Roundhill Fuels Reduction Project
Soil Quality Monitoring Report

USDA Forest Service
Lake Tahoe Basin Management Unit

November 2011

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Acknowledgements:

We'd like to give a special thanks to the technical reviewers of this report, including Jeff TenPas (Central Zone Soil Scientist, USFS), Emily Moghaddas (Soil Scientist Pacific Southwest Research Station, USFS), and Debbie Dumrose (Soil Scientist Rocky Mountain Research Station, USFS). Their thorough and insightful reviews added great value to this report.

I. EXECUTIVE SUMMARY

The Roundhill Fuels Reduction Project was implemented during the field seasons of 2008 and 2009. The project treated a stream environment zone (SEZ) unit with Cut-to-length (CTL) mechanical equipment, then masticated the branches and left the resulting woody debris on the ground as protective cover. The project also treated an upland unit using the same CTL equipment; however, the entire trees were forwarded out of the unit, which is termed "whole-tree forwarding" (hereinafter referred to as "WT forwarding"). Both the SEZ and WT forwarding units were monitored for soil quality effects that may result from project treatments. Monitoring metrics included saturated hydraulic conductivity (Ksat), bulk density, soil moisture and soil cover.

SEZ Unit In the SEZ treatment unit, median Ksat values decreased from 5.43 in/hr before the project to 2.08 in/hr after the project treatments, indicating that the soil permeability was decreased roughly three-fold as a result of the project treatments. To put this decrease in perspective, within the studied project site, pre-project undisturbed Ksat values ranged over two orders of magnitude, or at least a hundred-fold (i.e., Ksat ranged from 0.09 to 29.1 inches/hour). Therefore, the three-fold decrease in Ksat found after treatment is a fairly minor shift compared with its natural variability onsite. Bulk density values for soils sampled in the SEZ unit also did not change meaningfully as a result of the project treatments, despite the small range in pre-project bulk density values of soils in the SEZ unit. Soil cover was reduced very slightly, from 100% pre-project to 95% post-project. The Watershed Erosion Prediction Project (WEPP) model was applied and predicted that no measurable erosion or sediment delivery response would result from the SEZ unit, based on its actual site characteristics and measured post-project Ksat, bulk density, soil cover and canopy cover values. In summary, the conditions of the soils in the SEZ unit post-treatment were judged to be virtually unaffected by the treatment.

Whole-tree Forwarding Unit In the WT forwarding unit, there were no statistically significant reductions in Ksat, increases in bulk density, or decreases in porosity after treatment. Soil cover was only reduced slightly, from 98% pre-project to 93% post-project, even though the slash from CTL treatments was removed from the site rather than left as ground cover.

Future Monitoring Recommendations These results suggest that Ksat is not a good indicator of soil quality impacts that would result in erosion or sediment delivery on coarse textured soils; the three-fold changes observed are so small when compared with the hundred-fold natural variability in Ksat onsite as to be inconsequential. Future soil quality monitoring conducted by the LTBMU on coarse textured soils, such as those present in the Roundhill Project treatment units no longer need include Ksat monitoring.

Since 2006, the LTBMU has been using soil moisture determinations in the field to evaluate whether a unit is operable and ready for mechanical equipment operations. In the WT forwarding unit in this project, moisture conditions were operable in most of the unit, but "inoperable" according to this protocol in some parts of the unit (i.e. exhibited characteristics in the light shaded boxes in Table 9 of this report). However, the soil quality monitoring effort conducted in this unit demonstrated that no effects to soil quality resulted from project treatments, even under these wetter soil conditions. We therefore recommend that similar soil quality monitoring should be conducted in a treatment unit that is characterized entirely by the soil moisture criteria described in the light shaded boxes in Table 9. If the results support the findings from this report that no effects, or very minor effects similar to those that would be expected during dry soil conditions, result from project treatments, then only the dark shaded boxes in Table 9 would be used for future determinations of operability.

II. INTRODUCTION

The Roundhill Fuels Reduction Project was implemented during the field seasons of 2008 and 2009. The project included one stream environment zone (SEZ) unit that was treated with mechanical equipment and one unit that was proposed to be treated with conventional whole-tree (WT) harvesting equipment, including feller-bunchers and skidders. Both of these circumstances presented an opportunity to monitor the soil quality impacts of relatively new treatment techniques, or in the case of the WT treatment, techniques that hadn't been used in the Lake Tahoe Basin in many years.

The SEZ unit was three acres in size, and utilized low-ground-pressure equipment to treat overstocked fuels, consisting of a Rottne Rapid Six-Wheel Drive (6-WD) Cut-To-Length (CTL) harvester, and a Rottne Rapid 6-WD forwarder, within lands classified in the Tahoe Basin as SEZ. SEZs are defined by the Tahoe Regional Planning Agency (TRPA) and the Lahontan Regional Water Quality Control Board as biological communities that owe their characteristics to the presence of surface water or a seasonally high groundwater table. The criterion for defining SEZs includes indicators of vegetation, hydrology, and/or soil type (WQCP 1995; TRPA 2004).

The upland unit monitored for soil quality impacts resulting from vegetation management treatments included a proposed WT treatment unit totaling approximately 59 acres in size. Although this unit was analyzed for conventional WT treatment methods including the use of a feller-buncher and skidder, the contractor had the discretion to use a variety of equipment techniques, and instead used the same CTL equipment listed above. The primary difference between the treatment technique used in this unit and that typically used for CTL operations was that the entire trees were forwarded out of the unit, rather than leaving the branch material on the ground and later masticating it for ground cover. Therefore, this unit had less ground cover remaining after the treatments than a typical CTL unit, similar to that of a WT unit. However, the skidding that would normally be associated with a conventional WT harvest technique, and the subsequent potential soil quality impacts such as rutting and soil displacement, did not occur with this treatment. For the purposes of this report, the treatment technique employed in these units will be referred to as "whole-tree (WT) forwarding".

The specifications of the equipment used for treating both units monitored for this project are presented below:

- The harvester has a service weight of 31,300 pounds with a ground pressure of 6 pounds per square inch (psi) without tracks.

- The forwarder has a service weight of 26,000 pounds and a payload capacity of 26,000 pounds with a ground pressure of 6 psi unloaded and 13 psi fully loaded.

As mentioned above, CTL harvesting systems carry the products out of the forest without skidding. CTL equipment can either limb the cut trees in the treatment area or leave limbs attached and forward the entire tree out of the treatment area. In the SEZ unit, trees were limbed in the forest and, where available, the limbs were used to create slash mats for the equipment to

drive over to provide additional protection against soil compaction. In the WT forwarding unit, the entire trees were removed from the unit and as a result the equipment did not operate on a slash mat.

II.1. Project Description

SEZ unit

The Roundhill Project area is located within National Forest System land northeast of the CA/NV state line. The SEZ unit is located along the north side of Zephyr Creek, just upstream of the Highway 50 crossing (Figure 1).

The SEZ unit was characterized by dense conifer vegetation within the SEZ adjacent to the perennial channel, Zephyr Creek. Due to a lack of treatment in this area for many years, the conifers were encroaching on the riparian area. Common riparian vegetation in the unit includes horsetails, willow, alder, and various grass species.

The purpose of the treatments in the SEZ unit was to reduce accumulations of hazardous fuels and restore conifer and riparian vegetation to a healthy, diverse, fire-resilient structure that provides desired habitat conditions. Treatments included: 1) mechanical thinning and removal within dense conifer stands; 2) cutting and removing accumulations of dead standing and downed trees; and 3) conifer removal to promote non-conifer SEZ vegetation such as willow and alder. The pre-project basal area was approximately 169 sq ft and the post-project basal area was reduced to approximately 110 sq ft in this treatment unit.

The Roundhill Project upland treatments began in 2008. Treatments in the SEZ unit were not initiated in 2008 due to soil moisture limitations. Conditions during the 2009 field season allowed for the treatments to be conducted in the SEZ unit during July of that year.

WT forwarding unit

The WT forwarding unit is located south of Elks Point Road on the Lake Tahoe side of Highway 50 (Figure 2). The pre-project condition of this unit was characterized by areas of very dense conifer vegetation. However, much of the unit had been salvage logged in the 1990s after bug infestation killed several pockets of trees. The pre-project basal area ranged from approximately 153 sq ft in the western portion of the unit closer to Lake Tahoe to 227 sq ft in the larger portion of the unit to the east. After project treatments, basal area was reduced to approximately 130 sq ft. Treatment during the recent Roundhill Project acted to thin out some of the re-growth after the 1990s treatment, and to bring the stands into compliance with current wildland urban interface (WUI) fuel loading standards of up to 10 tons per acre.

This unit is a high use area for dispersed recreation, and fuel loading in the area was a hazard to the recreational users, including the adjacent campground. Because of the dispersed recreation use of the area, many user created trails exist throughout the unit. In addition, old skid trails and remnant roads were also visible on the landscape prior to the Roundhill Project treatments, and were confirmed to exhibit compacted soil based on shovel penetration tests conducted by the

project Soil Scientist. These impacts caused the average pre-existing level of disturbance in this unit to be higher than a typical forested unit.

Because of variable soil moisture conditions in this unit during the 2009 field season, operations did not begin until the week of June 8, 2009.

III. MANAGEMENT QUESTIONS AND MONITORING OBJECTIVES

The following management questions were addressed with the monitoring efforts:

1) SEZ unit – Can innovative technology systems be used in SEZs without causing significant adverse impact to physical soil properties or water quality? Can any potential impacts be mitigated utilizing accepted soil restoration techniques (i.e. subsoiling, replacement of soil organic matter, and effective soil cover)?
2) WT forwarding unit – Can whole-tree treatment systems be used in the LTBMU without causing significant adverse impact to physical soil properties or water quality?

Monitoring objectives to determine whether significant adverse impacts have occurred are listed below.

- Determine if soil permeability as measured by saturated hydraulic conductivity (Ksat) has been reduced significantly within the SEZ or WT forwarding units to levels that result in predicted sediment delivery to adjacent waterbodies, utilizing the WEPP runoff and erosion prediction model.

- Determine if major forwarder/harvester routes are developing the characteristics of a road through either visible signs of rutting or depressions, or Ksat measurements approaching 0.15 in/hr.
  - This threshold for Ksat was established for native surface forest roads on sandy loam soils by WEPP: Road model developers. If any forwarder/harvester trail segments are identified through visual observations and/or Ksat measurements to exhibit the characteristics of a native surface road, WEPP:Road will be used to evaluate erosion and sediment yield potential, and appropriate mitigations will be implemented as needed.

- Determine if surface organic matter is present as fine organic matter that occurs over at least 50% of the area, and is well distributed. Fine organic matter includes plant litter, duff, and woody material less than three inches in diameter. The 50% general soil cover threshold is documented in the USFS Region 5 Soil Quality Standards (USDA Forest Service, 1995).

- Determine if there is a 10% or greater decrease in soil porosity in the treatment units. A 10% reduction in porosity corresponds to a change in bulk density using the following relationship. A 10% reduction in porosity using this relationship indicates detrimental soil compaction according to the 1995 Region 5 Soil Quality Standards.

$\Delta P = (Dbi-Dbf)/ (Dp-Dbi)$

Where P = porosity, Dbi = initial soil bulk density found under pre-project conditions, Dbf = final bulk density after the project, and Dp = density of the individual soil particles, which is assumed to be 2.65 gm/cm^3.

- Determine if soil and water protection BMPs were implemented and effective on the project.
    - This monitoring objective was addressed by including the Roundhill Project in the pool for random selection of BMPs through the Regional Best Management Practices Evaluation Program (BMPEP). Two BMPEP evaluations were conducted in the WT forwarding unit for this project through random selection, and both were rated implemented and effective. These results are documented in the 2010 Annual BMPEP Report and are not discussed further in this report.

When this monitoring project was initiated, the 1995 Region 5 Soil Quality Standards (R5 2509.18-1) were in effect and used as a reference for the thresholds regarding total soil porosity change and percent soil cover retention. In November 2010, a new national soil manual (FSM 2550-2010-1) was issued and the national soil handbook (FSH 2509.18) was removed from the Forest Service directives system. These changes had the effect of also removing the Region 5 Soil Quality Standards (2509.18-1) from the Forest Service directives system. We have reported our findings in this monitoring report both as actual changes to total soil porosity and soil cover and kept the references to the superseded Region 5 Soil Quality Standards established thresholds.

IV. SOIL TYPES AND CHARACTERISTICS

SEZ Unit

The majority (90%) of the SEZ unit is underlain by soil map unit #7444, which corresponds to the Christopher-Gefo complex, on 0-5% slopes (NRCS, 2007). The Christopher-Gefo complex is characterized by loamy coarse sand and gravelly loamy coarse sand with a granitic parent material. Coarse fragment content was low throughout the samples collected. The remainder of this treatment unit is underlain by soil map unit #7422, the Cassenai gravelly loamy coarse sand, very stony, on 15-30% slopes; and map unit #9011, the Oxyaquic Cryorthents – Aquic Xerorthents – Tahoe complex, on 0-15% slopes which includes alluvium or colluviums derived from mixed and granitic parent material and is characterized by gravelly loamy coarse sand, sandy loam and gravelly silt loam (Figure 1). Surface soils in this treatment unit are characterized by weak surface structure.

Although only approximately 45% of the #9011 soil map unit and one component (5%) of the #7444 map unit are characterized as hydric soils, the majority of the SEZ unit was verified as exhibiting SEZ soil characteristics on the ground. The hydric rating for these specific soils is classified under several hydric criteria, primarily 2B3, which is described as “poorly drained or

very poorly drained with a water table at a depth of 1.0 foot or less during the growing season if permeability is less than 6 in/hr in any layer within a depth of 20 inches" (NRCS, 2007).

Field verification of the actual SEZ boundary indicated that some portions of the SEZ unit were not consistent with the TRPA SEZ criteria (including soil and vegetation indicators), but had been included in the SEZ unit because of proximity to the perennial channel. Field verification also suggested that soil types other than the primary components of the map units identified in the Soil Survey were present; however, surface soil textures were consistent throughout the areas sampled. SEZ indicators consistently decreased as the elevation above the channel and floodplain increased. Although these areas were included in the SEZ unit, they were not included in the soil quality monitoring area. The monitoring transects were intentionally located within the areas that clearly demonstrated SEZ soil and vegetation characteristics.

Soil types in this unit are fairly similar to those within the Heavenly Creek SEZ Demonstration Project (HSEZ) area (Norman et al., 2008). The majority of both treatment units are underlain by soils developed from a granitic parent material. In addition, the primary soil component in both the HSEZ and Roundhill SEZ units is characterized by loamy coarse sand soil textures (the Christopher-Gefo complex for this project and the Marla soil for HSEZ). Other soil textures exist within each unit, but are relatively consistent between the units, with soil textures including silt loam, coarse sandy loam, and gravelly loamy coarse sand in HSEZ, and gravelly loamy coarse sand, sandy loam, and gravelly silt loam in the Roundhill SEZ.

WT Forwarding Unit

According to the NRCS 2007 Soil Survey and field verification, the major soil map units that fall within the WT forwarding unit reflect a granitic geology. The majority (>80%) of the monitoring area is underlain by soil map unit #7444, which corresponds to the Christopher-Gefo complex, on 0-5% slopes. The remainder of this treatment area is underlain by map unit #7461, Jabu coarse sandy loam, 0-9% slopes; map unit #7492, Oneidas coarse sandy loam, 5-15% slopes; map unit #7411, Cagwin-Rock outcrop complex, 5-15% slopes, extremely stony; with minor portions of the treatment area in map units #7041 (Tahoe complex, 0-2% slopes) and #7421 (Cassenai gravelly loamy coarse sand, 5-15% slopes, very stony). The geographic distribution of soil types within the WT forwarding unit, and their relation to the transect locations can be seen in Figure 2. Surface soils in this unit are characterized by weak surface structure. Based on surface textures observed, there were no obvious inclusions of other soil types in the sampling areas.

Because most of the treatment unit is underlain by Christopher-Gefo complex soils, most of the data collection occurred within this soil type. Also, higher coarse fragment content and greater slopes in the portions of the unit underlain by map units #7492, 7411, and 7421 made monitoring in these locations difficult, and resulted in fewer equipment passes in these areas than the flatter portions of the unit. Therefore, the monitoring transects were not located within the rocky or stony soil types listed above that are present in this unit. Because a large portion of the treatment unit was underlain by map unit #7461, and slope limitations weren't an issue in this portion of the unit, this soil type was also included in the transect monitoring. Even though two soil map units were sampled, surface soil textures were fairly uniform throughout monitoring area.

There is a high level of existing dispersed recreation use in this treatment unit, resulting in a substantial amount of existing disturbance in the form of user created trails and pre-existing compaction. For this reason, the pre-project dataset does not represent an undisturbed condition, and it is important to evaluate the level of post-project disturbance not only resulting from the project treatments but also in combination with the existing user created trail disturbance.

V. METHODOLOGY

V.1. Sampling Protocols

Data were collected for the following soil parameters: gravimetric soil moisture content, saturated hydraulic conductivity (Ksat), soil cover, and bulk density. Sampling protocols used for this monitoring effort are detailed in Appendix A. The protocols utilized to collect soil quality data were developed by the Regional USFS soil scientists and staff with the Natural Resources Conservations Service (NRCS).

Ksat is a measure of the rate at which water will flow through the soil under saturated conditions. This soil parameter was used in this monitoring effort as an indirect measurement of soil compaction. As the soil is compacted by the weight of heavy equipment, the rate of water flow through the soil will decrease, and the potential for increased runoff and erosion may result. The 1995 Region 5 USFS Soil Quality Standards specify that compaction related soil impacts should be measured at 4 to 8 inches below the soil surface. Also, this is the depth at which the greatest compaction has been measured in recent research studies associated with vegetation management treatments such as this (Powers, et. al 2005). Therefore, this depth was used for monitoring compaction on this project, and the Ksat measurements were taken at four inches below the soil surface using a constant head permeameter.

Soil bulk density was measured by taking a soil core at approximately every third sampling location along each transect (see Sampling Design section below). Bulk density is another measure of soil compaction, and also of soil porosity. Soil bulk density samples were collected at the 4- to 8-inch depth using a 2-inch core sampler within a 4-inch sleeve, and were analyzed to determine whole soil bulk density. This monitoring depth was used for this parameter also because of the 1995 Region 5 Soil Quality Standards recommendation, and the results of recent research studies (Powers, et. al 2005).

A primary concern when working in SEZs is ensuring that ground-water levels and soil moisture content are at acceptably low levels to prevent soil disturbance that could result in increased erosion or sediment delivery to water bodies. Prior to project implementation, soil moisture conditions were measured within the SEZ and WT forwarding units. Soil moisture conditions were evaluated by digging up the soils from the 4- to 8-inch depth, trying to form a ball by squeezing a handful of soil very firmly and tossing it in the air and then comparing the results to the criteria appropriate for the soils in the treatment unit (presented in Table 1). No operations were to take place on soils which exhibit “very moist” or “wet” characteristics (Table 1) within the SEZ unit. This protocol was also utilized in the WT forwarding unit, however, in that unit

operations would continue if the majority of the unit (i.e. 70% or more) exhibited operable conditions.

Table 1. Criteria for Soil Moisture Determination

Soil Moisture % Increases Downward	*Loamy sands, fine sandy loam, very fine sands, coarse sands. Fine sandy loams, sandy loams, very fine sandy loam*	*Interpretation*
Dry soils	Dry, loose, single grained flows thru fingers, will not form a ball with pressure.	Operable
Moist soil	Tends to stick together slightly, sometimes forms a very weak ball, but will shatter into single grains easily when tossed to a few inches height and caught in the hand.	Operable
Very moist soil	Forms a weak ball, when tossed in the air may break into smaller chunks but will not shatter easily into single grains.	Not operable
Wet soils	Upon squeezing, free water may appear. Wet outline is left on hand. Non-plastic.	Not operable

Soil moisture conditions were also measured prior to implementing treatments in each unit by utilizing gravimetric soil-moisture measurement techniques to help fully characterize the soil moisture conditions in the unit prior to project operations, to support the adequacy of the qualitative soil moisture protocol described above, and to determine the strength of any possible correlation to measured changes in Ksat and bulk density. Pre-project bulk density measurements were also taken at this time, since the same soil sample could be used for both gravimetric soil moisture and bulk density tests.

Post project samples were taken immediately after implementation in each monitoring unit. In addition, BMP effectiveness monitoring was conducted in 2010 to determine whether visible signs of erosion, sediment transport, or deposition occurred as a result of project activities. This monitoring was conducted after the snow melted in the spring after the site had experienced one full winter season.

V.2. Sampling Design

Based on previous soil quality monitoring efforts conducted by the LTBMU, a sample size of approximately 60 Ksat samples is needed to perform statistical analyses of pre- vs. post-project data because of the high natural variability of this parameter. A sample size analysis conducted using SigmaStat confirmed that this sample size would be adequate to predict a 50% or greater change in Ksat, assuming that the Ksat data demonstrate a log-normal distribution. Therefore, three transects, each containing 20 samples, were placed within each unit to ensure 60 samples were collected in both the SEZ and WT forwarding units. In hindsight, this was too restrictive an assumption, since a 50% (or two-fold) reduction in Ksat has little practical significance in the context of the hundred-fold range of natural variability of Ksat measured in the SEZ and WT forwarding units.

For bulk density monitoring, fewer samples are needed to provide a statistically valid analysis due to the lower variability of bulk density samples. For this parameter, a sample size of 20 was determined to be adequate to provide a statistically valid analysis of a 10% or greater change in porosity resulting from project implementation for both the SEZ and WT forwarding units.

Samples were collected by establishing and monumenting representative transects within each treatment unit. The CTL harvester/forwarder trails are typically about 10 feet wide and generally travel perpendicular to the contour. Three transects, each 475 feet long, were established in approximately the center of the WT forwarding unit, in an attempt to intersect the anticipated paths of the CTL equipment. In the SEZ unit, because of the narrow nature of the unit, and the fact that CTL equipment typically moves perpendicular to the contour, the 3 transects were only 190 feet long, and roughly paralleled the channel and therefore paralleled the outer boundary of the unit. Although most of the equipment movement in the SEZ unit was perpendicular to the contour, material was transported uphill and out of the unit along slope contours to the landing. Where feasible (i.e., in the WT forwarding unit), the monitoring transects incorporated the existing roads and trails that were used as major haul routes to ensure an adequate sampling of these heavily disturbed areas. Another criteria for transect location was that more sensitive areas of the treatment units be included, such as the portion of the WT forwarding unit that borders the perennial Burke Creek. Sample points were located approximately every 25 ft along the transects in the WT forwarding unit and every 10 ft in the SEZ unit, for a total of 20 sample points along each transect (for a total of 60 sample points) both before and after treatment. As mentioned above, bulk density samples were collected at every third sampling location along each transect to provide a total of 20 samples. This sampling design was intended to enable a representative evaluation of disturbance within each unit.

VI. DATA ANALYSIS

VI.1. Statistical Analysis

SigmaStat 3.5 was used to conduct statistical analyses of the Ksat and bulk density sampling data. If the raw data for a given monitoring parameter did not exhibit a normal distribution and the standard deviations were large, this was considered an indication that the data may be log normally distributed. For the purposes of statistical analysis, the data were log transformed in this case. Whether the data represented a normal distribution to start with, or the data was normalized by log transformation, the student's T-test was used for statistical analysis. The "Student's t-test of equivalent means" is used to determine at what statistical confidence level the pre- and post-project mean values could be considered different. The student's t-test indicates whether or not there is a statistically significant difference between the mean values for the pre- and post-project dataset for a given parameter, or if the difference in mean values between pre- and post-project samples is not great enough to reject the possibility that the difference is due to random sampling variability.

However, if log transformation was not successful in normalizing the data, the nonparametric Mann-Whitney Rank Sum test was used to compare median values between the two groups. This analysis determines whether the difference between the median pre-project measurements and

those measured after treatments is statistically significant and at what level of significance. Therefore, this test indicates whether or not the difference in the median values between the two groups is greater than would be expected by chance. If not statistically significant, this analysis would indicate that the difference in the median values between the two groups is not great enough to exclude the possibility that the difference is due to random sampling variability.

Depending on the type of statistical test that was conducted for each dataset, either the means or medians of the pre- and post-project data are discussed in the following sections. If the Student's T-test was used for analysis, the means are compared, and if the Mann-Whitney Rank Sum Test was used, the median values are discussed for comparison.

VI.2. Saturated Hydraulic Conductivity (Ksat)

Ksat has a high level of natural variability due to the soil textures in this project area, and also to micro-site characteristics such as root channels in the soil, insect burrows, and voids around rocks. This high degree of natural variability makes a comparison between individual samples inappropriate, and a comparison of means the best analysis method to evaluate changes in this parameter.

SEZ Unit

During the post-project monitoring, it was determined that the median Ksat value for the entire unit was reduced between two- and three-fold (e.g., from 5.43 to 2.08 inches/hour). The resulting 2.08 inches/hour is still a relatively high Ksat value. Table 2 below provides the summary statistics for the comparison of all pre- and post-project Ksat values for the SEZ unit. In total, there were 60 Ksat samples taken in this unit, 20 on each of the 3 transects.

Table 2. Ksat (inches/hour) summary statistics for all pre- and post-project data for SEZ Unit.

	All Pre- Project	All Post-Project
Median	5.43*	2.08*
Mean	6.65	3.70
Std. Dev.	6.34	4.52

* Indicates that a statistically significant difference was found.

Saturated hydraulic conductivity is highly variable in nature; with values ranging from 0.09 in/hr to 29.13 in/hr in the pre-project data, as represented by the large standard deviations in the table above. Statistical analysis of these data determined that the difference between the median pre-project Ksat measurements and those measured after treatments is statistically significant at a high level of confidence (P=0.017, confidence level is 1.000-0.017= 98.3%).

WT Forwarding Unit

During the post-project sampling, it was determined that the Ksat values for the WT forwarding unit were greater post-project than pre-project (Table 3); which, though less than a two-fold change, is counter-intuitive (e.g., less compacted after the project than before). Pre-project saturated hydraulic conductivity was highly variable, ranging from 0.16 in/hr to 35.29 in/hr. The statistical analysis of this data determined that the difference between the mean pre-project Ksat measurements and those measured after treatments is not statistically significant (P=0.166).

Table 3. Ksat (inches/hour) summary statistics for all pre- and post-project data in the WT Forwarding Unit. Sample size is 60.

	All Pre- Project	All Post-Project
Median	3.54	5.71
Mean	6.44	7.56
Std. Dev.	7.24	7.64

VI.3. Bulk Density

SEZ Unit

The results of the analysis for the entire dataset of bulk density samples collected in the SEZ treatment unit are presented in Table 4 below.

Table 4. All pre- and post-project whole soil bulk density (BD) (gm/cm3) results for the SEZ Unit, including the associated calculated change in porosity. Sample size is 21.

	Pre-Project	Post-project	Calculated Porosity Change[1]
Mean	1.05	1.02	+1.8%
Std. Dev.	0.19	0.27	

The Regional Soil Quality Standards state that "a 10 percent reduction in total soil porosity corresponds to a threshold soil bulk density that indicates detrimental soil compaction" (USDA, 1995). Bulk densities measured after project treatments remained well under the bulk density value that corresponds to a 10% porosity reduction for this treatment unit (1.21 gm/cm^3). The calculated means indicate a small overall decrease in bulk density, resulting in an overall increase in porosity of about 1.8%. However this small calculated decrease in bulk density (0.03

[1] The change in porosity is given by:
$\Delta P = (Dbi-Dbf)/(Dp-Dbi)$
where Dbi is the initial soil bulk density found under pre-project conditions, Dbf is the final bulk density after the project, and Dp is the density of the individual soil particles, which is assumed to be 2.65 gm/cm^3. Similarly, the equation used to calculate the threshold bulk density (Dbt) corresponding to a 10% decrease in porosity is given by:
$Dbt = 0.1Dp + 0.9Dbi$

gm/cm^3) is well within the standard deviations of the means and was not found to be statistically significant (P=0.698). Therefore, there was no real change in bulk density for the SEZ unit.

WT Forwarding Unit

The results of the analyses for the bulk density samples collected in the WT forwarding unit are presented in Table 5 below. Because the transects were located outside of the rocky and stony soil types, rock fragments larger than fine and medium gravels (>20 mm) were not encountered during sampling, and bulk density values did not need to be corrected due to rock fragment content.

As demonstrated below, bulk densities after project treatments remained well under the 10% porosity reduction threshold bulk density value for this unit of 1.45 gm/cm^3. The calculated means actually represent a small overall decrease in bulk density, resulting in an overall increase in porosity of about 3.8%. However, this small calculated decrease in bulk density (0.05 gm/cm^3) is well within the standard deviations of the means and was not found to be statistically significant (P=0.175). Therefore, there was no real change in bulk density for the WT forwarding unit and soil porosity was not negatively affected by project treatments in this location, so project treatments did not result in detrimentally compacted soils.

Table 5. All pre- and post-project whole soil BD (gm/cm3) results for the WT Forwarding Unit, including the associated calculated change in porosity. Sample size is 21.

	Pre-Project	Post-project	Porosity Change
Mean	1.32	1.27	+3.8 %
Std. Dev.	0.08	0.13	

VI.4. Soil Moisture

SEZ Unit

A soil moisture classification was conducted prior to heavy equipment operations in the SEZ unit using the moisture determination protocol presented above in Table 1 to ensure that soil moisture levels represented operable field conditions. In 2008, moisture conditions were monitored on May 21, and were determined to be operable. Following that field assessment, scattered rain showers occurred in the project area between 5/22 and 5/27, prompting the monitoring crew to re-assess conditions. On May 27, 2008, moisture conditions were again monitored for operability; however, the wetting that occurred from the rainfall that week moistened the soil and changed the conditions, making them inoperable. For this reason, treatments in the SEZ unit were postponed until the 2009 field season. Monitoring of soil moisture conditions using this same protocol was conducted on June 15, 2009, however conditions at this time were still too wet to allow operations to begin. Again on June 22, 2009, soil moisture site conditions were

checked, and at this time only a small portion of the unit exhibited soils that were too wet to operate. Finally, on June 24, 2009 monitoring indicated that the site conditions had dried out sufficiently to allow operations to begin in the SEZ unit.

In addition to these field determinations, gravimetric soil moisture was measured as part of the bulk density lab analysis. These data were collected partly to determine the level of soil moisture actually present when performing the soil moisture squeeze tests to determine operability. In addition, this information can be used to correlate measured soil moisture to post-project Ksat and bulk density changes. The average gravimetric soil moisture value for the entire unit was the same for both pre- and post-project monitoring periods, 6.8% by mass.

This percent soil moisture is very low, and ranged from a mean of 4.9-9.4% pre-project and 4.3-8.3% post-project. These data can be used when comparing the results of this project to other projects, particularly where pre-project soil moisture conditions may be substantially different. The treatments in this unit were completed relatively quickly because of the small acreage of the unit, so only about three weeks passed between pre- and post-project monitoring. For this reason, the soil moisture conditions remained mostly unchanged between pre- and post-project sampling, and the average moisture content in the unit can be assumed to be representative of field conditions during implementation.

WT Forwarding Unit

Soil moisture classification was also conducted using the moisture determination protocol (Table 1) prior to starting work in the WT forwarding unit to ensure that moisture conditions represented operable field conditions. In June of 2009, soil moisture conditions were monitored and determined to be operable in the majority of the unit. Although some portions of this unit still exhibited inoperable soil moisture conditions at this time (i.e. exhibited “very moist” conditions according to Table 1), it was determined that operations could begin in the area due to the intensive soil quality monitoring effort planned and the localized and limited extent of the wetter soil areas. Operations began in this unit on June 8, 2009. At that time, several of the areas included in the sampling effort along the established transects still exhibited inoperable soil moisture conditions (i.e. very moist soil) according to Table 1.

The gravimetric soil moisture conditions were measured as part of the bulk density lab analysis for this project. The percent soil moisture content was very low, ranging from a mean of 4.9-9.3% before implementation began, for an average of 7.4 %, and ranging from 2.7-4.7% after implementation, for an average of 3.7%. Treatments in this unit spanned a much longer time period than those in the SEZ unit because of the larger relative size. For this reason, pre- project soil moisture was higher than that post-project. However, because there were no differences between pre- and post-project Ksat or bulk density values, it is assumed that the slightly higher soil moisture levels before project treatments did not affect project impacts on these soil parameters. Although the soil moisture classifications based on Table 1 identified areas of inoperable soil moisture conditions, all of the gravimetric soil moisture results indicated relatively low soil moisture conditions.

VI.5. Soil Cover

SEZ Unit

The percent ground cover was determined by ocular estimates and the depth of ground cover was measured at each of the sampling locations both before and after the project. In addition to measuring the percent and depth of ground cover, the type of ground cover was also recorded at each site. The ground cover in the SEZ unit before the project consisted of duff, litter, and small (<12") and large (>12") woody material. The ground cover after the project again consisted of these organic materials, and also consisted of slash, generally less than three inches in diameter. The average percent cover for pre-project and post-project conditions were 100% and 95%, respectively. The pre- and post-project values for average percent cover and depth of cover are presented in Table 6 below.

Table 6. Summary statistics for pre- and post-project percent cover and depth of cover for the SEZ Unit. Sample size is 60 for both pre- and post-project datasets.

	Pre-project Percent Cover	Pre-project depth of cover (inches)	Post-project Percent Cover	Post-project depth of cover (inches)
Mean	100	3.3	95	3.9
Range	100 to 100	1 to 14	40 to 100	0 to 12

As can be seen from these data, there was an approximate 5% reduction in soil cover between the pre-project and post-project data; however, soil cover remained extremely high and the depth of cover remained virtually unchanged. The Region 5 Soil Quality Standards require that sufficient soil cover is maintained in order to prevent accelerated soil erosion. The ground cover within this unit is clearly sufficient to prevent increased erosion, and well within the USFS Region 5 standard of 50% cover.

WT Forwarding Unit

The ground cover in the WT forwarding unit before the project consisted of duff, litter, small (<12") and large (>12") woody material and bare ground. The ground cover after the project consisted of these same organic materials and bare ground, and also consisted of slash (primarily broken limbs and braches with needles), generally less than three inches in diameter. The average percent cover for the pre- and post-project conditions in the project area were 98% and 93% respectively. The pre- and post-project values for average percent cover and depth of cover are presented in Table 7 below.

Table 7. Summary statistics for pre- and post-project percent cover and depth of cover for the WT Forwarding Unit. Sample size is 60 for both pre- and post-project datasets.

	Pre-project Percent Cover	Pre-project depth of cover (inches)	Post-project Percent Cover	Post-project depth of cover (inches)
Mean	98	2.12	93	1.44
Range	60 to 100	0 to 6	30 to 100	0 to 5

As can be seen from these data, there was an approximate 5% reduction in soil cover between the pre- and post-project data; however, soil cover remained extremely high. The Region 5 Soil Quality Standards require that sufficient soil cover is maintained to prevent accelerated soil erosion, and sets a threshold for soil cover of 50%. The ground cover within this treatment unit is clearly above that threshold value.

VII. WEPP ESTIMATES OF RUNOFF AND EROSION

The Watershed Erosion Prediction Project (WEPP) hillslope model was used to predict runoff and erosion response for both pre- and post-project conditions. This model was developed by the USFS Rocky Mountain Research Station in Moscow, ID to predict erosion from rangeland and forestland and was recently updated with Tahoe Basin specific files for climate, soil, and management. The model allows the user to input various parameters related to soils, vegetation, soil cover, slope and climate and produces estimated levels of runoff, erosion, and sediment yield. Measured values for Ksat, bulk density, ground cover, canopy cover and slope were manually entered into the model for each simulation. As noted above, the conditions in the WT forwarding unit did not change as a result of the project, with no measurable change in Ksat or bulk density identified. Therefore, hillslope simulations using the WEPP model were only conducted for the SEZ treatment unit.

The key infiltration parameter in the WEPP model is the Green-Ampt effective hydraulic conductivity (Keff). The median values of Ksat measured in the field were assumed to be the best representation of this parameter to reflect field conditions of Keff in the model simulations.

The WEPP model has an estimated accuracy of ±50%. Although this is a high level of uncertainty regarding model results, this model is a very valuable tool for evaluating the potential for increased erosion and sediment yield rather than predicting the actual magnitude of those responses.

SEZ Unit

Two hillslope profiles were constructed in WEPP to represent the different flow paths present within the SEZ treatment unit. The two hilllslopes were modeled at the approximate locations of transects in this unit where the upper hillslope flow connects with the perennial channel. The hillslope modeled flow paths were designed to represent the “worst case scenario”, by following

the longest flow path present and applying the greatest slope measured within that portion of the unit. The median Ksat values for the unit were used as an input for Keff for each hillslope simulation for the pre- and post-project condition (Table 8). The WEPP model is not as sensitive to changes in the bulk density metric as it is to changes in the Keff parameter. However, bulk density values did not change much between pre- and post-project datasets, and changes were not found to be statistically significant. Therefore, the bulk density value used for WEPP simulations was set to 1.05 gm/cm^3 for both hillslopes and for both the pre- and post-project simulations because this reflects the mean pre-project bulk density value in this unit and there was no change measured in bulk density resulting from treatments.

The soil file representing a Tahoe granitic soil was used in all simulations, with the following modifications. The Granitic Old Forest soil files were used for the entire length of each hillslope simulation for the pre-project condition and for the upper slope (non-SEZ) areas for the post-project simulations. The Granitic Bunch Grass soil files were used for the lower slope areas during the post-project model simulations because these SEZ areas were left with much less conifer and much more riparian vegetation cover after treatments. The depth to the restrictive layer for the soil types used in the simulations is approximately 16 inches and 32 inches for the Granitic Old Forest and Granitic Bunch Grass soil types, respectively. The value of Keff in the general project area was set to the median measured Ksat value of 5.43 in/hr for the pre-project simulations and 2.08 in/hr for the post-project simulations.

The model's management file representing Tahoe Old Forest was used for the pre-project simulations and the upper portions of the hillslope outside of the SEZ for the post-project simulations, and Tahoe Bunch Grass was used for the post-project simulations within the SEZ boundary (i.e. lower slope areas), since this was assumed to better represent a restored SEZ condition (e.g. the bunch grass management file does not assume an accumulation of a litter layer each year and the Old Forest management file does). However, the canopy cover, ground cover, and bulk density values measured in the field were substituted for the default values. Based on input from the project silviculturist, the value for canopy cover was set to 60% for the pre-project simulations and 30% for the post-project simulations.

The value for ground cover in the project area was set to the measured mean value of 100% for the pre-project simulations and to 95% for the post-project simulations. The Heavenly Valley SNOTEL climate data file was used to generate 30 years of climate data. The parameters used for the pre- and post-project simulations are presented in Table 8 below.

The first hillslope used for simulations was based on a "worst case scenario" that assumed an upper slope of 25% and length of 110 feet. The lower slope, which was the SEZ area along the perennial channel, was assumed to be 10% slope and 40 feet in length. The second hillslope represented the largest slope and length of flow paths present on the ground in this portion of the unit, with an upper slope of 23% and length of 100 feet. The lower/SEZ slope for the second hillslope was assumed to be 20 feet in length and 5% slope.

Table 8. Field based measurements used in WEPP hillslope simulations for the Roundhill SEZ Project

Land Use Type	Canopy Cover	Ground Cover	Keff (in/hr)	Bulk Density (gm/cm^3)
Pre-Project				
Hillslope 1 and 2	60%	100%	5.43	1.05
Post-Project				
Hillslope 1 and 2	30%	95%	2.08	1.05

30-Year Simulations

A 30 year simulation period was used because the WEPP model developers suggested that this would represent a worst case scenario for climate based on this dataset. Within 30 years of simulation, more frequent large storm events occur than are representative of a shorter or longer duration climate record for this area.

The 30-year simulations using the Heavenly Valley SNOTEL site climate data resulted in an average annual precipitation of 33.84 inches. For the first hillslope, the pre-project average annual runoff was 0.00 inches, and the average annual soil loss and sediment yield was 0.000 tons/acre. The output also demonstrated that although average annual runoff was less than 0.00 inches, no runoff occurred during rain events for the 30 year simulation, and the very small amount of runoff resulted from just six snowmelt or rain on snow events during the model simulation period. The post-project simulations for the first hillslope provided similar results. The average annual runoff was predicted to be 1.21 inches. However, the average annual soil loss and sediment yield was still predicted to be 0.000 ton/acre. For the post-project simulation, runoff resulted from one rain event, but 128 snowmelt and/or rain on snow events during winter months caused the majority of the runoff during this 30 year simulation.

For the second hillslope simulation, the pre-project average annual runoff was predicted to be 0.19 inches. The average annual soil loss and sediment yield was again predicted to be 0.000 ton/acre. In this hillslope scenario, the runoff generated during the 30 year simulation period came entirely from 16 snowmelt or rain on snow events during the winter. For the post-project conditions on hillslope 2, the average annual runoff was predicted to be 2.63 inches. The resulting average annual soil loss and sediment yield was still 0.000 ton/acre under this scenario. The runoff generated from this hillslope resulted from eight rain events and 184 snowmelt or rain on snow events during the 30 year simulation period.

The model output of 0.000 ton/acre of soil loss and sediment yield for all modeled scenarios indicates that the average annual soil loss and sediment yield was less than 0.001 ton/acre. Another useful feature of the WEPP hillslope model is the ability to look at graphical outputs for each simulation year. For each simulation (pre and post, hillslopes 1 and 2) the graphical outputs for sediment leaving the hillslope profile (i.e. sediment exiting the hillslope into the channel) and sediment leaving each overland flow element (i.e. sediment leaving both the upper and lower

slope segments of the hillslope and entering the next downhill segment) were also considered. In each case, the model predicted that no sediment would leave any of the overland flow elements and that no sediment would leave the hillslope profile during the 30 years of simulation.

WEPP Conclusions

In addition to performing model simulations using the measured conditions in the SEZ unit, WEPP model runs were also conducted to determine at what Ksat value a sediment delivery response could be expected from these units. The unit characteristics for this project were such that no erosion or sediment delivery response was predicted by the WEPP model until Ksat for the entire unit was reduced to approximately 0.15 in/hr, which is more than a ten-fold reduction in the average pre-project Ksat. The physical site characteristics may well explain this finding. Specifically, the SEZ unit was very well vegetated before the treatments occurred, and the treatment approach resulted in a large amount of slash material being left on the ground after treatments. Therefore, the groundcover conditions both before and after treatments were nearly 100%. In the WT forwarding unit, the slopes are very gentle (< 10%) and not subject to erosion and runoff except under extreme circumstances. In addition, the soil parent material in both units is granitic, which is inherently less prone to compaction than other soil types. Finally, the climate files for the Tahoe area assume a snowmelt driven system, which has more prolonged runoff events, rather than regular heavy rains. All these factors support the WEPP model finding that a substantial reduction in average Ksat (e.g., at least ten-fold) would be needed before erosion would occur.

VIII. CONCLUSIONS AND DISCUSSION

SEZ Unit

The soil quality data analysis for the SEZ unit determined that there is a statistically significant difference between Ksat measurements pre- and post-project for the entire dataset, resulting in a decrease in median Ksat values from 5.43 in/hr to 2.08 in/hr. Though statistically significant, the measured decrease has little practical significance. The results indicate that the fuels reduction treatments impacted the rate at which water will flow through the soil, but not so much as to change the erosion or sediment delivery rates because the post-project median Ksat value is still relatively high and the reduction was only a fraction of the natural variability of Ksat within the project. The management implication of this result is that such small measured reductions in Ksat values are not ecologically significant in regards to impacts to soil hydrologic function (i.e., infiltration rates and accelerated surface runoff). This is due to a combination of low gradient slopes, robust vegetative cover and ground cover, relatively high baseline infiltration capacities (due in part to coarse texture and weak surface structure of the soils), and the large natural range of Ksat within the unit.

Analysis of the bulk density monitoring data determined that there were no statistically significant differences in bulk density, or associated soil porosity, between pre-and post-project samples. In addition, monitoring results demonstrated only a 5% measured decrease in soil cover (100% pre-project, compared to 95% post-project). Therefore, the Region 5 USFS Soil Quality

Standards for changes in soil porosity (no more than 10% reduction) and residual soil cover (at least 50% cover) were easily met.

WEPP simulations utilizing this measured pre- and post-project soil quality data predicted that no soil loss or sediment delivery would result from the measured reductions in Ksat and the post-project canopy and ground cover. Although the rate at which water flows through the soil at approximately 4 inches below the soil surface (as represented by Ksat) was reduced slightly, it had no practical significance, as the post-project conditions proved to still be very resistant to generating an erosive runoff response. This further demonstrates that the fuels reduction treatments did not change the erosion or sediment delivery rates in the treatment area.

The results of this monitoring effort indicate that treatment of Tahoe Basin SEZs with similar CTL forwarder/ harvester technology can be implemented without causing detrimental soil disturbance under favorable soil conditions (e.g. coarse-textured soils and low soil moisture content). The measured percent soil moisture values presented above represent fairly dry conditions; dry soils compact much less than wet soils, so this was advantageous. The sandy nature of the soil in this unit, and the relatively dry soil moisture conditions present at the time of implementation seem to have effectively prevented adverse impacts to soil quality. These results are not surprising, and are generally consistent with other literature results. Operating on relatively dry soils and limiting aerial extent of equipment traffic are highly effective preventive strategies for minimizing compaction (Miller et al 2004). In addition, the method used for determining operable conditions in this project, estimating soil consistency and limiting operations to soils with moisture levels below the plastic limit, is generally accepted (McNabb et al 2001).

This treatment area represents somewhat different conditions than were monitored for SEZ mechanical operations in the Heavenly Creek SEZ Demonstration Project (HSEZ) (Norman, 2008) in that the SEZ is a narrow strip along a perennial channel, and steeper slopes are present in the forested area adjacent to the unit. However, results of the HSEZ monitoring effort were consistent with the results from the Roundhill SEZ unit, with only minor reductions in Ksat (which did not result in a predicted runoff or sediment delivery response according to the WEPP model, and were therefore assumed to not represent an ecologically significant reduction in soil permeability) and no differences in bulk density values before and after treatments. Even with the additional inherent sensitivities present in the Roundhill SEZ unit (e.g. greater slopes, narrow SEZ adjacent to perennial channel), CTL treatments were conducted successfully in this SEZ unit without detrimentally impacting soil or water quality.

WT Forwarding Unit

The monitoring in the WT forwarding unit presented some interesting results. This treatment technique, although considered to cause less impact than conventional whole-tree thinning operations (because of the lack of skidding), was assumed to have greater soil physical impacts than the standard CTL treatment technique due to the removal of all tree material, including the slash that would otherwise have been left on the ground as cover or used as a slash mat to limit compaction. However, statistical analysis of the Ksat and bulk density data determined that there was no change in these parameters after project treatments.

Although this site was treated in the recent past (1990s) and experiences a high volume of dispersed recreation use, the pre-project Ksat and bulk density conditions were not unlike the undisturbed SEZ unit. This could be because the impacts from the previous treatments and past disturbances were minor, because of site recovery that has occurred since the previous treatments were employed, or because soil textures were slightly different on the two sites. The very sandy nature of the soil in this unit, and the low ground-pressure equipment used for the treatments seem to have protected the soil from adverse impacts resulting from management activities associated with the project.

Future Soil Quality Monitoring Recommendations

Monitoring parameters

The LTBMU has used a similar monitoring approach as conducted for the Roundhill Project units in several other vegetation management treatment areas in the recent past (Christensen and Norman, 2007 and Norman et al., 2008). The results have been somewhat variable, partially due to the different soil textures involved. However, in both the Heavenly SEZ and Roundhill SEZ units (both of which exhibited coarse textured, granitic soils) Ksat was found to be reduced slightly after treatments, and though that reduction was found to be statistically significant in both cases, it proved to be of little practical significance. In both studies, the corresponding bulk density monitoring indicated no measured change in pre- and post-project bulk density values. Furthermore, when the WEPP model was applied using the measured post-project soil quality conditions, an erosion and sediment delivery response was not predicted for either the HSEZ or Roundhill SEZ units. This suggests that although Ksat was reduced in the HSEZ and Roundhill SEZ units, the Ksat reductions were not enough to increase the erosion or sediment delivery response from the treatment units. This is not uncommon because in these types of coarse textured soils, Ksat may be reduced by decreasing the volume and extent of macropores in the soil. These types of changes to the pore size distribution in the soil profile would decrease the rate of water movement through the soil (i.e. Ksat); however, the bulk density of the soil may not change as a result. This may be an indicator of a positive effect to these coarse soils, in that the water holding capacity of the soil may be increased, improving water availability for vegetation. This was the case in a recent research study, which showed that in sandy loam soils, compaction increased the amount of plant available water and was associated with increased tree growth (Gomez et al. 2002).

It is recommended at this time that Ksat monitoring in coarse textured soils (as described in Table 9 below) be discontinued when attempting to answer these monitoring questions under similar conditions. Until additional studies of this kind have been completed for finer textured soils (i.e. light, medium or heavy soils in Table 9), both Ksat and bulk density monitoring should be conducted similar to what was monitored here to ensure that comparable responses can be expected (e.g., treatment effects are limited to small reductions in Ksat relative to the natural range of Ksat within the project area). Note also that Ksat may still be a useful metric if a different monitoring question were being asked, such as for treatments on steep slopes.

Soil Moisture Determination Protocol

The LTBMU has been using soil moisture classifications made in the field to establish whether a unit is operable and ready for mechanical equipment operations, or if it is too wet to allow operations to begin. The criteria used for this project is shown in Table 1. Table 1 was derived from a larger table that includes other soil textures, shown in Table 9 below.

When this protocol was first adopted by the LTBMU for this purpose, the darker shaded boxes in Table 9 represented soil moisture conditions which were too wet to allow mechanical operations without potentially causing compaction or other soil quality impacts. Based on a recommendation at that time from a USFS Soil Scientist from the Pacific Southwest Research Station, the light shaded boxes were also assumed to represent inoperable soil moisture conditions for the Lake Tahoe area. The thought at the time was that because of the sensitive nature of Lake Tahoe, and the concerns in this area about sediment delivery effects on water quality, more conservative restrictions are appropriate here. Since this protocol began being used by the LTBMU in 2006, both sets of shaded boxes (i.e., light and dark) were assumed to represent inoperable soil moisture conditions. Only those soils which demonstrate the characteristics described in the non-shaded (white) boxes below were considered operable conditions, and equipment was then allowed to begin work in that area.

Table 9. **Soil Moisture determination protocol used by LTBMU, 2006-Present**

	Coarse Soils	**Light Soils**	**Med. Soils (<35% clay)**	**Heavy Soils (>35% clay)**
Soil Moisture % Increases Downward	Loamy sands, fine sand loam, very fine sands, coarse sands	Fine sandy loams, sandy loams, very fine sandy loam	Sandy clay loam, loam, silt loam, sandy clay loam, clay loam	Clay loam, sandy clay, silty clay loam, clay
Dry soils	Dry, loose, single grained flows thru fingers	Dry, loose, flows thru fingers	Powdery, dry, sometimes slightly crusted but breaks down into powdery conditions	Hard, baked, cracked sometimes has loose crumbs on surface
Moist soil	Still appears dry, will not form a ball with pressure	Still appears to be dry; will not form a ball	*Somewhat crumbly, but will hold together from pressure*	Somewhat pliable; will form ball under pressure. At plastic limit.
Moist soil	Still appears dry, will not form a ball with pressure	*Tends to ball under pressure but seldom will hold together*	Forms a ball and is very pliable, sticks readily if high in clay.	Easily ribbons out between fingers, has a slick feeling. At plastic limit.
Very moist soil	*Tends to stick together slightly, sometimes forms a very weak ball*	Forms a weak ball breaks easily, will not stick. Plastic limit or nonplastic.	Forms a ball and is very pliable, sticks readily if high in clay. Exceeds plastic limit.	Easily ribbons out between fingers, has a slick feeling. Exceeds plastic limit.
Wet soils	Upon squeezing, free water may appear. Wet outline is left on hand. Nonplastic.	Upon squeezing free water may appear. Wet outline left on hand.	Can squeeze out free water. Wet outline left on hand.	Puddles and free water forms on surface. Wet outline left on hand.

← Recommended not operable by USFS Regional Soil Scientist

← Proposed additional restriction based on recommendations by USFS PSW Soil Scientist

For the WT forwarding unit, the protocol used for field determinations of soil moisture conditions displayed in Table 1 indicated that some areas of the treatment unit exhibited inoperable soil moisture conditions. In other words, several of the soil samples collected exhibited characteristics consistent with the light shaded box in Table 9 above, which corresponds to very moist soil for the coarse soil texture. However, all of the gravimetric soil moisture results correspond to very dry soil conditions. In addition, even in areas of the WT forwarding unit that exhibited conditions in the light shaded box, no evidence of increased bulk density or decreased Ksat was observed.

Based on these findings, the additional soil moisture restrictions recommended for use in the Lake Tahoe Basin (i.e., light shaded boxes) are rejected as an overly conservative approach for determining operable conditions. The conditions displayed in Table 9 in the light shaded boxes (with italicized text) seem to represent operable conditions for mechanical operations with low ground pressure equipment, without resulting in adverse soil quality impacts. Additional studies are needed to fully test whether the light shaded boxes represent operable soil moisture conditions or not. It is recommended that a follow-up study be conducted on similar coarse textured soils to measure bulk densities pre- and post-project, in a unit that has soil moisture conditions consistent with those described in the light shaded boxes of Table 9, when using treatment equipment comparable to that used in this study.

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Figure 1

Roundhill Fuel Reduction Project SEZ Unit Map

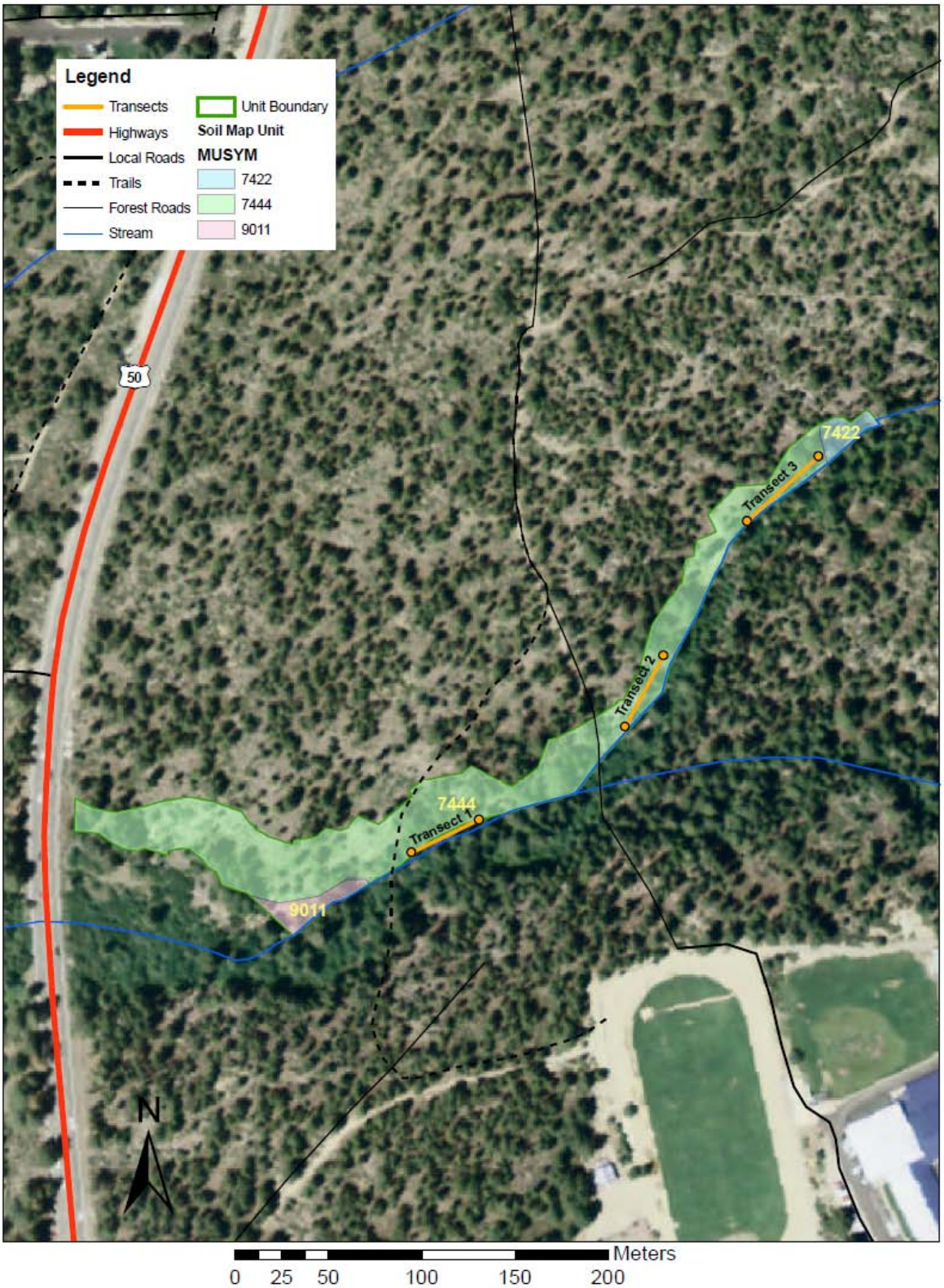
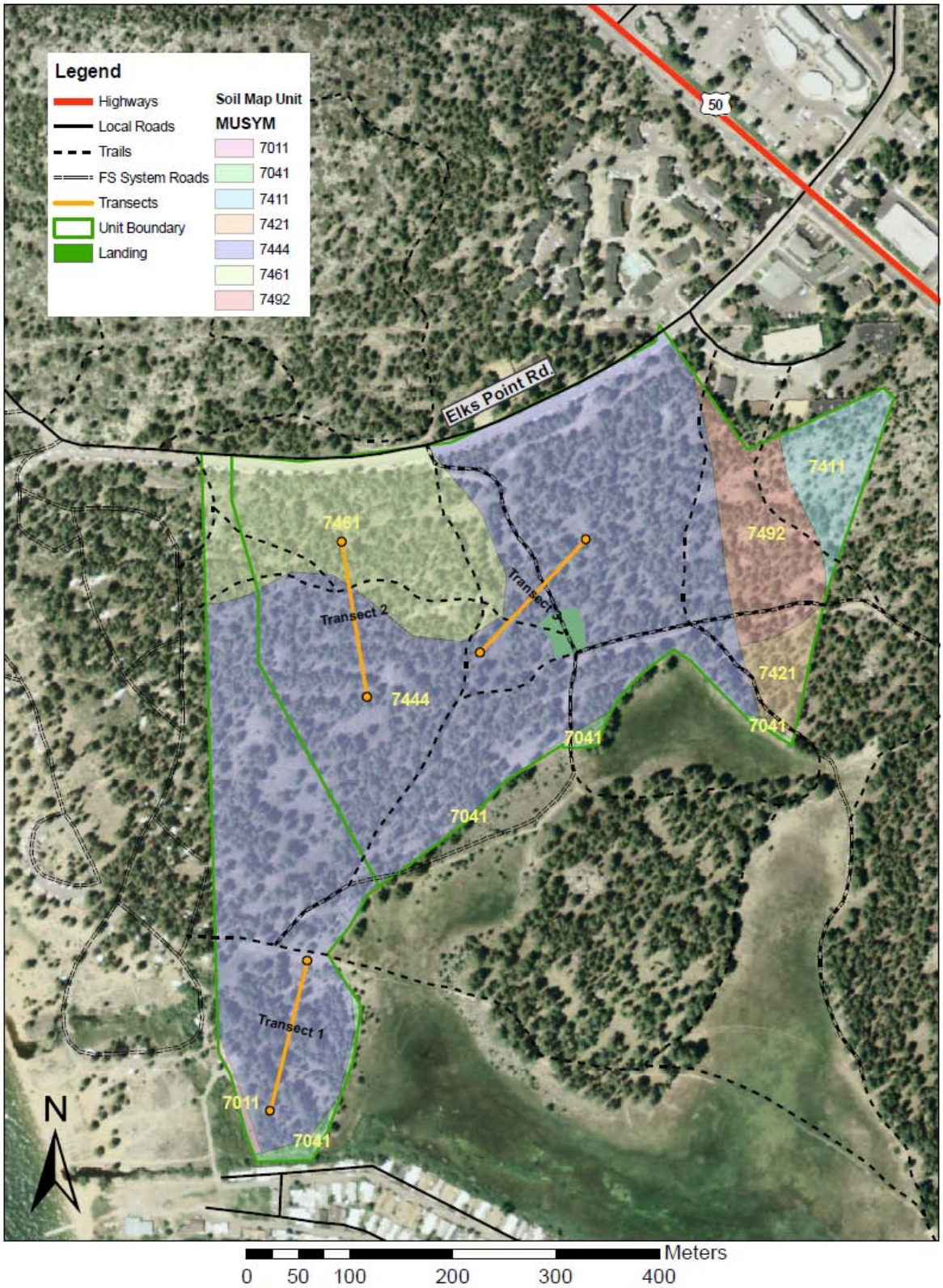


Figure 2

Roundhill Fuel Reduction Project Whole-tree Forwarding Unit Map



Appendix A: Monitoring Protocols

Establishing Monitoring Transects

Sampling along transects allows both the before treatment and after treatment samples to be taken in the same general area. The transect location should be representative of the treatment unit. This may involve positioning transects such that some of the main forwarder/skid trails or landings are included. Choose the ends of the transect so that a tape measure can be strung between them. Samples are then gathered at equally spaced intervals along the length of the tape measure. For example, if the two transect ends are spaced 180 feet apart and samples are taken every 20 feet along the transect (beginning at 0 feet) then that transect would have 10 sampling locations.

The ends of transects are monumented with rebar pounded flush with the ground. Caps should be used to identify the rebar as the transect starting point (zero feet on the tape measure) or ending point (the tape measure is stretched out to the end point monument). Additionally, the cap should have the transect number (T1 for transect #1, T2 for transect #2, etc.) and the year that transect was established. The GPS coordinates of the start and end points for the transects should be recorded with a high precision GPS such as a Trimble GeoXT, and the differentially corrected coordinates and datum recorded on the field data sheet. Also, a few trees near each end of the transect that are NOT going to be removed during treatments should be marked with an appropriate flagging color (see contract administrator to help determine what color flagging should be used) and/or livestock ear tags. Write the bearing from true north and the distance to the transect endpoint on this flagging or ear tag. If present, prominent landmarks such as boulders, trees, etc. should also be described along with the location of the transect end points relative to the landmarks. Using these methods, transect end point locations can still be identified even if a monument is missing after treatment.

Previous work has shown that a sample pool of approximately 60 Ksat measurements and 20 bulk density measurements was adequate to characterize the soil conditions in a treatment unit. In 2009 at the Roundhill Fuels Reduction Project treatment units, three transects were established and 20 sampling locations were established along each. Saturated hydraulic conductivity, soil cover, and disturbance class was measured at each sampling location, and bulk density samples were gathered at every third sampling location. This allowed for a large area to be sampled and to still gather enough samples to reach the target of 60 Ksat measurements and 20 bulk density measurements.

Measuring Saturated Hydraulic Conductivity (Ksat)

Ksat data at a depth of 4 to 8 inches will be collected in the field using a constant head permeameter (CHP) modified for use in the Lake Tahoe Basin by Wood Loftis of the NRCS. This device measures the rate at which water moves through the soil (saturated hydraulic conductivity or Ksat) and is recorded in inches per hour (in/hr).

The steps for measuring Ksat are as follows:

1) Create a hole 4 inches deep by 1.125 inches in diameter using a sharpened metal pipe slightly larger in diameter than the permeameter. The pipe is sharpened on the inside of the pipe in order to not cause compaction in the hole as the pipe is pounded into the ground. Use a hammer to drive the pipe to a depth of six inches, being careful not to dislodge soil from the pipe back into the hole or disturb the integrity of the hole as you remove the pipe. (Note: To prevent the sand from falling back into the hole as the pipe is extracted from dry, loose sandy soil, it may help to wet the soil by pouring water through the pipe before it is extracted). The diameter of the hole (1.125 inches) and the water depth (3.125 inches) will influence the multiplier in the Ksat equation given below.

2) Fill the CHP with water.

3) Place the "doughnut-shaped" acrylic spacer ring onto the small end of the CHP.

4) Insert the small end of the CHP into the hole created in step 1 until it just touches the bottom of the hole.

5) Slide the spacer ring and the locking collar down so that the spacer ring is touching the "doughnut-shaped" spacer ring. Lock the collar in place.

6) Lift the CHP slightly and insert the acrylic spacer with the "U" shaped opening between the doughnut-shaped spacer ring and the locking collar of the CHP. This should suspend the end of the CHP ¼ inch above the bottom of the hole. The CHP is designed so that the water level in the hole will automatically equilibrate to a depth of 3.125 inches.

7) Slowly open the valve on the CHP ¼ turn and allow the soil to become saturated. (The Ksat measurement requires that the soil be saturated for the measurements to be accurate and consistent). This can be achieved by either of two methods.
    a. Method #1. The first method simply requires that the CHP be left in the hole a sufficient time (~15-20 minutes) to allow the soil to become saturated, after which time the measurement can be made. (Note: This method allows more than one CHP to be active at one time. Several CHP units may be inserted and allowed to stand for sufficient time to become stable (i.e. soil is saturated), then measure a start time and water level of

each CHP. Once these measurements have been taken, make another round of measurements for the finish times and water levels.)

b. Method #2. The second method involves actively monitoring the change of the water level in the CHP until the rate of change stabilizes to within 10%, and is preformed as follows. Once the water level in the CHP reaches the next unit mark, start the timer. Record the time intervals for a given drop in water level. For soils with lower Ksat, the change in water level will be approximately one unit (~1/10 inch) every 20 seconds or more. For soils with higher Ksat it may be necessary to record the time interval for several (10) units of water level change. **The rate of change is stabilized when the time required for the given change of water level is consistent to within 10% for 3 consecutive measurements.** The average of the three final and consistent measurements is used to calculate the hydraulic conductivity (Step 8 below). The period of time needed to collect sufficient data to calculate hydraulic conductivity may range from several minutes to 30 minutes (including time required to saturate soil).

8) Calculate the Ksat using the data collected in step 7 above. The scale on the CHP is calibrated (to the Glover Solution) such that a direct reading of the CHP (in units per minute) translates directly into inches per hour of Ksat. For example, a change of one (small) increment of water level on the CHP in one minute translates to a Ksat value of one inch per hour. If a longer time interval is used, simply divide the number of increments of change as read directly from the CHP by the elapsed time and this will translate directly into inches per hour of Ksat. For example, if ten increments of change are recorded in five minutes, the Ksat value is simply 10 increments divided by 5 minutes for a Ksat of 2 inches/hour.

Measuring Soil Bulk Density

Bulk density samples will be taken immediately before and after mechanical treatment activities so that the soil moisture conditions will be representative of site conditions during treatment, in an attempt to link the direct affects of operating the equipment under varying amounts of soil moisture. Gravimetric soil moisture (described in Appendix G) can be calculated from the bulk density sample with little extra effort. The bulk density samples will be taken at the 4 to 8 inch depth at each location.

Soil compaction will be evaluated by comparing the bulk densities of core samples before and after treatments. In order to determine the background bulk density and the threshold level for detrimental compaction for a given area, undisturbed soil will be collected and analyzed either as pre-project sampling or concurrent with post-project sampling in nearby undisturbed areas. The bulk density of undisturbed (or pre-treatment) soil will be compared to the bulk density of disturbed (or post-treatment) soil to determine the level of compaction that has occurred. These bulk density measurements will allow for an examination of the level of compaction in the different soil types associated with various types and levels of disturbance. Bulk density samples are generally less variable than Ksat samples, thus fewer samples are required to obtain statistically significant results. Typically, 1/4 to 1/3 of the Ksat sample locations will be sampled for bulk density.

Soil cores will be taken along set transects at approximately equally spaced intervals and possibly at additional sampling points on landings. It is important that the core sampler remain sharp in order to take a good core. The cores should be taken from 4 to 8 inches below the soil surface to evaluate the potential for detrimental compaction. Care should be taken to avoid collecting cores that are significantly disturbed during collection by interference from roots or coarse fragments. If a core is significantly disturbed (more than 5% of the volume) it should be discarded and a new core should be taken. In gravelly or cobbley soils that require more than two attempts to obtain an undisturbed core, consider omitting these cores since they will likely be: 1) too disturbed during collection to represent the in situ bulk density of the area, or 2) not representative of the sampling location due to selectively sampling in an area that has a lower coarse fragment content, and therefore is more susceptible to compaction than the surrounding areas with coarser fragments. Document any significant problems that were encountered during core collection (roots, coarse fragments, excessively loose sediment).

To take a core sample:

1. Excavate a surface 4 inches below the soil surface and perpendicular to the slope.

2. Place the appropriate length core sleeve and spacers into the core sampler.

3. Hammer the core sampler into the ground, stopping when the solid head inside the sampler (or the upper most edge of the core sleeve) just reaches the excavated soil surface (avoid hammering the sampler any deeper into the ground as this will compact the soil sample).

4. Use the spade to help remove the core. This is essential in dry, loose soils. (Note: If you will use this sample to calculate soil moisture, be sure to store in a sealed, air-tight container such as a zip-lock bag, and keep it cool in a cooler or transfer it to a refrigerator until analyzed).

5. Extract the core sleeve from the sampler and trim the upper and lower surfaces of the soil core. Backfill any voids smaller than 5% of the total volume that result from coarse fragments that are half in the core section. Voids larger than 5% constitute a disturbed sample and a new core should be taken. A small diagonal cutter or snips is handy for roots.

6. If you hit large roots or much gravel while taking the sample, the soil was probably significantly disturbed and will not provide a representative bulk density sample.

Cores will be processed in the lab to determine their bulk density. Bulk density is the ratio of the dry weight to core volume. In the lab, the following steps will be followed to determine the dry soil weight and bulk density:

1. Weigh the pan into which the sample will be placed while drying.

2. Place the soil sample in the pan.

3. Weigh the "raw" or wet soil and the pan.

4. Place the sample in the oven and dry for 24 hours at 104° C.

5. Remove the sample and weigh the pan and dry soil.

6. Subtract the weight of the pan (determined in step 1) from the weight of the dry soil and pan (step 5) to obtain the weight of the dry soil.

7. The bulk density is calculated by dividing the dry soil weight (step 6) by the core volume. Dry soil weight / Core volume = Db

If you will use the same sample to measure the Gravimetric Soil Moisture, perform the additional steps below:

1. Calculate the weight of the water in the soil by subtracting the weight of the dry soil and pan from the weight of the wet soil and pan.

2. The gravimetric soil moisture is calculated as follows:
   Gravimetric soil moisture % = (weight of water / weight of dry soil) x 100%.

The amount of compaction can be estimated by comparing the bulk densities of undisturbed soil samples to the bulk densities of the disturbed soil samples. Region 5 Soil Quality Standards suggest that soil is detrimentally disturbed when compaction or puddling reduces the total soil porosity by more than 10% (as compared to undisturbed soil). This condition is often referred to as detrimental compaction. Threshold bulk densities which correspond to a porosity loss of 10% are derived from the following formula:

$$Dbt = 0.1\ Dp + 0.9\ Dbi$$

where Dp is the mean particle density (2.65 mg/cm^3) and Dbi and Dbt are the initial and threshold bulk densities, respectively.

Measuring Soil Cover

Make visual estimates of the percent soil cover over one square meter sections at all transect and landing sampling points. Choose a set distance along each transect for the one square meter sample area. In order to avoid introducing bias into the sample area selection, be as consistent in the selection method as possible (for example, the sampling area starts at every 50 ft increment and is taken from the north side of the tape). Record the estimated cover in percent and record the predominant cover with the following codes:

- **O** (for O horizon) - Duff, litter, and woody material <12 inches (O layer);
- **S** (for slash) - Logging slash;
- **R** (for rock) - Rock and rock fragments;
- **V** (for vegetation) - Vegetation or shrub canopy less than 2 feet above the soil surface;
- **B** (for bare) - bare soil, and use a subscript "f" if it resulted from fire;
- **W** (for large woody debris) - larger (>12 inch) woody debris including logs and stumps;
- **M** (for cover mixed into the soil) - litter mixed into soil to <50% cover.

Determining Gravimetric Soil Moisture

The gravimetric method for determining soil moisture measures the mass of the water contained in the soil sample. The soil moisture content is reported as a percentage and is given by the ratio of the mass of water to the mass of dry soil, then multiplied by 100 to convert to a percentage. The same sample used to measure bulk density (Appendix C) can also be used to calculate gravimetric soil moisture.

Equipment

Equipment needed includes zip-loc bags (preferably freezer bags) or other sealable container, a cooler, soil sampling tool, plastic zip-loc bags, and a scale with an accuracy of 0.1 grams or better. The soil sampling tool can be a soil core sampler, soil probe, auger, or even a post-hole digger. (If the same soil sample is to be used to calculate soil bulk density, then the core sampler should be used to collect a known volume of soil).

In-field Sampling

It is important to obtain a representative sample of the site in question. Sample the site at a minimum of three locations per soil type. Choose sample locations that are representative of the entire site being treated that day and avoid sampling small areas of low spots or ridges that do not represent the majority of the site.

First clear away the upper organic layer. Then excavate the top 4" of soil to form a flat surface parallel to the ground surface. Extract a core from 4 to 8 inches below the ground surface by following the protocol for Bulk Density Sampling (Appendix C), making sure to place the sample in a sealed container.

The samples should be removed from the core sampler and sealed in a zip-lock bag (or other sealed container) as quickly as possible to prevent the loss of moisture to evaporation. It is absolutely imperative that the samples are placed in a sealed container. The samples should then be placed in the cooler to keep the samples at a moderate temperature.

If the soil is too loose to collect a reliable bulk density sample, the soil is likely very dry. In this case a 50-100 gram sample can be collected and analyzed to obtain the wet and dry weights of the soil to quantitatively confirm the low soil moisture. Due to the lack of a known volume, there will be no bulk density data available for these samples.

Drying of Samples

After soil samples have been collected and taken to the office/lab, quick and careful procedures need to be taken. The following steps should be followed for drying the samples. Be sure to record the values on the Soil Moisture Data Sheet (Appendix H) as they are measured.

1. Thoroughly mix the sample while still in the zip-loc bag to ensure uniform distribution of the sample.
2. Weigh the *empty* tray into which the soil will be placed for drying (i.e., determine the tare weight of the tray). This value will be needed for the calculation of soil moisture.

3. Place the sample of wet/moist soil onto the tray and record the weight of soil and tray.
4. To determine the weight of the wet/moist soil, subtract the weight of the *empty* tray from the weight of the *tray with the wet/moist soil*.
5. Place the tray and sample in the oven at 104° and dry for 24 hours.
6. Remove the sample and tray from the oven (use insulated gloves and be careful of getting burned) and allow the sample to cool for a few minutes.
7. Weigh the dry soil and tray.
8. Determine the mass of water by subtracting the mass of the dry soil and tray (step 7) from the mass of wet/moist soil and tray (step 3).
9. To determine the weight of the dry soil, subtract the weight of the *empty* tray (step 2) from the weight of the *tray with the dry soil* (step 7).
10. Soil moisture % = [(mass of water) / (mass of dry soil)] x 100

Appendix B: Raw Data for SEZ Unit

Bulk Density and Gravimetric Soil Moisture Data

Sample #	Date Sample Collected	Gravimetric soil moisture (water wt/raw sample wt)	Moisture %	Bulk Density (g/cm3)	Pre or Post Project?
T1-0	6/23/2009	0.068	6.769	0.883	pre
T1-30	6/23/2009	0.060	5.994	0.990	pre
T1-60	6/23/2009	0.028	2.844	1.211	pre
T1-90	6/23/2009	0.025	2.488	1.275	pre
T1-120	6/23/2009	0.042	4.208	1.072	pre
T1-150	6/23/2009	0.063	6.326	1.050	pre
T1-180	6/23/2009	0.055	5.542	1.101	pre
T2-0	6/23/2009	0.051	5.056	1.404	pre
T2-30	6/24/2009	0.042	4.156	1.232	pre
T2-60	6/24/2009	0.130	12.959	0.737	pre
T2-90	6/24/2009	0.042	4.182	1.135	pre
T2-120	6/24/2009	0.095	9.478	0.691	pre
T2-150	6/24/2009	0.024	2.379	1.375	pre
T2-180	6/24/2009	0.038	3.768	1.191	pre
T3-0	6/24/2009	0.154	15.409	0.784	pre
T3-30	6/24/2009	0.105	10.477	0.921	pre
T3-60	6/24/2009	0.088	8.831	0.992	pre
T3-90	6/25/2009	0.079	7.925	0.948	pre
T3-120	6/25/2009	0.084	8.383	0.902	pre
T3-150	6/25/2009	0.068	6.783	1.088	pre
T3-180	6/25/2009	0.077	7.724	0.992	pre
T1-0	7/15/2009	0.063	6.267	0.857	post
T1-30	7/15/2009	0.057	5.674	1.049	post
T1-60	7/15/2009	0.021	2.062	1.360	post
T1-90	7/15/2009	0.035	3.478	1.078	post
T1-120	7/15/2009	0.041	4.072	1.132	post
T1-150	7/15/2009	0.046	4.551	1.191	post
T1-180	7/15/2009	0.037	3.702	1.187	post
T2-0	7/15/2009	0.034	3.436	1.406	post
T2-30	7/15/2009	0.056	5.573	0.995	post
T2-60	7/15/2009	0.126	12.564	0.824	post
T2-90	7/15/2009	0.084	8.426	0.881	post
T2-120	7/15/2009	0.057	5.746	0.948	post
T2-150	7/15/2009	0.081	8.125	0.785	post
T2-180	7/15/2009	0.101	10.129	0.780	post
T3-0	7/16/2009	0.131	13.052	0.889	post
T3-30	7/16/2009	0.089	8.899	1.029	post
T3-60	7/16/2009	0.110	10.976	1.063	post
T3-90	7/16/2009	0.061	6.062	1.091	post
T3-120	7/16/2009	0.073	7.324	1.100	post
T3-150	7/16/2009	0.058	5.754	1.193	post
T3-180	7/16/2009	0.058	5.841	1.237	post

Saturated Hydraulic Conductivity Data

Date	Sample #	Change in Water Level (unitless)	Time (s)	Ksat (inches/hour)	log (Ksat)	Pre or post project?
6/23/2009	T1-0	2	58.7	2.04	0.311	pre
6/23/2009	T1-10	10	79.3	7.57	0.879	pre
6/23/2009	T1-20	2	160	0.75	-0.125	pre
6/23/2009	T1-30	1	74.7	0.80	-0.095	pre
6/23/2009	T1-40	5	44	6.82	0.834	pre
6/23/2009	T1-50	2	99.7	1.20	0.080	pre
6/23/2009	T1-60	5	61	4.92	0.692	pre
6/23/2009	T1-70	5	164	1.83	0.262	pre
6/23/2009	T1-80	5	139	2.16	0.334	pre
6/23/2009	T1-90	5	57.3	5.24	0.719	pre
6/23/2009	T1-100	5	35.7	8.40	0.924	pre
6/23/2009	T1-110	5	37.3	8.04	0.905	pre
6/23/2009	T1-120	5	15.7	19.11	1.281	pre
6/23/2009	T1-130	5	22.3	13.45	1.129	pre
6/23/2009	T1-140	10	60.7	9.88	0.995	pre
6/23/2009	T1-150	5	20	15.00	1.176	pre
6/23/2009	T1-160	5	73.7	4.07	0.610	pre
6/23/2009	T1-170	5	60	5.00	0.699	pre
6/23/2009	T1-180	5	119	2.52	0.402	pre
6/23/2009	T1-190	5	36	8.33	0.921	pre
6/23/2009	T2-0	5	32	9.38	0.972	pre
6/24/2009	T2-10	5	23	13.04	1.115	pre
6/24/2009	T2-20	5	50.7	5.92	0.772	pre
6/23/2009	T2-30	5	34	8.82	0.946	pre
6/23/2009	T2-40	5	36	8.33	0.921	pre
6/24/2009	T2-50	5	23.3	12.88	1.110	pre
6/24/2009	T2-60	5	23.3	12.88	1.110	pre
6/24/2009	T2-70	5	58	5.17	0.714	pre
6/24/2009	T2-80	5	29	10.34	1.015	pre
6/24/2009	T2-90	5	21.3	14.08	1.149	pre
6/24/2009	T2-100	5	45	6.67	0.824	pre
6/24/2009	T2-110	5	37.4	8.02	0.904	pre
6/24/2009	T2-120	5	27.3	10.99	1.041	pre
6/24/2009	T2-130	5	53.3	5.63	0.750	pre
6/24/2009	T2-140	5	12	25.00	1.398	pre
6/24/2009	T2-150	5	10.3	29.13	1.464	pre
6/24/2009	T2-160	5	21.3	14.08	1.149	pre
6/24/2009	T2-170	10	42	14.29	1.155	pre
6/24/2009	T2-180	10	37	16.22	1.210	pre
6/24/2009	T2-190	10	100.3	5.98	0.777	pre
6/24/2009	T3-0	2	54.3	2.21	0.344	pre
6/24/2009	T3-10	1	155.2	0.39	-0.413	pre
6/24/2009	T3-20	5	109.8	2.73	0.437	pre
6/24/2009	T3-30	1	138.2	0.43	-0.362	pre

6/24/2009	T3-40	5	39.8	7.54	0.877	pre
6/24/2009	T3-50	1	488.3	0.12	-0.911	pre
6/24/2009	T3-60	5	63.7	4.71	0.673	pre
6/24/2009	T3-70	5	360.0	0.83	-0.079	pre
6/25/2009	T3-80	14	630.0	1.33	0.125	pre
6/25/2009	T3-90	2	1320.0	0.09	-1.041	pre
6/25/2009	T3-100	4	2100.0	0.11	-0.942	pre
6/25/2009	T3-110	3	560.0	0.32	-0.493	pre
6/25/2009	T3-120	5	30.0	10.00	1.000	pre
6/25/2009	T3-130	16	700.0	1.37	0.137	pre
6/25/2009	T3-140	25	840.0	1.79	0.252	pre
6/25/2009	T3-150	3	1140.0	0.16	-0.802	pre
6/25/2009	T3-160	6	780.0	0.46	-0.336	pre
6/25/2009	T3-170	4	540.0	0.44	-0.352	pre
6/25/2009	T3-180	2	1080.0	0.11	-0.954	pre
6/25/2009	T3-190	3	1980.0	0.09	-1.041	pre
7/14/2009	T1-0	5	54.33	5.52	0.742	post
7/14/2009	T1-10	2	85	1.41	0.150	post
7/14/2009	T1-20	3	67.67	2.66	0.425	post
7/14/2009	T1-30	2	163.67	0.73	-0.135	post
7/14/2009	T1-40	2	67.67	1.77	0.249	post
7/14/2009	T1-50	5	116	2.59	0.413	post
7/14/2009	T1-60	5	102	2.94	0.469	post
7/14/2009	T1-70	2	124	0.97	-0.014	post
7/14/2009	T1-80	2	72.67	1.65	0.218	post
7/14/2009	T1-90	10	39.67	15.12	1.180	post
7/14/2009	T1-100	10	74.33	8.07	0.907	post
7/14/2009	T1-110	5	48.67	6.16	0.790	post
7/14/2009	T1-120	10	53.67	11.18	1.048	post
7/14/2009	T1-130	5	118	2.54	0.405	post
7/14/2009	T1-140	5	154.67	1.94	0.288	post
7/14/2009	T1-150	5	90	3.33	0.523	post
7/14/2009	T1-160	5	133.67	2.24	0.351	post
7/14/2009	T1-170	2	26	4.62	0.664	post
7/14/2009	T1-180	5	188.33	1.59	0.202	post
7/14/2009	T1-190	2	51.67	2.32	0.366	post
7/15/2009	T2-0	60	270	13.33	1.125	post
7/15/2009	T2-10	11	390	1.69	0.228	post
7/15/2009	T2-20	10	43.6	13.76	1.139	post
7/15/2009	T2-30	5	58.3	5.15	0.711	post
7/15/2009	T2-40	2	107.3	1.12	0.049	post
7/15/2009	T2-50	5	45	6.67	0.824	post
7/15/2009	T2-60	5	113	2.65	0.424	post
7/15/2009	T2-70	5	46	6.52	0.814	post
7/15/2009	T2-80	10	55.6	10.79	1.033	post
7/15/2009	T2-90	3	58	3.10	0.492	post
7/15/2009	T2-100	5	76	3.95	0.596	post
7/15/2009	T2-110	5	54.3	5.52	0.742	post

7/15/2009	T2-120	5	121	2.48	0.394	post
7/15/2009	T2-130	5	207.3	1.45	0.161	post
7/15/2009	T2-140	5	59.6	5.03	0.702	post
7/15/2009	T2-150	5	63	4.76	0.678	post
7/15/2009	T2-160	20	50	24.00	1.380	post
7/15/2009	T2-170	10	53	11.32	1.054	post
7/15/2009	T2-180	3	147.6	1.22	0.086	post
7/15/2009	T2-190	3	53.3	3.38	0.529	post
7/16/2009	T3-0	2	54	2.22	0.347	post
7/16/2009	T3-10	11	810	0.81	-0.089	post
7/16/2009	T3-20	7	731	0.57	-0.241	post
7/16/2009	T3-30	7	815	0.52	-0.288	post
7/16/2009	T3-40	14	992	0.85	-0.072	post
7/16/2009	T3-50	9	747	0.72	-0.141	post
7/16/2009	T3-60	3	820	0.22	-0.659	post
7/16/2009	T3-70	12	854	0.84	-0.074	post
7/16/2009	T3-80	2	74.3	1.62	0.208	post
7/16/2009	T3-90	5	759	0.40	-0.403	post
7/16/2009	T3-100	8	860	0.56	-0.253	post
7/16/2009	T3-110	6	720	0.50	-0.301	post
7/16/2009	T3-120	6	860	0.42	-0.378	post
7/16/2009	T3-130	4	130.7	1.84	0.264	post
7/16/2009	T3-140	10	548	1.09	0.039	post
7/16/2009	T3-150	9	690	0.78	-0.106	post
7/16/2009	T3-160	3	725	0.25	-0.605	post
7/16/2009	T3-170	2	960	0.13	-0.903	post
7/16/2009	T3-180	3	962	0.19	-0.728	post
7/16/2009	T3-190	5	682	0.44	-0.357	post

Soil Cover Data

Transect #	Point (Distance)	Cover (%)	Depth of Organic Layer (in)	Pre or post project?
1	0	100	6	pre
1	10	100	3	pre
1	20	100	2	pre
1	30	100	2	pre
1	40	100	4	pre
1	50	100	5	pre
1	60	100	3	pre
1	70	100	3	pre
1	80	100	2	pre
1	90	100	3	pre
1	100	100	2	pre
1	110	100	2	pre
1	120	100	6	pre
1	130	100	2	pre
1	140	100	3	pre
1	150	100	3	pre
1	160	100	3	pre
1	170	100	3	pre
1	180	100	3	pre
1	190	100	2	pre
2	0	100	2	pre
2	10	100	2	pre
2	20	100	3	pre
2	30	100	2	pre
2	40	100	2	pre
2	50	100	2	pre
2	60	100	2	pre
2	70	100	1	pre
2	80	100	2	pre
2	90	100	1	pre
2	100	100	6	pre
2	110	100	5	pre
2	120	100	3	pre
2	130	100	3	pre
2	140	100	6	pre
2	150	100	3	pre
2	160	100	3	pre
2	170	100	2	pre
2	180	100	3	pre
2	190	100	3	pre
3	0	100	6	pre
3	10	100	5	pre
3	20	100	4	pre

3	30	100	4	pre
3	40	100	13	pre
3	50	100	2	pre
3	60	100	2	pre
3	70	100	3	pre
3	80	100	4	pre
3	90	100	2	pre
3	100	100	3	pre
3	110	100	11	pre
3	120	100	4	pre
3	130	100	4	pre
3	140	100	2	pre
3	150	100	3	pre
3	160	100	2	pre
3	170	100	2	pre
3	180	100	3	pre
3	190	100	2	pre
1	0	100	4	post
1	10	100	4	post
1	20	100	1	post
1	30	100	2	post
1	40	100	4	post
1	50	100	5	post
1	60	100	4	post
1	70	100	5	post
1	80	100	2	post
1	90	100	3	post
1	100	100	2	post
1	110	100	3	post
1	120	100	3	post
1	130	100	2	post
1	140	100	3	post
1	150	100	2	post
1	160	100	2	post
1	170	100	4	post
1	180	100	3	post
1	190	100	4	post
2	0	100	2	post
2	10	100	3	post
2	20	100	4	post
2	30	100	2	post
2	40	90	3	post
2	50	100	3	post
2	60	50	1	post
2	70	100	2	post
2	80	100	5	post
2	90	100	7	post
2	100	100	6	post

2	110	100	11	post
2	120	100	3	post
2	130	100	3	post
2	140	100	7	post
2	150	100	5	post
2	160	100	3	post
2	170	100	4	post
2	180	100	9	post
2	190	100	3	post
3	0	90	3.5	post
3	10	60	2	post
3	20	95	4	post
3	30	97	6	post
3	40	98	6	post
3	50	98	2	post
3	60	40	6	post
3	70	98	4	post
3	80	94	4.5	post
3	90	99	4	post
3	100	90	4	post
3	110	88	5.5	post
3	120	99	12	post
3	130	100	8	post
3	140	99	3	post
3	150	80	1.5	post
3	160	85	3.5	post
3	170	90	1	post
3	180	91	2	post
3	190	88	1	post

Appendix C: Raw Data for Whole Tree Forwarding Unit

Bulk Density and Gravimetric Soil Moisture Data

Sample #	Date Sample Collected	Gravimetric soil moisture (water wt/raw sample wt)	Moisture %	Bulk Density (g/cm3)	Pre or post project?
T1-0	5/11/2009	0.054	5.390	1.295	pre
T1-75	5/11/2009	0.054	5.365	1.353	pre
T1-150	5/11/2009	0.054	5.450	1.449	pre
T1-225	5/11/2009	0.039	3.924	1.391	pre
T1-300	5/11/2009	0.034	3.414	1.360	pre
T1-375	5/11/2009	0.050	4.964	1.274	pre
T1-450	5/11/2009	0.061	6.058	1.348	pre
T2-0	5/12/2009	0.059	5.918	1.412	pre
T2-75	5/12/2009	0.068	6.786	1.367	pre
T2-150	5/12/2009	0.062	6.171	1.189	pre
T2-225	5/12/2009	0.100	10.010	1.344	pre
T2-300	5/14/2009	0.085	8.499	1.270	pre
T2-375	5/14/2009	0.086	8.569	1.285	pre
T2-450	5/14/2009	0.110	10.965	1.187	pre
T3-0	5/14/2009	0.080	8.009	1.193	pre
T3-75	5/21/2009	0.076	7.587	1.242	pre
T3-150	5/21/2009	0.090	9.043	1.353	pre
T3-225	5/21/2009	0.115	11.523	1.264	pre
T3-300	5/21/2009	0.099	9.921	1.331	pre
T3-375	5/21/2009	0.109	10.864	1.498	pre
T3-450	5/21/2009	0.085	8.473	1.322	pre
T1-0	6/29/2009	0.027	2.728	1.350	post
T1-75	6/29/2009	0.027	2.718	1.373	post
T1-150	6/29/2009	0.027	2.743	1.377	post
T1-225	6/29/2009	0.022	2.208	1.376	post
T1-300	6/29/2009	0.025	2.495	1.290	post
T1-375	6/29/2009	0.029	2.924	1.290	post
T1-450	6/29/2009	0.032	3.194	1.354	post
T2-0	7/21/2009	0.026	2.552	1.335	post
T2-75	7/21/2009	0.030	2.996	1.321	post
T2-150	7/21/2009	0.032	3.231	1.265	post
T2-225	7/21/2009	0.040	4.004	1.245	post
T2-300	7/21/2009	0.038	3.766	1.204	post
T2-375	7/21/2009	0.042	4.187	1.144	post
T2-450	7/21/2009	0.047	4.733	1.212	post
T3-0	7/20/2009	0.037	3.742	1.261	post
T3-75	7/21/2009	0.074	7.439	0.791	post
T3-150	7/22/2009	0.045	4.468	1.256	post
T3-225	7/23/2009	0.047	4.670	1.249	post
T3-300	7/24/2009	0.049	4.908	1.355	post
T3-375	7/25/2009	0.041	4.134	1.362	post
T3-450	7/26/2009	0.035	3.506	1.350	post

Saturated Hydraulic Conductivity Data

Date	Sample #	Change in Water Level (unitless)	Time (s)	Ksat (inches/hour)	log (Ksat)	Pre or post project?
5/11/2009	T1-0	2	14.4	8.33	0.921	pre
5/11/2009	T1-25	5	14.5	20.69	1.316	pre
5/11/2009	T1-50	2	26.0	4.62	0.664	pre
5/11/2009	T1-75	5	35.8	8.38	0.923	pre
5/11/2009	T1-100	5	31.3	9.58	0.982	pre
5/11/2009	T1-125	5	58.3	5.15	0.711	pre
5/11/2009	T1-150	5	38.0	7.89	0.897	pre
5/11/2009	T1-175	5	35.0	8.57	0.933	pre
5/11/2009	T1-200	5	30.3	9.90	0.996	pre
5/11/2009	T1-225	5	21.4	14.02	1.147	pre
5/11/2009	T1-250	5	17.5	17.14	1.234	pre
5/11/2009	T1-275	5	21.7	13.82	1.141	pre
5/11/2009	T1-300	5	34.7	8.65	0.937	pre
5/11/2009	T1-325	5	14.7	20.41	1.310	pre
5/11/2009	T1-350	5	31.0	9.68	0.986	pre
5/11/2009	T1-375	10	23.0	26.09	1.416	pre
5/11/2009	T1-400	10	17.0	35.29	1.548	pre
5/11/2009	T1-425	10	28.3	21.20	1.326	pre
5/11/2009	T1-450	10	33.3	18.02	1.256	pre
5/11/2009	T1-475	5	23.3	12.88	1.110	pre
5/12/2009	T2-0	2	31.0	3.87	0.588	pre
5/12/2009	T2-25	2	26.8	4.48	0.651	pre
5/12/2009	T2-50	5	42.0	7.14	0.854	pre
5/12/2009	T2-75	4	66.0	3.64	0.561	pre
5/12/2009	T2-100	5	54.0	5.56	0.745	pre
5/12/2009	T2-125	5	45.0	6.67	0.824	pre
5/12/2009	T2-150	2	29.7	4.04	0.606	pre
5/12/2009	T2-175	1	22.5	2.67	0.426	pre
5/12/2009	T2-200	5	32.3	9.29	0.968	pre
5/12/2009	T2-225	2	38.0	3.16	0.499	pre
5/14/2009	T2-250	2	43.7	2.75	0.439	pre
5/14/2009	T2-275	2	62.3	1.93	0.285	pre
5/14/2009	T2-300	5	30.3	9.90	0.996	pre
5/14/2009	T2-325	2	44.0	2.73	0.436	pre
5/14/2009	T2-350	2	68.3	1.76	0.245	pre
5/14/2009	T2-375	4	131.0	1.83	0.263	pre
5/14/2009	T2-400	1	50.0	1.20	0.079	pre
5/14/2009	T2-425	2	54.0	2.22	0.347	pre
5/14/2009	T2-450	1	56.0	1.07	0.030	pre
5/14/2009	T2-475	1	42.3	1.42	0.152	pre
5/14/2009	T3-0	1	52.3	1.15	0.060	pre
5/14/2009	T3-25	5	87.3	3.44	0.536	pre
5/21/2009	T3-50	5	105.7	2.84	0.453	pre
5/21/2009	T3-75	2	48.3	2.48	0.395	pre

5/21/2009	T3-100	1	26.7	2.25	0.352	pre
5/21/2009	T3-125	1	62.3	0.96	-0.016	pre
5/21/2009	T3-150	1	73.8	0.81	-0.090	pre
5/21/2009	T3-175	1	24.3	2.47	0.393	pre
5/21/2009	T3-200	1	86.7	0.69	-0.160	pre
5/21/2009	T3-225	1	190.0	0.32	-0.501	pre
5/21/2009	T3-250	1	104.0	0.58	-0.239	pre
5/21/2009	T3-275	3	31.0	5.81	0.764	pre
5/21/2009	T3-300	2	56.7	2.12	0.326	pre
5/21/2009	T3-325	1	61.3	0.98	-0.009	pre
5/21/2009	T3-350	1	373.3	0.16	-0.794	pre
5/21/2009	T3-375	1	240.0	0.25	-0.602	pre
5/21/2009	T3-400	1	175.0	0.34	-0.465	pre
5/21/2009	T3-425	1	320.0	0.19	-0.727	pre
5/21/2009	T3-450	1	123.8	0.48	-0.315	pre
5/21/2009	T3-475	1	103.3	0.58	-0.236	pre
6/29/2009	T1-0	2	27	4.44	0.648	post
6/29/2009	T1-25	5	38.3	7.83	0.894	post
6/29/2009	T1-50	10	51	11.76	1.071	post
6/29/2009	T1-75	2	20.25	5.93	0.773	post
6/29/2009	T1-100	4	23	10.43	1.018	post
6/29/2009	T1-125	10	29.7	20.20	1.305	post
6/29/2009	T1-150	10	44	13.64	1.135	post
6/29/2009	T1-175	2	29.7	4.04	0.606	post
6/29/2009	T1-200	10	67.7	8.86	0.948	post
6/29/2009	T1-225	5	33.3	9.01	0.955	post
6/29/2009	T1-250	10	30.3	19.80	1.297	post
6/29/2009	T1-275	5	24.7	12.15	1.084	post
6/29/2009	T1-300	5	21.5	13.95	1.145	post
6/29/2009	T1-325	5	15	20.00	1.301	post
6/29/2009	T1-350	5	16.3	18.40	1.265	post
6/29/2009	T1-375	5	30	10.00	1.000	post
6/29/2009	T1-400	10	20.7	28.99	1.462	post
6/29/2009	T1-425	10	14	42.86	1.632	post
6/29/2009	T1-450	5	15.7	19.11	1.281	post
6/29/2009	T1-475	10	45.5	13.19	1.120	post
7/21/2009	T2-0	2	25.7	4.67	0.669	post
7/21/2009	T2-25	5	46.7	6.42	0.808	post
7/21/2009	T2-50	5	38.7	7.75	0.889	post
7/21/2009	T2-75	3	31	5.81	0.764	post
7/21/2009	T2-100	5	41.7	7.19	0.857	post
7/21/2009	T2-125	5	46.7	6.42	0.808	post
7/21/2009	T2-150	2	61	1.97	0.294	post
7/21/2009	T2-175	5	44.3	6.77	0.831	post
7/21/2009	T2-200	5	27.3	10.99	1.041	post
7/21/2009	T2-225	10	66	9.09	0.959	post
7/21/2009	T2-250	5	35.7	8.40	0.924	post
7/21/2009	T2-275	5	75	4.00	0.602	post

7/21/2009	T2-300	5	63.7	4.71	0.673	post
7/21/2009	T2-325	5	35.7	8.40	0.924	post
7/21/2009	T2-350	5	65.7	4.57	0.660	post
7/21/2009	T2-375	5	62	4.84	0.685	post
7/21/2009	T2-400	5	49.3	6.09	0.784	post
7/21/2009	T2-425	5	92.7	3.24	0.510	post
7/21/2009	T2-450	5	85.3	3.52	0.546	post
7/21/2009	T2-475	5	48	6.25	0.796	post
7/20/2009	T3-0	5	103.3	2.90	0.463	post
7/21/2009	T3-25	5	55	5.45	0.737	post
7/22/2009	T3-50	10	107	5.61	0.749	post
7/23/2009	T3-75	2	24.7	4.86	0.686	post
7/24/2009	T3-100	5	159.7	1.88	0.274	post
7/25/2009	T3-125	5	143.3	2.09	0.321	post
7/26/2009	T3-150	5	119	2.52	0.402	post
7/27/2009	T3-175	3	312	0.58	-0.239	post
7/28/2009	T3-200	1	41.3	1.45	0.162	post
7/29/2009	T3-225	1	63.3	0.95	-0.023	post
7/30/2009	T3-250	4	303	0.79	-0.101	post
7/31/2009	T3-275	2	45.7	2.63	0.419	post
8/1/2009	T3-300	1	40	1.50	0.176	post
8/2/2009	T3-325	1	43.3	1.39	0.142	post
8/3/2009	T3-350	1	186.7	0.32	-0.493	post
8/4/2009	T3-375	1	123.3	0.49	-0.313	post
8/5/2009	T3-400	2	721	0.17	-0.779	post
8/6/2009	T3-425	1	106.7	0.56	-0.250	post
8/7/2009	T3-450	1	111.7	0.54	-0.270	post
8/8/2009	T3-475	2	96	1.25	0.097	post

Soil Cover Data

Transect #	Point (Distance)	Cover (%)	Depth of Organic Layer (in)	Pre or post project?
1	0	100	2	pre
1	25	100	2	pre
1	50	100	4	pre
1	75	100	1	pre
1	100	100	3	pre
1	125	100	3	pre
1	150	100	2	pre
1	175	100	3	pre
1	200	100	3	pre
1	225	100	2	pre
1	250	100	2	pre
1	275	100	3	pre
1	300	100	6	pre
1	325	100	2	pre
1	350	100	6	pre
1	375	100	1	pre
1	400	100	1	pre
1	425	100	3	pre
1	450	100	2	pre
1	475	100	2	pre
2	0	100	3	pre
2	25	90	0	pre
2	50	100	3	pre
2	75	100	3	pre
2	100	60	0	pre
2	125	100	2	pre
2	150	100	3	pre
2	175	100	2	pre
2	200	100	3	pre
2	225	100	2	pre
2	250	100	3	pre
2	275	95	0	pre
2	300	100	3	pre
2	325	100	3	pre
2	350	100	2	pre
2	375	100	3	pre
2	400	100	1	pre
2	425	100	2	pre
2	450	100	1	pre
2	475	100	2	pre
3	0	100	2	pre
3	25	70	0	pre
3	50	80	0	pre
3	75	80	0	pre

3	100	100	3	pre
3	125	100	2	pre
3	150	100	3	pre
3	175	100	2	pre
3	200	100	3	pre
3	225	100	2	pre
3	250	100	1	pre
3	275	95	0	pre
3	300	100	1	pre
3	325	100	2	pre
3	350	100	2	pre
3	375	100	2	pre
3	400	100	2	pre
3	425	100	2	pre
3	450	100	2	pre
3	475	100	2	pre
1	0	100	1	post
1	25	100	2	post
1	50	100	3	post
1	75	100	1	post
1	100	100	2	post
1	125	100	2	post
1	150	100	2	post
1	175	100	3	post
1	200	100	2	post
1	225	100	1	post
1	250	100	2	post
1	275	100	2	post
1	300	100	2	post
1	325	100	1	post
1	350	100	2	post
1	375	100	2	post
1	400	100	1	post
1	425	100	1	post
1	450	80	0	post
1	475	90	0	post
2	0	100	1	post
2	25	100	1	post
2	50	100	2	post
2	75	100	2	post
2	100	50	0	post
2	125	100	2	post
2	150	90	1	post
2	175	90	0	post
2	200	100	3	post
2	225	100	4	post
2	250	100	3	post
2	275	80	0	post

2	300	100	1	post
2	325	100	5	post
2	350	100	2	post
2	375	100	2	post
2	400	90	0	post
2	425	100	1	post
2	450	100	1	post
2	475	40	0	post
3	0	100	1	post
3	25	60	0	post
3	50	100	1	post
3	75	90	0	post
3	100	100	5	post
3	125	100	2	post
3	150	100	1	post
3	175	100	2	post
3	200	90	0	post
3	225	90	0	post
3	250	90	0	post
3	275	100	2	post
3	300	100	3	post
3	325	100	2	post
3	350	100	1	post
3	375	50	0	post
3	400	30	0	post