with the user's selection of a treatment method. This parameter represents ground cover provided by vegetation. TBSM specifies a default value for each of the available cover types, although the user is encouraged to use site-specific values when available.

Percent Rock

The TBSM assumes that existing rock in the soil will interrupt the flow path of water as it infiltrates. Based on the value entered for this parameter, the TBSM will adjust the saturated hydraulic conductivity to account for reductions in the infiltration potential attributed to rock. Online documentation states that the modeled reduction in hydraulic conductivity will be configured directly proportional to the percent rock content (i.e., 50 percent rock results in a 50 percent decrease in saturated hydraulic conductivity); however, sensitivity testing revealed that modeled impacts from adjusting the percent rock parameter did not respond as expected. Preliminary correspondence with the TBSM development team was unable to isolate the cause (Elliot 2012). Error associated with this nuance was avoided during site-scale modeling by using the default value of 20 percent for all model runs.

4.3. Site-Scale Sensitivity Analysis

The Fuel Reduction Strategy will primarily impact the land cover and soil structure of forested lands. The Lake Tahoe Watershed Model represented five forest categories with erosion potential (EP) classified on a scale of 1–5, as cited in the watershed modeling report (Tetra Tech 2007) and shown in Figure 4-4. Those EP classifications were directly assigned from a spatial layer that was developed by Simon et al. (2003) and were partially based on K-factor and slope, which are related to the soil and slope components of the fuel reduction management categories. The K-factor is a parameter used to describe the process of soil detachment under runoff conditions.

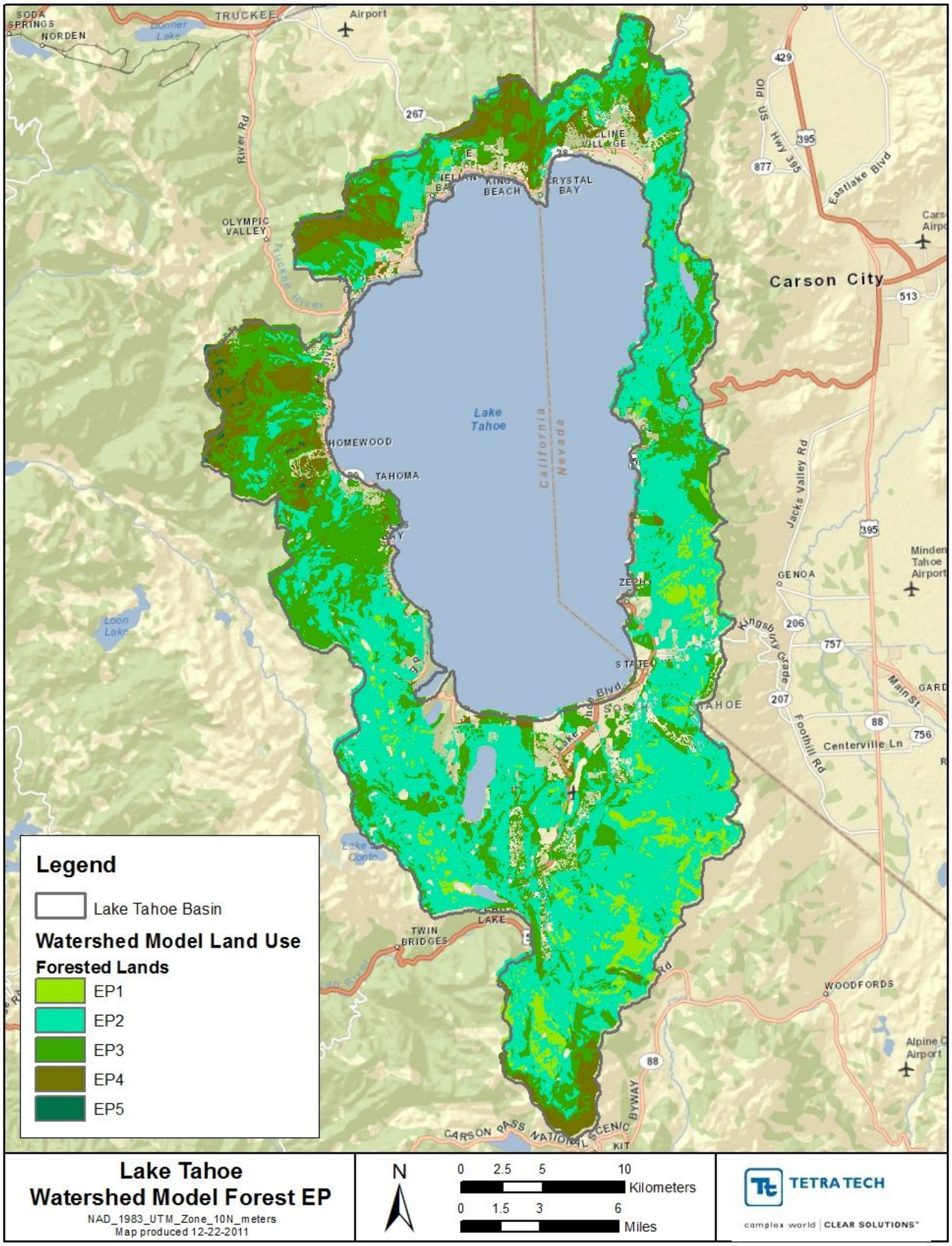

Figure 4-4. Lake Tahoe Watershed Model forest erosion potential (1-5).

As a preliminary step to explore the EP of the fuel reduction management categories, the sensitivity of TBSM soil and slope parameters was investigated. The model was run for the minimum, maximum, and mean slope of each category and the annual average sediment loads were ranked to determine the relative EP of each soil-slope combination.

TBSM runs were initially made using mature forest cover vegetation, but the variability of model results between management categories was too small to provide a meaningful comparison. Because the forest areas to be managed are in and around the urban fringes, these areas will not closely resemble pristine mature forest, before or after management. Consequently, the land cover vegetation *Poor Grass* was used as a basis for testing the sensitivity of soil-slope combinations, considering that the Fuel Reduction Plan treatments would generally convert forested areas to somewhat degraded open space. TBSM sensitivity runs used the Rubicon #2 SNOTEL climate gage (average annual precipitation of 43.2 inches), slope length (100 feet), and soil rock percentage (10 percent) to simulate sediment loads for each management category permutation. Model parameters were selected from within typical ranges given in online TBSM worksheet examples. Note that the parameters used for initial sensitivity runs are not the same as those ultimately used for the site-scale modeling discussed in Section 4.5.

The different combinations of soil type and slope used the three soil categories—granitic, volcanic, and alluvial—and the identified slope ranges. For slope, the minimum, mean, and maximum of each range were included in the tabulation, resulting in 24 variable combinations that were each run in TBSM. The model results were compiled and ranked from lowest to highest sediment yield, as presented in Table 4-4. Model output includes precipitation runoff, upland erosion, and sediment leaving the profile. By ranking the different combinations of variables according to sediment yield, the exercise provides insight as to the relative influence of each factor-combination on sediment yield.

By using a single climate representation to run all scenarios, precipitation influence was removed as a variable for this exercise. Consequently, the results reflect the influence of management categories (i.e. soil type and slope) on runoff and sediment yield. On the basis of the TBSM results, alluvial soils are the most erodible, followed by volcanic, then granitic soils. In addition, within each soil type, increasing slope increases soil erodibility. Note that for the matrix categories highlighted in Table 4-4, the listed soil-slope combination produced an anomalous zero load result in TBSM. To work around these model errors, the closest two slopes that bracket—and whose average equals—the listed slope were run with the associated soil and the results were averaged to give the value presented. For the Volcanic-35, Alluvial-20, and Alluvial-29 percent matrix categories, the percent slopes pairs used were [32%, 38%], [19%, 21%], and [28%, 30%], respectively.

Table 4-4. TBSM results for proposed management categories

	Runoff (inches)			Upland erosion		Sediment leaving profile		
Matrix category (soil-slope)	Rain	Snow	Total	tons/acre	kg/m^2	Tons/acre	kg/m	Rank
Granitic-Low slope (0%)	0	0	0	0	0	0	0	1
Volcanic-Low slope (0%)	0	0.04	0.04	0	0	0	0	2
Alluvial-Low slope (0%)	0.04	0.64	0.68	0	0	0	0	3
Granitic-Low slope (5%)	0.03	0	0.03	0	0	0	0.011	4
Granitic-Low slope (9%)	0.07	0	0.07	0	0	0	0.026	5
Granitic-Med. slope (10%)	0.07	0.01	0.08	0	0	0	0.028	6
Volcanic-Low slope (5%)	0.04	0.04	0.08	0.004	0.001	0.004	0.033	7
Volcanic-Low slope (9%)	0.06	0.04	0.1	0.004	0.001	0.004	0.063	8
Volcanic-Med. slope (10%)	0.07	0.04	0.11	0.004	0.001	0.004	0.081	9
Alluvial-Low slope (5%)	0.15	0.66	0.81	0.009	0.002	0.009	0.111	10
Granitic-Med. slope (20%)	0.08	0.01	0.09	0.009	0.002	0.009	0.127	11
Volcanic-Med. slope (20%)	0.08	0.05	0.13	0.018	0.004	0.018	0.214	12
Alluvial-Low slope (9%)	0.17	0.67	0.84	0.018	0.004	0.018	0.223	13
Granitic-Med. slope (29%)	0.09	0.01	0.1	0.018	0.004	0.018	0.236	14
Granitic-High slope (30%)	0.09	0.01	0.1	0.018	0.004	0.018	0.249	15
Alluvial-Med. slope (10%)	0.17	0.67	0.84	0.018	0.004	0.018	0.254	16
Granitic-High slope (35%)	0.09	0.01	0.1	0.022	0.005	0.022	0.315	17
Volcanic-Med. slope (29%)	0.08	0.05	0.13	0.022	0.005	0.022	0.317	18
Volcanic-High slope (30%)	0.08	0.05	0.13	0.022	0.005	0.022	0.328	19
Volcanic-High slope (35%)	0.08	0.05	0.13	0.029	0.0065	0.029	0.3795	20
Alluvial-Med. slope (20%)	0.19	0.66	0.85	0.049	0.011	0.049	0.6685	21
Alluvial-Med. slope (29%)	0.2	0.65	0.85	0.089	0.02	0.089	1.238	22
Alluvial-High slope (30%)	0.2	0.65	0.85	0.093	0.021	0.093	1.296	23
Alluvial-High slope (35%)	0.2	0.64	0.84	0.116	0.026	0.116	1.579	24

* Highlighted values are averaged values.

When the mean percent slope (5, 20, and 35 percent) of each management category is considered there is a general pattern of increasing erodibility for the low slope categories. Granitic, volcanic, and alluvial soils show progressively higher sediment yields, which are all lower than for the medium slope categories. For the medium and high slope categories, the pattern of volcanic soils giving higher sediment yields than granitic soils is maintained and again there is no overlap between the mean medium (20 percent) and high (35 percent) slopes. This is not the case for alluvial-medium slopes, however, which show greater sediment yields than the granitic- and volcanic-high slope categories.

While the 24-run sequence demonstrated that soil and slope have overlapping influence around the threshold values demarking the management categories, the central tendency progresses in a relatively orderly fashion. On the basis of the rankings of the mean slope management categories given in Table 4-4 a general ranking of the nine management categories presented in Table 4-5 can be made. The analysis suggests that both soil type and slope play an important role in determining sediment yield. Alluvial soils tend to be much more erodible than volcanic and granitic soils, with medium slope alluvial soils giving higher sediment yields than high slope granitic and volcanic soils. Sediment yields from granitic and volcanic soils show a defined relationship where volcanic soils are more erodible, and there is no overlap between slope categories (i.e., granitic-medium slopes are more erodible than volcanic-low slopes).

Table 4-5. Management Category Erodibility Ranks

Management category	General rank*
Granitic-Low slope (0%–9%)	1
Volcanic-Low slope (0%–9%)	2
Alluvial-Low slope (0%–9%)	3
Granitic-Med. slope (10%–29%)	4
Volcanic-Med. slope (10%–29%)	5
Granitic-High slope (> 30%)	6
Volcanic-High slope (> 30%)	7
Alluvial-Med. slope (10%–29%)	8
Alluvial-High slope (> 30%)	9

*Ranks are from least erodible (1) to most erodible (9)

Sensitivity testing was also performed on the TBSM treatment / vegetation type. The treatment / vegetation type selected in the TBSM assume default values for a number of parameters related to the land surface and subsurface hydrology. A sensitivity analysis was performed to test how the model would respond to different types of vegetative cover for the lower element vegetative cover. The upper OFE parameters were held constant with an assumed treatment / vegetation type of Thinned Forest, length of 500 ft., and ground cover of 85 percent. Table 4-6 presents the results of the lower OFE treatment / vegetation type sensitivity analysis for shrubs, good grass, and poor grass.

Table 4-6. Sensitivity analysis results of lower OFE treatment vegetation type

Management Category		Thinned Forest Upper OFE with 85% Cover, 500 ft. Length					
		Shrubs		Good Grass		Poor Grass	
Soil	Slope	Upland Erosion (ton/ac)	Leaving Profile (ton/ac)	Upland Erosion (ton/ac)	Leaving Profile (ton/ac)	Upland Erosion (ton/ac)	Leaving Profile (ton/ac)
Granitic	Low	0.000	0.000	0.000	0.000	0.013	0.000
	Med	0.000	0.000	0.000	0.000	0.022	0.000
	High	0.000	0.000	0.000	0.000	0.022	0.000
Volcanic	Low	0.000	0.000	0.000	0.000	0.018	0.000
	Med	0.000	0.000	0.004	0.000	0.049	0.004
	High	0.004	0.004	0.062	0.004	0.258	0.022
Alluvial	Low	0.000	0.000	0.004	0.000	0.022	0.000
	Med	0.018	0.000	0.058	0.004	0.289	0.027
	High	0.013	0.013	0.089	0.036	0.231*	0.080

* Anomalous result produced by TBSM (High < Med).

Both upland erosion and sediment leaving the profile decrease rapidly with treatment types above poor and good grass. Only high slope alluvial and volcanic soils show any sediment leaving the profile with a lower element treatment of shrubs.

The TBSM sets an upper threshold on hillslope length for a single OFE at 1,200 ft. A sensitivity analysis was designed to test assumptions of hillslope length for the upper OFE at three intervals (1) 200 feet (2) 500 feet, and (3) 1,000 feet. Both baseline forest and managed forest conditions were simulated to assess the effect of length on the relative change in loading after treatment. Table 4-7 presents TBSM results that represent a baseline forest condition for an upper OFE of Thinned Forest with 100 percent ground cover for each management category. Table 4-8 presents the TBSM results from a similar sensitivity analysis that represents a managed forest condition using 85 percent ground cover for the upper OFE.

Table 4-7. Hillslope length sensitivity analysis results for baseline forest condition

Management Category		Thinned Forest Upper OFE with 100% Cover					
		Length=200 ft.		Length=500 ft.		Length=1,000 ft.	
Soil	Slope	Upland Erosion (ton/ac)	Leaving Profile (ton/ac)	Upland Erosion (ton/ac)	Leaving Profile (ton/ac)	Upland Erosion (ton/ac)	Leaving Profile (ton/ac)
Granitic	Low	0.013	0.004	0.013	0.000	0.013	0.000
	Med	0.022	0.004	0.022	0.000	0.022	0.000
	High	0.027	0.004	0.022	0.000	0.022	0.000
Volcanic	Low	0.018	0.004	0.018	0.000	0.018	0.000
	Med	0.031	0.004	0.022	0.004	0.320*	0.013
	High	0.004*	0.009	0.271	0.027	0.076*	0.049
Alluvial	Low	0.027	0.004	0.027	0.004	0.027	0.000
	Med	0.058	0.013	0.307*	0.027	0.182*	0.049
	High	0.067	0.049	0.151*	0.085	0.165*	0.120

* Anomalous results produced by TBSM (High < Med).

Table 4-8. Hillslope length sensitivity analysis results for managed forest condition

Management Category		Thinned Forest Upper OFE with 85% Cover					
		Length=200 ft.		Length=500 ft.		Length=1,000 ft.	
Soil	Slope	Upland Erosion (ton/ac)	Leaving Profile (ton/ac)	Upland Erosion (ton/ac)	Leaving Profile (ton/ac)	Upland Erosion (ton/ac)	Leaving Profile (ton/ac)
Granitic	Low	0.013	0.004	0.013	0.000	0.013	0.000
	Med	0.022	0.004	0.022	0.000	0.022	0.000
	High	0.027	0.004	0.022	0.000	0.022	0.000
Volcanic	Low	0.018	0.004	0.018	0.000	0.018	0.000
	Med	0.031	0.004	0.049	0.004	0.307*	0.013
	High	0.000*	0.009	0.258	0.022	0.231*	0.045*
Alluvial	Low	0.022	0.004	0.027	0.004	0.027	0.000
	Med	0.053	0.009*	0.289*	0.027	0.187	0.049
	High	0.067	0.049	0.231*	0.080	0.200	0.116*

* Anomalous results produced by TBSM (High < Med).

Table 4-7 and Table 4-8 show that while length does affect the upland erosion, sediment leaving the profile is largely unchanged with two notes. First, a longer hillslope appears to generate slightly less erosion for granitic which is composed of 90 percent sand, meaning a longer overland flow path provides more opportunity for larger particles to get trapped by surface cover or settle out with low flow. Second, a longer hillslope tends to generate more erosion for the alluvial soils; however, alluvial soils make up a small portion of the basin and an even smaller portion of the managed areas.

4.4. Fuel Reduction Treatments and Impacts

From a hydrology perspective, the impact of fuel reduction treatments can be summarized as changes to (1) ground cover, (2) canopy cover, and (3) soil compaction. Ground cover influences soil erodibility, while canopy cover impacts rainfall interception and evapotranspiration. Soil compaction influences infiltration potential. Ground cover and soil compaction are the two parameters that most closely relate to the proposed fuel reduction treatment impacts. Initial managed values for both forest and road parameters were derived from local WEPP modeling reports discussed in Section 4.1 and USFS guidance (USFS 1999). These values correspond to each type of fuel reduction treatment are presented below in Table 4-9. No literature values were available to inform selection of values for percent rock. Consequently, this parameter was held constant at 20 percent for all model scenarios, which is the WEPP default parameter value.

Table 4-9. Management action parameters for the TBSM

Fuel reduction treatment	Rock (%)	Forest ground cover (%)		Road ground cover (%)		Skid Trail cover (%)
		Literature[a,b]	Revised	Literature[a,b]	Revised	
WTS	20%	85%	85%	40%	5%	10%
CTL	20%	85%	85%	40%	45%	n/a
Hand Crew	20%	90%	85%	40%	85%	n/a

Note:
a. LTBMU 2011
b. LTBMU 2008

The available literature did not provide the degree of stratification that one might intuitively expect from the different types of fuel reduction treatments. For example, consider the forest roads shown in Figure 4-5. This photograph shows some examples of landscape features associated with road access for forest management activities. The landscape in and around the road more closely resembles poor grass more than mature or even thinned forest. Other visible features include low ground cover, compaction, and tire tracks. In light of these observations, the literature value of 85 percent for ground cover associated with WTS did not seem appropriate. Based on personal communication with Hannah Schembri and Doug Cushman at the Lahontan Regional Water Quality Control Board about their field observations, it was recommended that the percent cover on roads from WTS should be closer to zero to reflect the greater impact it has on the landscape relative to CTL and HC treatments. The first phase of this modeling effort focused on ground cover to represent management activity, but Phase II of this study will further investigate the sensitivity of these assumptions and other WEPP model parameters (e.g. poor grass, ground cover, compaction, and skid trails) on predicted sediment yield associated with fuel reduction activity.

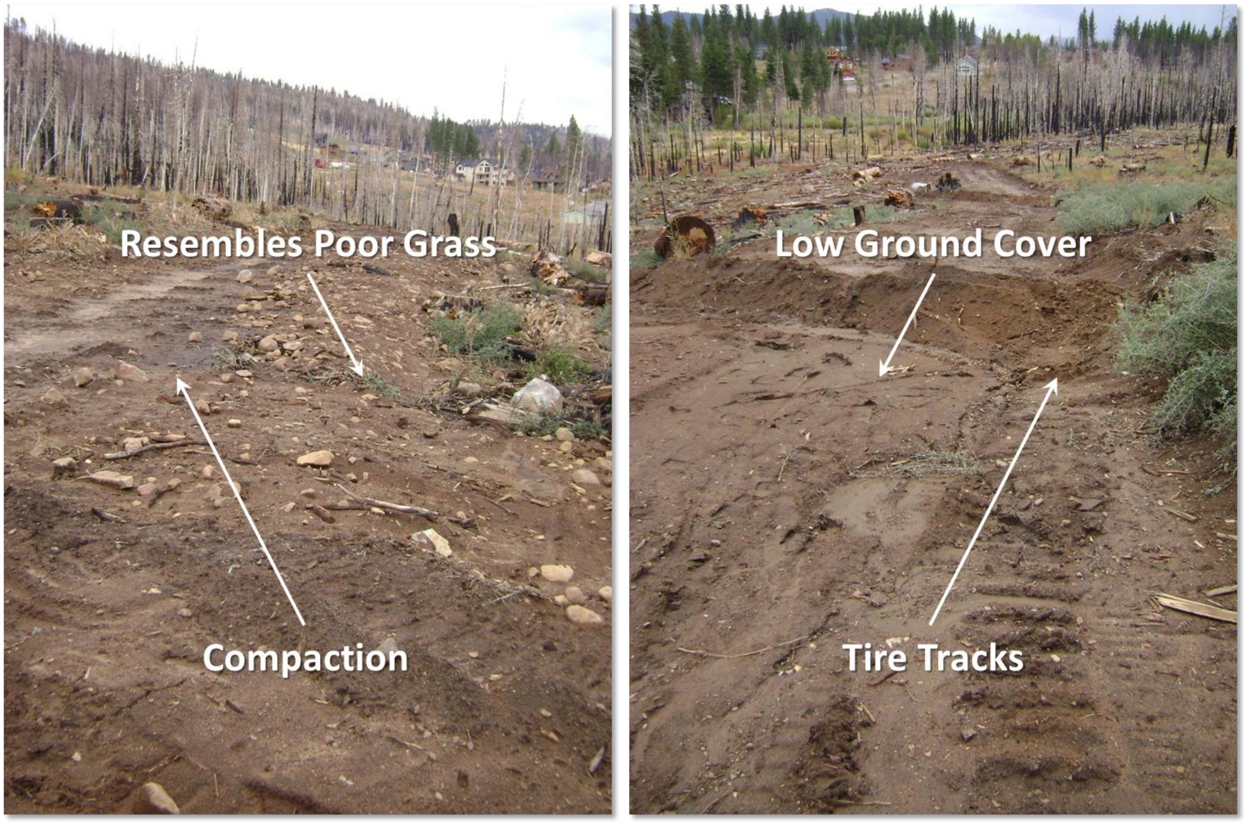

Figure 4-5. Photographs from the Angora hazard tree inspections, October 4-5, 2010.

In areas of the South Shore project a mastication technique will also be applied as a secondary fuel reduction treatment, shredding material that is left on the ground and leaving a mat of organic matter. In many instances this treatment may actually increase the ground cover of the forest; however, compaction of soil from the weight of the mastication equipment is a concern. A 2002 study published by California Agriculture analyzed field data collected from sites subjected to the mastication fuel reduction treatment. The conclusions of this study found that no adverse impacts were discernible from the collected data and that erosion was driven largely by the slope, soil type, and climate (Hatchet 2006).

4.5. Site-Scale TBSM Modeling

A series of TBSM runs were configured to simulate the effects of the three fuel reduction treatments, WTS, CTL, and HC on managed forest sediment yields. Increased erosion from fuel reduction treatments can be attributed to (1) sediment yield from thinned or burned forest land (2) sediment yield from new or existing USFS roads used to access the site, and (3) sediment yield from skid trails when WTS is used for fuel management. For a fuel management site with an arbitrary area (acres), the unit-area sediment yield can be calculated as follows:

$$Sediment\ Yield = (Y_F)(\%Forest)(Area) + (Y_R)(\%Road)(Area) + (Y_S)(\%Trail)(Area)$$

Equation 1. Sediment Yield from Site-scale Model (Aggregate of Forest and Road).

Where Y_R is the sediment delivery in tons/acre of sediment from road areas and Y_F is the delivery in tons/acre of sediment from forested areas. While the forest sediment delivery rate may be the same for multiple fuel reduction treatments, the sediment delivery from the road may vary, and vice versa. Also, the road area needed for each treatment may increase or decrease, changing the fraction of the treated area classified as road. Hand crews, for instance, may not require any additional roads to access a site.

The TBSM was configured for road and forest areas, to simulate the effects of the three fuel reduction treatments on managed forest sediment yields. As described above, the average annual sediment load can be calculated as the combined yield from forest areas (Y_F) and roads (Y_R) that constitute a treated site. For each area, road and forest, TBSM requires the configuration of an upper and lower element as shown in Figure 4-1.

For forest areas, the upper element was modeled using a cover of *Thin or Young Forest*, while the lower element was represented using a cover of *Poor Grass*. Treatments of the Fuel Reduction Plan are intended to enhance defensible space in and around the wildland-urban interface, which is defined as peripheral forest areas within a quarter-mile buffer of urban land that generally experiences more human traffic than deeper forest areas. For this reason, a slightly degraded treatment of *Poor Grass* was selected as the fringe of areas receiving treatment. Based on the sensitivity testing on treatment/vegetation type presented in Section 4.3, it is expected that the selection of *Poor Grass* will produce a more conservative estimate of potential erosion than if another treatment/vegetation type was selected for the lower OFE. Both low and high traffic roads were modeled using a cover of *Low Traffic Road* or *High Traffic Road* for the upper element and *Thin or Young Forest* for the lower element, representing the adjacent forest undergoing treatment.

Slopes were evaluated according to the management categories given in Table 4-10 for forest areas and at 4 percent for roads, which represents a typical forest road grade (USFS 1999). Note that the categories in Table 4-10 are identical to those given in Table 3-1, except that the slopes are the mean of the range identified for each management category as discussed in Section 4.3. In addition, the Echo Peak SNOTEL climate station was used for all runs for consistency with the majority of geospatial data in the vicinity of South Lake Tahoe and in consideration of the fact that variations in climate will be simulated when the site-scale modeling is extrapolated to the Lake Tahoe Watershed Model.

Table 4-10. Matrix of management categories

Management Matrix		Soil Type		
		Granitic	**Volcanic**	**Alluvial**
Slope	**Low (5%)**	Granitic Low Slope	Volcanic Low Slope	Alluvial Low Slope
	Med (20%)	Granitic Medium Slope	Volcanic Medium Slope	Alluvial Medium Slope
	High (35%)	Granitic High Slope	Volcanic High Slope	Alluvial High Slope

Table 4-11 and Table 4-12 present the suite of parameter values used to represent baseline forest and road areas in the TBSM, respectively. The percent cover of *Thinned Forest* in the forest upper element and the road lower element were adjusted as specified in Table 4-9 to represent the three fuel reduction treatments. Based on lessons learned from the sensitivity analysis presented in Section 4.3, a 200 foot upper OFE length was selected as a representative site-scale model length representing approximately one acre of hillslope. For the road site-scale model configuration, 200 feet represents the length of road segment between waterbars used to break up the length of overland flow.

Table 4-11. Site-scale model configuration for baseline forest

Overland Flow Element		Upper			Lower		
Element Cover		Thinned Forest			Poor Grass		
Slope	Soil	Length (ft)	Slope (%)	Cover (%)	Length (ft)	Slope (%)	Cover (%)
Low	Granitic	200	5	100	50	5	40
	Volcanic	200	5	100	50	5	40
	Alluvial	200	5	100	50	5	40
Medium	Granitic	200	20	100	50	20	40
	Volcanic	200	20	100	50	20	40
	Alluvial	200	20	100	50	20	40
High	Granitic	200	35	100	50	35	40
	Volcanic	200	35	100	50	35	40
	Alluvial	200	35	100	50	35	40

Table 4-12. Site-scale Model Configuration for Baseline Road

Overland flow element		Upper			Lower		
Management cover		Road			Thinned forest		
Slope	Soil	Length (ft)	Slope (%)	Cover (%)	Length (ft)	Slope (%)	Cover (%)
Low	Granitic	200	4	85	50	5	100
	Volcanic	200	4	85	50	5	100
	Alluvial	200	4	85	50	5	100
Medium	Granitic	200	4	85	50	20	100
	Volcanic	200	4	85	50	20	100
	Alluvial	200	4	85	50	20	100
High	Granitic	200	4	85	50	35	100
	Volcanic	200	4	85	50	35	100
	Alluvial	200	4	85	50	35	100

The relative change in sediment load due to the application of fuel reduction treatments over the baseline condition can be expressed as follows:

$$Percent\ Change = 1 - \frac{Baseline\ Sediment\ Yield}{Treatment\ Sediment\ Yield}$$

Equation 2. Percent change in sediment yield (pre- and post-treatment).

The TBSM modeled baseline and post-treatment yields and the percent difference between the two are discussed in the following section.

5. TBSM Results

Two sets of model results were generated for this analysis, including using local literature values and using the revised ground cover stratification. These results show dramatically different results at the small-scale in terms of unit-area loading. Section 5.1 presents TBSM results using input parameter values derived from literature, while Section 5.2 presents results using the revised stratified ground cover values.

5.1. Literature-Based Ground Cover Results

Figure 5-1 shows the TBSM erosion simulation results on a log scale by management category for the baseline condition and targeted fuel reduction treatments in forested areas with low and high traffic roads. Low traffic road results are shown on the left hand side, while high traffic road results are given on the right. Both traffic scenarios were modeled to test the difference in loading between the two cover types. The fuel reduction treatments WTS and CTL are parameterized the same in the TBSM and, thus, are combined in the same plot. The baseline conditions are shown in the top plots and are used as the basis for determining the percent loading changes attributed to the implementation of fuel reduction treatments.

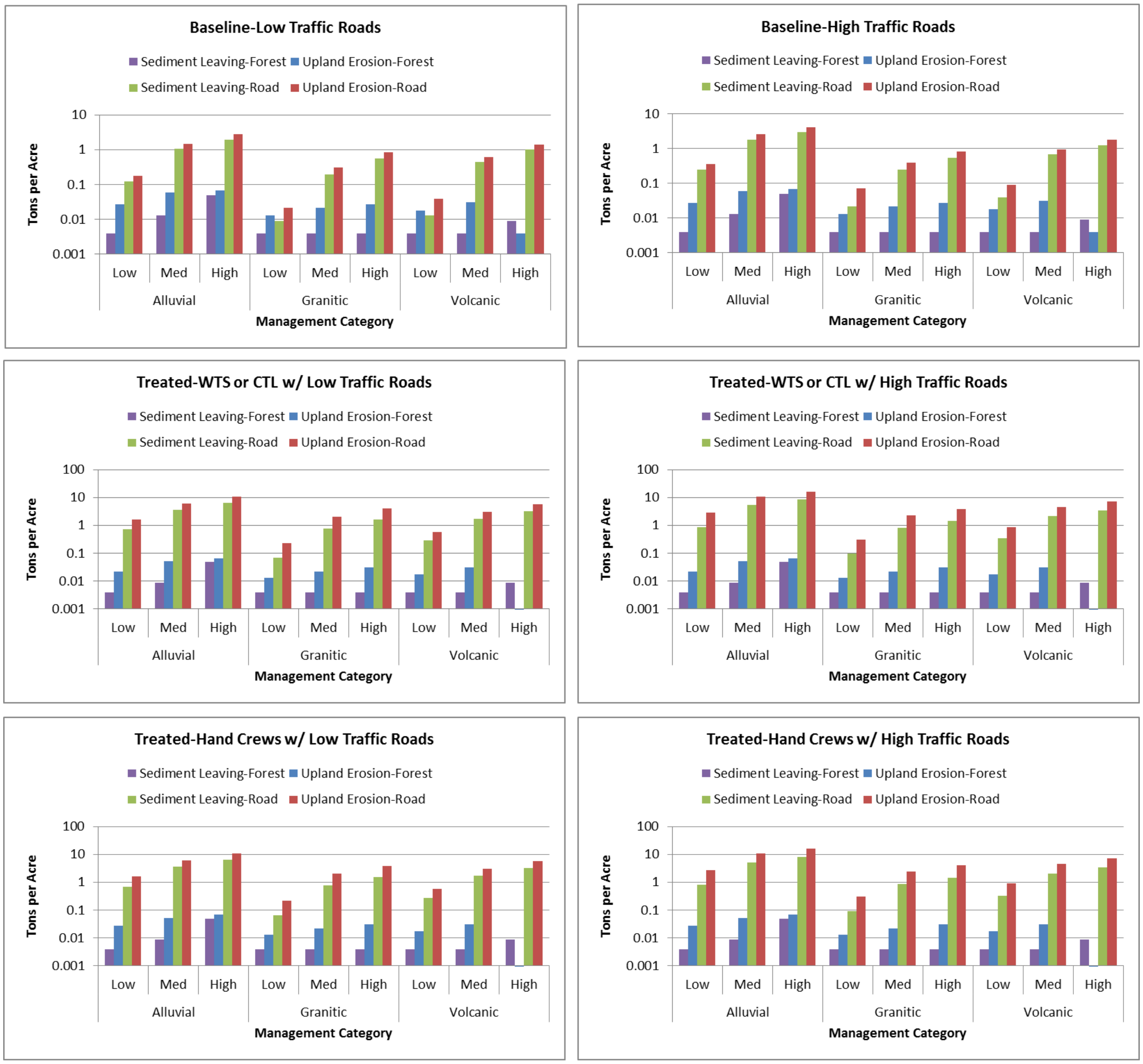

Figure 5-1. Unit area sediment loading on a log scale for treatments by management category with low and high traffic roads.

The TBSM simulates two types of loading on a unit area basis (tons per acre), *upland erosion* and *sediment leaving profile*, which represent the total detached soil and detached soil leaving the modeled hillslope profile, respectively. Model results typically show that sediment leaving the profile is less than the upland erosion because some portion of the detached sediment will resettle or get trapped before leaving the hillslope profile. Loading trends for both by slope are consistent across soil types for all treatment practices. In general, the load increases as slope increases. The only exception is for forest upland erosion on volcanic soils, where a smaller load is simulated for the high slope management category as compared to both low and medium slopes. This result is shown in the baseline, as well as for all treatments in both low and high traffic road areas. Note that the TBSM predicts zero forest upland erosion for the high slope volcanic soil management category across all treatments suggesting that this result is a model anomaly as identified during site-scale sensitivity analysis discussed in Section 4.3. The work around of selecting two slopes that bracket—and whose average equals—the target slope did not produce a usable result within a reasonable number of iterations, therefore the anomalous results are presented. Anomalous values are indicated with an asterisk in each table.

The TBSM results are presented in detail for forest upland erosion (Table 5-1), forest sediment leaving profile (Table 5-2), road upland erosion (Table 5-3), and road sediment leaving profile (Table 5-4). To give more insight into the model trends, the results have been color coded to represent their respective rank within each loading matrix. The color scale increases from green to yellow to red, where green represents the lowest values and red represents the highest.

Table 5-1. Unit area forest upland erosion for treatments by management category

Forest Upland Erosion (tons/acre)				
Management Category		Fuel Reduction Treatment		
Soil	Slope	Baseline	WTS/CTL	Hand Crews
Granitic	Low	0.013	0.013	0.013
	Med	0.022	0.022	0.022
	High	0.027	0.031	0.031
Volcanic	Low	0.018	0.018	0.018
	Med	0.031	0.031	0.031
	High	0.004	0*	0*
Alluvial	Low	0.027	0.022	0.027
	Med	0.058	0.053	0.053
	High	0.067	0.067	0.071

Color Scale: Low Med High

* Anomalous results produced by TBSM

Table 5-2. Unit area forest sediment leaving profile for treatments by management category

Forest Sediment Leaving Profile (tons/acre)				
Management Category		Fuel Reduction Treatment		
Soil	Slope	Baseline	WTS/CTL	Hand Crews
Granitic	Low	0.004	0.004	0.004
	Med	0.004	0.004	0.004
	High	0.004	0.004	0.004
Volcanic	Low	0.004	0.004	0.004
	Med	0.004	0.004	0.004
	High	0.009	0.009	0.009
Alluvial	Low	0.004	0.004	0.004
	Med	0.013	0.009	0.009
	High	0.049	0.049	0.049

Color Scale: Low Med High

Table 5-3. Unit area road upland erosion for treatments by management category

Management Category		Road Upland Erosion (tons/acre)					
		Low-Density Roads			High-Density Roads		
		Fuel Reduction Treatment			Fuel Reduction Treatment		
Soil	Slope	Baseline	WTS/CTL	Hand Crews	Baseline	WTS/CTL	Hand Crews
Granitic	Low	0.02	0.23	0.21	0.07	0.32	0.32
	Med	0.30	2.01	2.03	0.39	2.33	2.42
	High	0.84	3.95	3.94	0.99	4.45	4.67
Volcanic	Low	0.04	0.58	0.58	0.09	0.87	0.89
	Med	0.61	3.07	3.08	0.94	4.48	4.50
	High	1.42	5.65	5.69	2.07	8.24	8.30
Alluvial	Low	0.17	1.61	1.59	0.36	2.80	2.76
	Med	1.43	6.10	6.10	2.50	10.80	10.79
	High	2.72	10.48	10.51	4.78	18.55	18.63

Color Scale: Low Med High

Table 5-4. Unit area road sediment leaving profile for treatments by management category

Management category		Road sediment leaving profile (tons/acre)					
		Low-density roads			High-density roads		
		Fuel reduction treatment			Fuel reduction treatment		
Soil	Slope	Baseline	WTS/CTL	Hand Crews	Baseline	WTS/CTL	Hand Crews
Granitic	Low	0.01	0.07	0.07	0.02	0.10	0.09
	Med	0.20	0.79	0.76	0.25	0.84	0.87
	High	0.57	1.59	1.53	0.67	1.66	1.74
Volcanic	Low	0.01	0.29	0.28	0.04	0.34	0.33
	Med	0.44	1.74	1.70	0.67	2.13	2.07
	High	1.02	3.25	3.20	1.44	4.15	4.00
Alluvial	Low	0.13	0.71	0.69	0.25	0.85	0.81
	Med	1.04	3.70	3.64	1.79	5.29	5.12
	High	1.95	6.48	6.44	3.35	9.69	9.48

Color Scale: Low Med High

A comparison of loadings by soil type affirms the conclusions discussed in Section 4.3, where alluvial soils are the most easily eroded, followed by volcanic, and then granitic soils for both forest and road areas. Loading trends by treatment, however, show mixed trends depending on whether the modeled area is road or forest, as well as the type of load—upland erosion or sediment leaving the profile.

The TBSM predicts that WTS and CTL increase the unit area amount of sediment leaving the profile from roads more than HC regardless of management category, except for high-density roads on volcanic soil with medium and high slopes. Conversely, there is no true trend for upland erosion from road areas, with WTS and CTL treatments causing larger loads for some management categories, but HC causing higher loads for others. These anomalies seem to be a result of the narrow range of literature values that were available to parameterize model inputs. In addition, as might be expected, higher sediment loads are simulated for high traffic roads as compared to low traffic roads independent of management category and treatment practice.

For forested areas, the upland erosion rate for HC is slightly larger or equal on alluvial soils than for WTS and CTL—once again, a result of the narrow range of literature values available for parameterizing the impacts of these treatments. For all other soils the forest land upland erosion rate is the same. Similarly, the forest sediment leaving profile load is the same for all fuel reduction treatments when holding management categories constant. Note that the modeled forest upland erosion load for WTS and CTL treatments on alluvial soils with low slope; WTS, CTL, and HC on alluvial medium slope soils; and sediment leaving the profile loads on alluvial medium slope soils appear to be anomalous TBSM values. Fuel reduction treatments on forest land are parameterized identically to the baseline, except for a smaller percent cover value. This should result in a load greater to or equal to the baseline.

Figure 5-2 and Figure 5-3 show the percent difference in the TBSM simulated unit area sediment loads between fuel reduction treatments and the baseline condition across management categories for low and high traffic roads, respectively. These results are based on a composite of *sediment leaving profile* loads for forest and road areas and do not explicitly consider the upland erosion load. This is because the sediment leaving the profile load is considered to be the actual sediment yield, as mentioned previously.

The composite was calculated based on GIS analysis of the areal density of roads in forested areas of the various treatment types for the existing South Shore treatment area according to Equation 1. The densities were applied to the unit area forest and road loads given in Table 5-2 and Table 5-4 resulting in the final composite load. Roads in the South Shore are shown in Figure 2-4. Road densities as percent area of a treatment type are 0.301, 0.328, and 0.322 percent, respectively for WTS, CTL, and HC, but were averaged to a single value (0.317 percent) applied to all treatments because of the similarity in the percentages.

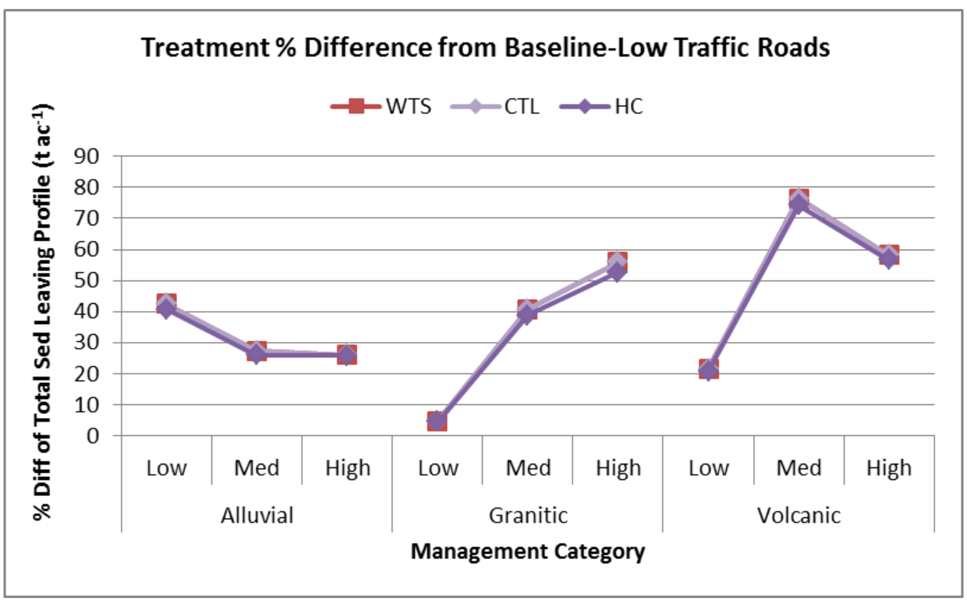

Figure 5-2. Percent difference of unit area sediment loading resulting from treatments by management category with low-traffic roads.

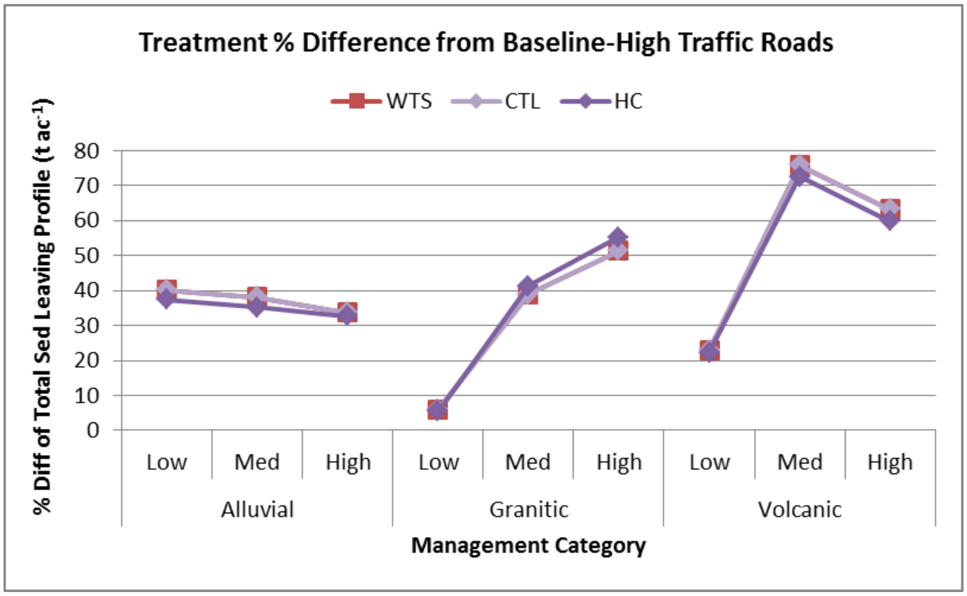

Figure 5-3. Percent difference of unit area sediment loading resulting from treatments by management category with high traffic roads.

All treatments result in increased sediment loading as compared to the baseline regardless of management category. The percent differences in loading across treatments generally reflect the results of the TBSM results given in Table 5-1 through Table 5-4, where the greatest percent increase is seen for WTS and CTL, followed by HC. However, because of the relatively narrow range of literature values used for model parameterization, there is relatively little difference in the modeled impact, regardless of the severity of the fuel reduction treatment, as shown in Figure 5-2 and Figure 5-3.

Interestingly, within each management category, increasing slope does not have a consistent effect on the percent difference in sediment loading. For granitic and volcanic soils, loading percent difference trends are consistent for low and high traffic road areas. A uniform increase in percent difference is seen in granitic soils as slope increases, with the greatest increase seen between low and medium slopes. Volcanic soils also show a large percent difference increase between low and medium slopes, though because of anomalous TBSM values, it is smaller for high slopes than medium slopes. The general trend of the results suggest that for granitic and volcanic soils, increased slope tends to make the impacts of fuel reduction treatments more pronounced. However, for alluvial soils the trend is the exact opposite. For both low and high traffic road areas, the percent difference in loading generally decreases with increasing slope. Therefore, for alluvial soils, the greatest increases in sediment loading due to fuel reduction treatments are seen in low slope areas.

5.2. Revised Ground Cover Results

Figure 5-4 and Figure 5-5 show the TBSM erosion simulation results (using the revised ground cover and skid trail parameters) on a log scale by management category for the baseline condition and targeted fuel reduction treatments in forested areas with low and high traffic roads. Low traffic road results are shown on the left hand side, while high traffic road results are given on the right. Both traffic scenarios were modeled to test the difference in loading between the two cover types. The baseline conditions are shown in the top plots and are used as the basis for determining the percent loading changes attributed to the implementation of fuel reduction treatments that include WTS, CTL, and HC.

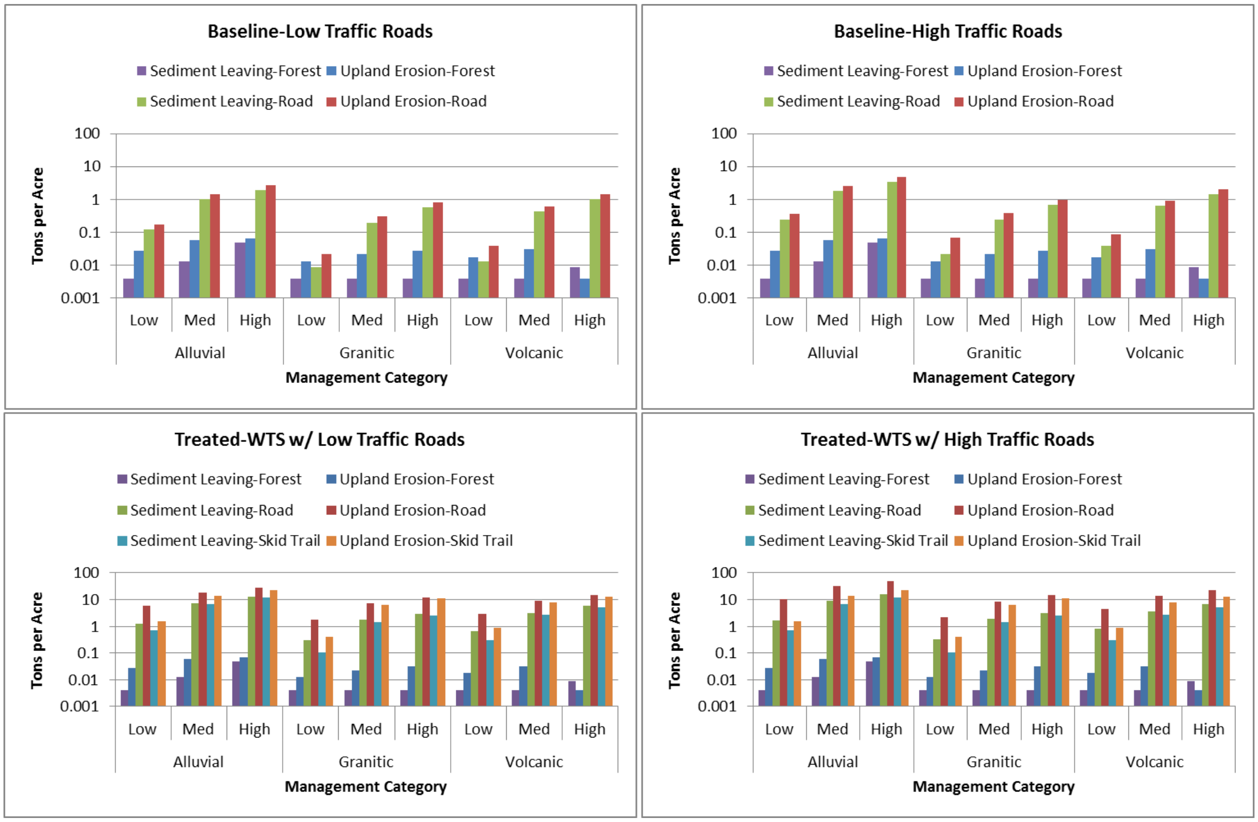

Figure 5-4. Unit area sediment loading on a log scale for treatments (baseline and WTS) by management category with low and high traffic roads.

Figure 5-5. Unit area sediment loading on a log scale for treatments (CTL and Hand Crews) by management category with low and high traffic roads.

The revised ground cover results are presented in detail for forest upland erosion (Table 5-5), forest sediment leaving profile (* Anomalous TBSM results were set equal to baseline
Table 5-6), road upland erosion (Table 5-7), road sediment leaving profile (

Table 5-8), and skid trail sediment loads (Table 5-9). As before, the results have been color coded to represent their respective rank within each loading matrix, with green representing the lowest values and red representing the highest. This time, the anomalous TBSM forest erosion values were presented as equal to baseline levels.

Table 5-5. Unit area forest upland erosion for treatments by management category

Forest Upland Erosion (tons/acre)					
Management Category		Fire Treatment Practice			
Soil	Slope	Baseline	WTS	CTL	HC
Granitic	Low	0.013	0.013	0.013	0.013
	Med	0.022	0.022	0.022	0.022
	High	0.027	0.031	0.031	0.031
Volcanic	Low	0.018	0.018	0.018	0.018
	Med	0.031	0.031	0.031	0.031
	High	0.004	0.004*	0.004*	0.004*
Alluvial	Low	0.027	0.027	0.027	0.027
	Med	0.058	0.058	0.058	0.058
	High	0.067	0.067	0.067	0.067

Color Scale: Low Med High

* Anomalous TBSM results were set equal to baseline

Table 5-6. Unit area forest sediment leaving profile for treatments by management category

Forest Sediment Leaving Profile (tons/acre)					
Management Category		Fire Treatment Practice			
Soil	Slope	Baseline	WTS	CTL	HC
Granitic	Low	0.004	0.004	0.004	0.004
	Med	0.004	0.004	0.004	0.004
	High	0.004	0.004	0.004	0.004
Volcanic	Low	0.004	0.004	0.004	0.004
	Med	0.004	0.004	0.004	0.004
	High	0.009	0.009	0.009	0.009
Alluvial	Low	0.004	0.004	0.004	0.004
	Med	0.013	0.013	0.013	0.013
	High	0.049	0.049	0.049	0.049

Color Scale: Low Med High

Table 5-7. Unit area road upland erosion for treatments by management category

Road Upland Erosion (tons/acre)									
Management Category		Low-Density Roads				High-Density Roads			
		Fire Treatment Practice				Fire Treatment Practice			
Soil	Slope	Baseline	WTS	CTL	HC	Baseline	WTS	CTL	HC
Granitic	Low	0.02	1.73	0.14	0.02	0.07	2.11	0.22	0.07
	Med	0.30	7.21	1.68	0.32	0.39	8.57	1.92	0.41
	High	0.84	12.06	3.36	0.86	0.99	14.23	3.89	1.01

Volcanic	Low	0.04	2.80	0.42	0.04	0.09	4.57	0.70	0.09
	Med	0.61	9.25	2.58	0.66	0.94	14.10	3.77	1.01
	High	1.42	14.98	4.81	1.42	2.07	23.14	7.01	2.08
Alluvial	Low	0.17	5.83	1.27	0.18	0.36	10.34	2.23	0.37
	Med	1.43	17.57	5.22	1.46	2.50	32.16	9.18	2.55
	High	2.72	27.36	9.03	2.75	4.78	50.16	16.00	4.82
Color Scale:	Low	Med	High						

Table 5-8. Unit area road sediment leaving profile for treatments by management category

Road Sediment Leaving Profile (tons/acre)									
Management Category		Low-Density Roads				High-Density Roads			
		Fire Treatment Practice				Fire Treatment Practice			
Soil	Slope	Baseline	WTS	CTL	HC	Baseline	WTS	CTL	HC
Granitic	Low	0.01	0.30	0.05	0.01	0.02	0.33	0.07	0.03
	Med	0.20	1.73	0.73	0.21	0.25	1.85	0.77	0.27
	High	0.57	2.89	1.46	0.60	0.67	3.11	1.58	0.71
Volcanic	Low	0.01	0.64	0.25	0.01	0.04	0.81	0.31	0.04
	Med	0.44	3.02	1.55	0.47	0.67	3.59	1.94	0.71
	High	1.02	5.67	2.90	1.03	1.44	6.65	3.77	1.50
Alluvial	Low	0.13	1.26	0.65	0.13	0.25	1.62	0.78	0.25
	Med	1.04	7.26	3.24	1.08	1.79	8.87	4.84	1.84
	High	1.95	12.74	5.75	1.97	3.35	15.55	8.94	3.39
Color Scale:	Low	Med	High						

Table 5-9. Unit area sediment loads for skid trail areas by management category

Skid Trail Sediment Loads (tons/acre)			
Management Category			
Soil	Slope	Upland Erosion	Sediment Leaving Profile
Granitic	Low	0.409	0.107
	Med	6.301	1.424
	High	11.134	2.452
Volcanic	Low	0.881	0.298
	Med	7.538	2.648
	High	12.892	4.997
Alluvial	Low	1.491	0.73
	Med	13.261	6.577
	High	22.548	11.459
Color Scale:	Low	Med	High

Figure 5-6 and Figure 5-7 show the percent difference in the TBSM simulated unit area sediment loads between fuel reduction treatments and the baseline condition across management categories for low and high traffic roads, respectively. These results are based on a composite of "sediment leaving profile" loads for forest, skid trail, and road areas and do not explicitly consider the upland erosion load.

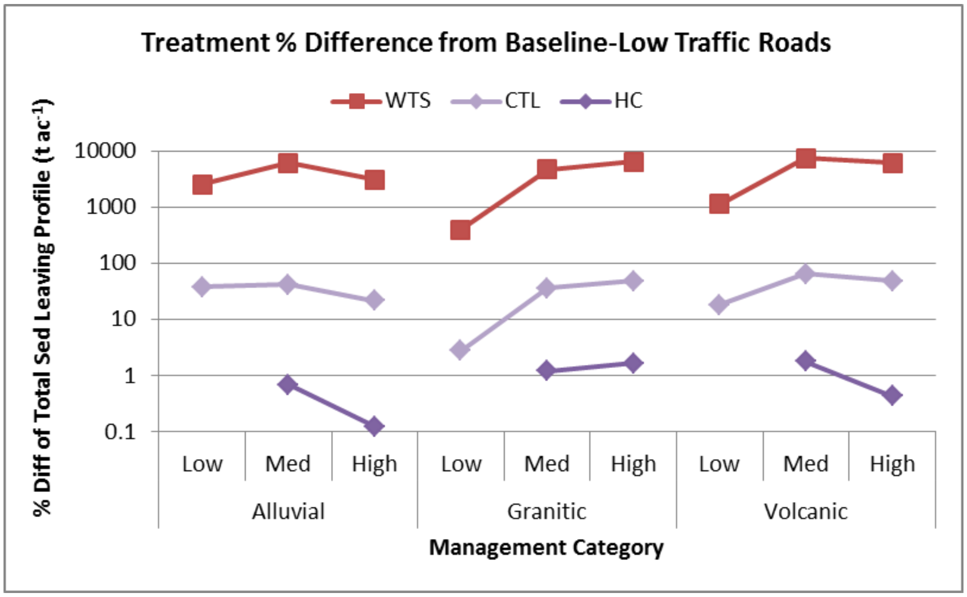

Figure 5-6. Percent difference of unit area sediment loading resulting from treatments by management category with low traffic roads (*Note: Missing data points (low slope) for HC are 0 and do not plot on a log scale*).

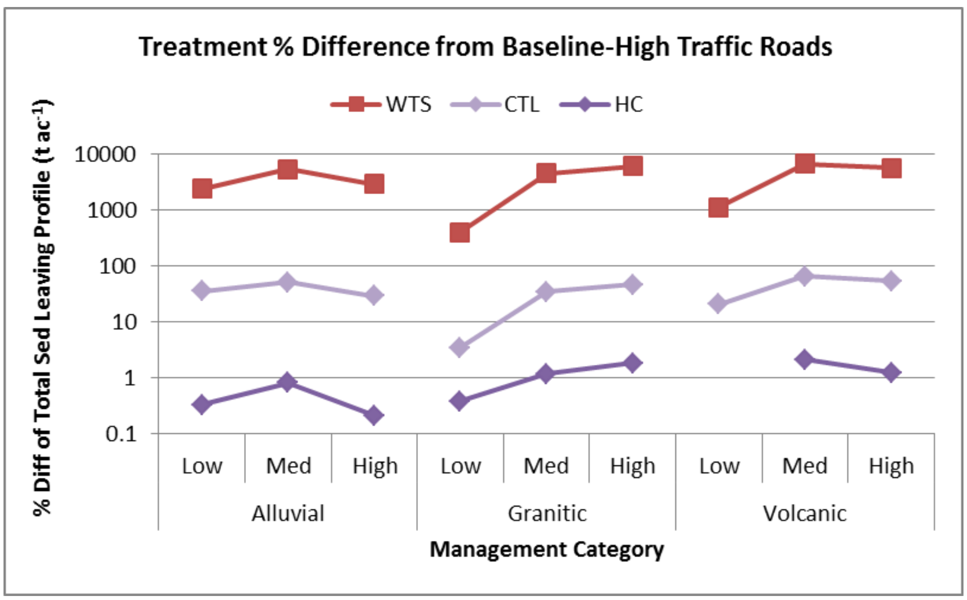

Figure 5-7. Percent difference of unit area sediment loading resulting from treatments by management category with high traffic roads (*Note: Missing data points (low slope) for HC are 0 and do not plot on a log scale*).

The results show much more stratification between the three fuel reduction treatments compared to the TBSM results generated using the literature based values. This illustrates just how sensitive the ground cover value can be for predicting sediment yield and the significant impact of including skid trails as a sizeable component (15 percent) of WTS treatment areas. The results show the greatest percent increase for WTS, followed by CTL, while HC show the lowest relative impact. Note that ground cover for HC was increased from 40 percent to 85 percent, which is much closer to the baseline value of 90 percent.

In consideration of the fact that the feasibility of applying certain fuel reduction treatments may be limited to certain management categories for physical and regulatory reasons, the percent difference of sediment loading for certain treatment-management category combinations were capped. The cap was set at the worst case loading scenario, parameterized as unpaved road in the watershed model. The factors that informed the cap are discussed fully in the Watershed Model Linkage Section 6.2 but are dependent on the underlying land use categories used in the watershed model. As a result, the caps on percent difference can vary within each management category-fuel reduction treatment combination. Figure 5-8 and Figure 5-9 present the mean capped percent differences of unit area sediment loading for low and high traffic roads, respectively.

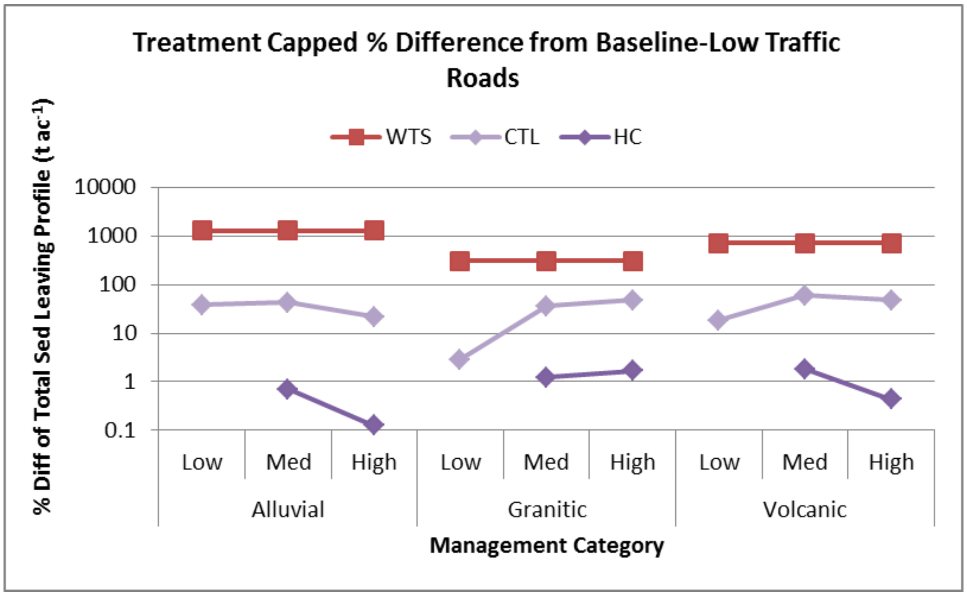

Figure 5-8. Capped percent difference of unit area sediment loading resulting from treatments by management category with low traffic roads (*Note: Missing data points (low slope) for HC are 0 and do not plot on a log scale*).

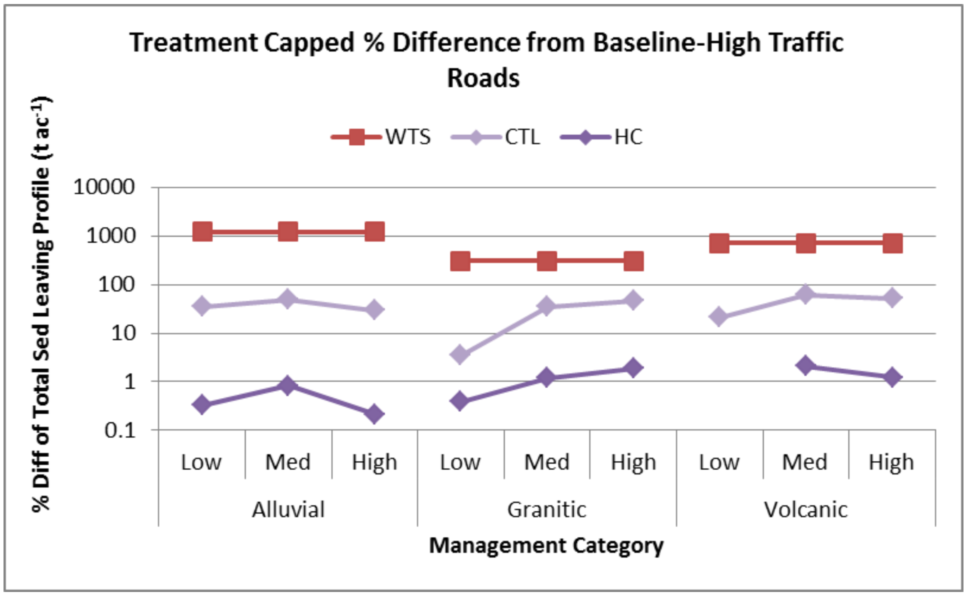

Figure 5-9. Capped percent difference of unit area sediment loading resulting from treatments by management category with high traffic roads (*Note: Missing data points (low slope) for HC are 0 and do not plot on a log scale*).

As before, all treatments result in increased sediment loading as compared to the baseline regardless of management category but with much more stratification between the different treatment impacts. The next section shows what happens when both of these sets of unit-area results are extrapolated to the watershed scale.

6. Basinwide Extrapolation

The TBSM runs discussed in the previous section provide a method for assessing relative change in sediment loading due to fuel reduction treatments on site-scale areas. The collection of modeled erosion responses were organized in terms of physical location (management category), which provides a natural link to the Lake Tahoe Watershed Model. Extrapolation of site scale modeling to the watershed model allows for the assessment of impacts on sediment loading due to fuel reduction treatments on a basinwide scale.

6.1. Fuel Reduction Treatment Extrapolation

As discussed in Section 2, spatial information on fuel reduction projects were available in three GIS data sets, the Lake Tahoe Fuel Reduction Strategy and proposed projects for the South Shore and Carnelian areas of the basin (Figure 6-1). The Fuel Reduction Strategy lays out an inter-jurisdictional plan of fuel reduction projects throughout the basin, while the South Shore and Carnelian projects represent jurisdictional projects managed by the USFS LTBMU.

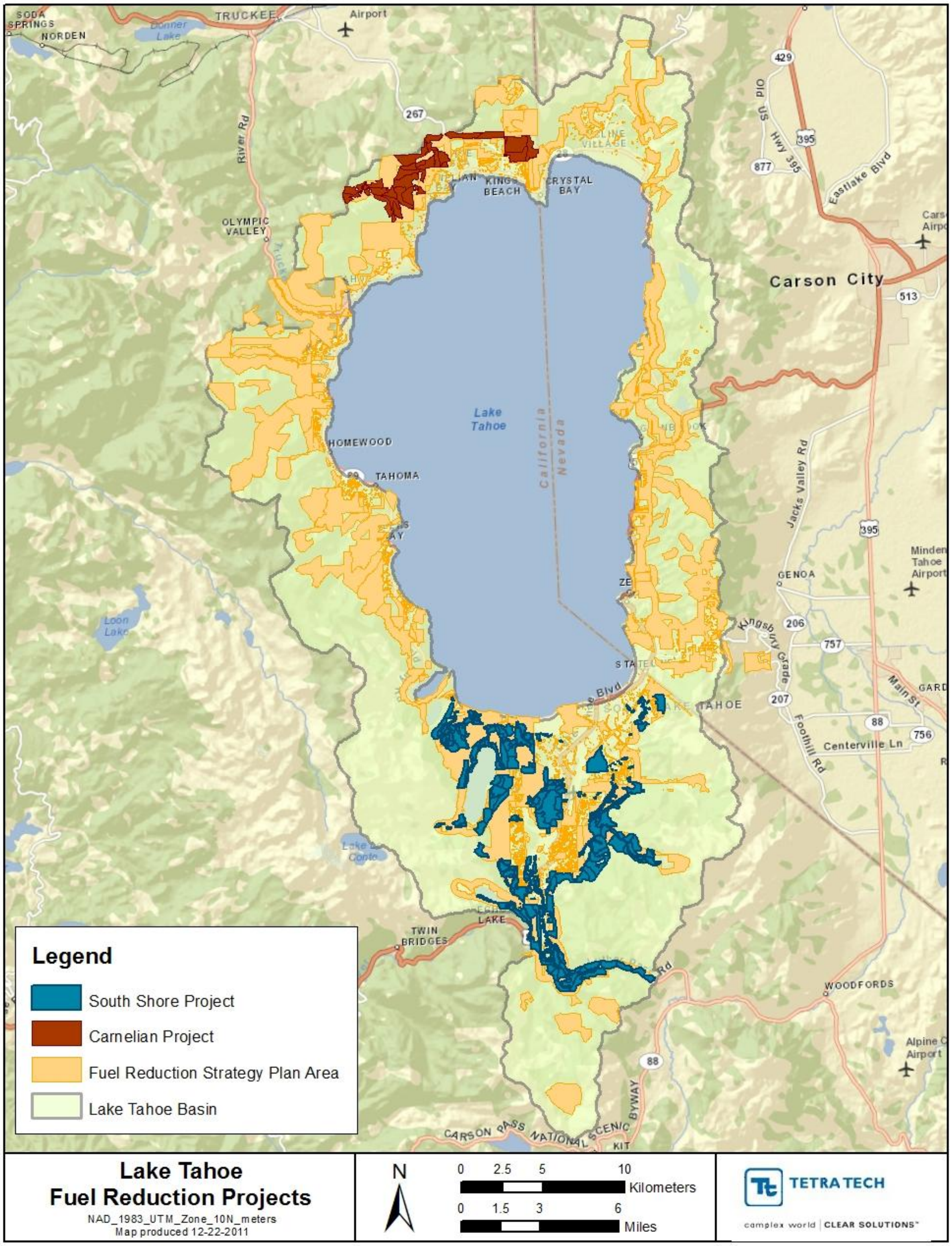

Figure 6-1. Lake Tahoe fuel reduction project areas.

Projects in the South Shore area are defined at the treatment level, while those in the Carnelian area are defined more generally as either manual or mechanical. Project treatments are not explicitly defined for all areas for the Fuels Reduction Strategy; therefore, a methodology was needed for determining the highest probable fuel reduction treatments for each of these areas, as well as for those that were only coarsely defined in the Carnelian dataset. The extrapolated data reflects a projected distribution of fuel reduction treatments throughout the basin using the Lake Tahoe Watershed Model.

According to the Fuel Reduction Strategy, ground-based mechanical thinning is generally restricted from slopes greater than 30 percent and on sensitive areas, such as stream environment zones. Alternatively, HC is generally limited to the removal of smaller trees on steeper slopes and in sensitive areas (USDA 2007). Taking into account the restrictions that slope can place on applicable project treatments, the hill slopes of proposed projects for the South Shore and Carnelian project areas were analyzed to determine if a relationship between slope and fuel reduction treatments could be defined. These projects are generally representative of USFS fuel reduction projects, which account for roughly 85 percent of all projects currently planned for the Lake Tahoe Basin (USDA 2007). Therefore, they can be considered representative of fuel reduction projects that are planned throughout the basin and, thus, form a good basis for estimating the distribution of treatments in the Fuel Reduction Strategy.

Slopes for the fuel reduction treatment areas were derived from 30-meter digital elevation models (DEMs) of the Lake Tahoe Basin (USGS 2009). The mean slopes of defined treatments within the Carnelian and South Shore project areas are presented in Table 6-1. Treatments in the South Shore area have been specifically defined as HC, CTL, or WTS. Treatments in the Carnelian area are defined more generally and include HC and mechanical treatment, which can include both CTL and WTS.

Table 6-1. Slopes of fuel reduction treatment areas in the South Shore and Carnelian project areas

General treatment	Location	Defined treatment	Min slope (%)	Max slope (%)	Mean slope (%)
Hand	Carnelian	HC	12.2%	37.0%	26.6%
	South Shore	HC	1.1%	56.1%	20.7%
Mechanical	Carnelian	Undefined	10.9%	23.6%	17.5%
	South Shore	CTL	0.1%	46.3%	8.1%
		WTS	2.5%	24.6%	11.3%

For the directly comparable treatment of HC, the mean slope of an area in both the Carnelian and South Shore project areas is greater than 20 percent (approximately 27 and 21 percent slopes, respectively). Consequently, it was determined that for slopes greater than 20 percent, HC was the most likely fuel reduction treatment to be employed.

For mechanical treatments, the Carnelian dataset indicates that the mean slope is approximately 18 percent, which is significantly steeper than the 10 percent mean slopes calculated for both of the defined mechanical treatments (WTS and CTL) in the South Shore area. Even so, it is below the 20 percent slope threshold identified for the application of HC. The South Shore data suggest that CTL operations are better suited to lower slopes than WTS. The difference in slope between the two mechanical treatments provided a basis to project that CTL operations would generally be restricted to slopes less than 10 percent, while WTS is performed on slopes between 10 and 20 percent.

Fuel reduction treatments were assigned to the Carnelian and Multi-Jurisdictional Fuels Plan areas using the slope-treatment relationship described. Because treatments areas are already defined for the South Shore project area these were not altered. In addition, for areas within the Carnelian, the general treatments already defined provided a starting point for defining practices, so that HC would not be applied in areas already defined as mechanical regardless of hill slope and vice versa.

To assign fuel reduction treatments to the Fuels Reduction Strategy Plan area a method for assigning slopes was developed using hypothetical treatment footprints. This was required because boundaries of individual treatments within the general project area are not defined, which would serve as the basis for assigning slope and applying the slope-treatment relationship.

The hypothetical footprint of treatment areas was defined as the mean area of treatments in the South Shore project area—32 acres. A grid of 32 acre squares that covered the Lake Tahoe Basin was developed in GIS and overlain with the basin boundary as shown in Figure 6-2. After the mean slope of each 32 acre parcel was calculated, the grid was overlain with the Fuels Reduction Strategy Plan area, and the treatments were assigned as described above. Treatment areas throughout the Lake Tahoe Basin are shown in Figure 6-3.

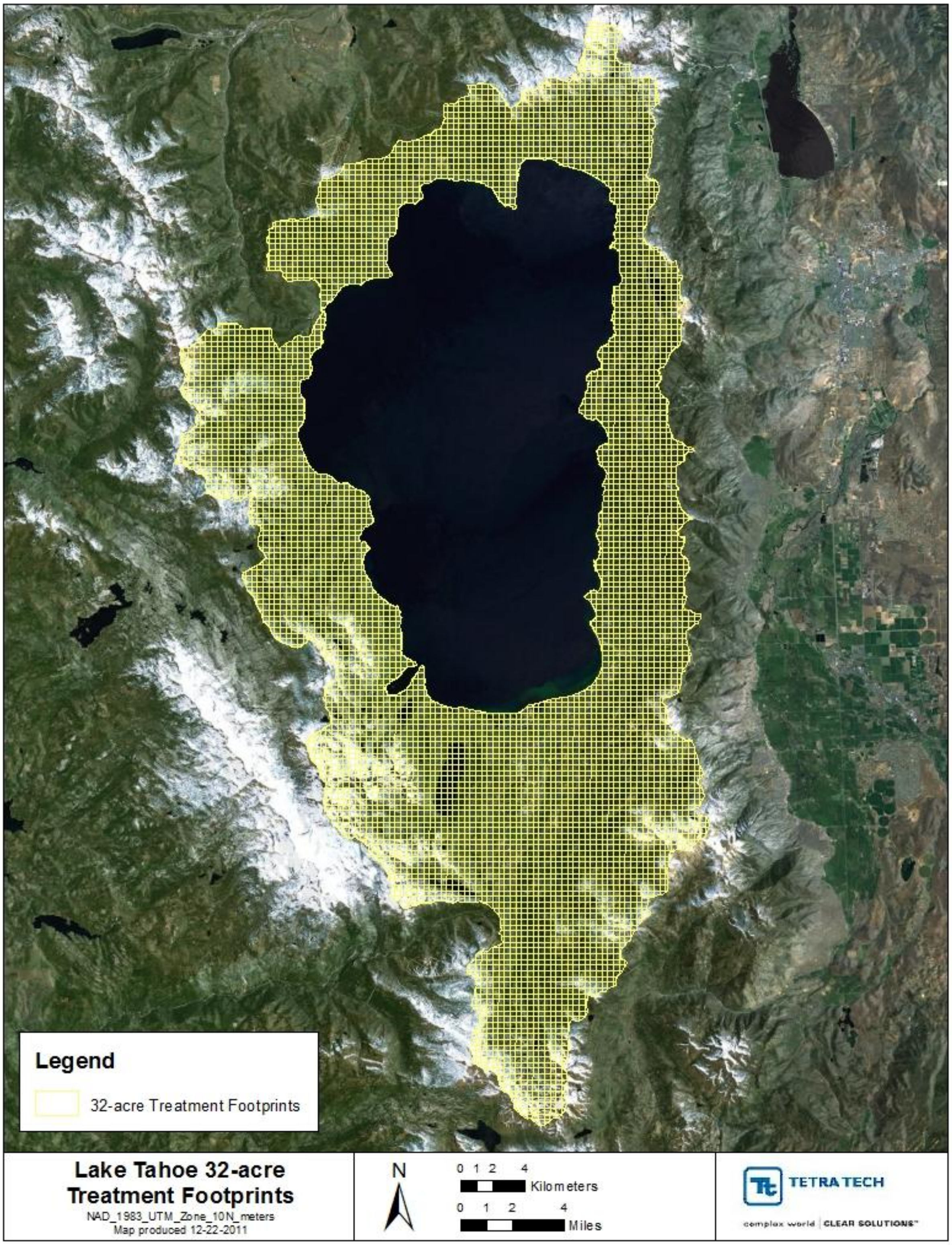

Figure 6-2. Basinwide grid of hypothetical 32-acre fuels reduction treatment areas.

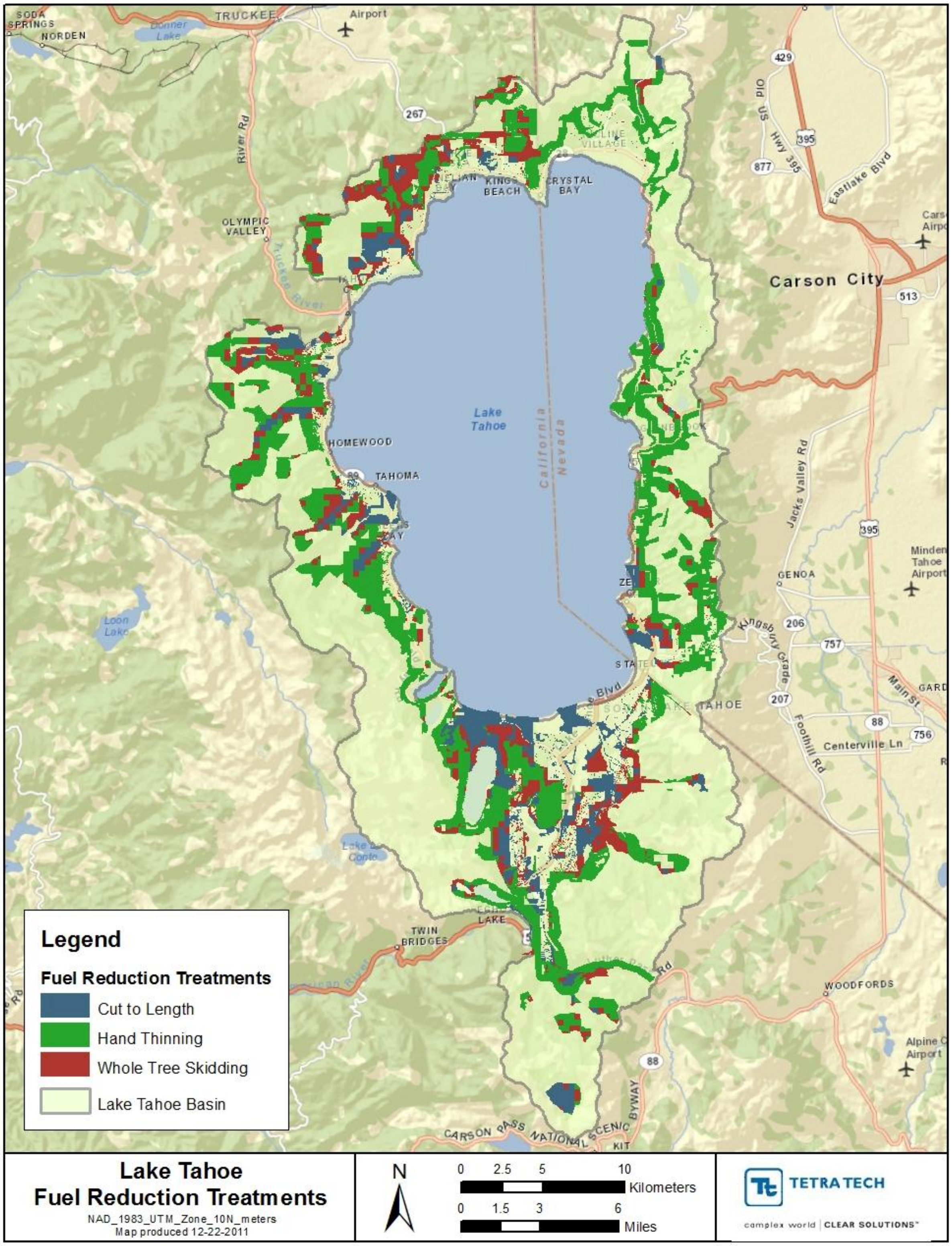

Figure 6-3. Lake Tahoe fuel reduction treatments.

As a final validation of the projected assignment of fuel reduction treatments, the treatment areas for the South Shore and Fuels Reduction Strategy projects were summarized by treatment to see if the slope-based projection approach derived from Table 6-1 was appropriate. If the distribution of fuel reduction treatments is comparable between the two, it can be concluded that the method used to perform the extrapolation from the site-scale level to the basinwide level is reasonable. As seen in Table 6-2, the distribution of treatments for the two project areas is nearly identical. This suggests the thresholds and treatment footprints selected are appropriate.

Table 6-2. Comparison of treatment areas in the Fuels Plan Strategy and South Shore

Location	Treatment	Area (acres)	% Area
Fuel Reduction Strategy	CTL	10,467	19.3%
	Hand thinning	31,974	59.1%
	WTS	11,689	21.6%
South Shore	CTL	1,970	19.6%
	Hand thinning	5,949	59.1%
	WTS	2,138	21.3%

6.2. Watershed Model Linkage

The Lake Tahoe Watershed Model was used to perform a basinwide extrapolation of site-scale responses to management actions to estimate overall changes to Lake Tahoe hydrology and pollutant loading. An overlay of the extrapolated fuel reduction treatments and management categories was mapped to the existing watershed model subwatershed network. This overlay represents treatment-management categories consisting of twenty-seven possible combinations (three fuel reduction treatments for each of the nine management categories). Once mapped to the watershed model, the management categories provided a framework to which the original watershed model land use forest erosion potential (EP) areas could be redistributed according to the projected treatment. The forest area assigned to each category was based on the extrapolated treatment areas discussed in Section 6.1 and the distribution of forest EP areas in each subwatershed. The combination of twenty-seven management categories and five forest EPs resulted in a total of 135 new potential land uses. The existing forest land event-mean concentrations (EMCs) were adjusted according to the percent difference of the baseline and fuel reduction treatment-management category site-scale TBSM sediment loads leaving the profile, as presented in Section 5. The watershed model was then run and compared to the 2004 TMDL watershed model baseline (LRWQCB & NDEP 2010) to quantify the impact of the proposed Fuel Reduction Strategy on sediment load.

Site scale EMCs were validated for each of the 135 potential new land uses, derived from a combination of fuel reduction treatment and management category, by comparing against the maximum value used in the baseline watershed model for unpaved road of 1,015 mg/L. Table 6-3 presents a summary of the fuel reduction treatments developed through site-scale modeling discussed in previous sections. Although the matrix presents a full suite of possible modeled scenario combinations for completeness, the feasibility of certain fuel reduction treatments on certain lands may be limited due to physical and regulatory reasons.

Table 6-3. Comparison of fuel reduction treatment EMCs derived from site-scale modeling

Forest Land Use	EMC mg/L	Fuel Reduction Treatment	Treatment EMC (mg/L)								
			Granitic			Volcanic			Alluvial		
			Low	Med	High	Low	Med	High	Low	Med	High
EP1	14	WTS	71	676	919	174	1,066	890	373	879	458
		CTL	14	19	21	17	23	21	19	20	17
		HC	14	14	14	14	14	14	14	14	14
EP2	37.6	WTS	191	1,815	2,468	468	2,864	2,391	1,002	2,360	1,231
		CTL	39	51	56	45	62	56	52	54	46
		HC	38	38	38	38	38	38	38	38	38
EP3	100.9	WTS	512	4,871	6,624	1,255	7,686	6,417	2,690	6,334	3,302
		CTL	104	138	150	120	167	150	139	144	123
		HC	101	102	103	101	103	101	101	102	101
EP4	270.7	WTS	1,374	13,067	17,771	3,367	20,620	17,216	7,217	16,993	8,859
		CTL	278	369	403	321	448	403	374	387	330
		HC	271	274	275	271	276	272	271	273	271
EP5	726.6	WTS	3,688	35,075	47,700	9,037	55,346	46,211	19,371	45,612	23,780
		CTL	747	991	1,082	861	1,202	1,083	1,004	1,039	885
		HC	727	736	739	727	740	730	727	732	728

Analysis of Table 6-3 shows that some site-scale estimated EMCs do go beyond the threshold of 1,015 mg/L used in the baseline watershed model for unpaved road; however, not all scenarios are realistic given environmental regulations and physical limitation of some machinery. For instance, almost every instance of WTS on high slopes results in an EMC above the unpaved road threshold; however, limitations of the equipment would likely prevent this scenario from occurring on the ground. The analysis of slope and fuel reduction treatment presented in Table 6-1shows that the maximum slope of all WTS practices planned for the South Shore is 24.1 percent while the mean slope is only 11.3 percent. The maximum slope of WTS is also well below the maximum slope of the other fuel reduction treatments. Therefore, this analysis recognizes that WTS is unlikely to occur on anything other than low slope management categories.

Further investigation of Table 6-3 shows that highest EMC values fall within the forest land use categories of EP-4 and EP-5, which represent the highest potential for sediment erosion. These categories are coincident with the most erosive soils and highest slopes. As a validation of the likely application of fuel reduction treatments in these categories, the total watershed area planned for fuel reduction treatments was summarized by EP category and is presented as Figure 6-4.

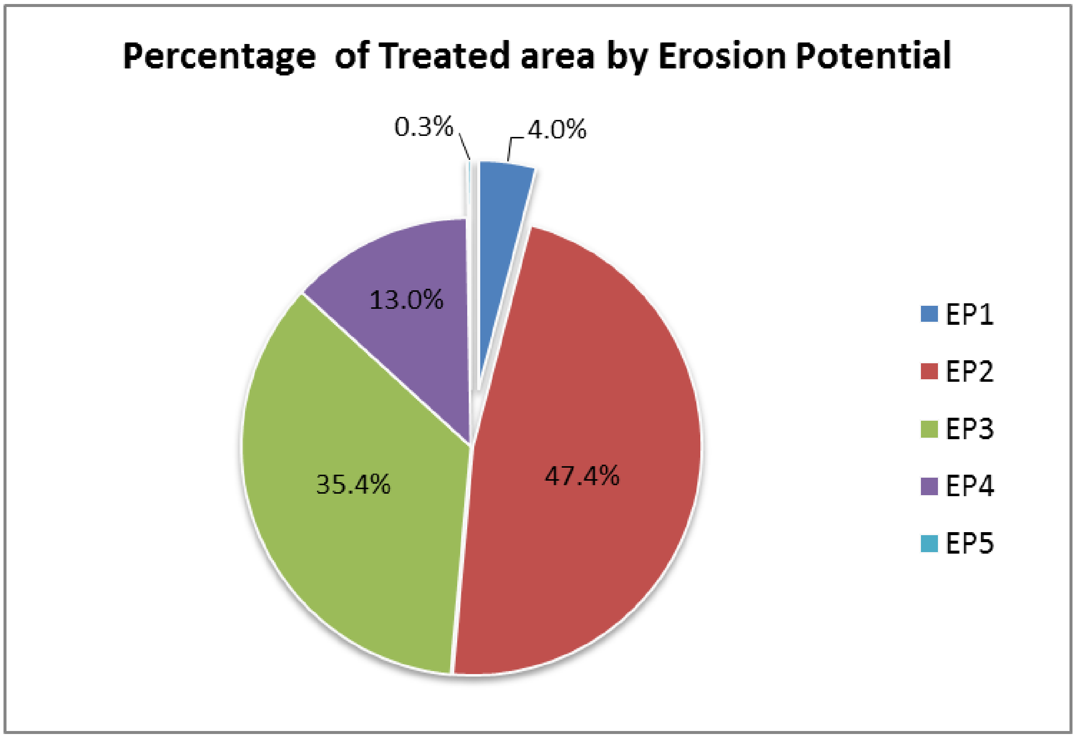

Figure 6-4. Percentage of total treated area by erosion potential.

Figure 6-4 shows that the majority of the fuel reduction treatments occur on land areas within EP-2 and EP-3. These two erosion potential groups alone account for 82 percent of the total watershed area planned for fuel reduction treatments. EP-5, which was presented in Table 6-3 as having some of the most extreme EMC values, accounts for less than 1 percent of the total area planned for fuel reduction treatments. The watershed model linkage recognizes that:

- slope and soil limitations exist on the feasible application of some fuel reduction treatments
- there is some uncertainty associated with the extent of forest BMP implementation to mitigate the effects of fuel reduction treatments
- the unpaved road EMC value of 1,015 mg/L was derived from observed data and represents a reasonable upper bound on the sediment concentration that would be expected following application of fuel reduction treatments

As such, the values presented in Table 6-3 were capped at a maximum value of 1,015 mg/L in recognition of this realistic upper boundary.

In 6 subwatersheds—3007, 3030, 5050, 6020, 6110, and 8007— the total treated area was greater than the amount of area categorized as forest (EP1 to EP5). It was initially observed that treated area sometimes included tree removal from peripheral areas of developed residential or other parcels not classified as forest, as shown in Figure 6-5 where the entire subwatershed has been targeted for treatment without accounting for developed land uses. These occurrences affected 249 of the 68,000 acres (about 0.4 percent). For example, in subwatershed 3007, 42 percent of the treated area was on land not classified as forest in the watershed model. Upon further review, it was also learned that the treated area in 3 of these 6 subwatersheds was greater than the total amount of *pervious* area in the subwatershed in some cases. For these instances, the maximum amount of managed land was capped at the total available forest land. This occurrence suggested that the planned management boundaries were probably generated at a coarser scale than the land use layer; therefore, extrapolated model results from a larger area are probably more reliable than individual subwatershed results.

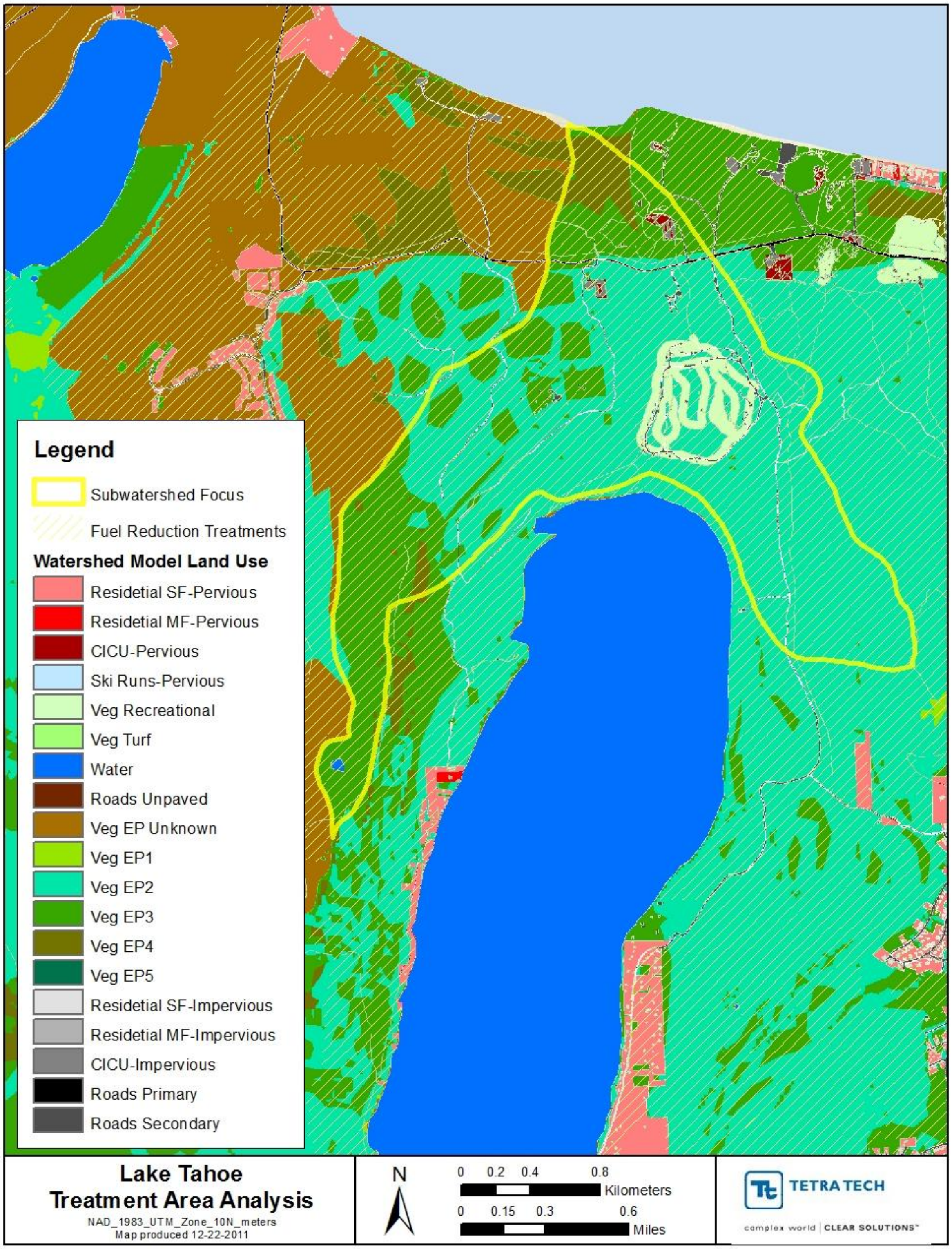

Figure 6-5. Small-scale overlay of fuel reduction treatment with land use.

7. Watershed Model Results

The percent change in upland sediment loads associated with site-scale fuel reduction treatments were extrapolated for both the South Shore project and basinwide to investigate loading change relative to TMDL baseline load from the Lake Tahoe Watershed Model. As previously described, the Watershed Model land use table was updated to include treated forest areas as defined by the extrapolated Fuels Reduction Strategy treatment areas shown in Figure 6-3 and given in Table 6-2. TBSM results for the both the literature-based and revised parameterization of the fuels reduction treatments were both extrapolated to the Lake Tahoe Watershed Model. The sections below present results in terms of change in upland sediment load relative to the Lake Tahoe Watershed Model baseline.

7.1. Literature-Based Parameterization Results

Table 7-1 presents the Lake Tahoe Watershed Model results for implementation of the Fuels Reduction Strategy Basinwide. The sediment load given represents application of the literature based fuel reduction treatment parameters and shows a 22.2 percent increase for the South Shore project area, but a 15.3 percent increase in sediment loads when projected to the basin as a whole.

Table 7-1. Lake Tahoe Watershed Model sediment loads for the baseline and implemented fuels reduction strategy conditions (literature-based TBSM parameters)

	Sediment load (tons/yr)		
Project area	Baseline model	Literature	Percent change
South Shore Project	155	190	+22.2%
Basinwide Projection	18,172	20,957	+15.3%

Figure 7-1 presents the sediment load changes at the subwatershed level. Loads increase anywhere from 0 to about 52 percent and the greatest load increases are seen in the western and northern portions of the Basin. Because the Lake Tahoe Watershed Model considers the variability of weather conditions around the basin, the results reflect increased loads in western parts of the watershed relative to the eastern part for areas having similar treatments. Also, large increases in loading predicted for the northern portion of the basin are likely linked to the high concentration of planned WTS projects in this area where volcanic soils are prevalent.

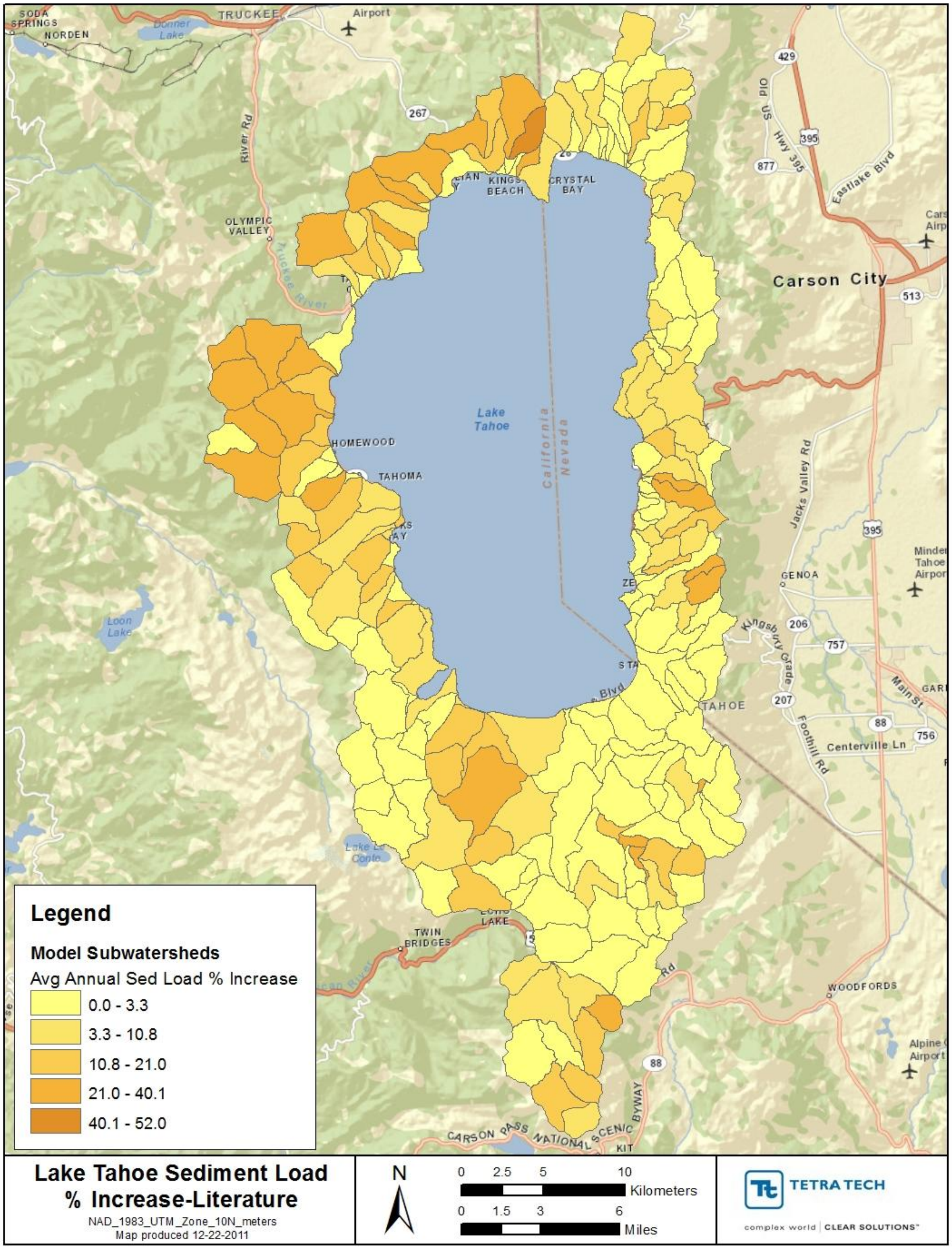

Figure 7-1. Modeled subwatershed sediment load increase (literature-based parameters).

7.2. Comparison of Literature-Based and Revised Load Projections

Table 7-2 presents the Lake Tahoe Watershed Model results for implementation of the South Shore project and the Fuels Reduction Strategy basinwide. It also includes a comparison of the extrapolated results from both the literature and the capped revised parameterization of treatments from the TBSM model runs. For the South Shore project area, the revised parameters show a larger overall impact than the estimates derived from literature. The approximately doubled sediment load for the area is essentially a result of the entire South Shore area being targeted for some type of fuel reduction treatment, including large areas targeted for WTS. When aggregated for the entire basin, the revised results again show a large increase of projected loadings (36 percent) at the field scale, but the increase is far lower than predicted for the South Shore Project area due to large portions of the basin not being targeted for treatment. It is important to note that not all of the sediment generated at the field scale reaches the lake. Assuming the same relative delivery rates for fine sediment as the TMDL baseline load, Table 7-2 also estimates the change in fine sediment load delivered to the Lake from both the South Shore and basinwide scenarios.

Table 7-2. Lake Tahoe Watershed Model Sediment Loads for the Baseline and Implemented Fuels Strategy Conditions

		Sediment load (tons/yr)		Percent change (Total sediment load)		Percent change (Fines to Lake Tahoe)	
Project area	**Baseline**	**Literature**	**Revised**	**Literature**	**Revised**	**Literature**	**Revised**
South Shore Project	155	190	312	+22.2%	+101.2%	+0.09%	+0.15%
Basinwide Projection	18,172	20,957	24,637	+15.3%	+35.6%	+10.1%	+11.7%

Figure 7-2 presents the sediment load changes at the subwatershed level for application of the revised reduction treatment parameters. Loads increase anywhere from 0 to about 247 percent and the greatest load increases are seen on the western side of the Basin, corresponding to larger annual average precipitation totals observed there. As might be expected, the largest percent change at the subwatershed scale occurs in the northwestern portion of the basin, where a large concentration of WTS is projected to occur (Figure 6-3), which when coupled with the larger precipitation totals of the area, will potentially cause significant increases in sediment loading.

There are stark differences in how both the revised and literature sets of results are manifested at the subwatershed scale due to the significant changes made (see Table 4-9) to the revised TBSM parameterization of fuel reduction treatments. Figure 7-3 presents the percent change in sediment loading between the literature and revised parameterization of the Watershed Model. Yellow and light yellow shading shows areas where the literature model runs predicted larger sediment loads, while green and blue shadings show areas where the revised runs showed larger loads. In general, the northwestern and southern portions of the Basin saw the largest increases in sediment loading for the revised model runs, while the western and eastern sides saw the largest decreases. This result is directly related to the distribution of fuel reduction treatments shown in Figure 6-3, where WTS is concentrated in the northwest and south, while HC is the dominant treatment in the west and east.

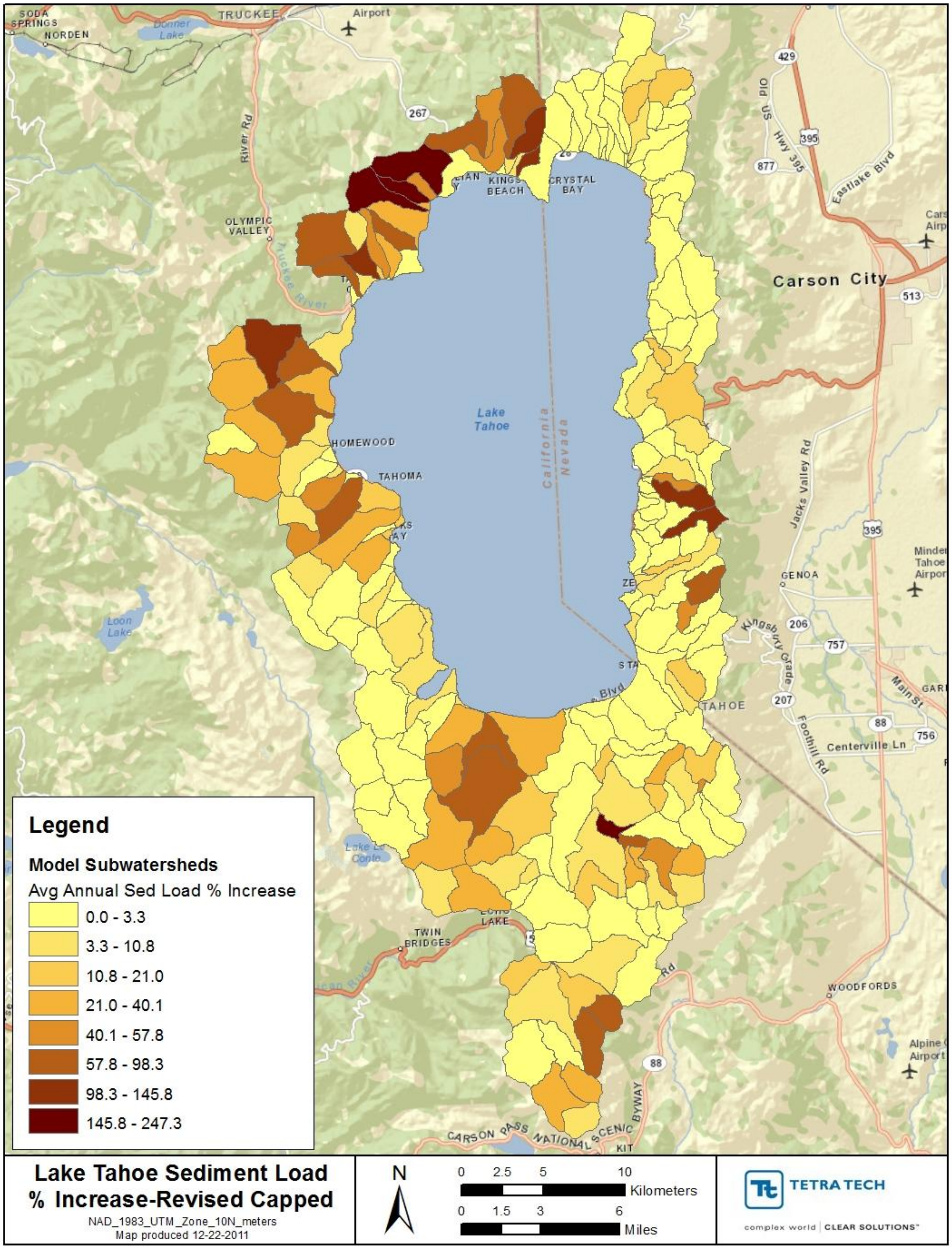

Figure 7-2. Modeled subwatershed sediment load increase (revised treatment parameters).

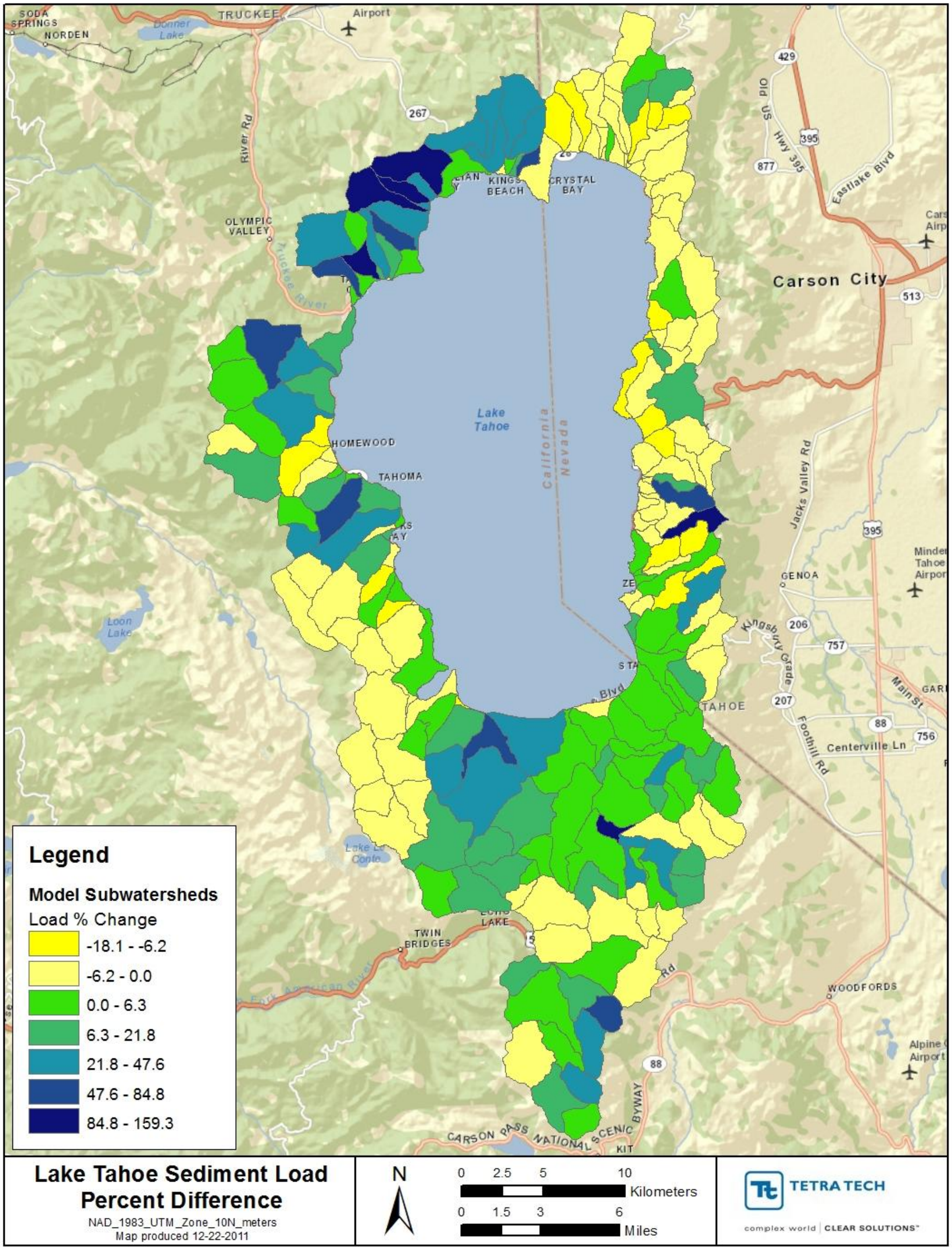

Figure 7-3. Percent change in extrapolated sediment loading between the revised and the literature-based TBSM parameterization

7.3. Revised Load Projections for the Universal Application of Individual Fuel Reduction Treatments

The revised TBSM results were used to run simulations of applying a single fuel reduction treatment throughout the Fuels Reduction Strategy Plan Area to investigate the relative impact of each. The projected annual sediment loads for the entire basin in tons per year are shown in Figure 7-4 along with percent loading increase from the baseline condition. As expected, the universal application of WTS would have the biggest impact on sediment loading increases in the basin, with the Lake Tahoe Watershed Model showing a greater than two-fold loading increase over the baseline for this scenario. The application of only CTL treatments throughout the Fuels Reduction Plan area is projected to result in approximately a 13 percent increase in annual sediment loading, while using only HC treatments would cause a less than one percent increase. The comparison of these hypothetical scenarios suggests that if the management of fuel reduction areas can be accomplished with predominantly CTL and hand thinning treatments, the impact on sediment loading to Lake Tahoe may be significantly reduced.

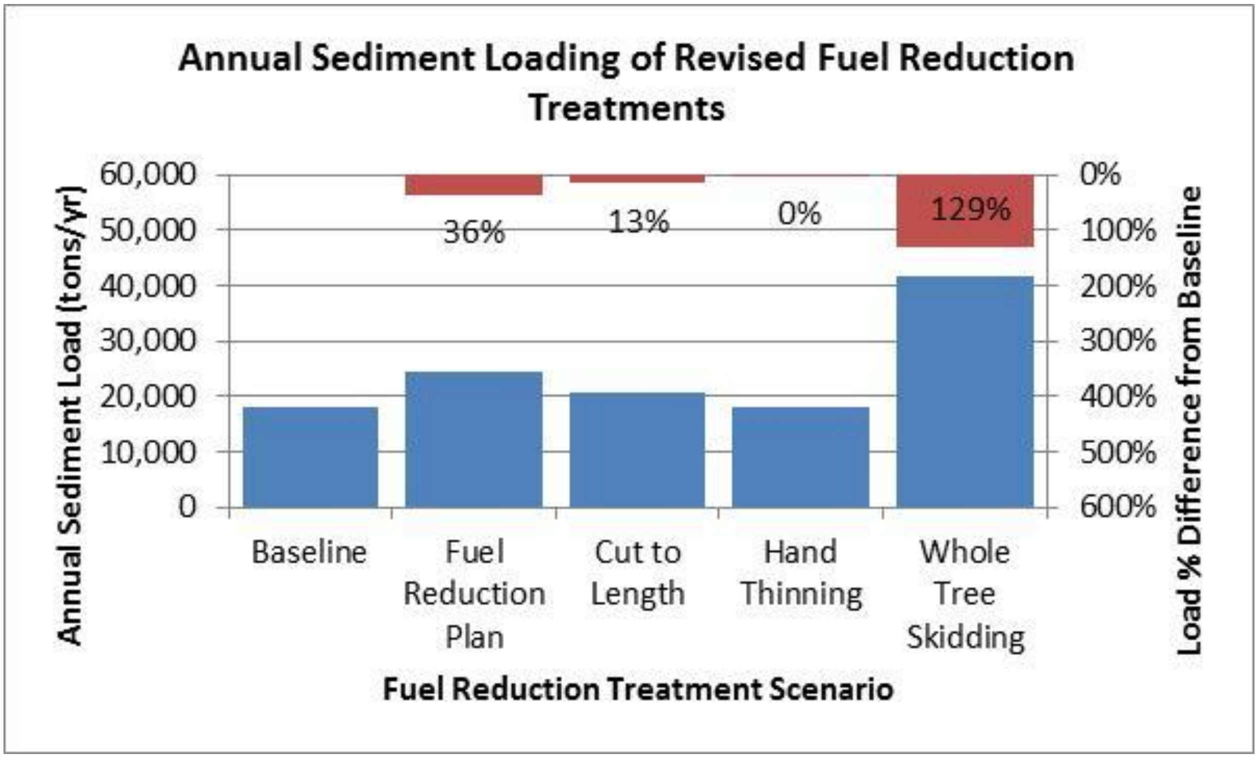

Figure 7-4. Annual sediment loading projections for applying single fuel reduction treatments throughout the Fuel Reduction Strategy Plan Area.

8. Conclusions and Recommendations

This report documents development and application of a coupled multi-scale model for extrapolating the impacts of site-scale fuel reduction treatments to the watershed level. The results of this study provide an estimated range of potential impacts associated with the proposed Fuel Reduction Strategy in the Lake Tahoe Basin. There are a number of assumptions that have been made at multiple stages of the process, the sensitivities of which have been further evaluated to better understand the potential impact that those assumptions may have on the predicted model results. The original scope of the project called for a review of existing WEPP model results from studies around the basin, from which load estimates of fuel reduction projects could be derived. These studies were not readily available to the extent needed to characterize the spatial variability of the watershed. As a result, the technical approach was revised to include developing WEPP models to characterize loadings from fuel reduction activities.

The watershed was first characterized into areas having similar physiographical and geological characteristics (i.e. management categories) that might be expected to respond similarly to the same actions. The nine management categories were based on the different combinations of slope (low, medium, high), and soil type (alluvial, granitic, volcanic). Second, a representative WEPP model run was configured for each management category to derive a WEPP baseline model run. Third, the loading impacts of three different management strategies (hand-crews, cut-to-length, whole tree skidding) was modeled on each management category, resulting in 27 possible fuel reduction response profiles, relative to the 9 WEPP baseline runs.

A number of important assumptions were made during the WEPP modeling. For example, during site-scale model development, the use of *mature forest* and even *thinned forest* vegetation yielded virtually no measurable amount of sediment. However, field experience suggests that fuel reduction treatments will potentially have more of an impact than what the TBSM model predicts. For this reason, the site-scale model was derived using a compromise of *thinned forest* vegetation for the upper WEPP segment and *poor grass* for the lower WEPP segment to represent the wild-land urban interface. A common occurrence for the practice of WTS is the creation of skid trails along the forest profile, as shown in Figure 8-1. In some cases, the fallen trees are mechanically dragged along the forest floor from the place where they are fallen down to the road, creating a degree of channelization in the landscape that potentially conveys runoff and sediment during a storm. As a result, the skid trail network resembles an artery with tributaries for conveying runoff and sediment loading during storms. Figure 8-2 shows an intersection of two unpaved forest road during a rain storm. Although this figure does not show skid trails; it illustrates how roads can act as runoff and sediment conveyances in a forest landscape. When skid trails connect to roads, the result is an extended network that allows runoff and sediment to more efficiently travel across the forest landscape, increasing the potential loading impact.

Photo Source: Douglas Cushman – Angora hazard tree inspections, October 4-5, 2010

Figure 8-1. Angora skid trails network entering a landing.

Photo Source: Douglas Cushman – Angora, October 13, 2009 Rain Storm

Figure 8-2. Unpaved forest roads during a rain storm.

In order to estimate watershed-scale response of fuel reduction, the South Shore project was super-imposed upon the map of management categories. This exercise revealed a convincing relationship between management category and the type fuel reduction that was conducted. For example, the more intensive practices (CTL, WTS) were done on land with lower slopes and more stable soils, while less intensive practices (HC) were done on steeper slopes with less stable soils. On the basis of the South Shore fuel reduction project overlay, management categories were used to extrapolate the most likely fuel reduction activities across the basin. Finally, the *relative* percent change in loading between the WEPP fuel reduction and WEPP baseline runs was super-imposed on the TMDL baseline by spatially adjusting EMCs accordingly. Some of the key assumptions are listed below:.

- All model results are relative estimated relative to the TMDL baseline, and does not consider any of the pollutant reduction opportunities associated with TMDL implementation.
- The extrapolation assumes complete implementation of the 10-year Fuel Reduction Strategy at a single point in time.
- The model assumes a constant spatial footprint of the management activities (at the moment of application) throughout the entire simulation. Decommissioning of temporary roads does not occur. In practice not all roads will remain active; furthermore, erosion impact will be mitigated in time through regrowing ground cover or with litter from fuel reduction treatments.

There is also an important distinction to draw between (1) total sediment yield from the land, (2) the distribution of particles sizes from different land use categories, (3) and increased loading of fine sediment to Lake Tahoe. The Lake Tahoe TMDL is focused on lake clarity, which is most affected by the presence of fine sediment particles. Coarser particles, like sand, tend to settle out rather than remain in the lake water column where they can influence clarity. This study focused on the potential for increases in total sediment fluxes from forest lands from fuel reduction treatment activities. Estimates of sediment load increase presented in Table 7-2 are total sediment load, both coarse and fine particles. The particle size distribution varies between land uses, for instance the TMDL baseline used a particle distribution for forest that is weighted towards coarse, larger particles. Therefore, with respect to forested land in this study, of the 35.6% increase in total sediment load basinwide estimated using the revised site-scale model parameters, a smaller proportion of that increased load would be attributable to fine sediment particles.

To test the sensitivity of certain WEPP modeling assumptions, two fuel reduction treatment scenarios were conducted in this study using TBSM ground cover parameters. The first scenario used model parameter values derived from review of USFS literature, while the second used a set of revised values based on field observations of documented site conditions from previous fuel reduction activities. The literature-based values generally had higher ground cover values than the revised scenario because they probably reflected the impact of extensive implementation of mitigating practices and BMPs such as waterbars, mulch, forest litter or other material used to cover exposed soil. By running two sets of assumptions, this study bracketed the expected range of impacts that could be reasonably expected from planned fuel reduction treatment activities in the Lake Tahoe Basin. Implementation of advanced BMPs or other erosion mitigation measures not explicitly modeled in this study could result in impacts to total sediment yield lower than those scenarios presented in Table 7-2.

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10. Appendices

Appendix A: WEPP Modeling Online Interface—Interfaces Parameter Comparison

The Water Erosion Prediction Project (WEPP) Fuel Management Erosion Analysis (FuME) online tool was developed to estimate erosion impacts from common fuel management activities including prescribed burning, mechanical thinning, low-impact thinning technologies, and low/high traffic roads. This model interface integrates two other online tools designed specifically for modeling forest roads and disturbances such as fuel management activities. The Tahoe Basin Sediment Model (TBSM) is a publicly available, customized interface of the WEPP model specifically parameterized for the Lake Tahoe Basin. The online interfaces provide a user-friendly environmental for modeling and ensure some degree of quality control for a complex modeling package. To fully describe a soil profile, WEPP uses twenty-four unique parameters (Elliot and Hall 2010).

Both models were considered and evaluated for performing site-scale sediment modeling of fuel reduction activities. The functionality of WEPP FuME makes it an ideal tool for evaluating the erosion response to a range of fuel reduction activities on forested land; however, the generic parameterization of the WEPP model needs to be further evaluated for use in the Lake Tahoe Basin.

The major difference in these online modeling interfaces is the parameterization of the WEPP soil properties. The TBSM provides three choices of soils categorized as granitic, volcanic, and alluvial. WEPP FuME categorizes soil types slightly different providing the user with three choices of clay loam, silt loam, and sandy loam. These broad categories offer little detail about the underlying properties that are used when modeling a hillslope. Further evaluation of the internal WEPP parameters for old growth forest and thinned forest treatment types was performed for each of the models described above.

A complete profile of the available soil parameters was documented and included as Appendix A and Appendix B below. The most sensitive soil parameter in the WEPP model is effective hydraulic conductivity (K_{eff}), which controls the rate at which water can infiltrate the soil column (Alberts et al. 1995). The soil particle content, percent sand and percent clay, are also key parameters that affect the void space and control the flow paths through the soil profile. These two particle types also erode and settle under different conditions and have different water quality effects when introduced into receiving waters.

A summary of these three key parameters described above for the WEPP FuME model is presented below in Table 10-1. Effective hydraulic conductivity ranges from 23 to 42 mm/hr. The percent sand content varies from 25 to 55 percent while the percent clay content varies from 10 to 30 percent.

Table 10-1. Summary of Soil Parameters for WEPP FuME model

Scenario	Soil Type	K_{eff} (mm/hr)	Sand (%)	Clay (%)
Mature Forest	Clay Loam	35	25%	30%
	Silt Loam	28	25%	15%
	Sandy Loam	42	55%	10%
Thinned Forest	Clay Loam	33	25%	30%
	Silt Loam	23	25%	15%
	Sandy Loam	40	55%	10%

A summary of these three key parameters described above for the TBSM is presented below as Table 10-2. Effective hydraulic conductivity values are generally higher than those in WEPP FuME ranging from 30 to 45 mm/hr; however, differences in the sand and clay content are even more noticeable from WEPP FuME. Sand content is generally two times higher in the TBSM ranging from 60 to 90 percent, while clay content is less than half ranging from 2 to 10 percent.

Table 10-2. Summary of Soil Parameters for WEPP TBSM

Scenario	Soil Type	K_{eff} (mm/hr)	Sand (%)	Clay (%)
Mature Forest	Granitic	45	90%	2%
	Volcanic	40	65%	7%
	Alluvial	35	60%	10%
Thinned Forest	Granitic	40	90%	2%
	Volcanic	35	65%	7%
	Alluvial	30	60%	10%

Both low and high traffic roads were evaluated as additional treatment scenarios when considering the erosion response from creating or decommissioning forest service access roads. These scenarios are presented below as Table 10-3 for WEPP FuME and Table 10-4 for the TBSM. Note that the effective hydraulic conductivity changes when modeling roads, but the soil particle content does not change from the scenarios evaluated above.

Table 10-3. Summary of Road Soil Properties for WEPP FuME

Scenario	Soil Type	K_{eff} (mm/hr)	Sand (%)	Clay (%)
High Traffic Road	Clay Loam	6.3	30%	30%
	Silt Loam	8.9	30%	15%
	Sandy Loam	12.5	65%	5%
Low Traffic Road	Clay Loam	6.3	30%	30%
	Silt Loam	8.9	30%	15%
	Sandy Loam	12.5	65%	5%

Table 10-4. Summary of Road Soil Properties for WEPP TBSM

Scenario	Soil Type	K_{eff} (mm/hr)	Sand (%)	Clay (%)
High Traffic Road	Granitic	10	90%	2%
	Volcanic	8	65%	7%
	Alluvial	6	60%	10%
Low Traffic Road	Granitic	10	90%	2%
	Volcanic	8	65%	7%
	Alluvial	6	60%	10%

Discussion

While the WEPP FuME interface is easily run and includes a comprehensive list of scenarios covering fuel management activities (thinning, prescribed burns, etc.), the limitations on model parameterization lead to the conclusion that it is not necessarily applicable to the Lake Tahoe Basin. One of the most important to the assumption of clay content for all soils types, which is much higher than the values used in the TBSM. This assumption could prove problematic for this analysis, which seeks to quantify overall impact to fine sediment loading. Using WEPP FuME would likely overestimate the quantity of fine sediment in the baseline soils.

The TBSM, while not intrinsically as comprehensive as WEPP FuME, is capable of running the same range of scenarios through more manual user interaction. For each model run the user selects a treatment for the upper and lower hillslope elements. The type of treatment selected is then modeled by changing four key WEPP parameters, including plant height, leaf area index and root depth; percent live biomass; soil till and interrill erodibility; and hydraulic conductivity (Elliot and Hall 2010). Table 10-5 presents the list of the available treatment types, and the corresponding default parameter values for hydraulic conductivity and percent cover, for each of the three soil types.

Table 10-5. Key parameter Values by Soil and Treatment Type

Treatment Type	Granitic K_{eff} (mm/hr)	Granitic Cover (%)	Volcanic K_{eff} (mm/hr)	Volcanic Cover (%)	Alluvial K_{eff} (mm/hr)	Alluvial Cover (%)
Mature Forest	45	100%	40	100%	35	100%
Thin Forest	40	100%	35	100%	30	100%
Shrubs	35	80%	30	80%	25	80%
Good Grass	35	60%	25	60%	20	60%
Poor Grass	25	40%	20	40%	15	40%
Low Severity Fire	20	85%	15	85%	10	85%
High Severity Fire	15	45%	10	45%	8	45%
Base	25	--	20	--	15	--
Mulch Only	30	20%	25	20%	20	20%
Mulch & Till	35	80%	30	80%	25	80%
Low Traffic Road	10	10%	8	10%	6	10%
High Traffic Road	10	10%	8	10%	6	10%
Skid Trail	10	10%	8	10%	6	10%

Individual hillslope models can be developed for each management activity included in the multi-jurisdictional fuel reduction plan as described above in Table 10-5. The values for percent cover could also be used-defined; however, the hydraulic conductivity is not variable. Several strategies are available for integrating these site-scale sediment delivery results with the Loading Simulation Program in C++

(LSPC) watershed model, including representation as an event-mean concentration or a percent increase in sediment yield over an agreed upon baseline condition.

Appendix B: Tahoe Basin Sediment Model Soil Parameters

Table 10-6. Mature Forest, Granitic Soils

Parameter	Value	Units
Albedo of the bare dry surface soil	0.1	
Initial saturation level of the soil profile	0.5	m/m
Baseline interrill erodibility parameter (k_i)	250,000	kg-s/m^4
Baseline rill erodibility parameter (k_r)	0.00003	s/m
Baseline critical shear parameter	4	N-m^2
Effective hydraulic conductivity	45	mm/hr
Depth from soil surface	800	mm
Percentage of sand	90	%
Percentage of clay	2	%
Percentage of organic matter	6	%
Cation exchange capacity	4	meq/100g
Percentage of rock fragments	20	%

Table 10-7. Thinned Forest, Granitic Soils

Parameter	Value	Units
Albedo of the bare dry surface soil	0.1	
Initial saturation level of the soil profile	0.5	m/m
Baseline interrill erodibility parameter (k_i)	400,000	kg-s/m^4
Baseline rill erodibility parameter (k_r)	0.00004	s/m
Baseline critical shear parameter	4	N-m^2
Effective hydraulic conductivity	40	mm/h
Depth from soil surface	600	mm
Percentage of sand	90	%
Percentage of clay	2	%
Percentage of organic matter	5	%
Cation exchange capacity	4	meq/100g
Percentage of rock fragments	20	%

Table 10-8. Mature Forest, Volcanic Soils

Parameter	Value	Units
Albedo of the bare dry surface soil	0.1	
Initial saturation level of the soil profile	0.5	m/m
Baseline interrill erodibility parameter (k_i)	600,000	kg-s/m^4
Baseline rill erodibility parameter (k_r)	0.00002	s/m
Baseline critical shear parameter	1.5	N-m^2
Effective hydraulic conductivity	40	mm/h
Depth from soil surface	800	mm
Percentage of sand	65	%
Percentage of clay	7	%
Percentage of organic matter	6	%
Cation exchange capacity	9	meq/100g
Percentage of rock fragments	20	%

Table 10-9. Thinned Forest, Volcanic Soils

Parameter	Value	Units
Albedo of the bare dry surface soil	0.1	
Initial saturation level of the soil profile	0.5	m/m
Baseline interrill erodibility parameter (k_i)	700,000	kg-s/m^4
Baseline rill erodibility parameter (k_r)	0.00003	s/m
Baseline critical shear parameter	1.5	N-m^2
Effective hydraulic conductivity	35	mm/h
Depth from soil surface	600	mm
Percentage of sand	65	%
Percentage of clay	7	%
Percentage of organic matter	5	%
Cation exchange capacity	9	meq/100g
Percentage of rock fragments	20	%

Table 10-10. Mature Forest, Alluvial Soils

Parameter	Value	Units
Albedo of the bare dry surface soil	0.1	
Initial saturation level of the soil profile	0.5	m/m
Baseline interrill erodibility parameter (k_i)	500,000	kg-s/m^4
Baseline rill erodibility parameter (k_r)	0.00001	s/m
Baseline critical shear parameter	1	N-m^2
Effective hydraulic conductivity	35	mm/h
Depth from soil surface	900	mm
Percentage of sand	60	%
Percentage of clay	10	%
Percentage of organic matter	7	%
Cation exchange capacity	13	meq/100g
Percentage of rock fragments	20	%

Table 10-11. Thinned Forest, Alluvial Soils

Parameter	Value	Units
Albedo of the bare dry surface soil	0.1	
Initial saturation level of the soil profile	0.5	m/m
Baseline interrill erodibility parameter (k_i)	600,000	kg-s/m^4
Baseline rill erodibility parameter (k_r)	0.00002	s/m
Baseline critical shear parameter	1	N-m^2
Effective hydraulic conductivity	30	mm/h
Depth from soil surface	700	mm
Percentage of sand	60	%
Percentage of clay	10	%
Percentage of organic matter	6	%
Cation exchange capacity	13	meq/100g
Percentage of rock fragments	20	%

Table 10-12. High Traffic Road, Granitic Soils

Parameter	Value	Units
Albedo of the bare dry surface soil	0.2	
Initial saturation level of the soil profile	0.75	m/m
Baseline interrill erodibility parameter (k_i)	900,000	kg-s/m^4
Baseline rill erodibility parameter (k_r)	0.005	s/m
Baseline critical shear parameter	4	N-m^2
Effective hydraulic conductivity	10	mm/h
Depth from soil surface	200	mm
Percentage of sand	90	%
Percentage of clay	2	%
Percentage of organic matter	1	%
Cation exchange capacity	2	meq/100g
Percentage of rock fragments	50	%

Table 10-13. Low Traffic Road, Granitic Soils

Parameter	Value	Units
Albedo of the bare dry surface soil	0.2	
Initial saturation level of the soil profile	0.75	m/m
Baseline interrill erodibility parameter (k_i)	225,000	kg-s/m^4
Baseline rill erodibility parameter (k_r)	0.0013	s/m
Baseline critical shear parameter	4	N-m^2
Effective hydraulic conductivity	10	mm/h
Depth from soil surface	200	mm
Percentage of sand	90	%
Percentage of clay	2	%
Percentage of organic matter	1	%
Cation exchange capacity	2	meq/100g
Percentage of rock fragments	20	%

Table 10-14. High Traffic Road, Volcanic Soils

Parameter	Value	Units
Albedo of the bare dry surface soil	0.2	
Initial saturation level of the soil profile	0.75	m/m
Baseline interrill erodibility parameter (k_i)	1,000,000	kg-s/m^4
Baseline rill erodibility parameter (k_r)	0.004	s/m
Baseline critical shear parameter	1.5	N-m^2
Effective hydraulic conductivity	8	mm/h
Depth from soil surface	200	mm
Percentage of sand	65	%
Percentage of clay	7	%
Percentage of organic matter	1	%
Cation exchange capacity	7	meq/100g
Percentage of rock fragments	50	%

Table 10-15. Low Traffic Road, Volcanic Soils

Parameter	Value	Units
Albedo of the bare dry surface soil	0.2	
Initial saturation level of the soil profile	0.75	m/m
Baseline interrill erodibility parameter (k_i)	250,000	kg-s/m^4
Baseline rill erodibility parameter (k_r)	0.001	s/m
Baseline critical shear parameter	1.5	N-m^2
Effective hydraulic conductivity	8	mm/h
Depth from soil surface	200	mm
Percentage of sand	65	%
Percentage of clay	7	%
Percentage of organic matter	1	%
Cation exchange capacity	7	meq/100g
Percentage of rock fragments	20	%

Table 10-16. High Traffic Road, Alluvial Soils

Parameter	Value	Units
Albedo of the bare dry surface soil	0.2	
Initial saturation level of the soil profile	0.75	m/m
Baseline interrill erodibility parameter (k_i)	950,000	kg-s/m^4
Baseline rill erodibility parameter (k_r)	0.003	s/m
Baseline critical shear parameter	1	N-m^2
Effective hydraulic conductivity	6	mm/h
Depth from soil surface	200	mm
Percentage of sand	60	%
Percentage of clay	10	%
Percentage of organic matter	1	%
Cation exchange capacity	10	meq/100g
Percentage of rock fragments	50	%

Table 10-17. Low Traffic Road, Alluvial Soils

Parameter	Value	Units
Albedo of the bare dry surface soil	0.2	
Initial saturation level of the soil profile	0.75	m/m
Baseline interrill erodibility parameter (k_i)	240,000	kg-s/m^4
Baseline rill erodibility parameter (k_r)	0.0008	s/m
Baseline critical shear parameter	1	N-m^2
Effective hydraulic conductivity	6	mm/h
Depth from soil surface	200	mm
Percentage of sand	60	%
Percentage of clay	10	%
Percentage of organic matter	1	%
Cation exchange capacity	10	meq/100g
Percentage of rock fragments	20	%

Appendix C: WEPP FuME Soil Parameters

Table 10-18. Mature Forest, Clay Loam Soils

Parameter	Value	Units
Albedo of the bare dry surface soil	0.06	
Initial saturation level of the soil profile	0.5	m/m
Baseline interrill erodibility parameter (k_i)	400,000	kg-s/m^4
Baseline rill erodibility parameter (k_r)	0.0002	s/m
Baseline critical shear parameter	1	N-m^2
Effective hydraulic conductivity	35	mm/hr
Depth from soil surface	400	mm
Percentage of sand	25	%
Percentage of clay	30	%
Percentage of organic matter	5	%
Cation exchange capacity	25	meq/100g
Percentage of rock fragments	20	%

Table 10-19. Thinned Forest, Clay Loam Soils

Parameter	Value	Units
Albedo of the bare dry surface soil	0.06	
Initial saturation level of the soil profile	0.5	m/m
Baseline interrill erodibility parameter (k_i)	400,000	kg-s/m^4
Baseline rill erodibility parameter (k_r)	0.0002	s/m
Baseline critical shear parameter	1	N-m^2
Effective hydraulic conductivity	33	mm/h
Depth from soil surface	400	mm
Percentage of sand	25	%
Percentage of clay	30	%
Percentage of organic matter	5	%
Cation exchange capacity	25	meq/100g
Percentage of rock fragments	20	%

Table 10-20. Mature Forest, Silt Loam

Parameter	Value	Units
Albedo of the bare dry surface soil	0.06	
Initial saturation level of the soil profile	0.5	m/m
Baseline interrill erodibility parameter (k_i)	1,000,000	kg-s/m^4
Baseline rill erodibility parameter (k_r)	0.0004	s/m
Baseline critical shear parameter	0.5	N-m^2
Effective hydraulic conductivity	28	mm/h
Depth from soil surface	400	mm
Percentage of sand	25	%
Percentage of clay	15	%
Percentage of organic matter	5	%
Cation exchange capacity	15	meq/100g
Percentage of rock fragments	20	%

Table 10-21. Thinned Forest, Silt Loam

Parameter	Value	Units
Albedo of the bare dry surface soil	0.06	
Initial saturation level of the soil profile	0.5	m/m
Baseline interrill erodibility parameter (k_i)	1,000,000	kg-s/m^4
Baseline rill erodibility parameter (k_r)	0.0004	s/m
Baseline critical shear parameter	0.5	N-m^2
Effective hydraulic conductivity	23	mm/h
Depth from soil surface	400	mm
Percentage of sand	25	%
Percentage of clay	15	%
Percentage of organic matter	5	%
Cation exchange capacity	15	meq/100g
Percentage of rock fragments	20	%

Table 10-22. Mature Forest, Sandy Loam

Parameter	Value	Units
Albedo of the bare dry surface soil	0.06	
Initial saturation level of the soil profile	0.5	m/m
Baseline interrill erodibility parameter (k_i)	400,000	kg-s/m^4
Baseline rill erodibility parameter (k_r)	0.0005	s/m
Baseline critical shear parameter	1	N-m^2
Effective hydraulic conductivity	42	mm/h
Depth from soil surface	400	mm
Percentage of sand	55	%
Percentage of clay	10	%
Percentage of organic matter	5	%
Cation exchange capacity	15	meq/100g
Percentage of rock fragments	20	%

Table 10-23. Thinned Forest, Sandy Loam

Parameter	Value	Units
Albedo of the bare dry surface soil	0.06	
Initial saturation level of the soil profile	0.5	m/m
Baseline interrill erodibility parameter (k_i)	400,000	kg-s/m^4
Baseline rill erodibility parameter (k_r)	0.0005	s/m
Baseline critical shear parameter	1	N-m^2
Effective hydraulic conductivity	40	mm/h
Depth from soil surface	400	mm
Percentage of sand	55	%
Percentage of clay	10	%
Percentage of organic matter	5	%
Cation exchange capacity	15	meq/100g
Percentage of rock fragments	20	%

Table 10-24. High Traffic Road, Clay Loam

Parameter	Value	Units
Albedo of the bare dry surface soil	0.12	
Initial saturation level of the soil profile	0.45	m/m
Baseline interrill erodibility parameter (k_i)	1.5E+6	kg-s/m^4
Baseline rill erodibility parameter (k_r)	0.0002	s/m
Baseline critical shear parameter	2.0	N-m^2
Effective hydraulic conductivity	6.3	mm/h
Depth from soil surface	300	mm
Percentage of sand	30	%
Percentage of clay	30	%
Percentage of organic matter	4	%
Cation exchange capacity	26	meq/100g
Percentage of rock fragments	20	%

Table 10-25. Low Traffic Road, Clay Loam

Parameter	Value	Units
Albedo of the bare dry surface soil	0.12	
Initial saturation level of the soil profile	0.45	m/m
Baseline interrill erodibility parameter (k_i)	1.5E+6	kg-s/m^4
Baseline rill erodibility parameter (k_r)	0.0002	s/m
Baseline critical shear parameter	2.0	N-m^2
Effective hydraulic conductivity	6.3	mm/h
Depth from soil surface	300	mm
Percentage of sand	30	%
Percentage of clay	30	%
Percentage of organic matter	4	%
Cation exchange capacity	26	meq/100g
Percentage of rock fragments	20	%

Table 10-26. High Traffic Road, Silt Loam

Parameter	Value	Units
Albedo of the bare dry surface soil	0.6	
Initial saturation level of the soil profile	0.5	m/m
Baseline interrill erodibility parameter (k_i)	2.0E+6	kg-s/m^4
Baseline rill erodibility parameter (k_r)	0.0003	s/m
Baseline critical shear parameter	10	N-m^2
Effective hydraulic conductivity	8.9	mm/h
Depth from soil surface	300	mm
Percentage of sand	30	%
Percentage of clay	15	%
Percentage of organic matter	4	%
Cation exchange capacity	13	meq/100g
Percentage of rock fragments	20	%

Table 10-27. Low Traffic Road, Silt Loam

Parameter	Value	Units
Albedo of the bare dry surface soil	0.6	
Initial saturation level of the soil profile	0.5	m/m
Baseline interrill erodibility parameter (k_i)	2.0E+6	kg-s/m^4
Baseline rill erodibility parameter (k_r)	0.0003	s/m
Baseline critical shear parameter	10	N-m^2
Effective hydraulic conductivity	8.9	mm/h
Depth from soil surface	300	mm
Percentage of sand	30	%
Percentage of clay	15	%
Percentage of organic matter	4	%
Cation exchange capacity	13	meq/100g
Percentage of rock fragments	20	%

Table 10-28. High Traffic Road, Sandy Loam

Parameter	Value	Units
Albedo of the bare dry surface soil	0.12	
Initial saturation level of the soil profile	0.45	m/m
Baseline interrill erodibility parameter (k_i)	2.0E+6	kg-s/m^4
Baseline rill erodibility parameter (k_r)	0.0004	s/m
Baseline critical shear parameter	2	N-m^2
Effective hydraulic conductivity	12.5	mm/h
Depth from soil surface	300	mm
Percentage of sand	60	%
Percentage of clay	5	%
Percentage of organic matter	4	%
Cation exchange capacity	4	meq/100g
Percentage of rock fragments	20	%

Table 10-29. Low Traffic Road, Sandy Loam

Parameter	Value	Units
Albedo of the bare dry surface soil	0.12	
Initial saturation level of the soil profile	0.45	m/m
Baseline interrill erodibility parameter (k_i)	2.0E+6	kg-s/m^4
Baseline rill erodibility parameter (k_r)	0.0004	s/m
Baseline critical shear parameter	2	N-m^2
Effective hydraulic conductivity	12.5	mm/h
Depth from soil surface	300	mm
Percentage of sand	60	%
Percentage of clay	5	%
Percentage of organic matter	4	%
Cation exchange capacity	4	meq/100g
Percentage of rock fragments	20	%