Synthesis of LTBMU Fuels Reduction Project Soil Quality Monitoring Results
Period of Record, 2006-2011
LTBMU Technical Report

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I. Introduction

The Lake Tahoe Basin is a sensitive environment, with stringent regulations in place to avoid or reduce water quality impacts associated with land management activities. Before experimenting with new treatment techniques in sensitive areas, monitoring is often required to evaluate the effects of project activities on water quality. However, water quality sampling in surface waters adjacent to forest treatments is costly, often inconclusive, and difficult to evaluate the results in the context of the larger watershed disturbance. Therefore, the LTBMU initiated a soil quality monitoring program in 2006 to evaluate the impacts of vegetation management activities on Tahoe Basin soils, as an indirect measure of potential water quality effects of the treatments. Bare, compacted soils can lead to accelerated runoff and erosion, creating potential for sediment transport into adjacent water bodies. Soil monitoring to date has focused on soil compaction and soil cover metrics.

Over the past decade, the LTBMU has implemented mechanical treatment of forest fuels with contractors who utilize low ground pressure equipment, or other innovative technology treatments as a means to minimize soil disturbance. For the purposes of this report, these methods will be termed "light on the land". This equipment (including harvesters, forwarders, masticators, and chippers) can run on large rubber tires, which limits soil displacement; or on tracks, which limits compaction. Research has been conducted in other parts of the nation, which indicates that this type of equipment can have minimal impacts on soil quality when operated under appropriate soil moisture conditions (Sang-Kyun Han et. al, 2009; Han Sup Han, 2006; Powers et al., 2005; Ares et al., 2005; Gomez et al., 2002; and Hatchett et al., 2006; and Miller et al. 2004). Tahoe Basin vegetation management treatments are typically less intensive than those documented in much of the literature in that the amount of the existing trees removed is less (i.e. "thin from below") and soil moisture conditions are typically drier. Due to the high level of concern for water quality degradation in Lake Tahoe, the LTBMU soil quality monitoring program aims to determine the soil quality, and subsequent potential water quality impacts of vegetation management activities in the Tahoe Basina.

Between 2006 and 2011, the LTBMU collected data on soil quality at four separate fuel reduction projects around the Basin, which utilized low ground pressure harvesting and forwarding equipment and chippers and masticators. These fuels reduction projects were conducted on a variety of soil types around the Basin from the west shore (Ward Unit 5), south shore (Heavenly SEZ) and east shore (Roundhill and Slaughterhouse). The Heavenly SEZ fuels

reduction project was conducted as a pilot project to evaluate mechanical treatments on granitic soils in an area classified as stream environment zone (SEZ). The Roundhill Project also included an SEZ treatment unit and another unit treated through whole-tree removal (i.e. low tire pressure equipment was used to cut and remove the trees, but entire trees were removed from the site rather than trees being de-limbed on site and leaving the resulting material as ground cover). The full monitoring reports for these four projects are posted on the LTBMU public website. This document presents a summary of the findings from these individual monitoring efforts (LTBMU, 2007), (LTBMU, 2008), (LTBMU, 2011) and (LTBMU, 2012).

II. Methodology

Similar methodology was used for monitoring all four projects. For the Ward, Heavenly SEZ and Roundhill Projects, measured soil quality parameters included

- gravimetric soil moisture (the amount of water present in the soil by mass),
- saturated hydraulic conductivity (Ksat, measure of soil permeability at a certain depth),
- bulk density (density of the soil, used to calculate soil porosity), and
- soil cover.

The protocols for these measurements are documented in the LTMBU soil quality monitoring plan (LTBMU, 2010). Soil porosity and Ksat are measures of the amount and hydraulic characteristics of pore space in the soil, which affects the ability of soils to infiltrate water as a result of precipitation events. Soil cover is an important protection measure against erosion and sediment delivery. Combined, these monitoring metrics constitute soil quality conditions related to runoff and erosion, and are an effective means of predicting the potential of water quality effects resulting from management activities.

Approximately 60 samples were collected at each site for Ksat and soil cover measurements, and 20 samples for bulk density, both before and after the project. Data were then analyzed to determine pre and post project differences. Measured soil data including Ksat, bulk density and soil cover, in addition to other specific site characteristics (i.e. slope, % canopy cover, generalized soil texture groups) were input into the WEPP Hillslope model to determine to what degree measured changes in soil quality parameters resulted in predicted changes to runoff and erosion response.

Bulk density samples were collected at the 6 to 10 inch mineral soil depth for the Ward and Heavenly SEZ projects. The depth for soil moisture and bulk density measurements was changed to the 4 to 8 inch mineral soil depth for the Roundhill and Slaughterhouse projects, based on the USFS regional soil scientist interpretation of the results from recent research (Powers et al., 2005; Moghaddas et al., 2008). This research indicates this is the zone of the soil profile shown to exhibit the greatest long-term compaction associated with these types of activities.

For the Slaughterhouse project, soil bulk density was the only metric measured, and soil operability was determined in the field through a qualitative test based on the correlation between soil moisture and plastic limit ("soil moisture squeeze test"). For this project monitoring, post-project conditions were compared to an untreated control area, rather than to undisturbed pre-project conditions. In this case, the decision to monitor was made after

implementation, when it was determined that part of this project was operated under "very moist" soil conditions, based on the field squeeze test.. Therefore an undisturbed reference site was established to compare with the post project bulk density data, to determine the compaction effects of operating on "very moist" soils for the coarse texture category.

III. Results

Soil Map Unit Characteristics

Table 1 displays the predominant soil map unit characteristics and the NRCS soil survey data for Ksat and bulk density for the five treatment areas evaluated. The following are the key points from this data:

- Estimated Ksat values for these soil map units range from 1.41 to 19.98 inches per hour. This indicates that saturated hydraulic conductivity in these soil map units is highly variable, and soils are capable of transmitting large amounts of water through the soil due to the naturally coarse texture and lack of structure.
    - Note: This is not a measure of infiltration rates at the surface, which in this area may be highly influenced by natural seasonal hydrophobicity.
- Bulk density values for these soil map units range from 0.91 to 1.45 g/cm^3.
- The Ward treatments occurred on soils derived from volcanic rock (Paige soil), while the remainder of the treatments occurred on granitic soils. The Paige soil has a similar clay content but slightly higher silt content (26%) in the surface horizons than the granitic soils in the other project areas (16-18%). The Paige sand content is also slightly lower than the grantitic soils (67% as opposed to 78-82%).

Table 1. Soil Characteristics in Monitoring Units (according to NRCS Soil Survey 2007).

Project	Primary Soil Map Unit	Soil Parent Material	Soil Survey Estimated Range Ksat (in/hr)	Soil Survey Average BD (g/ cm^3)
Ward Unit 5	Page medial sandy loam (7181)	Volcanic	2-6	0.91
Heavenly SEZ	Marla loamy coarse sand (7471)	Granitic	2-6	1.4
Roundhill SEZ	Christopher-Gefo complex, loamy coarse sand and gravelly loamy coarse sand (7444)	Granitic	6- 20	1.45
Roundhill upland	Christopher-Gefo complex, loamy coarse sand and gravelly loamy coarse sand (7444)	Granitic	6-20	1.45
Slaughterhouse	Cagwin-Rock outcrop complex, extremely stony	Granitic	1.4-14.1	1.26

	(7411 and 7412)			

Pre-project soil moisture conditions

Average pre-project soil moisture conditions were measured for the Ward, Heavenly and Roundhill project sites and were estimated for the Slaughterhouse project using a qualitative squeeze test procedure. The results are presented below.

Average Gravimetric Soil Moisture by mass

Ward = 12.3%
Heavenly = 6.7%
Roundhill SEZ = 6.8%
Roundhill upland = 7.4% pre, 3.7% post

Soil Moisture based on Squeeze Test

Slaughterhouse = Very moist, coarse soil texture

It's important to note that the gravimetric soil moisture ranges for the treatment areas where this was measured in the lab were very low, ranging from 3.7 to 12.3%. These soil moisture values represent conditions drier than field capacity (field capacity is the maximum amount of water a particular soil can hold) for these soil types. Field capacity or wetter soil moisture conditions have been shown to be most prone to compaction impacts (McNabb et al. 2001).

Soil Quality Monitoring Parameter Results

The following 3 tables summarize the pre and post project results at the treatment sites related to Ksat, bulk density, and soil cover. The P values are a measure of the statistical significance of the differences measured in pre and post project data comparisons. For the purposes of the discussion presented in this paper, statistical significance is determined at an 80% confidence interval (P<0.20).

Table 2: Pre and Post Project Ksat Median Values

	Ksat medians (in/hr)			
Project Name	**Pre**	**Post**	**% Difference**	**P-value**
Ward Unit 5	4.64	3.7	-30%	0.13
Heavenly SEZ	5.7	1.9	-67%	0.001
Roundhill SEZ	5.43	2.08	-62%	0.02
Roundhill upland	3.54	5.71	+61%	0.17

Notice that measured Ksat values both pre- and post-project were generally within the ranges documented for those soil map units in the NRCS soil survey (refer to Table 1). Three of the four sites evaluated for Ksat experienced substantial reductions (30 to 67%) from the pre project conditions, and these reductions were statistically significant at the 80% confidence limit.

For the Roundhill upland unit measured median Ksat actually increased by 61%. One explanation for this result is that Ksat measurements were highly variable in the field, with

values ranging between 0.17 inches per hour to 42.9 inches per hour among the 60 sampling points in the Roundhill upland post-project data set. In fact, a high degree of variability in the Ksat datasets was found in all the project areas. Ksat is inherently a highly variable property, affected by soil voids associated with insect and animal burrows, root channels, and spaces around rocks. For this reason, it is commonly reported as a range of values in soil surveys. Although our initial analysis indicated that 60 sample points would be sufficient to detect change with this degree of variability, it is probable that many more sample points are necessary to increase the statistical power of the analysis to detect real change.

For two of the treatment Units at the Heavenly SEZ project, a subset of Ksat and bulk density measurements in the visible tire tracks left by harvesting equipment were analyzed separately. Field measurements determined that approximately 16% of these Units were covered with visible equipment tracks. Statistical analysis determined there was no significant difference between the post project data collected within the visible equipment tracks and the post project data collected outside of the visible equipment tracks for either Ksat or bulk density, although Ksat medians in both data sets were significantly less that the pre-project values . The scope and scale of data collected is not sufficient to support a conclusion as to why post project results both within and without the visible equipment tracks would be similar.

Another interesting finding from the Heavenly SEZ monitoring report was that Ksat measurements taken within the CTL tracks that did not operate on slash mats (due to a lack of available material), still had a median post-project Ksat of 1.6 inches per hour, and statistically was not significantly different from the median Ksat of 2.1 inches per hour measured within the CTL tracks that did operate over a slash mat. This suggests that under these circumstances, slash mats were not effective at reducing compaction. This may be because of the smaller sized material used to create the slash mats, primarily limbs and branches. Research conducted by Han et al., 2006 suggests that smaller diameter slash is less effective than larger material at preventing compaction because it gets crushed into pieces which can no longer distribute and absorb the machine's ground pressure and vibration. Another factor that may have contributed to this result is that most of the HSEZ site had been burned in a wildfire prior to vegetation management treatments. Therefore, the slash material used for slash mats may not have been as green as would typically be used for this purpose, again making the slash more prone to breaking into smaller pieces and rendering the slash mats less effective.

The change in bulk density between pre- and post-project conditions was only found to be statistically significant for the Ward and Roundhill upland treatment areas (Table 3). Bulk density values for the other project areas do not represent a change in conditions that is outside of what would be expected due to natural variability. Measured bulk density consistently resulted in very small differences in corresponding soil porosity between pre- and post-project conditions (ranging from -2.5 to +3.8%). The 1995 Region 5 Soil Quality Standards used a 10% reduction in porosity as the threshold standard to determine if the soil is detrimentally compacted. Recent research has shown that a 10% porosity threshold may in fact be overly conservative as it relates to tree growth, where compacted soil was found to retain more water than non-compacted soil and no negative effects on tree growth were observed although the area compacted was greater than 15% and the soil bulk density increase exceeded 20% (Ares et al., 2005). The porosity

changes measured in the monitoring for these treatment areas were well below the 10% threshold at all sites, and were not statistically significant at 3 of the 5 sites.

Table 3: Pre and Post Project Bulk Density Means

	Bulk Density means (gm/cm3)			
Project Name	**Pre**	**Post**	**% Change in Porosity****	**P-value**
Ward Unit 5	0.84	0.88	-2.5%	0.05
Heavenly SEZ	1.19	1.16	+2.0%	0.55
Roundhill SEZ	1.05	1.02	+1.8%	0.70
Roundhill upland	1.32	1.27	+3.8%	0.18
Slaughterhouse*	1.27	1.25	+1.4%	0.75

* pre-project data for Slaughterhouse was compared to undisturbed control site. ** Change in soil porosity is calculated from bulk density measurements using an established equation, which is presented in the individual reports.

Although a reduction in Ksat was measured in 3 of the treatment areas as a result of utilizing "light on the land" equipment and treatment techniques, differences in bulk density (and the associated porosity) were not measured. Although both Ksat and bulk density are indicators of soil compaction, there is a large disparity between the changes in Ksat compared to changes in bulk density/soil porosity between pre- and post-project conditions. Bulk density is used to calculate soil porosity, a measure of the total volume of pore space present in the soil profile, whereas Ksat is a measure of the ability of water to move through the soil.

The results indicate that while the total volume of pores is not changing substantially between the pre- and post-project conditions, the relative size and distribution of these pores is changing in a manner that reduces the soil's ability to transmit water. It is possible that the number of larger sized pores (macropore space) decreased as result of the treatments, and the number of smaller sized pores (micropore space) increased. A potential side benefit of this result is that in sandy soils, such as those present in much of the Tahoe Basin, the water retention capacity of the soil is also increased, possibly improving growing conditions for vegetation. Recent research has found that on sandy soils, increases in bulk density and decreases in soil porosity have increased water holding capacity, and tree growth was either not affected or benefited from the effects (Gomez et al., 2002; Powers et al., 2005; and Ares et al., 2005). Of course the potential benefits of compaction are limited, because after a certain compaction threshold is reached it becomes a detriment to plant growth.

Table 4 below displays the results of the soil cover measurements taken at most of the treatment sites. Post-project mean soil cover ranged between 89 to 100%, indicating a very minor change from the pre-project condition. Ground cover is an important component for reducing erosion potential, and the ground cover measured after project treatments was clearly adequate to prevent increased erosion potential.

Table 4: Pre- and Post-Project Mean Soil Cover

	Mean Soil Cover (%)		
Project Name	**Pre**	**Post**	**% Difference**
Ward Unit 5	100	100	0
Heavenly SEZ	98	89	-9%
Roundhill SEZ	100	95	-5%
Roundhill WT	98	93	-6%

WEPP Modeling Results

As stated previously, measured soil quality characteristics, along with documented hillslope characteristics adjacent to treatment area stream channels or drainage features were input into the Watershed Erosion Prediction Project (WEPP): Hillslope model to estimate runoff and erosion response from both pre- and post-project conditions for three of the projects. Two to three hillslopes were modeled in each treatment area (Table 5).

A 20 year climate simulation was used for the Ward project modeling, and a 30 year climate simulation was used for the subsequent Heavenly and Roundhill SEZ treatment projects. The 30-year climate was suggested by the model development team for a conservative estimate of climate, since it includes a greater proportion of large magnitude precipitation events.

Table 5: Pre and Post Project WEPP: Hillslope Modeling Results

Project Name	Hillslope topography (modeled)	Average annual sediment yield (tons/acre)	
		Pre-project	Post-project
Ward Unit 5 – Hillslope 1	Complex slope, range from 8 to 26% percent, for 2900 feet	0.3	0.4
Ward Unit 5 – Hillslope 2	Complex slope range from 6 to 20% for 2900 feet	0.8	0.8
Ward Unit 5 – Hillslope 3	Complex slope, range from 5 to 23% for 2800 feet	1.4	1.5
Heavenly SEZ – Hillslope 1	10% convex for 475 feet	<0.001	<0.001
Heavenly SEZ – Hillslope 2	15% constant for 213 feet	<0.001	<0.001
Heavenly SEZ – Hillslope 3	10% convex for 282 feet	<0.001	<0.001
Roundhill SEZ – Hillslope 1	25% for 110 feet, 10% for 40 feet	<0.001	<0.001
Roundhill SEZ - Hillslope 2	23% for 100 feet, 5% for 20 feet	<0.001	<0.001

The treated hillslopes adjacent to channels in the Heavenly and Roundhill SEZ treatment units were relatively short (120 to 475 feet) in length. For both of these projects no surface runoff or erosion response was predicted under either pre- or post-project conditions. The hillslopes adjacent to drainage features in the Ward Unit 5 project were much longer in length (2,800 to

2,900 feet). Relatively small amounts of erosion were predicted on the Ward project hillslopes for both pre- and post-project conditions, and the increase in sediment yield from two of these hillslopes as a result of project treatments was predicted at 0.1 ton/acre per year. Note that ground cover after project treatments was still very high, and proved adequate to prevent increased erosion potential, contributing to the lack of sediment delivery estimated from modeling.

The WEPP model accuracy is ±50%, so the estimated magnitude of erosion and sediment delivery response is only approximate. However, these model simulations are very useful for making pre- vs. post-project comparisons and for evaluating the relative magnitude of erosion response from forest management activities.

IV. Conclusions and Recommendations

The following conclusions can be drawn from these monitoring efforts.

- "Light on the land" equipment and treatment techniques used for mechanical vegetation treatments have not resulted in ecologically significant adverse effects on the Tahoe Basin soils evaluated.
    - Although saturated hydraulic conductivity was reduced by 30% to 67% as a result of management activities, median Ksat measurements post-project were still between 1.9 and 5. 7 inches per hour. Soil cover after treatments averaged around 90% and soil porosity decreases were less than 5%.

      The combination of robust soil cover, small decreases in soil porosity, and relatively high post-project soil permeability (i.e. saturated hydraulic conductivity) prevented increases in overland flow that resulted in accelerated erosion. Soil hydrologic function and soil productivity were maintained at levels adequate to sustain vegetation and maintain water quality.

- Soils in the Tahoe Basin are primarily coarse textured, with high sand content and naturally high infiltration capacities. The high sand content makes them less prone to compaction than finer textured soils. The soil moisture conditions during project implementation ranged from dry to very moist soil conditions, all below the plastic limit for the given soil.

It's important to note the other variables that influence the impacts of vegetation management treatments on soil and water quality. Specifically, equipment operator skill and experience is often mentioned in the literature as an independent variable that can have significant effects on post-project site conditions related to soils (Miller et al., 2001). In addition, soil types and textures and organic matter content are also important variables influencing soil impacts from land management activities.

Recommendations

It is recommended that some level of soil quality monitoring continue on fuels reduction and vegetation management projects conducted in the Tahoe Basin whenever:

- higher impact equipment is used (such as tractor skidding),
- site conditions (i.e. soil moisture conditions or slope gradients) are higher risk than the sites already evaluated in this synthesis.
- mechanical treatment in SEZs are not operated over slash mats, or where SEZs are present on soil types with substantially different physical properties than those previously monitored.

Future monitoring (scope, scale, and monitoring design) should be considered as part of project NEPA analysis or regulatory permit applications, to confirm assumptions about the ability of proposed design features to prevent unacceptable levels of compaction or soil disturbance.

References

Ares, A., T.A. Terry, R.E. Miller, H.W Anderson, and B.L. Flaming. 2005. Ground-Based Harvesting Effects on Soil Physical Properties and Douglas-Fir Growth. Soil Sci. Soc. Am. J. 69: 1822-1832.

Gomez, A., R.F. Powers, M.J. Singer, W.R. Horwath. 2002. Soil Compaction Effects on Growth of Young Ponderosa Pine Following Litter Removal in California's Sierra Nevada. Soil Sic. Soc. Am. J. 66: 1334-1343.

Han-Sup Han, D. Page-Dumroese, Sang-Kyan Han, and J. Tirocke. 2006. Effects of Slash, Machine Passes, and Soil Moisture on Pentration Resistance in a Cut-to-length Harvesting. International Journal of Forest Engineering. 17(2): 11-24.

Hatchett, B., M.P. Hogan, and M.E. Grismer. 2006. Mechanical mastication thins Lake Tahoe forest with few adverse impacts. California Agriculture. 60(2): 77-82.

LTBMU. 2007. 2006 Ward Unit 5 Soil Monitoring Report. US Forest Service, South Lake Tahoe, CA.

LTBMU. 2008. Heavenly SEZ Demonstration Project, 2007 Soil Monitoring Report. US Forest Service, South Lake Tahoe, CA

LTBMU. 2010. USDA Forest Service Lake Tahoe Basin Management Unit Soil Quality Monitoring Plan 2010. US Forest Service, South Lake Tahoe, CA.

LTBMU. 2011. Roundhill Fuels Reduction Project Soil Quality Monitoring Report, US Forest Service, South Lake Tahoe, CA

LTBMU. 2012. Slaughterhouse Fuels Reduction Project Soil Quality Monitoring Report, US Forest Service, South Lake Tahoe, CA

McNabb, D.H., A.D. Startsev, and H. Nguyen. 2001. Soil Wetness and Traffic Level Effects of Bulk Density and Air-Filled Porosityof Compacted Boreal Forest Soils. Soil Sci. Soc. Am. J. 65: 1238-1247.

Miller, R.M., Colbert, S.R., and L.A. Morris, 2004. Effects of heavy equipment on physical properties of soils and on long-term productivity: a review of literature and current research. National Council for Air and Stream Improvement, Technical Bulletin No. 887, October, 2004, Research Triangle Park, NC.

Miller, R.O., R. Heyd, R. Rummer, and D. Jerome. 2001. Gentle Logging System Evaluation (Quantitative Measurements Report). Published by Michigan State University Upper Peninsula Tree Improvement Center Escanaba, Michigan. 14 pp.

Moghaddas, E.Y. and S.L. Stephens. 2008. Mechanized fuel treatment effects on soil compaction in Sierra Nevada mixed-conifer stands. Forest Ecology and Management. 255: 3098-3106.

Powers, R., D.A. Scott, F.G. Sanchez, R.A. Voldseth, D. Page-Dumroese, J.D. Elioff, and D.M. Stone. 2005. The North American long-term soil productivity experiment: Findings from the first decade of research. Forest Ecology and Management. 220: 31-50.

Sang-Kyun Han, Han-Sup Han, D.S. Page Dumroese, and L.R. Johnson. 2009. Soil compaction associated with cut-to-length and whole-tree harvesting of a coniferous forest. Can J. For. Res. 39: 976-989.

USDA Forest Service 2009. General Technical Report WO-82a and b. Forest Soil Disturbance Monitoring Protocol, Volumes I and II. September 2009.

USDA Forest Service 2012. Forest Service Manual, FSM 2500 – Watershed and Air Management, Chapter 2550 – Soil Management. Supplement No. 2500-2012-1, April 3, 2012.