2006 Ward Unit 5 Soil Monitoring Report
USDA Forest Service
Lake Tahoe Basin Management Unit

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June 2007

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Executive Summary

Monitoring of soil properties at the Ward (Unit 5) fuels reduction project was conducted as part of a multi-year monitoring plan designed to evaluate the impacts of fuels reduction projects on soil and water quality. Ward Unit 5 was treated with a “cut-to-length” (CTL) system, which uses innovative equipment with low ground pressure (5-13 psi) and operates on a slash mat derived from discarded limbs. The important soil properties measured include: the percent ground cover, depth of ground cover, type of ground cover, slope, and disturbance type, as well as the following measures of compaction: soil bulk density and saturated hydraulic conductivity (Ksat). The above properties were measured at 67 sites before and after the project, with the exception of soil bulk density, which was measured at 45 pre-project sites and 35 post-project sites. Pre- and post-project data were analyzed to determine the impact of the fuels reduction treatment and whether or not this impact was statistically significant.

There was no appreciable change in the percent of ground cover or the depth of ground cover for pre- and post-project. The type of ground cover changed from predominantly duff, needles, and decaying wood to coarse slash, generally under three inches in diameter, scattered over the relatively undisturbed pre-project duff layer.

The median value of Ksat pre-project was 4.64 in/hr and the post-project value 3.7 in/hr. This difference was statistically significant at P=0.126 (87% confidence interval). This level of confidence is due to the relatively large variance of the data compared to the small difference in median values.

Soil bulk density averaged 0.83 prior to treatments and 0.88 after treatments. Analysis of these data generated porosity estimates for the before and after conditions. The results indicate a statistically significant decrease in soil porosity of 2.5%, as measured by the change in soil bulk density. This value is well below the 10% threshold included in the Regional soil quality guidelines.

The measured soil properties described above were used in the Water Erosion Prediction Project (WEPP) model to compare sediment and runoff prediction between pre- and post-project conditions. The model used a 20-year climate simulation based on recorded weather data from Tahoe City, CA. Three separate hillslope profiles were modeled. The predicted average annual increase in sediment yield for the 20-year simulations was approximately 0.1 ton/acre/year: pre-project sediment yield rates were 0.8 tons/acre/year, compared to 0.9 ton/acre/year post-project.

USDA Forest Service Lake Tahoe Basin Management Unit
Soil Quality Impacts from Cut-To-Length
Operations on Ward Unit 5

I. Introduction

Monitoring of soil properties at the Ward (Unit 5) fuels reduction project was conducted as part of a multi-year monitoring plan designed to evaluate the impacts of fuels reduction projects on soil and water quality. This is documented in the LTBMU 5-Year Monitoring Plan (2006) as well as the program-specific monitoring plan related to soil and water quality impacts from fuels reduction projects (Soils Monitoring Plan, USFS, 2006). Future fuels reduction program monitoring will incorporate the insights gained from this monitoring effort to refine our sampling approach and ensure the collection of relevant data from a variety of soil types and treatments.

This report addresses the following project level monitoring questions set forth in the Five-Year Plan for the Lake Tahoe Basin Management Unit for vegetation and fuels management.

Are regional soil quality standards being achieved within vegetation management project areas?

> Methodologies for measuring and evaluating Regional Soil Quality Standards presented in the FSH 2509.18 Soil Management Handbook (USFS, 1995) through a statistically robust sampling design have not been well established. The results of data collection and analysis conducted in 2005 on another project concluded that many of the parameters and protocols seem to have limited usefulness on the LTBMU (Crag Report, USFS, 2006). Therefore, the monitoring at Ward 5 did not place emphasis on specifically addressing these Regional soil productivity standards. However, the Regional standards for the following soil characteristics are addressed to some extent in this report: 1) soil cover to evaluate changes in soil organic matter, and 2) bulk density and saturated hydraulic conductivity to evaluate changes in soil porosity and detrimental compaction.

What is the sediment and runoff loading potential from vegetation management activities, based on measured changes in soil cover, soil porosity and infiltration capacity?

> Measurement of key soil properties (soil cover, Ksat, bulk density) before and after the project in conjunction with WEPP model simulations provide a practical way to estimate the effects of management activities on soil hydrologic response. Models were run for specific hillslopes using measurements of pre- and post-project soil properties in order to compare the predicted response in sediment yield and runoff.

The primary objectives of the soil quality monitoring on the Ward 5 unit were:

> 1) evaluate the impacts of mechanical treatment methods on soil cover, bulk density, and saturated hydraulic conductivity (Ksat),

2) apply soil cover observations, bulk density measurements, hydraulic conductivity measurements, and topographic data to the Water Erosion Prediction Project (WEPP) model to estimate the anticipated change in sediment yield and runoff from management activities,

3) compare physical soil parameters to the Equivalent Roaded Acreage (ERA) coefficients used for vegetation management practices in the cumulative watershed effects analysis,

4) provide data on measured changed in soil parameters and the resulting WEPP model predictions to inform the disturbance coefficients for fuels reduction activities in the Tahoe Basin Watershed TMDL Model, and

5) determine whether Regional Soil Quality thresholds, as established in the FSH 2509.18 Soil Management Handbook (USFS, 1995), are being achieved within vegetation management units for soil cover, porosity (bulk density) and detrimental compaction (as estimated by changes in infiltration capacity (Ksat)).

A summary of the Regional Soil Quality Standards can be found in Appendix A.

II. Site Description

The treatment area analyzed is a 116-acre unit contained within the Ward Management Area Fuel Hazard Reduction Project (Ward EA, USFS, 2002). The unit exhibits a dominantly eastern exposure on the west side of Lake Tahoe (Figure 1). The elevation ranges from 6560' to 6920' with slopes less than 26%. The soils in the project area belong to the Paige medial sandy loam map unit, with various slope categories, and the Kneeridge gravelly sandy loam map unit (NRCS, 2007). These units were not differentiated in the 1974 Soil Survey (USDA Soil Conservation Service, et al., 1974). Our transect locations were chosen to coincide with areas that had higher erosion potential based on higher slopes. As a result, all of the transects were located on the Paige medial group. Soils from both map units have a sandy loam texture and were derived from the decomposition of volcanic rocks. These soils have an expected permeability rate of around 3.97 in/hr at the soil depth of 6 to 10 inches, an expected depth to bedrock of 61 inches, and a moderate erosion hazard potential. The design storm used by regulatory agencies for Tahoe Basin BMPs is the 20-year/1-hour storm which is 1" of rain. The project area contained approximately 5.2 acres of existing native surface road and no new roads were added during the project. Erosion and runoff are dominated by spring snow melt and rain on snow events with occasional summer thunderstorms.

The vegetation treatment consisted of removing trees up to 24 inch diameter at breast height (DBH), depending on tree species, spacing, and health. The equipment used, along with ground pressure and width, is summarized in Table 1.

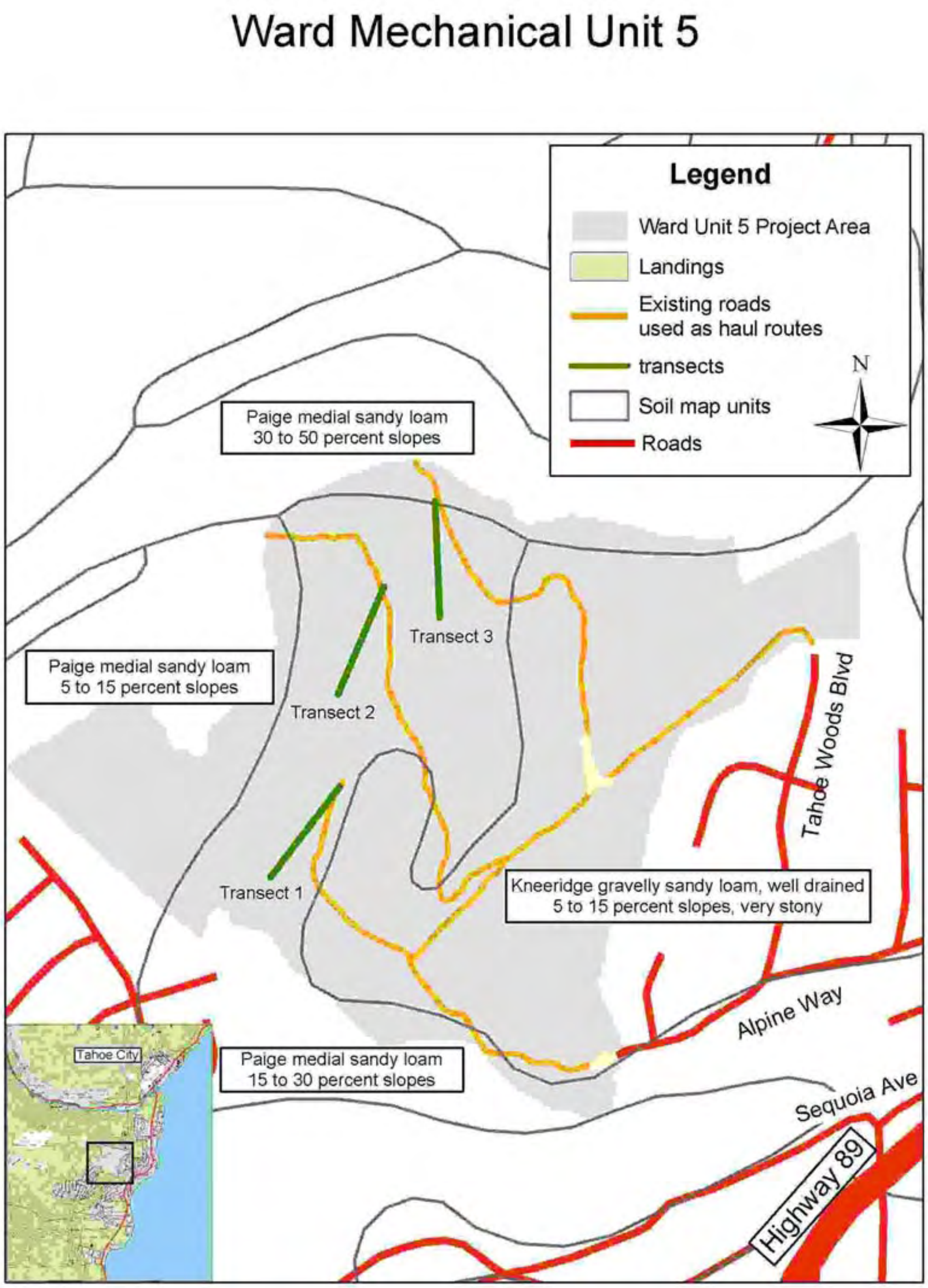

Figure 1: Location and general overview of Ward Unit 5.

Equipment used for vegetation treatment consisted of a cut-to-length harvester, forwarder, masticator, and chipper. The harvester cut and delimbed the trees in place, providing a slash mat for the machinery to work on top of. This slash mat provided ground cover and helped reduce soil compaction. The delimbed trees were set aside and later gathered by the forwarder, which transported them to the closer of the two landing to be dispersed as saw logs, firewood, or biomass. The remainder of the material in the unit was masticated and spread over the unit to provide ground cover. The exception was material within 200-300 feet of the houses which was chipped rather than masticated due to the ability of the chipper to control the direction of the material compared to the more random scattering of the relatively large material produced by the masticator. This process as a whole will be referred to as a "cut-to-length" or CTL operation.

Table 1: List of equipment used on Ward Unit 5, along with reported ground pressure and width.

Description	Equipment	Ground Pressure (psi)	Width (feet)
Harvester	SMV Rapid, 6 wheel	6.0	9.5
Forwarder	SMV Rapid, 6 wheel	6.0-13.0	9.5
Masticator	John Deere Excavator, 200C LC	4.7	10.5
Chipper	Morbark Mountain Goat, 30/36	6.0-6.5	10.5

III. Methodology

Pre-project monitoring began in May of 2006 and post-project monitoring was completed in October 2006. The data collected included disturbance code, disturbance type, soil bulk density, soil moisture, Ksat, soil cover, depth of cover, and cover type. The disturbance code is a qualitative estimate of the degree of disturbance ranging from undisturbed (D0) to heavily disturbed (D3). Disturbance type has four categories: 1) undisturbed, 2) forwarder, harvester, and masticator trail (referred to as cut-to-length or CTL for convenience), 3) road or haul route, and 4) landings.

Bulk density samples were taken for the depth of six to ten inches using a two-inch AMS core sampler with a four inch sleeve. These samples were oven dried at 105 C to get the dry bulk density. The difference in "wet" and "dry" weight was used to calculate the gravimetric soil moisture of each sample. Due to the lack of appreciable summer rainfall, these soil moisture measurements give a reasonable estimate for the range of soil moisture conditions during operations.

Ksat measurements were made using a modified constant head permeameter developed by Woody Loftis at NRCS. Since Ksat is not affected by variations in soil moisture, meaningful comparisons can be made between pre- and post-treatment values despite potential differences in soil moisture. Ocular estimates of the percent and type of soil cover were also made. Percent soil cover, Ksat, bulk density, and percent canopy were used as input for the WEPP model simulations and resulting erosion estimates. Bulk density was measured on a whole soil basis (i.e., gravel and roots were not taken out, and not much of this type of material was present in this soil).

III.a. Sampling Design

The soils in Ward Unit 5 have an expected permeability of 3.97 in/hr at a depth of 6-10 inches (NRCS, 2007). Sediment yield predictions using the WEPP model suggest there is a critical Keff value of around 1.0 in/hr, below which there is a significant increase in erosion. This critical value represents a 75% decrease in Ksat from the expected value of 3.97 in/hr. A sample size analysis conducted on the pre-project Ksat data collected in the summer of 2005 for a timber sale unit on the north shore suggested that approximately 70 sample points would be sufficient to detect a 50% reduction in Ksat, with $\alpha<0.1$ and $\beta<0.2$ (Norman et al., 2006). Preliminary data analysis from the Ward Unit 5 soils showed less variability in the data and suggested that considerably fewer sample points would be needed. Based on this sample size analysis and the availability of field personnel, it was determined that three transects consisting of 20 points each would be established, for a total of 60 Ksat measurements before and after treatment. Percent cover, depth of cover, type of cover, disturbance type, and local slope were also collected at each of those 60 points.

A decrease in porosity of 10% corresponds to a bulk density threshold that indicates detrimental soil compaction as described in the Regional Soil Quality Standards. Similar sample size analysis based on the bulk density data collected in 2005 from the Crag Units 3 and 4 suggest that 20 samples would be adequate to detect a 10% decrease in porosity based on the threshold bulk density (Crag Report, USFS, 2006). Based on this sample size analysis, the availability of field personnel, and the potential difficulty of collecting reliable bulk density samples, the goal of collecting 20-30 bulk density samples was established.

The CTL trails are approximately 10 feet wide and generally travel perpendicular to the contour. Three transects, each 500 feet long, were established along contour in an attempt to intersect the anticipated paths of the CTL equipment. These transects were started near the existing roads that were used as major haul routes to ensure an adequate sampling of these heavily disturbed areas. Sample points were located approximately every 25 feet for a total of 60 sample points, both before and after treatment. This sampling design was intended to provide a representative sample of different disturbance types within the unit.

Two landings were established for this project; however, work was started on the southern landing before monitoring transects could be established. As a result, sampling was only conducted on the eastern landing where we established seven additional sample points.

IV. Results

A total of 67 pre-project sample points were evaluated between May 19, 2006, and July 25, 2006. Adjacent points along the same transects were evaluated between August 24, 2006, and October 18, 2006, after the ground disturbing work in those areas was complete. Of the 67 pre-project sample locations, 57 were in undisturbed areas during the pre-project evaluation and 10 were in existing roads. The post-project evaluations indicated 14 of the 57 (25%) previously undisturbed locations still appeared undisturbed, 40 (70%) were obviously disturbed by the CTL equipment, and 3 (5%) were disturbed by the landing. Post-project evaluations also indicated that of the 10 points located in existing roads, six remained in roads, and four were located in the landing (Table 2).

For all statistical comparisons, a P-value less than or equal to 0.10 was considered significant (90 % confidence interval).

Table 2: Distribution of sampling location by disturbance type.

	Undisturbed Forest	Native Surface Roads	CTL	Landings	Total
Pre-project	57	10	NA	NA	67
Post-project	14	6	40	7	67

IV.a. Soil Parameter Data Analysis

Ground Cover

The percent ground cover was determined by ocular estimate and the depth of ground cover was measured at each of the 67 locations both before and after the project. The ground cover before the project consisted of duff, needles, and decaying wood, while the ground cover after the project consisted of coarse slash, generally under three inches in diameter, scattered over the relatively undisturbed pre-project ground cover. The means and (standard deviation) for percent cover for pre-project and post project in the CTL areas was 98% (±8) and 89% (±23), respectively. The range and mean values for percent cover and depth of cover are presented in Table 3.

Table 3: Range and median values for percent cover and depth of cover.

	Min Cover (%)	Max Cover (%)	Median Cover (%)	Mean Cover (%)	Std. Dev.	Min Depth (in)	Max Depth (in)	Median Depth (in)	Mean Depth (in)	Std. Dev.
Pre-Project										
Undisturbed	50	100	100	98	8	0	7	2	1.9	1.2
Roads	25	100	85	80	23	0	4	0	0.6	1.2
Post-project										
CTL	10	100	100	89	23	0	7.75	1.5	2.3	1.9
Roads	2	100	43	48	45	0	2	0.25	0.6	0.8
Landing	90	100	95	95	4	NA	<8	NA	NA	NA

As can be seen from this data, there was essentially no change in soil cover between the pre-project and post-project data collected from the area treated with CTL equipment, and soil cover remained extremely high (mean of 89%). Road cover decreased from a mean of 80% to 48%. The Regional Soil Quality Standards require that sufficient soil cover is maintained in order to prevent accelerated soil erosion (FSH 2509.18-95-1, SNFPA 2004). The kind, amount, and distribution of soil cover necessary to prevent accelerated erosion is determined using the

California Interagency Erosion Hazard Rating (EHR), developed by the California Soil Survey Committee (FSH 2509.22). In this unit, a value of 50 % ground cover is needed to maintain an erosion hazard rating of low on slopes under 26%, and 11% ground cover is required on slopes under 16% (all roads). The ground cover in the general CTL area, roads, and landings is clearly sufficient to prevent the erosion hazard rating from increasing to moderate.

Saturated Hydraulic Conductivity

As a general rule, the Student's t-test is more powerful than non-parametric tests when comparing two data sets that exhibit normal distribution and equal variance. Since the Ksat data for a given disturbance type shows a log-normal distribution, all data was log transformed and the Student's t-test was used for statistical comparisons. Data beyond two inter-quartile ranges below and above the first and third quartile, respectively, were excluded as outliers. These outliers consisted of one pre-project undisturbed point and two post-project CTL equipment trail points. SigmaStat 3.5 was used to check the log (Ksat) data for normality and equal variance, as well as evaluate statistical differences between disturbance types and project phases using the Student's t-test.

The median values for pre- and post-project Ksat for different disturbance types are given in Table 4, along with the P-values for various changes in Ksat due to disturbance. P-values of less than or equal to 0.10 are assumed to be statistically significant, meaning that we have a 90% confidence that the measured difference is real. There is not a statistically significant difference in Ksat value between the previously undisturbed soils and the general forest disturbed by the CTL equipment (P=0.126), nor between the roads before and after the project (P=0.90). Not surprisingly, there is a statistical difference (P=0.002) in pre- and post-project Ksat values for points that fell within the area used for the landing (P=0.002).

Table 4: Median values for pre- and post-project saturated hydraulic conductivity (Ksat).

Disturbance Type	Pre-Project Median Ksat (in/hr)	n	Post-Project Median Ksat (in/hr)	n	P-value	Power
Undisturbed to CTL	4.64	56	3.70	52	0.126	0.199
Road to Road	2.59	10	2.47	6	0.895	0.050
Road or Undisturbed to Landing	3.98	7	1.32	7	0.002	0.953

Sample Size Analysis for Ksat

The low value of Power for the comparison between the Ksat values for the undisturbed soils and those disturbed by the CTL equipment indicates a low probability of detecting the reported difference if that difference actually exists. That is, a larger number of samples would be needed in order to say with certainty whether or not there is a difference between pre- and post-project Ksat. The high number of samples required to make a statistically significant comparison can be attributed to the high variability encountered in Ksat measurements relative to the small difference between the medians of the two data sets. If, however, there is no difference due to the treatment, a larger sample size will only confirm this lack of difference. Such results are typical in forest monitoring where naturally high variability overshadows minor differences due to management. The discrepancy between the required samples from the analysis of the Crag units discussed in section IIIa and this sample size analysis results from trying to detect a smaller difference in median Ksat in this sample size analysis.

Bulk Density

Bulk density samples were attempted at every sampling point, but due to rocky soils, equipment failure, time constraints, and the smaller sample size required for statistically valid comparisons, only 45 pre-project samples and 35 post-project samples were collected.

SigmaStat 3.5 was also used to evaluate the soil bulk density data. The soil bulk density data exhibited a normal distribution with equal variance for each disturbance types. There were no outliers identified in the bulk density data for any of the disturbance types. Statistical differences were evaluated using the Student's t-test and the results are given in Table 5. Bulk density changed by only .05 gm/cm3 in the area treated by CTL, which represents a 2.5 % change in porosity. This calculation is described below.

Table 5: Mean values of bulk density along with calculated change in porosity.

Disturbance Type	Pre-Project Mean (gm/cm^3)	n	Post-Project Mean (gm/cm^3)	n	P-value	Porosity Change
Undisturbed to CTL	0.835	33	0.880	33	0.047	-2.48%
Road to Road	0.941	10	0.975	5	0.715	-7.71%
Road or Undisturbed to Landing*	0.910	9	1.054	2	0.297	-12.07%

*Limited post-project bulk density samples are due to equipment failure and the end of the field season.

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" (FSH 2509.Soil Management Handbook). The change in porosity is given by:

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

where Dbi is the initial soil bulk density found under natural conditions, which is assumed to be 0.835 gm/cm^3 based on pre-project measurements of bulk density in areas that appeared to be undisturbed, Dbf is the final bulk density after the project, and Dg 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:

$$Dbt = 0.1Dp + 0.9Dbi$$

The bulk densities for the general CTL area and the roads remained under the threshold bulk density value of 1.017 gm/cm^3. The bulk density on the landings exceeded the value of threshold bulk density by 0.037 gm/cm^3, but it is important to note that the post-project values of bulk density for the landings is only based on 2 sample points.

When the change in porosity is weighted by the relative area of the different disturbance types (CTL, roads, and landings), the overall change in bulk density for the entire project area is -2.76%. However, the Regional Soil Quality Standards state that the activity area does not include areas such as roads and trails that are not dedicated to growing vegetation. As such, adherence to the Regional Soil Quality Standards should be evaluated using the portion of the project area that does not include roads, in which case the area weighted change in porosity is -2.52%.

V. WEPP Modeling

The WEPP model is a physically-based model developed by the USDA to evaluate erosion at the hillslope to small watershed scale. The model is based on the fundamentals of stochastic weather generation, infiltration theory, hydrology, soil physics, plant science, hydraulics, and erosion mechanics. This model has been calibrated and validated in a variety of field settings which can be found under the WEPP Publications Bibliography List on the WEPP Software website (http://topsoil.nserl.purdue.edu/nserlweb/weppmain/wepp.html). The model was used to compute the amount of soil loss along a hillslope, as well as the sediment yield and runoff at the bottom of that hillslope. The sediment yield and runoff at the bottom of the hillslope profile will be used for comparisons in this study.

Three hillslope profiles were constructed in WEPP to represent three different flow paths on the unit (Figure 2). The northern flow path includes the steepest section of the unit (slope = 26%) as well as two sections of road, and terminates at the county road drainage within the adjacent subdivision. The middle flow path has a maximum slope of 20%, contains two sections of road, and terminates in the county road drainage system. The southern flow path contains a small section of road and terminates in an ephemeral channel after flowing through an undisturbed area for approximately 700 feet. The resulting hillslope profiles are shown in Figure 3. Post-project observations confirmed that proper drainage structures were installed on all forest roads and it is assumed that all runoff from the roads is diverted after flowing no more than 250 feet along any road surface. This assumption is consistent with field observations of waterbar spacing.

The soil file representing a mature sandy loam was used in all simulations with the following modifications. The key infiltration parameter in the WEPP model is the Green-Ampt effective hydraulic conductivity (Keff). Although median values were used to compare statistical differences in Ksat between pre- and post-project conditions, we decided that the mean values of Ksat measured in the field would be a better representation of this parameter to reflect field conditions of Keff for the model simulations. The anisotropy ratio is used to describe the relative predominance of lateral versus vertical flow. When a value is not known, the default value of 25 is entered (WEPP Model Version: 2006.500). The NRCS Web Soil Survey (2007) was used to determine particle size and the depth to any restrictive layer for the applicable soil map units. The Paige medial unit consists of 31% sand, 14% silt, 2% clay, and 46% organic matter. The depth to any restrictive layer was reported as 61 inches for this unit. These parameters were assumed to not vary between project phases. The value of Keff in the general forest CTL area was set to the mean measured Ksat value of 6.33 in/hr for the pre-project simulations and 4.74 in/hr for the post-project simulations. The value of Keff for the roads was set to the mean measured Ksat value of 3.12 in/hr for the pre-project simulations and 2.94 in/hr for the post-project simulations.

Ward Mechanical Unit 5

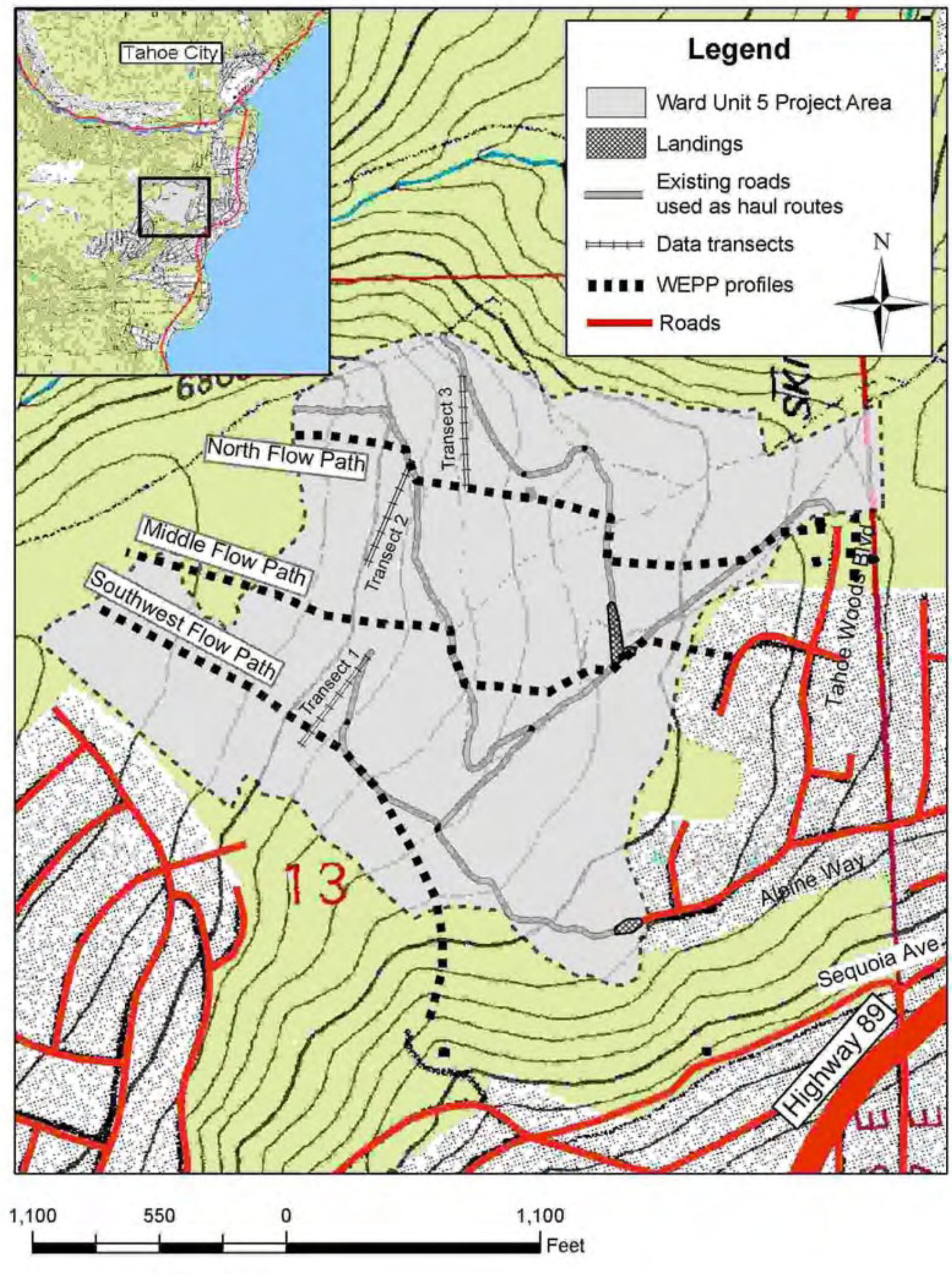

Figure 2: Location of flow paths used for WEPP model simulations.

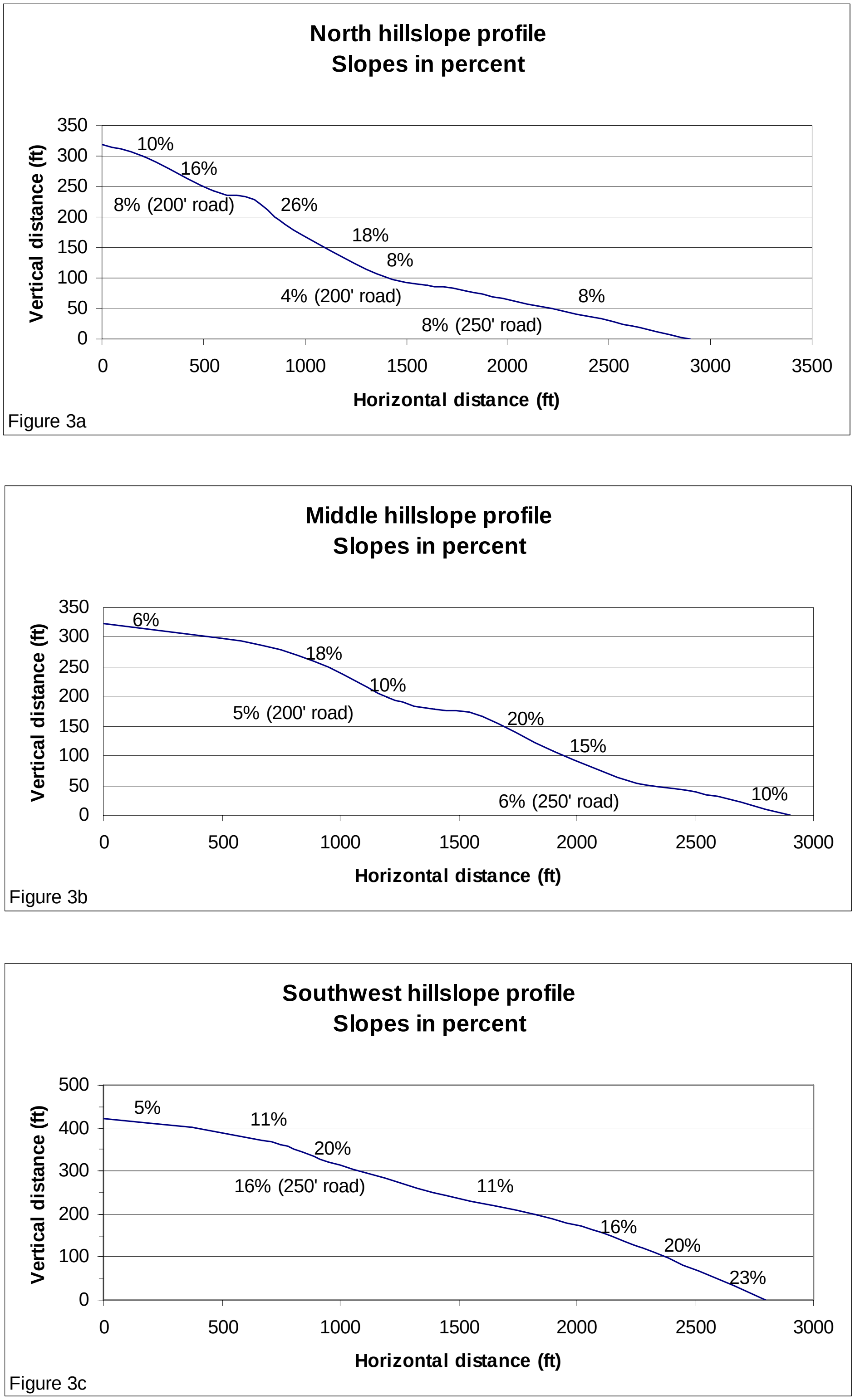

Figure 3: Hillslope profiles for the North, Middle, and Southwest flow paths used in the WEPP model simulations.

The model's management file representing a mature coniferous forest was used for both the pre-project and post-project simulations. The canopy cover, ground cover, and bulk density values measured in the field were substituted for the default values. Based on stand exam data, the value for canopy cover was set to 75% for the pre-project simulation and 50% for the post-project simulation. The value for ground cover in the general forest area was set to the median value of 100% for both simulations. The value for ground cover on the roads was set to the median value of 85% for the pre-project simulations and 43% for the post-project simulations. The bulk density for the general forest was set to 0.835 gm/cm^3 for the pre-project simulations and 0.880 gm/cm^3 for the post-project simulations. The bulk density for the roads was set to 0.941 gm/cm^3 for the pre-project simulations and 0.975 gm/cm^3 for the post-project simulations. The stochastic weather model CLIGEN, version 4.3, was used to generate 20 years of climate based on data from Tahoe City, CA. The climate file was edited to ensure that the largest water year would occur in the first year of the simulation in order to compare results from a worst case scenario. The maximum 1-hour precipitation intensity occurs on February 28 of the first year and produces 1.07 inches per hour. The storm with the overall maximum precipitation intensity occurs on April 20 of the first year and produces 0.66 inches in 0.57 hours, which is equivalent to 1.15 inches per hour. The following 20 years of simulated climate were left unchanged.

The parameters that changed for the pre- and post-project simulations are presented in Table 6 below.

Table 6: Field based measurements used in WEPP hillslope simulations for Ward Unit 5.

Land Use Type	Canopy Cover	Ground Cover	Keff (in/hr)	Bulk Density (gm/cm^3)	Notes
Pre-Project					
Untreated	75%	100%	6.33	0.835	Undisturbed hillslope
Road	75%	85%	3.12	0.941	Assumed effective drainage
Post-Project					
CTL - Measured	50%	100%	4.74	0.880	Post-project ground cover and Ksat data
Road	50%	43%	2.94	0.975	Assumed waterbars with 250 feet spacing

<u>20-Year Simulations:</u>

The WEPP model predictions for sediment yield and runoff for pre- and post-project simulations are reported in Table 7. The predicted average annual sediment yield for the northern hillslope changed from 0.3 ton/acre for pre-project conditions to 0.4 ton/acre for post-project condition. There was no predicted change in average annual sediment yield for the middle hillslope. The predicted average annual sediment yield for the southwestern hillslope changed from 1.4 ton/acre to 1.5 ton/acre. The average predicted increase in annual sediment yield over all three hillslopes using the 20-year simulated climate is less than 0.1 ton/acre. The predicted increase in annual runoff is also negligible for the 20-year simulated climate.

Table 7: WEPP model predictions of the average annual sediment yield and mean annual runoff at the end of the hillslope profiles for a 20-year climate simulated using CLIGEN.

20-year climate simulation	Predicted Average Annual Sediment Yield (ton/acre)		Predicted Mean Annual Runoff (in/yr)	
Hillslope Profile	**Pre-Project**	**Post-Project**	**Pre-Project**	**Post-Project**
Northern hillslope	0.3	0.4	1.5	1.4
Middle hillslope	0.8	0.8	1.3	1.3
Southwestern hillslope	1.4	1.5	0.7	0.8
Average	0.8	0.9	1.2	1.2

1-year Simulations:

Additional WEPP simulations were run using the first year of simulated climate, which has the highest overall water year, has the highest 1-hour precipitation intensity, and has the highest individual storm intensity for any year in the 20-year climate simulation. The results are reported in Table 8. The WEPP model predicted a decrease of 0.2 ton/acre in annual sediment yield between pre- and post-project conditions for this high water year simulation. The predicted runoff decreased for the northern and middle hillslopes, but increased slightly for the southwestern hillslope. It is unclear why the model actually predicts a decrease in sediment yield and runoff for these hillslope simulations, but it can likely be attributed to the timing of saturation of soils (and hence increased overland flow) in the lower portion of the profiles due to subsurface flow. The average decrease in predicted runoff was 0.1 in/yr.

Table 8: WEPP model predictions of the sediment yield and annual runoff at the end of the hillslope profiles for a 20-year design storm of 1 inch/hour.

Design Storm of 1 in/hr, 20-year event	Predicted Average Annual Sediment Yield (ton/acre)*		Predicted Mean Annual Runoff (in/yr)	
Hillslope Profile	**Pre-Project**	**Post-Project**	**Pre-Project**	**Post-Project**
Northern hillslope	0.0	0.0	5.0	4.8
Middle hillslope	0.4	0.2	4.5	4.3
Southwestern hillslope	1.7	1.2	1.8	1.9
Average	0.7	0.5	3.8	3.7

VI. Applicability to TMDL and CWE

The Lake Tahoe Basin watershed is listed as “water quality limited” under Section 303(d) of the Clean Water Act by the Lahontan Regional Water Quality Control Board and Nevada Department of Environmental Protection. As such, the development of a Total Maximum Daily Load (TMDL) is required by law. The development of the TMDL is a complex process that involves determining sediment and nutrient loads, and the associated variability from different source categories (such as urban areas, stream channels, fuels reduction projects, roads, etc) at applicable temporal and spatial scales.

The methodology used to evaluate the Cumulative Watershed Effects for the Ward Management Area Environmental Assessment (EA) was based on Bailey's (1974) land capability classification system (Revised Soils and Hydrology Report, Ward Management Area, 2002). In this classification system, the capability of an area to tolerate disturbance is based on soil type, geology, erosion potential, runoff potential, and slope. The capability class is weighted by area to come up with a threshold of concern (TOC), above which the watershed may begin to exhibit significant and potentially permanent damage due to runoff and the associated erosion. The TOC can be viewed as the equivalent of impervious surface that a watershed can accommodate before adverse impacts may be expected.

The disturbance to a watershed is expressed in terms of a standardized measurement unit called an Equivalent Roaded Acre (ERA). Appropriate ERA coefficients are multiplied by the areas of the disturbance within the watershed and summed to give the total Equivalent Roaded Acres for the watershed. The ERA coefficients used to estimate the CWE impacts for this project are listed in Table 9. The total ERAs assumed to result from the project was 13.63 acres.

Table 9: ERA coefficients, acres of land use type, and resulting ERA value used in the Ward Management CWE analysis (Ward EA, USFS, 2002).

Disturbance Type	CWE ERA Coefficient	Acres	Total ERA
CTL	0.07	114.82	8.04
Native Surface Road	1.00	5.05	5.05
Landing	1.00	0.54	0.54

ERA coefficients were given to the TMDL model developers as our current best estimate of the level of impact from fuels reduction management activities. However, it was also noted that these ERA coefficients have never been field tested or validated; rather, they are based on decades of observations and professional judgment of hydrologists throughout Region 5.

Although the CWE methodology does predict a level of disturbance above which watershed impacts from fuels reduction and other management activities may occur, the methodology does not provide an estimate of actual changes in runoff and sediment yield. Rather, the methodology attempts to convert project impacts to equivalent roaded acres, which assumes that the response from the management activity would be the same as that resulting from an "equivalent" area of impervious surface.

It is not clear how these ERA values are being used in the TMDL model, but the information in this report may be useful to modelers to provide actual data regarding the physical changes in soil characteristics from this type of management activity that can affect erosion response. WEPP modeling results could also be compared to TMDL model results to determine whether the more physically-based WEPP model is producing results similar to the more empirical TMDL model.

VII. Summary

This monitoring effort was intended to address the impacts of current hazardous fuels reduction practices on soil resources in the Lake Tahoe Basin Management Unit. These practices involve operating innovative equipment with light ground pressure, referred to as cut-to length, on slash mats that provide protection for the soil and ample ground cover.

There was a small reduction in the percent soil cover (from a mean 98% to 89%); however, soil cover was still well above the regional standard of 50% and the 11% required to maintain a low erosion hazard rating.

A 20% reduction in median saturated hydraulic conductivity (Ksat) for the general forest disturbed by the CTL equipment was observed, although this difference (4.64 in/hr to 3.70 in/hr) was not statistically significant at the 90% C.I. (P=0.126).

There was a statistically significant difference at the 90% C.I. between values of pre- and post-project bulk density for the general forest areas disturbed by the CTL equipment. However, this difference represents a decrease in porosity of no more than 2.5%, well below the 10% threshold described in the Regional Soil Quality Standards. A recent study by Han, et al (2006) reported a statistically significant increase in soil bulk density resulting from CTL operations. There was an increase of 27% at the three inch (7.5 cm) depth and 15% at the six inch (15 cm) depth. The Han study was conducted on an ashy silt loam with soil moisture ranging from 20-30%. The significantly lower increase in soil bulk density for the Ward 5 unit (2%) can be attributed to the lower soil moisture during operations (11-13%) and the coarser texture of these soils.

The WEPP model results, using the measured changes in soil parameters, indicate a predicted increase in sediment yield of 0.1 ton/acre for the 20-year simulations, and a decrease in sediment yield of 0.2 ton/acre for the 1-year simulations. This estimate is based on simulations of three separate representative hillslope profiles using field measurements of bulk density, Ksat, and soil cover, with climate parameters generated using the CLIGEN model. These sediment predictions assume that the measured mean Ksat is essentially equivalent to Keff in the model. This assumption is yet to be validated through field testing in the Tahoe Basin.

Suggestions for Future Monitoring and Analysis

Similar monitoring could be done 10 to 20 years after the project is complete in an attempt to quantify the soil hydrologic recovery of the unit.

Because the WEPP model has not been calibrated for the Tahoe Basin, there are two primary parameters that may lead to inaccurate representations of actual hillslope response. It is recommended that research be conducted to:

- Determine the appropriate anisotropy coefficient(s) represented throughout the Basin to use in the WEPP model.

- Determine the relationship in the Tahoe Basin between mean measured Ksat and model parameter Keff.

The number of bulk density samples needed for a statistically significant comparison between pre- and post-treatment values appears to be approximately 20.

Because the susceptibility to compaction will vary based on baseline soil characteristics, the soil monitoring and analysis strategy presented in this report should be conducted on future fuels reduction projects if they contain considerably different soil types than the Paige medial sandy loam that was analyzed in this report.

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Appendix A
Regional Soil Quality Standards

(FSH 2509.18-95.01,Section 2.2)

2.2 - SOIL QUALITY STANDARDS. Soil quality analysis standards provide threshold values that indicate when changes in soil properties and soil conditions would result in significant change or impairment of the productivity potential, hydrologic function, or buffering capacity of the soil. Detrimental soil disturbance is the resulting condition when threshold values are exceeded.

The extent of detrimental soil disturbance that affects soil productivity, shall not be of a size or pattern that would result in a significant change in production potential for the activity area. The size or extent of detrimental soil disturbance allowable that affects hydrologic function is determined by the Region 5 Cumulative Watershed Effects Analysis (R-5 FSH 2509.22, Ch. 20) and/or the Region 5 Soil Erosion Hazard Rating system (R5 FSH 2509.22, Ch. 50, ex. 2, IIC) depending on which method is sensitive to the size of the area being analyzed.

See paragraphs 4a and 4b for project planning and implementation procedures for avoiding detrimental soil disturbance.

Use the following soil properties, conditions, and associated threshold values to avoid detrimental soil disturbance and to evaluate management effects on soil productivity, soil hydrologic function, and soil buffering capacity.

1. Soil Productivity.

   a. Soil loss should not exceed the rate of soil formation (approximately the long-term average of 1 ton/acre/year). Maintain sufficient soil cover to prevent accelerated soil erosion from exceeding the rate of soil formation.

   Use Region 5 Soil Erosion Hazard Rating system (R-5 FSH 2509.22, Ch. 50) to determine the kind, amount and distribution of soil cover necessary to avoid detrimental accelerated soil erosion. Locally adapted standard erosion models and measurements can be used to refine soil cover requirements.

   Effective soil cover for reducing the risk of accelerated soil erosion includes living vegetation (grasses, forbs and prostrate shrubs), plant and tree litter (fine organic matter), surface rock fragments, and applied mulches (straw or chips). Depending upon the kinds of soil cover present and other erosion hazard factors, the amount of fine organic matter necessary to reduce the risk of detrimental soil loss may be more or less than the amount needed for nutrient cycling (item c).

   Prescribe the kinds and amounts of soil cover that would not elevate wildfire risk or severity to the point that fuel management and soil quality objectives cannot be met. If there is no viable alternative for providing soil cover without elevating the risk of adverse wildfire effects, prescribe minimum soil cover needed to avoid detrimental soil loss.

b. Soil porosity should be at least 90 percent of total porosity found under natural conditions. A 10 percent reduction in total soil porosity corresponds to a threshold soil bulk density that indicates detrimental soil compaction.

Use the table or formula in Exhibit 01 to find the threshold soil bulk density that corresponds to the appropriate initial soil bulk density. Measure initial soil densities within an activity area where there is a potential for soil compaction to occur. For post-activity assessment, measure adjacent uncompacted areas. Compare threshold density with post-activity density between 4 and 8 inches below the soil surface to evaluate the potential for detrimental soil compaction.

c. Organic matter is maintained in amounts sufficient to prevent significant short- or long-term nutrient cycle deficits, and to avoid detrimental physical and biological soil conditions.

Prescribe surface organic matter in amounts that would not elevate wildfire risk or severity to the point that desired organic matter for nutrient cycling cannot be achieved or maintained because of increased wildfire risk potential. If there is no viable alternative for providing surface organic matter without elevating wildfire risk, prescribe an amount that does not significantly increase wildfire risk and monitor soil nutrient status. Apply mitigation measures if decreased nutrient supply has the potential to affect ecosystem health, diversity or productivity. The prescribed amount shall not reduce the amount needed for soil cover to prevent accelerated erosion (section 2.2, paragraph 1a).

Use the kinds and amounts of organic matter identified below. These may be supplemented with local analyses.

(1) Soil organic matter in the upper 12 inches of soil is at least 85 percent of the total soil organic matter found under natural conditions for the same or similar soils. Soil organic matter is used as an indicator of soil displacement effects on nutrient and soil moisture supply.

(2) Surface organic matter is present in the following forms and amounts.

(a) Fine organic matter occurs over at least 50 percent of the area. Fine organic matter includes plant litter, duff, and woody material less than 3 inches in diameter. The dry weight of fine organic matter without woody material is about 0.2 to 3 tons per acre.

The preference is for fine organic matter to be undisturbed, but if disturbed, the quantity and quality should avoid detrimental short and long-term nutrient cycle deficits. Determine minimum organic layer thickness and distribution locally and base it on amounts sufficient to persist through winter season storms and summer season oxidation.

Use the presence of living vegetation that could contribute significant annual litter fall to compensate for conditions when immediate post-disturbance fine organic matter coverage is too thin or less than 50 percent.

If the soil and potential natural plant community are not capable of producing fine organic matter over 50 percent of the area, adjust minimum amounts to reflect potential soil and vegetation capability.

(b) Large woody material is at least 5 well distributed logs per acre representing the range of decomposition classes defined in Exhibit 02. To alleviate the risk of adverse fire effects, dry weight should be less than about 3 tons per acre.

Desired logs are at least 20 inches in diameter and 10 feet long. Protect logs in decomposition classes 3 through 5 from mechanical disturbance. Do not count logs less than 12 inches in diameter or stumps as large woody material.

Adjust the minimum logs per acre to account for ecological type (FSH 2090.11) potential and specific site needs as data becomes available. To help meet fuel management objectives, minimum logs can be adjusted to take advantage of short-term large woody material contributions in snag recruitment areas.

(c) Fine organic matter and large woody material together should amount to less than about 6 tons per acre dry weight to alleviate the risk of potential detrimental wildfire effects. Other surface organic matter (3 inches to 20 inches in diameter) or amounts of fine organic matter and large woody material in excess of amounts described in detail above need not be retained.

Large woody material and fine organic matter amounts (except when needed for essential erosion control) may be reduced to meet fuel management objectives in strategic fuel treatment areas, on fuel breaks, and in other critical areas. Evaluate or monitor soil nutrient status in fuel treatment areas and other areas that lack sufficient large woody material and fine organic matter.

(d) Soil Moisture Regime is unchanged where productivity or potential natural plant community is dependent upon specific soil drainage classes. Use natural soil drainage classes to evaluate the effect of management induced water table or subsurface flow changes on plant growth or potential plant community composition.

2. Soil Hydrologic Function. To avoid accelerated surface runoff, infiltration and permeability are not reduced to ratings of 6 or 8 as defined in Region 5 Erosion Hazard Rating system (R-5 FSH 2509.22, Ch. 50).

3. Soil Buffering Capacity. Materials added to the soil must not alter soil reaction class, buffering or exchange capacities, or microorganism populations to the degree that significantly affects soil productivity, bioremediation potential, soil hydrologic function, or the health of humans or animals.

Develop local threshold values as the need arises and submit to the Regional Forester for standardization among forests.

2.2 - Exhibit 01

THRESHOLD SOIL BULK DENSITIES FOR SPECIFIC INITIAL SOIL BULK DENSITIES BASED ON A 10 PERCENT REDUCTION IN TOTAL SOIL POROSITY

INITIAL SOIL BULK DENSITY	THRESHOLD SOIL BULK DENSITY	INITIAL SOIL BULK DENSITY	THRESHOLD SOIL BULK DENSITY
0.6	0.81	1.15	1.3
0.65	0.85	1.2	1.35
0.7	0.9	1.25	1.39
0.75	0.94	1.3	1.44
0.8	0.99	1.35	1.48
0.85	1.03	1.4	1.53
0.9	1.08	1.45	1.57
0.95	1.12	1.5	1.62
1.0	1.17	1.55	1.66
1.05	1.21	1.6	1.71
1.1	1.26	1.65	1.75

Threshold soil bulk density values are derived with the following formula

Dbt = 0.1 Dp + 0.9 Dbi

Where Dp is the mean particle density (2.65 Mg/m^3), and Dbi and Dbt are the initial and the threshold bulk densities, respectively.

Appendix B
Field Data

Transect	Distance (feet)	Disturbance class	Disturbance type	Period	Soil moisture (grams)	Bulk density at 6-10" (g/cm3)	Cover (%)	Ground cover depth (inches)	Ksat (in/hr)
1	0	D1	S	post	12.36%	0.909	100	4.00	3.01
1	0	D0	U	pre	16.80%	0.894	100	4.00	5.03
1	25	D1	S	post	13.19%	0.712	100	4.00	8.39
1	25	D0	U	pre	18.61%	0.767	100	3.00	5.03
1	50	D0	S	post	13.57%	0.806	100	3.00	9.07
1	50	D0	U	pre	17.41%	0.845	100	2.00	7.56
1	75	D2	S	post	15.28%	0.774	100	0.50	1.00
1	75	D1	U	pre	11.43%	0.858	100	1.00	2.53
1	100	D2	R	post	11.07%	0.918	90	1.00	7.40
1	100	D2	R	pre	17.63%	1.039	75	0.00	2.53
1	125	D3	R	post	9.94%	1.006	2	0.00	1.94
1	125	D2	R	pre	14.48%	1.072	75	0.00	1.26
1	150	D1	S	post	10.31%	0.903	100	4.00	6.86
1	150	D0	U	pre	15.79%	0.813	100	3.00	2.53
1	175	D0	U	post	10.99%	0.824	100	2.50	2.15
1	175	D0	U	pre	17.78%	0.743	100	2.00	0.83
1	200	D1	S	post	12.06%	0.816	100	7.50	2.56
1	200	D0	U	pre	15.51%	0.860	100	2.00	3.77
1	225	D2	S	post	10.88%	0.904	100	3.00	16.81
1	225	D0	U	pre	14.93%	0.775	100	4.00	5.03
1	250	D2	S	post	10.62%	0.790	100	1.50	6.05
1	250	D0	U	pre	16.46%	0.791	100	1.50	1.26
1	275	D2	S	post	11.64%	0.993	50	2.00	2.45
1	275	D0	U	pre	13.84%	0.668	100	0.25	12.59
1	300	D2	S	post	NA	NA	50	2.50	13.42
1	300	D1	U	pre	NA	NA	100	0.00	1.05
1	325	D2	S	post	9.90%	0.825	100	5.50	5.70
1	325	D0	U	pre	13.65%	0.891	100	1.50	7.56
1	350	D1	S	post	11.41%	0.822	100	7.75	5.22
1	350	D0	U	pre	13.94%	0.792	100	2.00	10.09
1	375	D1	S	post	9.29%	0.995	100	4.50	3.34
1	375	D0	U	pre	13.34%	0.843	100	1.50	2.53
1	400	D1	S	post	10.21%	1.049	100	5.00	2.39
1	400	D0	U	pre	15.45%	0.792	100	1.75	2.53
1	425	D1	S	post	9.76%	1.049	100	4.00	4.33
1	425	D0	U	pre	12.93%	0.893	100	4.50	5.03
1	450	D1	S	post	10.18%	0.895	100	3.00	53.96
1	450	D0	U	pre	10.07%	0.954	100	1.00	3.15

Transect	Distance (feet)	Disturbance class	Disturbance type	Period	Soil moisture (grams)	Bulk density at 6-10" (g/cm3)	Cover (%)	Ground cover depth (inches)	Ksat (in/hr)
1	475	D2	S	post	9.95%	0.962	100	2.50	5.81
1	475	D0	U	pre	11.12%	0.815	100	1.50	2.04
2	0	D1	S	post	NA	NA	100	1.00	3.44
2	0	D1	U	pre	NA	NA	100	1.00	2.85
2	25	D1	S	post	NA	NA	100	1.00	7.69
2	25	D0	U	pre	NA	NA	100	2.00	0.94
2	50	D3	R	post	11.54%	0.972	10	0.00	1.83
2	50	D3	R	pre	15.94%	0.894	25	0.00	2.37
2	75	D0	U	post	NA	NA	100	1.00	5.35
2	75	D0	U	pre	NA	NA	100	2.00	4.47
2	100	D2	S	post	11.86%	0.870	100	2.00	2.53
2	100	D0	U	pre	12.50%	0.761	100	0.75	18.40
2	125	D0	U	post	NA	NA	100	1.00	10.65
2	125	D0	U	pre	NA	NA	100	1.00	2.82
2	150	D1	S	post	11.10%	0.914	100	1.00	3.93
2	150	D0	U	pre	10.95%	0.881	100	1.00	6.48
2	175	D2	S	post	NA	NA	100	1.00	1.26
2	175	D0	U	pre	NA	NA	100	1.00	7.69
2	200	D1	S	post	11.25%	0.934	100	3.00	3.79
2	200	D0	U	pre	13.61%	0.703	100	1.00	0.48
2	225	D2	S	post	NA	NA	100	1.00	0.30
2	225	D0	U	pre	NA	NA	100	3.00	5.11
2	250	D0	U	post	11.72%	0.739	100	3.00	1.26
2	250	D0	U	pre	12.13%	0.728	100	3.00	3.66
2	275	D0	U	post	NA	NA	100	4.00	9.93
2	275	D0	U	pre	NA	NA	100	2.50	14.04
2	300	D0	U	post	11.95%	0.723	50	0.50	5.30
2	300	D0	U	pre	13.74%	0.948	100	1.50	2.99
2	325	D0	U	post	NA	NA	100	2.00	4.73
2	325	D0	U	pre	NA	NA	100	1.00	40.59
2	350	D2	S	post	13.05%	0.786	100	3.00	2.93
2	350	D0	U	pre	14.31%	0.718	100	4.00	4.68
2	375	D0	U	post	NA	NA	50	0.50	5.27
2	375	D0	U	pre	NA	NA	100	7.00	2.69
2	400	D0	U	post	10.79%	0.892	100	1.00	1.08
2	400	D0	U	pre	11.41%	0.833	100	2.50	54.71
2	425	D2	S	post	NA	NA	100	1.00	3.82
2	425	D0	U	pre	NA	NA	100	1.50	5.97
2	450	D1	S	post	10.84%	0.703	50	1.00	1.00
2	450	D0	U	pre	12.93%	0.843	100	1.00	2.64
2	475	D2	S	post	NA	NA	100	0.50	2.96
2	475	D0	U	pre	NA	NA	100	2.50	6.29
3	0	D3	R	post	10.34%	1.114	10	0.00	2.64

Transect	Distance (feet)	Disturbance class	Disturbance type	Period	Soil moisture (grams)	Bulk density at 6-10" (g/cm3)	Cover (%)	Ground cover depth (inches)	Ksat (in/hr)
3	0	D3	R	pre	10.91%	1.070	90	0.00	0.62
3	25	D3	R	post	NA	NA	75	0.50	1.32
3	25	D3	R	pre	NA	NA	85	0.00	6.13
3	50	D3	R	post	12.67%	0.866	100	2.00	2.53
3	50	D1	R	pre	11.66%	0.728	100	0.50	2.53
3	75	D1	S	post	NA	NA	100	1.00	3.17
3	75	D0	U	pre	NA	NA	100	3.00	7.69
3	100	D0	U	post	9.25%	0.942	100	2.00	1.29
3	100	D0	U	pre	10.50%	0.848	100	3.50	4.82
3	125	D2	S	post	NA	NA	50	0.50	10.38
3	125	D0	U	pre	NA	NA	100	0.00	4.28
3	150	D0	U	post	10.35%	0.890	100	1.00	1.48
3	150	D0	U	pre	10.61%	0.884	50	1.50	4.28
3	175	D2	S	post	NA	NA	100	4.00	3.07
3	175	D0	U	pre	NA	NA	75	0.50	3.39
3	200	D0	U	post	10.67%	0.911	100	5.00	4.49
3	200	D0	U	pre	11.64%	0.789	95	1.50	3.79
3	225	D1	S	post	NA	NA	100	1.00	1.05
3	225	D0	U	pre	NA	NA	100	1.00	3.58
3	250	D1	S	post	9.90%	0.977	25	0.00	6.05
3	250	D0	U	pre	8.78%	0.964	95	1.50	6.27
3	275	D2	S	post	NA	NA	10	0.00	3.69
3	275	D0	U	pre	NA	NA	100	1.50	10.46
3	300	D2	S	post	10.03%	0.949	90	1.00	5.76
3	300	D0	U	pre	10.18%	0.908	100	0.50	10.84
3	325	D2	S	post	NA	NA	100	1.00	8.07
3	325	D0	U	pre	NA	NA	100	2.50	3.39
3	350	D1	S	post	9.36%	0.908	75	1.00	7.67
3	350	D2	R	pre	8.18%	1.096	100	0.00	11.19
3	375	D2	S	post	NA	NA	50	0.50	7.48
3	375	D0	U	pre	NA	NA	95	1.00	12.27
3	400	D2	S	post	NA	NA	50	0.00	2.91
3	400	D0	U	pre	NA	NA	100	1.50	14.26
3	425	D0	U	post	11.25%	0.908	100	3.00	1.96
3	425	D0	U	pre	15.12%	0.793	100	2.00	14.42
3	450	D0	U	post	9.39%	0.956	100	6.00	1.21
3	450	D0	U	pre	10.37%	0.869	100	3.00	5.54
3	475	D2	S	post	NA	NA	100	2.00	1.29
3	475	D1	U	pre	NA	NA	100	1.00	7.91
L2a	10	D2	R	pre	10.54%	0.924	100	1.50	2.39
L2a	20	D3	L	post	21.35%	1.061	95	NA	0.83
L2a	20	D3	R	pre	9.86%	1.092	75	0.25	2.91
L2a	70	D1	R	pre	12.10%	0.942	60	0.25	5.41

Transect	Distance (feet)	Disturbance class	Disturbance type	Period	Soil moisture (grams)	Bulk density at 6-10" (g/cm3)	Cover (%)	Ground cover depth (inches)	Ksat (in/hr)
L2a	80	D1	R	pre	15.45%	0.523	100	4.00	5.06
L2a	90	D2	L	post	NA	NA	100	NA	0.62
L2a	130	D2	L	post	NA	NA	100	NA	1.88
L2b	10	D3	L	post	10.46%	1.048	95	NA	0.83
L2b	70	D2	L	post	NA	NA	100	NA	0.97
L2b	70	D0	U	pre	NA	NA	100	1.00	4.73
L2b	110	D3	L	post	NA	NA	90	NA	3.79
L2b	110	D0	U	pre	NA	NA	80	0.50	3.77
L2b	150	D3	L	post	NA	NA	90	NA	2.34
L2b	150	D0	U	pre	NA	NA	100	2.00	4.73