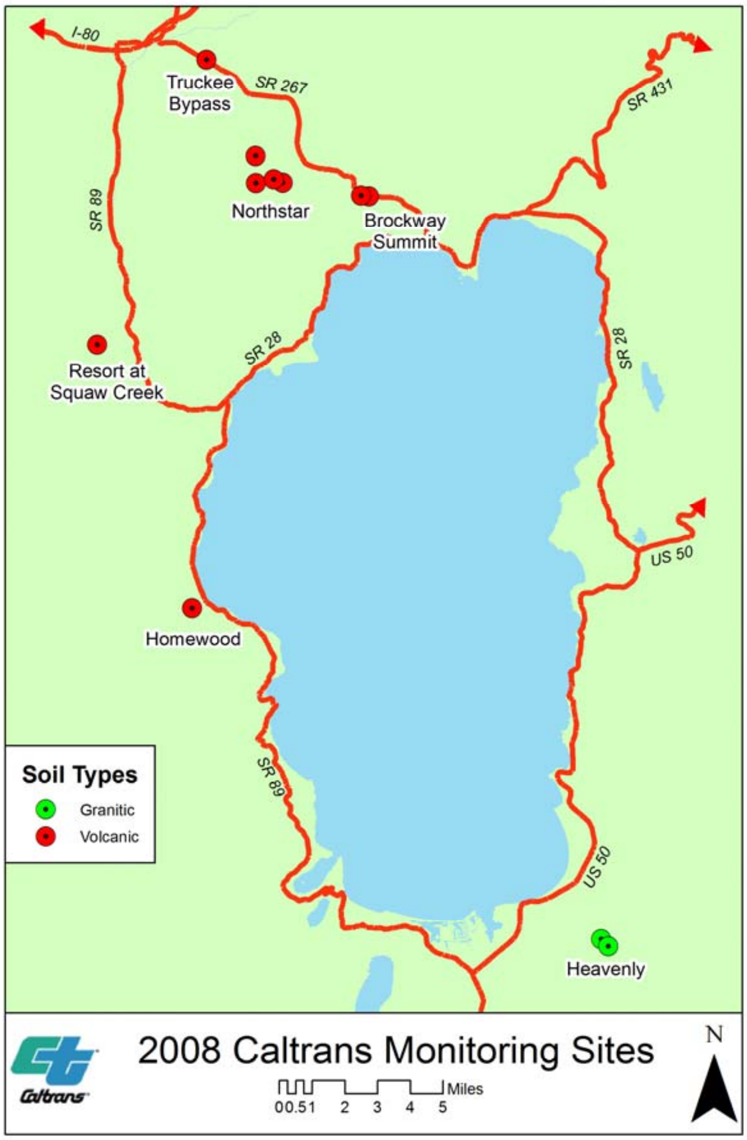
Monitoring and Assessment of the Erosion Control Treatments in and around the Lake Tahoe Basin



2008 Summary Report

May 2009

Executive Summary

Caltrans is one of the largest land managers in the Lake Tahoe region and, as such, is tasked with protecting water quality within its jurisdiction by two primary agencies: Lahontan Regional Water Quality Control Board and the Tahoe Regional Planning Agency. In a proactive effort to address current and upcoming water quality regulations and needs, Caltrans has been engaged for nearly 10 years in the Demonstration and Development (D&D) Program, an ongoing, adaptively-managed sediment source control improvement program. This program is based on the development, demonstration, and monitoring of cutting-edge erosion control techniques and is targeted on providing the highest level of cost-effectiveness and environmental benefit to Caltrans. This report summarizes monitoring results and presents recommendations from the ongoing D&D program.

Rehabilitation of soil function has been shown to be the foundation of sediment reduction on disturbed Tahoe Basin sites. Systematic soil restoration treatments (full treatment), aimed at restoring hydrologic and nutrient cycling function (including deep incorporation of amendments during the soil loosening process, addition of organic slow-release fertilizer, and application of native seed and mulch) were found to reduce sediment by 3 to 981 times when compared to typical surface treatments (such as Caltrans Erosion Control Type D surface treatment composed of compost, seed, fertilizer, fiber, tackifier, and mulch). The program has thus far identified the full soil restoration treatment as having the highest effectiveness based on up to 7 years of monitoring data for nutrient poor and highly disturbed sites (<u>Section 3: Recommended Specifications</u> and Figure 7).

In the Caltrans D&D program, site conditions are assessed prior to treatment using specific monitoring techniques (see individual site reports) to ascertain soil density and organic matter content. Replacement of organic matter, when needed, should be accomplished with the addition of compost composed of 25% screened, fine material and 75% coarse overs (the woody material remaining after the composting process) at a ratio that is between 0.4 to 0.5 of the soil loosening depth, depending on soil type. This organic material is then incorporated by either tilling or ripping soil loosening methods to a depth of at least 12 inches. Next, 2,000 pounds per acre of organic fertilizer, an appropriate native grass, shrub, and forb seed mix at 125 lbs/acre, and 2 inches of pine needle mulch, are applied. Landscape-type irrigation (3-5 times per week) is not recommended; however, initial irrigation, applied with a low flow system, is recommended on steep slopes directly following restoration. While a number of questions regarding the relative effectiveness of materials and methods remain, the information contained in this report is expected to help Caltrans continue to improve and quantify sediment source control and erosion control efforts in the Lake Tahoe Basin, as well as to help Caltrans comply with upcoming water quality regulations such as the Total Maximum Daily Load (TMDL) sediment reduction requirements.

Introduction

Given the upcoming TMDL programs both in the Lake Tahoe Basin and elsewhere, the ability to understand and consistently implement techniques that can reduce fine sediment at its source is imperative. Further, the cost and technical resources necessary for treating fine sediment are prohibitive in many cases. Sediment source control, the target of this work, is undoubtedly the most cost and environmentally effect approach to fine sediment reduction. However, a number of challenges exist within the current erosion control project delivery process. Outcomes are often uncertain and techniques are not clearly articulated or well understood. Success criteria are often not linked to the implicit project goals (for example, revegetation versus reduction of sediment). Ongoing project improvement in the realm of techniques and materials is often hit or miss and can be partially dependent upon luck or other equally hard-to-define variables. This D&D Program has been designed to: 1) decrease the uncertainty with which most erosion control projects are implemented, 2) develop and defend success criteria that are linked to project goals, and 3) to lead TMDL efforts through a process of careful and defensible monitoring whose outcome is easy to understand and whose results feed into ongoing project improvement. Each year, this Program has provided continual improvement of understanding of materials and methods to achieve sediment reduction and revegetation goals. It has been the primary practical program for the implementation and field-testing of a range of new and existing research findings.

This report describes the Program efforts thus far and suggests processes and materials to achieve the goals stated above. In 2008, 11 sites and over 150 plots were monitored to determine the effects of different restoration techniques on sediment source control. Study sites included existing disturbed sites, surface treatment sites, native reference sites, and a variety of full treatment sites. The results of each study site are presented in detail in the individual site reports. This document summarizes the findings of these site reports and presents suggestions and recommendations for Caltrans erosion control specifications. A list of study sites with treatment descriptions, soil parent material, and most recent year monitored are in Table 1.

The study sites included a wide range of drastically disturbed sites, including cut and fill slopes along roadsides. Some ski resort sites, where conditions were similar to road cuts or fills, were studied. Large areas were available at these resorts to install replicated test plots and public disturbance was not a concern, as it can be on roadsides. Drastic disturbance is defined as the removal or mixing of topsoil and the removal of most or all of the existing vegetative cover from a given site. These sites are extremely problematic to stabilize and are typical of Caltrans road cuts and fills. Much of the fine sediment produced from Caltrans road cuts is thought to come from these types of sites. Therefore, the ability to stabilize these sites with long-term, sustainable erosion control will lead to a major reduction in sediment pollution from Caltrans sites, thus helping Caltrans meet its Waste Discharge requirements. Furthermore, this information and data are likely to help Caltrans meet its obligations for sediment reduction under the Tahoe Basin TMDL, which is currently in development. This D&D program helps to define Caltrans as a leader in sediment source control development and demonstrates its commitment to create a cleaner Lake Tahoe.

Table 1. Study sites with treatment descriptions, soil parent material, and range of years monitored. Soils derived from volcanic parent material will be referred to as volcanic soils throughout the report. Similarly, soils derived from granitic parent material will be referred to as granitic soils.

Study Site Name	Treatment Types / Native Reference	Soil Type	Monitoring Years
Brockway Basins	Full Treatment Surface Treatment Native Reference	volcanic	2006-2008
Brockway Summit	Full Treatment Surface Treatment Native Reference	volcanic	2006-2008
Heavenly Canyon	Full Treatment Surface Treatment Native Reference	granitic	2004-2008
Heavenly Gunbarrel	Full Treatment Surface Treatment	granitic	2007-2008
Homewood Wedding Road	Full Treatment	volcanic	2008
Meyers Airport	Full Treatment Surface Treatment Native Reference	granitic	2006-2007
Northstar Bearpaw	Full Treatment Surface Treatment	volcanic	2007-2008
Northstar Highlands View Road	Full Treatment	volcanic	2008
Northstar Lookout Mountain	Full Treatment Surface Treatment Native Reference	volcanic	2004-2007
Northstar Unit 7	Full Treatment Surface Treatment	volcanic	2002-2008
Northstar Woods Run Bridge	Full Treatment	volcanic	2008
Resort at Squaw Creek	Full Treatment Surface Treatment Native Reference	volcanic	2003-2008
Tahoma Soil Boxes	Full Treatment	volcanic and granitic	2005-2007
Truckee Bypass Test Plots	Full Treatment Surface Treatment Native Reference	volcanic	2006-2008

Document Overview

This report is organized as follows:

Section 1: Current Level of Knowledge – This section of the report provides a brief summary of results from several years of monitoring and highlights the main findings. Each treatment component (amendment, soil loosening, fertilizing, seeding, mulch, etc.) is discussed in terms of its effect on infiltration, sedimentation, soil density, cover, and soil nutrient status.

Section 2: Comparative Results – This section compares results for a several treatment methods and provides guidance for erosion control and revegetation practices based on the monitoring results.

Section 3: Recommended Specifications – This section outlines the recommended specifications for volcanic or granitic parent material soil with high or low existing nutrient conditions based upon the monitoring results.

Section 4: Draft Success Criteria – This section presents suggested criteria based on monitoring findings to date.

Section 5: Information Gaps – This section discusses what has yet to be learned (information gaps) and provides direction for future testing and monitoring that will best address the needs for erosion control at Caltrans sites.

Section 1: Current Level of Knowledge

During the past decade, a concentrated effort has been made to study the sources of clarity loss in Lake Tahoe. Silts (between 2 and 63 microns) and especially clays (less than 2 microns) are now understood to have the greatest impact on lake clarity. The majority (72%) of particles 20 microns or less entering Lake Tahoe are reported to come from urban upland locations, 23% of which are under Caltrans jurisdiction[1].

The D&D program and related work has shown that plant cover alone does not control erosion, but instead that plant cover is part of an integrated soil and plant system that, when operating at a high level of function, can control erosion at its source and sustain itself into the future. This information has redirected the focus of erosion control strategies from conveyance and treatment, for which fine particles can only be captured at an extremely high relative cost, to sediment source control, which is designed to keep soil and sediment where it originates. Sediment source control reduces or eliminates down slope and downstream movement of fine particles and thus the need for large expensive conveyance and treatment systems. Vegetation cover alone is no longer the primary indicator for erosion control project success. Monitoring has shown that sediment reduction depends on a number of factors, including adequate infiltration capacity, low soil density, robust mulch cover, suitable plant cover, appropriate soil nutrients, and soil structure. It has been shown that surface treatment plots with up to 90% plant cover produced sediment yields up to 1,400 lbs/acre/in, compared to little to no sediment yield at full treatment plots at the same location, with lower plant cover (as little as 20%). In fact, plots without any plant cover have been shown to infiltrate 100% of applied water.

One of the critical information gaps in soil restoration treatment is the long-term performance of treatments for particular site conditions. There are few long-term (greater than 3 year) studies available to help fill this gap. The information presented in this report contains data from one of the only long-term erosion control monitoring sites in the Lake Tahoe Basin. Some of the data is based on seven years of monitoring, although most data is from shorter-term monitoring. The following is a summary of our understanding thus far.

Full Treatment

Full treatment is the process of restoring soil function to the highest obtainable level. The process includes:

- assessment of pre-treatment soil conditions to identify treatment needs,
- replacement of soil organic matter,
- incorporating that organic matter to a depth of 12-18 inches,
- addition of an organic, slow-release fertilizer,

[1] DRAFT Lake Tahoe Total Maximum Daily Load Technical Report California and Nevada, September 2007 California Regional Water Quality Control Board, Lahontan Region and Nevada Division of Environmental Protection.

- application of native meadow and forest grass, forb, and shrub seed (depending on project goals), and
- application of native pine needle or woody mulch.

The D&D program research has been instrumental in furthering understanding of the types and amounts of each variable required for successful full soil restoration. Variations in full treatment restoration that are continually being refined for better understanding include type and rate of species in the seed mix, type and ratio of organic amendment to soil loosening depth, amount of fertilizer, and type and amount of mulch. A complete list of information gaps is presented in Section 5: Information Gaps. This report presents the latest data and information in that refinement process.

Full treatment has been shown to be the most effective method for treating highly disturbed areas. A comparison of full and surface treatment monitoring results is shown in Table 2. Although the initial cost of full treatment is 4 to 5 times higher than surface treatment, full treatment is less costly over the long term (based on up to seven years of data). Full soil restoration is a one-time investment and re-treatments are typically not necessary, whereas multiple re-treatments are generally anticipated with surface treatment.

When properly implemented, full treatment can achieve sediment source control goals, stabilize soils, and eliminate slope failures in the first one to seven years after treatment. Further study is necessary to determine success after seven years. Initial post-treatment infiltration rates at full treatment sites are similar to or exceed those at most native sites. Sediment yields, which were greatly reduced (by 3 to 981 times in 2008) or eliminated by implementing full treatment, were comparable to or less than yields at most native areas.

While sediment yields have remained steady or decreased over time (since installation) at most full treatment areas, in 2008, large increases over 2007 sediment yields were measured at surface treatment areas. For instance, at the Truckee Bypass, sediment yields increased from 86 to 1,238 lbs/acre/in between 2007 and 2008, while the full treatment plot sediment yields remained at zero (except one plot, which had a minimal sediment yield of 19 lbs/acre/in).

Plant diversity and native plant cover was highest and increased over time at most full treatment plots (without a seed source for invasive plants). This result is notable because the previous two monitoring seasons (2007 and 2008) were preceded by lower-than-average precipitation winters and plant cover has been observed to decrease during low water years. Plant species diversity and composition is directly linked to the increased nutrient content from addition of organic amendments and fertilizer at full treatment plots. Total foliar cover varied over time at long-term full treatment plots and ranged from 2.1 to 5.5 times higher than at most surface treatment sites (Figure 1 and Figure 2). Soil nutrient contents were up to 1.3 to 6.8 times higher than at surface treatment plots. Many full treatment plots had soil nutrient levels that were comparable to those at native sites over three years of sampling. For those that did not reach native levels, an increase in the ratio of organic amendments to soil loosening depth is recommended.

Volcanic Soils

Volcanic and granitic soils perform quite differently across a range of variables and are treated separately here. Soil density, which generally increased over time for volcanic soil after one to seven years, remained 1.6 to 4.1 less dense than at surface treatment plots. These volcanic soil densities were generally lower with coarser amendments versus finer amendments and for sites with higher amendment to soil loosening ratios (the amount of soil amendment applied compared to the depth of soil loosening) versus lower amendment to soil loosening ratios. Although treated volcanic soil densities were higher than at some native areas, infiltration and sedimentation rates were not adversely affected.

Granitic Soils

Granitic soil densities remained fairly stable over time and were comparable to native densities regardless of whether amendments were incorporated. Incorporation of amendments serves as a way to re-capitalize granitic soil, rather than to maintain low densities. Further study is necessary at a variety of sites to determine whether this result is consistent for all granitic soils.

Figure 1. Full treatment site with high cover by desirable native species

Figure 2. Surface treatment site with low plant cover and high bare ground.

Surface Treatment

Surface treatment is easy to implement and has a relatively low initial cost. Therefore, it has been used for many years by Caltrans and many other land managers on erosion control projects. Caltrans Erosion Control Type D treatment is an application of light compost, seed, fertilizer, fiber, tackifier, and mulch to the soil surface. This surface treatment has been shown to be ineffective for sediment reduction in highly disturbed sites where topsoil, nutrients, and a native seed bank are absent. Re-treatments are often necessary to achieve sediment reduction and vegetation goals, thereby rapidly increasing the project's cost beyond the initial treatment cost. Vegetation at surface treatment plots usually decreases over time, making existing erosion problems more apparent. Irrigation is sometimes employed with surface treatments in an attempt to produce more plant cover, which further increases the cost. While initial costs can be low without irrigation, the soil at disturbed sites is rarely adequately capitalized to sustain sediment reduction or plant cover.

Rainfall simulations at surface treatment plots have shown that sediment yields are extremely unpredictable and inconsistent over time, regardless of soil type. For instance, at the Truckee Bypass surface treatment plots, sediment yields were an average of 155 lbs/acre/in in 2006, and average of 73 lbs/acre/in during 2007, but increased by more than 10 times to an average of 775 lbs/acre/in in 2008. In comparison, a steady and low to non-existent sediment production was measured at the full treatment plots, which ranged from 0 to 4 lbs/acre/in over the same time period.

When compared to full treatment sites, surface treatment sediment yields were up to 981 times higher than many full treatment sites, though a majority of full treatment sites did not produce any sediment. Infiltration rates were similarly low at surface treatment sites and large improvements over time were not observed. The sediment yields at surface treatment plots were 1.2 to 60 times higher than those observed at native plots. Non-native plants or annuals, which can out-compete desirable native plants, are prevalent at many surface treatment plots, regardless of applied seed. Plant cover by desirable species was up to 9.6 to 67 times lower at some surface treatment plots. Most surface treatment plots exhibited low cover by mulch (mulch has been shown to reduce sediment) and high cover by bare ground. This may have contributed to their poor performance in terms of sediment source control. Soil density, which can also affect infiltration, remained consistently high over time and was up to 4.1 times denser than at full treatment plots.

Table 2. Monitoring results and comparison for full treatment and surface treatment.

	Full Treatment	Surface Treatment	Comparison
Sediment Yield	• None to very little • 0-68 lbs/acre/in • Steady to decreasing over time	• High • 60-1,866 lbs/acre/in • Increasing over time	• 3 to 981 times higher at surface treatment plots
Infiltration Rates	• High • 4.5-4.7 inches/hr • Steady to decreasing over time	• Moderate • 3.0-4.1 inches/hr • Increasing over time	• 1.1 to 1.6 times lower at surface treatment plots
Soil Density	• High • 4-15 inches • Steady to decreasing slightly over time	• Low • 2-4 inches • Steady over time	• 1.6 to 4.5 times lower at surface treatment plots
Plant Cover	• Moderate • 27-56% • Increasing or variable over time	• Low • 5-16% • Decreasing or variable over time, no increasing trend apparent.	• 5.5 times lower at surface treatment plots
Mulch Cover	• High • 72-90% • Steady to slight decreases over time	• Variable • 16-88% • Variable over time, some decreases a result of erosion	• 5.6 times lower at surface treatment plots
Nitrogen	• Similar to native levels • 1,104-4,844 ppm volcanic • 789-1,109 ppm granitic • Variable over time	• Lower than native levels • 738-1,902 ppm volcanic • 546-863 ppm granitic	• 6.6 times lower at surface treatment plots
Organic Matter	• Similar to native levels • 4.1-10.7% volcanic • 2.4-3.0% granitic • Variable over time	• Lower than native levels • 3.5-6.7% volcanic • 1.5-2.0% granitic • Variable over time	• 1.6 times lower at surface treatment plots

Amendment Type and Rate

Soil amendments play a fundamental role in the re-capitalization of soil nutrients. There are a number of amendment types and rates currently under study; however, definitive results have not yet been produced. More test plots need to be constructed to test different amendment types and to compare performance and cost-effectiveness. Different types of organic matter, such as compost, coarse overs (composted coarse woody material), woodchips, tub grindings, topsoil, fill soil, and various combinations of these are in the initial stages of study. To date, research results have been highly variable. Soil type, compost feedstock, initial soil conditions, and the nature of the year in which the plot were installed have all contributed to the variable results. Based on initial results, a blend of 75% coarse overs and 25% screened compost is recommended.

Caltrans has recently embraced the use of compost, which is sometimes associated with the presence of invasive species. Compost is also the most expensive of the amendments tested. The following materials are under study and results are discussed in detail in Section 2:

- Compost (100% fines)
- Compost blend (25% fines/75% coarse overs)
- Coarse overs
- Tub grindings
- Aged woodchips
- Woodchips
- Topsoil

Research in 2008 indicated that finer amendments, such as screened compost, may not prevent soil re-compaction at volcanic sites in the long term. Over three years, trends of increasing soil density were observed at two volcanic sites where screened compost and a coarse amendment were compared. Finer amendments may be able to be incorporated in conjunction with coarse amendments to achieve nutrient re-capitalization and soil density goals at the same time. A high-nutrient coarse amendment such as a compost blend of 25% fines and 75% coarse overs or 100% coarse overs could be applied to reduce compaction. These amendments have been studied, with positive results, but not at an application depth that would be required to reduce compaction. Use of a fine amendment alone is not recommended for volcanic soils at this time. Topsoil also shows promise, but is not readily available at most Caltrans restoration sites. Further research is necessary to determine whether re-compaction is an issue with granitic soils.

In general, higher nutrient amendments produce higher cover by plants. For instance, at the Truckee Bypass test plots, plots with a compost blend (75% coarse overs/25% screened compost) produced cover that was higher by 2 times (48% compared to 24%) compared to plots with tub grindings. However, compost or a compost blend should not be used at areas with a weed source, as the compost addition can increase cover by weeds. For example, at the Brockway Summit test plots, plots with a compost blend produced up to 50% plant cover, but a majority of the composition was cheatgrass. Here, the plots with tub grindings produced just 5% plant cover, but a majority of the cover was composed of desirable, native species. More research needs to be conducted to recommend a suitable amendment for sites with a weed seed source. The compost blend of 75% coarse overs and 25% screened compost is recommended for sites without a weed seed source.

Fertilizer and Fertilizer Rate

Biosol organic fertilizer has been extensively tested for both purity and release characteristics. Other types of organic fertilizers are currently on the market. However, due to either a lack of information, a lack of testing, or concerns about product purity, D&D program testing has been focused on amounts of Biosol slow-release organic fertilizer rather than broad-scale fertilizer research. Another Caltrans publication describes a broad range of fertilizers and their release characteristics.[2] Biosol rates of approximately 0; 1,000; 2,000; 4,000; and 8,000 lbs/acre were studied. In volcanic soils, it was found that the Biosol rate of 2,000 lbs/acre was most effective over the long term. In granitic soils, it was found that a Biosol rate of 8,000 lbs/acre was most effective at providing the appropriate soil conditions to produce native plant cover when used in conjunction with irrigation.

Seed Type

Seed mixes dominated by bunchgrasses native to the Tahoe-Truckee area produce more plant cover, respond better to fluctuations in precipitation, and are better suited to controlling erosion than seed mixes composed solely of shrubs and/or forbs, or non-native grasses. The majority of test plots were seeded with a mix with four native bunchgrass species (squirreltail, mountain brome, Western needlegrass, and blue wildrye) at a total rate of 125 lbs/acre, with a range of applications from 50 to 150 lbs/acre. At several plots, native forbs and shrubs were added to the grass-dominated seed mix to encourage species diversity.

Over one to seven years of sampling, seeded bunchgrasses composed a majority of plant cover at 7 out of 9 test plots that did not have a seed source for cheatgrass. Most plots seeded with bunchgrasses had seeded cover that was at least 50% of the total cover, as measured by the cover point method. However, many plots had greater than 75% of foliar cover by seeded grasses. Bunchgrass roots were observed up to 4 feet deep at the Tahoma soil boxes in 2007. Seeded grasses did not initially dominate plots with a cheatgrass seed source. However, over the course of three years, cheatgrass levels decreased and seeded grasses became more prevalent. After only two growing seasons, this trend was not apparent, which signifies the importance of continued study of sites deemed unsuccessful because of weed populations. More study is needed to determine appropriate seed and amendment types and rates for cheatgrass problem areas.

Squirreltail

Squirreltail (*Elymus elymoides*) showed increases in cover over time regardless of solar exposure and soil nutrient levels. Cover by squirreltail increased in both 2007 and 2008, which were low water years. In 2007, cover increased at four of the seven sites where it was seeded, and in 2008, cover increased at five of the six sites where it was seeded

Squirreltail did not dominate at any of the 27 plots (except one) that were treated in 2007 and monitored in 2008. It also produced low cover in 2008 when seeded as a monoculture during 2007 treatments. This indicates that squirreltail does not establish well during the first year after treatment, regardless of whether other species are seeded with it. Squirreltail may take two or three years to become well-established. Squirreltail was observed to dominate at one plot that was treated in 2006, but where growth did not appear until 2008. This plot was on granitic soil where 8,000 lbs/acre of Biosol was applied. This indicates that high nutrients at the time of treatment may encourage squirreltail to grow in areas in year one where it might otherwise not dominate until two to three years after seeding. It was previously

[2] Claassen, V., and M. Hogan, 1998. Generation of water-stable soil aggregates for improved erosion control and revegetation success. California Department of Transportation. RTA # 53X461.

thought that squirreltail was more drought resistant than mountain brome (*Bromus carinatus*) and therefore it dominated over mountain brome in 2007, which was a low water year. It is now thought that squirreltail is unable to produce high cover in the first year when there is low to moderate available nitrogen, while mountain brome is able to thrive in those conditions., This creates a successional process in which mountain brome decreases when squirreltail becomes more established and out-competes mountain brome.

Mountain brome

In 2007 and 2008, the proportion of cover by mountain brome decreased at most plots that were established more than two years earlier. Mountain brome is often the dominant species during the first year after treatment when Western needlegrass is not present in the seed mix. This was observed at three sites with volcanic soil in 2008 that were treated in 2007. At Homewood Wedding Road, where Western needlegrass was included in the seed mix, mountain brome was no longer the dominant in the first year; it was out-competed by Western needlegrass.

Blue wildrye

Blue wildrye (*Elymus glaucus*) decreased at most plots where it was present during 2007. In 2008, increases were observed at Northstar Unit 7, where blue wildrye was dominant in most years, with the exception of 2007. Increases were also observed at the Resort at Squaw Creek. At Homewood Wedding Road, when blue wildrye was seeded as a monoculture, moderate cover was observed. However, at plots at the same site, when blue wildrye was seeded as part of a mix, little to no cover by blue wildrye was observed. This indicates that other native bunchgrasses such as squirreltail, mountain brome, and needlegrass have a competitive advantage over blue wildrye when seeded together. If cover by blue wildrye is desired, seeding a small area within the larger treatment area as a monoculture is recommended.

Western needlegrass

The proportion of cover by Western needlegrass (*Achnatherum occidentale*) increased during 2007 and 2008, even at plots with low soil nutrients (Heavenly Canyon and the Resort at Squaw Creek). In 2008, cover by needlegrass increased from small quantities in 2007 at one site where it was not seeded (Resort at Squaw Creek).

In 2008, Western needlegrass dominated at Wedding Road (treated in 2007) at the plots where it was dominant in the seed mix. It had the highest cover compared to squirreltail, mountain brome, and blue wildrye when seeded as a monoculture.

Western needlegrass has just recently begun to be tested in our plots. This species appears to be very promising and is the intended focus of further study.

Native shrubs and forbs

The seeded native shrubs, bitter brush (*Purshia tridentata*) and sagebrush (*Artemisia tridentata*), germinated at the Truckee Bypass but, because of a slower growth rate, did not comprise more than 7% of total plant cover. Of the seeded forb species, lupine and buckwheat were the most prevalent; however, these species only comprised a majority of cover at one test site.

Seed Rate

There are indications that plots seeded at a higher rate (125-150 lbs/acre) produced slightly higher cover by seeded grasses, but further study needs to be done. Plots with higher seed rates in conjunction with fertilizer use, showed a trend toward higher cover by seeded species. At some areas, plots seeded with higher rates had cover similar to plots seeded at lower rates (50 lbs/acre). These conflicting results indicate that: 1) more study is necessary and, that 2) specific site conditions, including nutrient availability and water holding capacity, may influence optimal seed rates.

Mulch

Many types of mulch are currently available, including various forms of woody material and pine needles, both examined in this study. Pine needles are the most promising mulch because they are: 1) derived from native or local sources, thus minimizing potential for importation of non-native vegetation and weeds, 2) they are removed from the waste stream, thus reducing vehicle miles and associated CO_2 emissions, 3) they are highly effective at trapping and filtering sediments, and 4) they have an interlocking tendency that aids in resisting displacement. They are long-lasting on plots without continual disturbance and they match the native aesthetic. Pine needles also provide most of the nutrients in native forest ecosystems throughout the Lake Tahoe Basin and thus serve as a long-term nutrient source on erosion control projects as they decompose. Potential nutrient content is currently under study and not yet fully understood. Tub grindings may be most practical at steeper sites, and can be used when pine needles are not available. Woody mulches need to be applied at shallower depths than pine needles, as deep cover can prevent sunlight from reaching the soil and can inhibit plant growth.

Section 2: Comparative Results

This section details the results of tests between different treatment types in test plots and the results of measurements of specific treatments and materials.

Full Treatment versus Surface Treatment

Full treatment and surface treatment were compared at six of the eleven study sites. Two sites with granitic soil (Heavenly Canyon and Heavenly Gunbarrel) and four with volcanic soil (Resort at Squaw Creek, Northstar Unit 7, Truckee Bypass, and Brockway Summit) were compared.

Full treatment plots exhibited the following when compared to surface treatment plots over seven years of study:

- either no sediment (where runoff did not occur), or sediment reductions of 3 to 981 times
- infiltration rates that were 1.1 to 1.6 times higher
- soil density that was 1.6 to 4.5 lower (3.6 to 15 inches for full treatment plots compared to 1.8 to 4.4 inches at surface treatment plots)
- total plant cover that was up to 5.5 times higher (5-16% at surface treatment plots compared to 27-56% at full treatment plots)
- mulch cover that was up to 5.6 times higher
- bare soil that was up 117 times lower
- total Kjeldahl nitrogen (TKN) content that was up to 6.6 times higher
- organic matter content that was up to 1.6 times higher

In 2008, newly collected data indicated that sediment yields at surface treatment plots were more variable than monitoring in 2007 and previous years indicated. In 2007, some decreases in sediment yield were observed at surface treatment plots, which suggested the possibility of improvement over time at surface treatment plots. Results from 2008 refuted this trend. It is now understood that surface treatment performance is extremely variable and cannot be predicted over time, whereas full treatment plots have consistently produced low sediment yield (Figure 3).

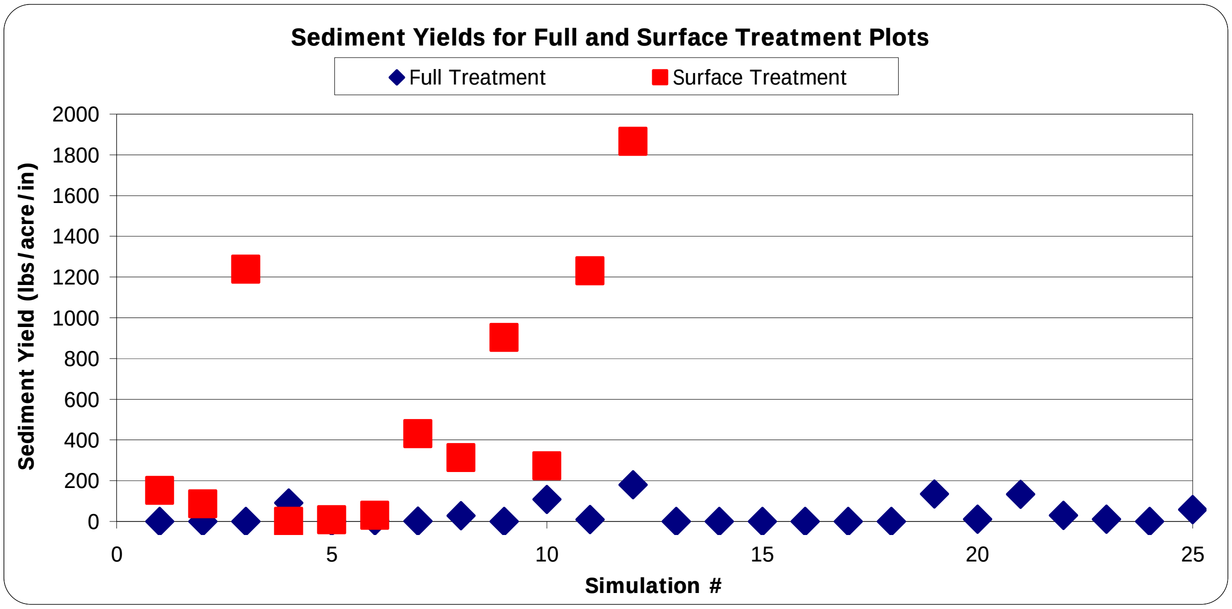


Figure 3. Sediment Yields for Full and Surface Treatment Plots. Full treatment plot performance was consistent and remained below 200 lbs/acre/in for all simulations. Surface treatment plots produced variable sediments ranging from 0 to 1,866 lbs/acre/in. Each simulation consisted of an average of two or more frames for a treatment type in a particular year.

Soil Loosening Methods: Tilling versus Ripping

Tilling and ripping were compared at one site with volcanic soil (Truckee Bypass). Ripped and tilled plots at this site did not produce any sediment yield and had similar soil densities over three years. Ten of the eleven study sites in this project had plots with tilling that performed well, therefore tilling is recommended over ripping for new treatments.

Soil Loosening (Tilling) Depth: 14 inches versus 9 inches

Soil loosening depths were compared at one volcanic soil site over three years: Brockway test plots. Soil loosening to 14 inches is recommended over soil loosening to 9 inches; however, more tests need to be conducted before 14 inches is recommended over the current 12 inch recommended specification. Plots tilled to 14 inches exhibited the following:

- soil density that was 1.5 times lower than at plots tilled to 9 inches three years following treatment

Plots with either soil loosening depth exhibited:

- little to no sediment production and similarly high infiltration rates

Surface Treatment with Subsequent Woodchip Ripping versus Surface Treatment

Surface treatment with subsequent re-treatment, which includes incorporation of woodchips by ripping, was tested at the volcanic soil site Resort at Squaw Creek over five years. This technique is recommended for unsuccessful existing surface treatments where adequate vegetation cover exists but sediment yields are high. The surface treatment plot with subsequent ripping and wood chip incorporation exhibited the following when compared to the surface treatment plot:

- a sediment yield that was an average of 12 times lower over six years of sampling
- an infiltration rate that was 1.1 times higher over four years of sampling
- soil density that was 1.7 to 1.9 times lower
- similar plant cover and composition
- similar nitrogen (TKN) values in 2008
- organic matter content that was up to 1.3 times higher

Amendments versus No Amendments

In 2008, Heavenly Canyon (granitic soil) test plots with the same treatments, with the exception of amendment incorporation, were compared over five years. Soil loosening was used at all plots, regardless of amendment presence. Plots with amendments exhibited:

- similar infiltration (92-96%)
- similar sediment yields (17 to 21 lbs/acre)
- similar plant cover
- nitrogen (TKN) that was 1.2 to 1.3 times higher
- organic matter that was 1.1 to 1.4 times higher

In 2007, all plots in the amendment versus no amendment tests included the application of native seed, fertilizer, and pine needle mulch. Some plots without amendments were tilled, while others were not. Plots with hydroseed treatments were not included in this comparison. Two volcanic soil sites were used for study: Northstar Lookout Mountain and the Tahoma Soil Boxes. Incorporation of amendments is recommended for the following reasons. Plots with amendments exhibited the following over 4 years of study:

- plant biomass that was up to 4 times higher
- nitrogen (TKN) that was 1.8 times higher
- cover by perennial species that was up to 9 times higher
- plant cover that was up to 10 times higher
- soil density that was up to 1.5 times lower

Amendment Type

Many amendments were applied at only one study site. Only three sites contained amendment comparison plots, making evaluations of amendment performance between plots at a particular site limited. Most amendments that contained a mix of screened compost and coarse overs (the woody material remaining after the composting process) performed well. Plots with a coarser amendment, such as woodchips or tub grindings only, did not provide sufficient nutrient levels in many cases; however, plots with tub grindings at the Brockway test plots did not produce any cheatgrass, which was a dominant species at many of the plots with compost. Higher amendment to soil loosening ratios of tub grindings or woodchips may result in sufficient nutrient content or in the case of granitic soils, the addition of Biosol in excess of 2,000 lbs/acre may be necessary when using tub grindings or woodchips. Most treatment plots with amendments exhibited high infiltration rates and low sediment yields (or no sediment). A difference in soil density among amendment types was found at some sites, but not others. In most cases, woody amendments resulted in lower soil densities compared to finer amendments such as compost. Plots amended with topsoil did not show large amounts of re-compaction after one year. Some plots with finer amendments do not have more than one year of monitoring data, making conclusions about re-compaction over time impossible. Screened compost is not recommended as the only amendment for sites with volcanic soil because soil re-compaction occurred at some sites with this amendment. A woody amendment may increase the performance of sites amended with screened compost or topsoil, but more research is necessary to recommend this. A compost blend is recommended over woodchips and tub grindings in areas without a cheatgrass seed source to encourage plant growth. More research is necessary to make a recommendation for cheatgrass problem areas.

Based on the results of the three different types of compost used (0% coarse overs, 75% coarse overs, or 100% coarse overs), the mixture composed of 75% coarse and 25% fine material is recommended. This mixture provides the best proportion of fine, nutrient-rich material for soil recapitalization to coarse material for maintaining low soil density. Each amendment that was tested is presented below with noteworthy monitoring results.

Compost with 25% coarse overs/75% fines

Plots amended with a compost mixture of 25% coarse material and 75% fine material:

- produced up to 1.4 times higher biomass and plant cover than 100% coarse overs (2007 monitoring)
- produced 1.3 times higher perennial plant cover than 100% coarse overs (2007 monitoring)

Compost with 75% coarse overs/25% fines

This is the recommended amendment. Plots amended with compost composed of 75% coarse and 25% fines exhibited:

- similar sediment yields, infiltration rates, and soil densities when compared to plots with tub grindings or composted woodchips
- foliar cover that was up to 2 times higher compared to plots with tub grindings
- seeded cover that was higher by up to 2.3 times when compared to plots amended with tub grindings
- nitrogen (TKN) that is up to 2.2 times higher than at the plot with tub grindings and up to 1.7 times higher than the plot with composted woodchips
- organic matter that is up to 1.4 times higher than at the plot with tub grindings or the plot with composted woodchips

100% coarse overs

Plots amended with 100% coarse overs exhibited:

- similar sediment yields, infiltration rates, and soil densities when compared to plots with 25% compost or woodchips
- nitrogen (TKN) that was up to 1.5 times higher than compost and 1.9 times higher than plots with woodchips over three sampling years
- organic matter that was 1.7 times higher than compost and 1.6 times higher than plots with woodchips over three sampling years

Compost/woodchip mix (50/50)

Plots amended with a 50/50 compost and woodchip mix exhibited:

- similar sediment yields, infiltration rates, soil densities, plant cover, and plant composition when compared to plots with compost only or woodchips only
- up to 1.5 times higher nitrogen (TKN) than plots with compost alone and 1.7 times higher than plots with woodchips alone
- up to 1.3 times higher organic matter compared to plots with compost alone or woodchips alone

Tub grindings

Plots amended with tub grindings exhibited:

- soil densities that were 1.5 times lower than at plots with compost or compost and tub grindings for plots tilled to 14 inches
- foliar cover by cheatgrass 7 times less compared to plots with compost and 5.7 times less compared to plots with compost and tub grindings

Topsoil

One volcanic site was amended with topsoil: SR 267 cut slope plot (Northstar Unit 7 site report). The nutrients at this site were 1.1 to 2.3 times lower than native levels, though application depths may have been too low. The sediment yield was 134 lbs/acre/in, which is relatively high when compared to other full treatment sites. Initial results from the first year of study in 2008 are promising; however, further study is necessary to determine whether topsoil should be combined with woody material for reuse to reduce sediment yields.

Amendment Rate (2 inches versus 6 inches of compost)

Amendment rate was tested for both soil types at the Tahoma Soil Boxes. Results were conflicting between soil types:

In the granitic boxes:

- plant cover was 1.3 to 1.9 times higher at boxes with 6 inches of amendments
- nitrogen (TKN) was 2 times higher at boxes with 6 inches of amendments

In volcanic boxes:

- root density was 1.4 to 3.3 times higher in the boxes with 2 inches of amendments
- biomass was 1.4 to 1.5 times higher at the boxes with 2 inches of amendments in the first year, and similar between boxes with 2 inches and 6 inches in the subsequent years

At Heavenly Canyon, results were similar between plots with different amounts of compost.

Amendment Rates and Soil loosening Depths

The depth to which a site is loosened will affect the concentration of amendment within the loosened profile, and thus will affect the nutrient concentration in that profile. Amendment amounts should be considered in combination with soil loosening depths. It is important that the proportion of amendment to soil loosening depth be uniform and in adequate amounts. In the past, many specifications have called for a fixed amendment depth, with a soil loosening depth range of 12-18 inches. Beyond usual variation during soil loosening, a large range can result in inconsistent site performance. In general, a soil loosening depth of 12 inches is recommended, although deeper soil loosening depths with greater amendment amounts are feasible if the site conditions permit.

In 2008, the relationship between first year penetrometer depths to refusal (DTRs) and the ratio of amendment to soil loosening depth became clear. In 2008, four new (first year) sites were monitored, which provided the data to support this relationship. Penetrometer DTR is used as an index for soil density, with deeper DTRs indicating looser soil and shallower DTRs indicating denser soil. First year penetrometer DTR increases linearly with the amendment ratio (Figure 4). The amendment ratio is the amount of amendment applied to the depth of soil loosening. Typically, amendments are specified by application depth. Thus, an application depth of 4 inches of woodchips, which is then tilled to a depth of 12 inches, is an amendment ratio of 0.25. Initial recommendations for higher amendment ratios between 0.4 and 0.5 are recommended to prevent re-compaction over time. The same pattern was observed for volcanic soils four years following treatment (Figure 5). However, more data for a range of amendment types are needed to further understand the pattern measured during year four. Only three volcanic sites were monitored during year four.

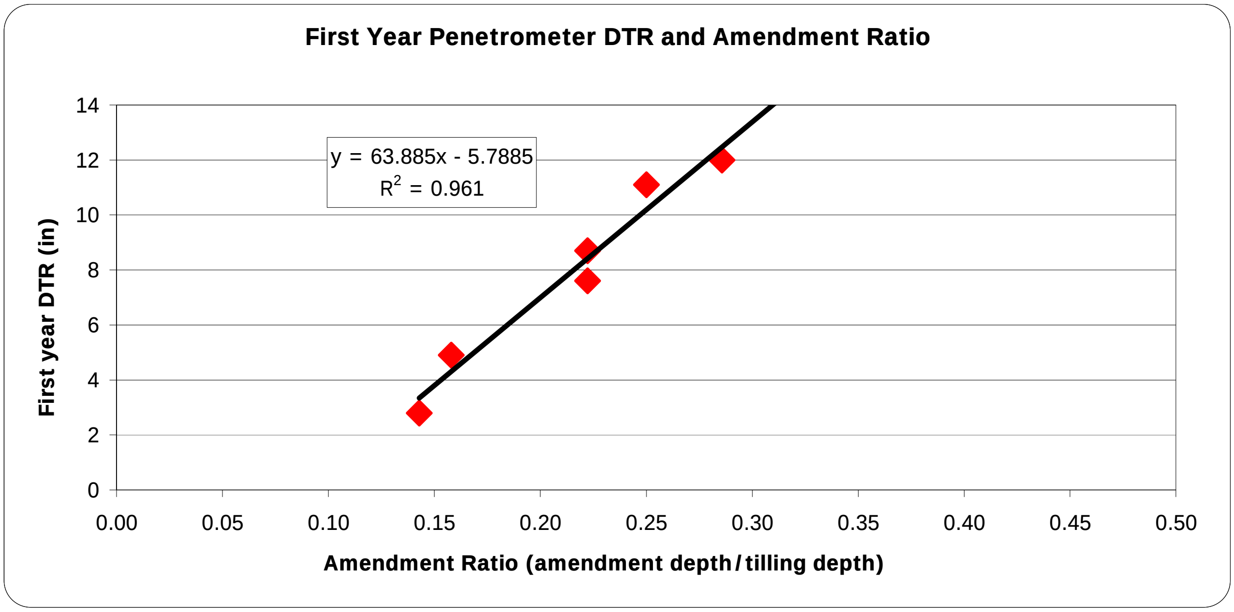


Figure 4. First Year Penetrometer DTR and Amendment Ratio. Amendment ratio is calculated by dividing the amendment application depth by the soil loosening depth. Higher amendment ratios result in deeper first year penetrometer DTRs regardless of amendment or soil type.

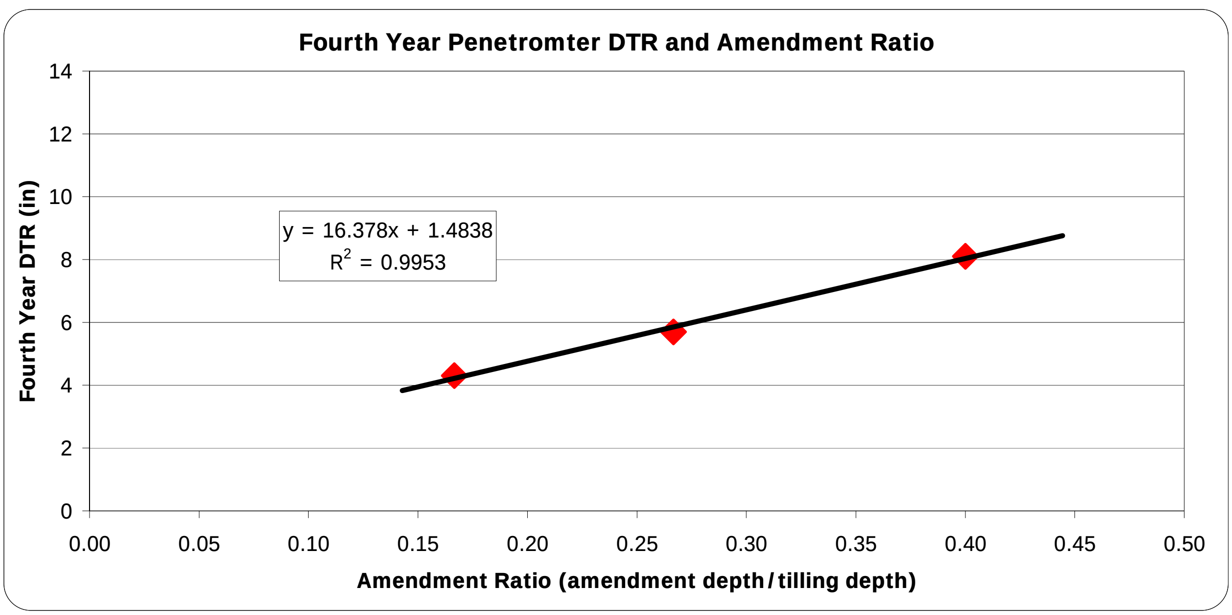


Figure 5. Fourth Year Penetrometer DTR and Amendment Ratio. Amendment ratio is calculated by dividing the amendment application depth by the soil loosening depth. Higher amendment ratios result in deeper four year penetrometer DTRs for any amendment type for volcanic soil.

Granitic Soils

For high-nutrient (within 20% of native levels) granitic soils, a 12 inch soil loosening depth with 5 inches of tub grindings is recommended. The purpose of the tub grindings is to provide greater infiltration and lower compaction as well as a long-term, slow-release nutrient source. For low-nutrient granitic soils (20% or more below native levels), a 12 inch soil loosening depth with 6 inches of amendment, composed of 4 inches of coarse overs and 2 inches of a nutrient-rich amendment (such as screened compost), is recommended. The addition of a fine, nutrient rich amendment to low-nutrient soils is necessary to achieve the re-capitalization needed for nutrient-poor granitic soils. The recommended ratio of tilled soil to amendment depth is 0.4 for high-nutrient soils, while the ratio for low-nutrient soils is 0.5.

Volcanic Soils

For high-nutrient (within 20% of native levels) volcanic soils, a 12 inch soil loosening depth with 5 inches of tub grindings are recommended (ratio of 0.4). The purpose of tub grindings is to provide greater infiltration and lower compaction. For low-nutrient volcanic soils (20% or more below native levels), a 12 inch soil loosening depth with 6 inches of amendment, composed of 5 inches of coarse overs and 1 inch of a nutrient-rich amendment (such as screened compost), is recommended (ratio of 0.5). The ratio of tilled soil to amendment depth is 0.4 for high-nutrient soils, while the ratio for low-nutrient soils is 0.5. Volcanic soils generally require fewer nutrients than granitic soils for re-capitalization; therefore, a lower proportion of the amendment depth should contain readily available nutrients, such as those found in screened compost. Volcanic soils tend to re-compact following soil loosening treatments with fine amendments. Therefore, a larger portion of the volcanic amendment should be a woody material such as tub grindings, woodchips, or coarse overs.

Organic Slow-Release Fertilizer

Plots in which full treatments with and without fertilizer were compared in 2008 are located at Heavenly Canyon (granitic) and Northstar Highlands View Road (volcanic). The Tahoma Soil Boxes (granitic and volcanic) and Northstar Lookout Mountain were compared in 2007. All plots compared the rate of 2,000 lbs/acre to no fertilizer addition, with the exception of Northstar Highlands View Road (first studied in 2008), where a rate of 1,000 lbs/acre was compared to no fertilizer addition. Based on the results of monitoring at these sites, fertilizer application is recommended over no fertilizer application. A rate of 1,000 lbs/acre, as tested at Northstar Highlands View Road, may be satisfactory for high-nutrient volcanic soils. Further recommendations will be discussed in the following sections, where different fertilizer rates were tested. Full treatment plots with fertilizer exhibited the following when compared to full treatment plots without fertilizer:

- plant growth that was up to 3.3 times higher
- seeded plant cover that was up to 3.3 times higher
- plant biomass that was up to 2 times higher
- nitrogen (TKN) that was up to 1.5 times higher
- organic matter that was up 1.8 times higher

Fertilizer Rate (2,000 versus 4,000 lbs/acre for Volcanic Soils)

Two fertilizer rates were examined at one site with volcanic soil: Brockway test plots. The lower rate of 2,000 lbs/acre) is recommended for the following reasons

- after three years, fertilizer rate did not affect foliar plant cover or the proportion of annual plant cover, the soil nitrogen (TKN) or the soil organic matter
- higher rates of fertilizer are more costly

Fertilizer Rate (2,000 versus 4,000 versus 8,000 lbs/acre for Granitic Soils)

Three fertilizer rates were studied at the full treatment Heavenly Gunbarrel granitic soil test plots, in conjunction with second season irrigation. The higher rate of 8,000 lbs/acre is recommended for low-nutrient soils with irrigation for the following reasons:

- Foliar plant cover was 7.9 times higher for 8,000 lbs/acre compared to the lower rate (2,000 lbs/acre)

A lower rate may be used of the soil is nutrient rich before treatments.

Granitic soils generally have less available nutrients per area compared to volcanic soils. Therefore a higher level of fertilizer may be required to achieve moderate plant cover.

Seed Rate

Most plots received an application of seed close to 125 lbs/acre. Three test areas, which compared two different seed rates, were studied to determine whether higher rates produced more plant cover. The three study sites on volcanic soil were: Truckee Bypass (150 versus 50 lbs/acre), Brockway test plots (150 versus 50 lbs/acre), and Northstar Highland View Road (125 versus 37.5 lbs/acre). The results varied between sites.

- At Truckee Bypass and Northstar Highlands View Road, the higher rate did not produce statistically significantly higher cover. However, there seemed to be a trend toward higher cover with the higher rate at Northstar Highlands View Road
- At Brockway test plots, the higher seed rate produced significantly higher cover by 2.6 to 5.5 times by seeded species, though the overall vegetation was low (less than 10%)

These results do not lead to a clear recommendation and further study is recommended. The rate of 125 lbs/acre, which was applied to most plots in this study, remains the recommended rate until further research is completed. Initial investigation suggests that rate effects are impacted by other variables and cannot be considered alone.

Seed Composition

The following seed composition, by percent of pounds of pure live seed (PLS) is recommended for all soil types, in areas with high to moderate solar exposures:

- 10% blue wildrye
- 36% squirreltail
- 36% mountain brome
- 8% Western needlegrass
- 5% native forbs (lupine, buckwheat, etc.)

- 5% native shrubs (bitterbrush, sagebrush, etc.)

The support for these recommendations is as follows:

- Squirreltail and mountain brome should be present in similar quantities because mountain brome will dominate in the earlier years and squirreltail will dominate over the long term (after three years)
- Blue wildrye should be present in small quantities unless monoculture seeding before the seed mix application is planned. Blue wildrye cannot compete well with other species, such as mountain brome initially or squirreltail after two or three years. At some areas, blue wildrye dominates for unknown reasons. Due to its low cost, removal from the seed mix is not recommended as dominance can be achieved in certain situations.
- The Western needlegrass recommendation is lower than the tested rates of 12-36% of the seed mix at Homewood Wedding Road because Western needlegrass is hard to obtain and has a high cost. Higher rates would be recommended if the availability increased and the cost decreased. Subsequent study will focus on varying and lower rates of Western needlegrass.

Mulch

Pine needle mulch, which was applied at all sites, was successful when applied to a depth of 2 to 3 inches and 99% cover. Higher cover by mulch has been shown to increase infiltration and decrease sediment yields in other studies.[3] The reasons for the recommendations are as follows:

- Plots with a 2 or 3 inch mulch application had mulch cover that was greater than 78% after one to six years.
- Mild disturbance can displace mulch. The effect of disturbance may not be as great with higher initial mulch application.

Only one area with tub grinding mulch was studied and only for one year, therefore pine needle mulch is recommended. More data on other mulches is necessary to make an alternate recommendation.

Plots with both 2 and 3 inches of mulch were studied and performed well, but 2 inches of mulch is recommended at this time. The additional cost of applying 3 inches of mulch may not result in large gains.

Irrigation

Different types of irrigation systems were studied for the first time in 2008. In 2007, data showed that a high pressure, landscape-style irrigation was not successful. This led to the study of low pressure systems applied only initially in 2008. Landscaping irrigation typically

[3] Schnurrenberger, C., M. Hogan and R. Arst. 2008. Upper Cutthroat Sediment Source Control Effectiveness Monitoring Project. Truckee, CA: Placer County. April 2008.

consists of regular, frequent application. The intent is to develop a robust native plant community on surface treatment sites (Caltrans EC Type D). Typically, this type of irrigation is used on compacted areas. This site condition (surface treatment, compacted soils) produces a very slow infiltration rate, thus retarding downward movement of water. Roots tend to stay in the shallow soil regions where water is plentiful.

This type of irrigation was studied at a surface treatment site and is not recommended for the following reasons:

- The irrigated site did not perform well in rainfall simulations and produced a three-year average sediment yield of 176 lbs/acre/in, compared to less than 6 lbs/acre/in of sediment at fully treated sites.
- Plant cover at the irrigated site decreased from 48 to 12% one year after the irrigation was removed because plants at the irrigated site were dependent on artificial irrigation for growth. The second year, after irrigation was removed, plant cover increased to 24%; however, the cover was dominated by yarrow, an undesirable species for erosion control because it forms a sod-like mat and sometimes prevents infiltration.
- Annual species, such as Spanish clover, were dominant during the irrigation cycle, rather than native, perennial bunchgrasses.
- The nitrogen (TKN) at the irrigated plot was lower than any other treatment plot in 2006 (790 ppm) and 2007 (785 pm), both of which are below native levels. However, two years after irrigation was removed, the TKN increased to native levels.

Although landscape-style irrigation was not studied at a full treatment site, it has been shown that the amount of water applied during landscape-style irrigation is unnecessary at full treatment sites. An alternate type of irrigation, low flow initial irrigation, tested at full treatment sites with soil loosening, has been shown to be beneficial. This type of irrigation includes initial irrigation, which consists of several cycles, usually during the season an area is treated. This approach uses three to five deep, slow applications three to four days apart and is then reduced to once per week for two to four cycles, and then either stopped or continued every other week until early fall. This type of irrigation can also be used one or two years after treatment if the site has not been previously irrigated and seeded plants are not germinating.

- At Heavenly Gunbarrel, initial irrigation was not used during the treatment season; however, it was applied during year two after treatment. After less than 5% cover in year one, the native, seeded, perennial grasses thrived after irrigation in year two and plant cover reached nearly 40% at one plot.
- At Northstar Highlands View Road, treatment was completed too late in the fall to apply irrigation during the treatment season. When plant cover was not observed during the year one growing season, the decision to apply several deep-soaking irrigation cycles was made. The irrigation produced cover at all seeded areas during year one.

Low flow, initial irrigation with water conserving heads (for example: MP rotator heads) at approximately 4 gal/min, is recommended with the following schedule:

Initial: A deep watering cycle, then two to three hour cycles to keep moisture levels high to encourage seed germination.

After germination: three times a week for two weeks to encourage plant roots to penetrate deeper into the soil.

After vegetation reaches 2-3 inches in height: every two weeks or as needed to maintain moisture at depth of 8 inches.

Late fall (October): cease irrigation.

This type of irrigation is only recommended with full soil treatment where soil loosening and organic amendments allow deep penetration of irrigation water.

This irrigation equipment and schedule is recommended for the following reasons:

- Increased plant growth was visually observed after irrigation was employed in 2008
- First-year plant growth ranged from 5 to 18%
- Visual signs of erosion (rills) were not present. Rills are commonly observed after irrigation with higher flow (landscape-style) systems (Figure 6).

Figure 6. Rills following high flow irrigation.

Section 3: Recommended Specifications

This D&D Program has supported improvement in cost and environmental effectiveness of Caltrans sediment source control treatments and has provided quantified support for the use of those treatments. While these recommendations are based on focused development, testing, and monitoring, further, ongoing testing and monitoring are necessary to continue to improve upon the current recommendations (Section 5: Information Gaps). The following is a general specification for treatment or re-treatment of highly disturbed soils and cannot be applied in all situations. Figure 7 provides guidance through the important considerations in specification creation, based on findings thus far. Appendix A lists all materials and their recommended applications. All suggested specifications are recommendations based upon current research. High-nutrient soils are defined as falling within 20% of native nutrient levels, while low-nutrient soils are defined as having nutrient levels 20% or more below native levels.

Soil loosening: 12 inches (18 inches if site conditions allow)

Amendment:

Volcanic high-nutrient soils: 5 inches of tub grindings tilled to 12 inches

Granitic high-nutrient soils: 5 inches of tub grindings tilled to 12 inches

Volcanic low-nutrient soils: 6 inches total, composed of 5 inches compost blend (75% coarse overs, 25% fines) and 1 inch of screened compost, tilled to 12 inches

Granitic low-nutrient soils: 4 inches total, composed of 5 inches compost blend (75% coarse overs, 25% fines) and 2 inches of screened compost tilled to 12 inches

Fertilizer:

Volcanic high-nutrient soils: 1,000 lbs/acre

Granitic high-nutrient soils: 2,000 lbs/acre

Volcanic low-nutrient soils: 2,000 lbs/acre

Granitic low-nutrient soils: 8,000 lbs/acre

Mulch: 2 inches of pine needle mulch

Seed**:** pounds of pure live seed (PLS) by percent:

Table 3. Recommended Seed Mix

Scientific Name	Common Name	% lbs of Pure Live Seed (PLS)
Elymus glaucus	blue wildrye	10
Elymus elymoides	squirreltail	36
Bromus carinatus	mountain brome	36
Achnatherum occidentale	Western needlegass	8
Native forbs (lupine, buckwheat)		5
Native shrubs (antelope bitterbrush, sagebrush)		5
Total		**100**

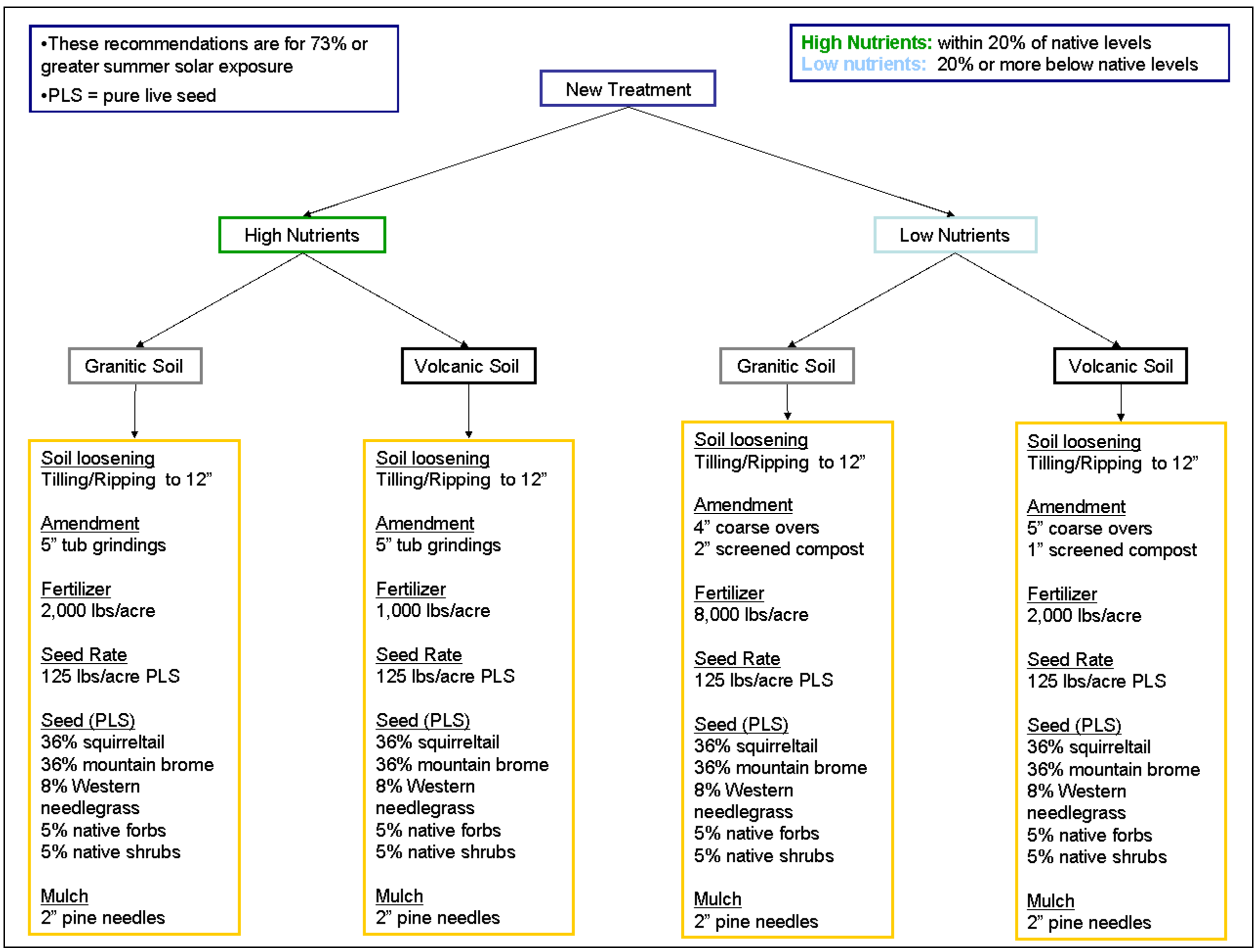


Figure 7. Specification recommendations by nutrient level and soil type (granitic or volcanic).

Section 4: Draft Success Criteria

These success criteria are intended to give Caltrans an indication of whether current treatments are successful and whether further improvements (management responses) are necessary to improve performance.

These success criteria were developed from the results of short- and long-term monitoring at over 150 plots over one to seven years. The following are suggestions are intended to be iterated with Caltrans, TRPA, and Lahontan staff. Additional focused data will help further define these criteria. Separate success criteria were developed for granitic and volcanic soils based on the differences in soil characteristics. The granitic soils were more likely to have higher infiltration rates and lower sediment yields than volcanic soils, but were also more likely to have lower soil nutrient levels when performance was equal. The success criteria for volcanic soil are in Table 4, while the success criteria for granitic soil are in Table 5. A different criterion was set for each year after monitoring. Year one is the first growing season after project completion. For instance, if a project were completed in July of 2009, year one monitoring would take place during the summer season of 2010 and would be expected to meet the year one criteria.

If the criteria are not met for a particular year, a suggested management response is listed for each measurement. It is unclear when management responses will be triggered. If one criterion is unmet, such as plant cover, should the response be mandatory? It is possible that a response may not be necessary if all other criteria are met and monitoring is conducted in the following growing to re-assess conditions. A management response may be required if the sediment criteria is not met, even if all other criteria are met. Sites may need to be examined on an individual basis to determine whether a response is necessary before more concrete regulations are established in regards to management responses.

Table 4. Success Criteria for soil with volcanic soil.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Management Response
DTR (in)	10	9	8	7	7	7	Soil loosening with incorporation of woody amendment
Sediment Yield (lbs/acre/in)	200	150	150	150	150	150	Soil loosening with incorporation of woody amendment
Total Kjeldahl Nitrogen (TKN; ppm)	1,200	1,200	1,200	1,200	1,200	1,200	Soil loosening with incorporation of amendments (include woody amendment if DTR is low or sediment yield is high)
Organic matter (%)	4	4	4	4	4	4	Soil loosening with incorporation of amendments (include woody amendment if DTR is low or sediment yield is high)
Mulch Cover (%)	90	90	85	80	80	80	Mulching
Plant Cover (%)	10	10	15	15	15	15	Check DTR, and TKN and OM. If those meet criteria, additional seeding with organic slow-release fertilizer
Visible Signs of Erosion	No visible signs of erosion including rotational failures, rilling, gullying, or other sediment transport and deposition.						Identify causes of erosion. Develop and implement site-specific management response plan
Other information	Penetrometer depths, TKN, and organic matter need to fall within 5% of listed value for criteria to be met. Sediment yields need to fall within 15% of the listed value. Plant cover needs to fall within 10% of listed value and mulch cover needs to fall within 3% of the listed value.						

Table 5. Success Criteria for soil with granitic soil.

	Year 1	Year2	Year 3	Year 4	Year 5	Year 6	Management Response
DTR (in)	10	9	8	7	7	7	Soil loosening with incorporation of woody amendment
Sediment Yield (lbs/acre/in)	50	50	50	50	50	50	Soil loosening with incorporation of woody amendment
Total Kjeldahl Nitrogen (TKN; ppm)	800	800	800	800	800	800	Soil loosening with incorporation of amendments (include woody amendment if DTR is low or sediment yield is high)
Organic Matter (%)	2	2	2	2	2	2	Soil loosening with incorporation of amendments (include woody amendment if DTR is low or sediment yield is high)
Mulch Cover (%)	90	90	85	80	80	80	Mulching
Plant Cover (%)	5	10	10	15	15	15	Check DTR, and TKN and OM. If those meet criteria, additional seeding with organic slow-release fertilizer
Visible Signs of Erosion	No visible signs of erosion including rotational failures, rilling, gullying, or other sediment transport and deposition.						Identify causes of erosion. Develop and implement site-specific management response plan
Other Information	Penetrometer depths, TKN, and organic matter need to fall within 5% of listed value for criteria to be met. Sediment yields need to fall within 15% of the listed value. Plant cover needs to fall within 10% of listed value and mulch cover needs to fall within 3% of the listed value.						

Section 5: Information Gaps

A great deal of information has been gained from the Caltrans Demonstration and Development Program. This work has filled many critical information gaps. However, as with any ecological scientific endeavor, each question that is answered is likely to lead to another question. For instance, once soil conditions are ideal for plant growth, weedy annuals such as cheatgrass become part of the plant community. Then, one must ask which types of soil amendments will offer a competitive advantage to the native grasses over cheatgrass. The topics discussed below reflect emerging, unanswered questions that, when answered, will allow projects to be more successful.

Long-term trends

Perhaps the most important information gap consists of the lack of long-term trends for both soil and vegetation treatments. Short-term vegetative growth is relatively easy to produce, but it does not necessarily predict long-term performance. To understand which treatments offer the greatest cost and environmental benefit over time, the cost of sediment reduction per pound per year must be considered.

Amendment type

Compost blends have been shown to be highly productive during this reseach. However, compost is relatively expensive; therefore, lower-cost alternatives should be developed. One cost-effective material may be aged woodchips. Green (new) woodchips have been shown to limit plant growth for at least two seasons; however, aged woodchips, composted woodchips, or woodchips with other nutrient-rich amendment and fertilizer combinations, offer an intriguing option. There is excess woody material being produced as a result of forest thinning in the Tahoe Basin. High-carbon materials such as woodchips or tub grindings are also likely to lessen the presence of cheatgrass and other weedy annuals when incorporated into the soil.

Root strength on tilled steep slopes

The ability of plant roots to provide shear strength on steep slopes is well accepted. However, there is limited data on the amount of that strength. However, as more steep slopes are treated, this information will be critical for engineering purposes and to allow vegetation treatment to substitute for compaction to achieve slope stability requirements.

Root penetration depth

In the past, plant species have been recommended for their ability to produce cover from seed. Root penetration depth, which can be related to root strength, soil stability, and erosion resistance, has not been studied in depth.

Irrigation effects

The effects of various types and cycles of irrigation are not well known. If irrigation is to be used on roadside projects, it will be critical to understand whether frequent irrigation produces shallow rooted plants and whether it encourages weedy species.

Shrub seed types and rates

More information is needed regarding which types of shrubs can be directly seeded and what type of cultural practices will enhance their growth. Seeding can be much more cost-effective than planting if seeding can be shown to produce a robust response.

Seed mixes and rates

More information is needed to address the seed rate debate. Some information is presented here. However, limited information exists regarding which seed rates produce the highest cover and affect weed growth. Also, more research is underway to determine which seed mix compositions will be most effective at sites with different soil types and solar exposures. The proper seed mix is important to optimize plant growth throughout all seasons.

Topsoil as an amendment

Topsoil can be used as amendment for restoration following large-scale excavation. This can lead to a low cost, but it is unclear how effectively it can re-capitalize the soil or if it can maintain un-compacted soil in the long term.

Hydromulch fiber and tackifier

Fiber and tackifier are widely used for roadside revegetation projects; however, their effects on erosion control, especially after the first year following treatment, are unknown.

Erosion control blankets

Further study is necessary on the use of erosion control blankets. Current research, conducted in 2008 at one site, indicates that erosion control blankets do not prevent erosion and may in fact encourage it. In areas with low solar exposure, the blanket may prevent plant growth, which is essential for erosion control on steep slopes. Further study is necessary at additional sites to determine whether the measured results at one test site are Basin-wide trends.

Native grasses solar exposure/aspect

Further study is necessary to determine how solar exposure and aspect influence native perennial plant growth and which species should be seeded for which aspects and exposures.

Biosol and seed rates

Short-term studies have been conducted to isolate either Biosol or seed rate to determine the optimal rate. Current research indicates that the two factors are interdependent and that a Biosol rate can only be recommended for the seed rate at which that study was conducted and vice versa. More study is needed to determine the relationship between Biosol and seed rates.

Mulch types and depths

Pine needles were applied at most study sites. More research is necessary to determine whether other mulches can perform as well as pine needles and whether the most performance and cost effective depths of pine needles are being applied. Tub grindings are often inexpensive and readily available, and may be a good candidate for mulch, especially in steep areas. It is unknown whether the heavier nature of tub grinding mulch could restrict sunlight and reduce seed germination.

Appendix A - Material Information

Compost Blends

When applying compost in the Lake Tahoe area, the material that will be composted should consist of 50%, by volume, indigenous forest vegetation from the Lake Tahoe Basin. The fine material should pass through a 3/8 inch screen and the coarse material (coarse overs) should be between 3/8 and 3 inches. Coarse and fine material should be separated and re-mixed in the proper proportions. Examples of frequently used of compost mixtures are below in Table 6.

Table 6. Compost Blend Examples

Blend Name	Fines Composition (%)	Coarse overs Composition (%)
Screened Compost	100	0
25% Compost Blend	25	75
Coarse overs	0	100

Tub Grindings

Tub grindings should be derived from clean, disease-free trees or tree stumps, not from construction or building materials, since paint, metal and other toxic/inorganic materials can harm soil and water quality. They should be produced by a machine capable of shredding large woody debris into pieces of uneven shapes and sizes (such as a hammer mill-type tub grinder, not a chipper). Spear lengths should range from 2 to 10 inches with the following size classifications: no greater than 25% of material less than two inches in length; at least 50% of material between two and eight inches in length; no greater than 25% of material greater than eight inches in length. More than 5% pine needles, garbage, or other non-wood shred material is not recommended. The tub grindings should be aged for at least six months prior to application, whenever possible. One year is preferable. This helps to inoculate organic acids naturally released by wood and encourage microbial growth and decomposition.

Woodchips

Woodchips should be derived from clean, disease-free trees or tree stumps, not from construction or building materials, because paint, metal and other toxic/inorganic materials can harm soil and water quality. Woodchips are produced by a standard wood chipper and are of relatively even consistency. More than 5% pine needles, garbage, or other non-wood shred material is not recommended.

Aged or "Composted" Woodchips

Aged woodchips should be derived from clean, disease-free trees or tree stumps, not from construction or building materials, because paint, metal and other toxic/inorganic materials can harm soil and water quality. Woodchips are produced by a standard wood chipper and are of relatively even consistency. More than 5% pine needles, garbage, or other non-wood shred material is not recommended. The woodchips should be aged for at least six months prior to application; however, one year or more is preferable. This helps to inoculate organic acids naturally released by wood and encourage microbial growth and decomposition.

Topsoil

Topsoil is the upper, outermost layer of soil, and usually consists of the top 2 to 8 inches of soil. Plants generally concentrate their roots in and obtain most of their nutrients from this layer. When topsoil is incorporated into the existing soil during restoration treatments, the nutrient and microbial benefits can improve soil conditions.

Fertilizer

There are a large number of organic fertilizers available, though only one (with two different N-P-K ratios) was tested in this study: Biosol. In general, fertilizer performance varies widely due to a variety of feed stocks used. A great deal of testing still needs to be done. Interim recommendations include the following: Fertilizer should be slow-release, have 100% organic content, and an N-P-K ratio of 6-1-3 or 7-2-3. Slow-release formulas minimize the nutrient leaching potential and provide nutrients in a more sustained manner, making re-applications less frequent. Biosol was tested for its release characteristics in another study and was found to release a steady rate over time. The fertilizer should hygienic and free of weed seeds.

Brockway Summit Basins Site Report

May 2009

Introduction

Monitoring results and erosion control treatment recommendations for a series of detention basins near Brockway Summit will be presented in this report (Figure 1). Data was collected in three locations: Media Filter Basin #2 (Basin #2), Hold and Release Detention Basin #5 (Basin #5), and a native reference plot. Monitoring was conducted in 2006, 2007, and 2008, but not at all areas during all years. The basin plots are located downhill of State Route (SR) 267 in Placer County, California. They are one-quarter of a mile south of Brockway Summit on the west side of the highway, approximately halfway between Kings Beach and the Northstar-at-Tahoe Resort. The Basin #2 plots are adjacent to and just north of the Tahoe Rim Trail parking area on the shoulder of SR 267 (Figure 2), while the Basin #5 plot is several hundred yards downhill of Basin #2. The native reference plot is located on the opposite side of SR 267, above the cut slope. These plots are representative of Caltrans roadside conditions in the Lake Tahoe area; therefore, monitoring results from these plots will be applicable Basin-wide and throughout the Sierra Nevada.

Figure 1. Satellite image of the Brockway Summit project area location. The project area is just north of Lake Tahoe, California.

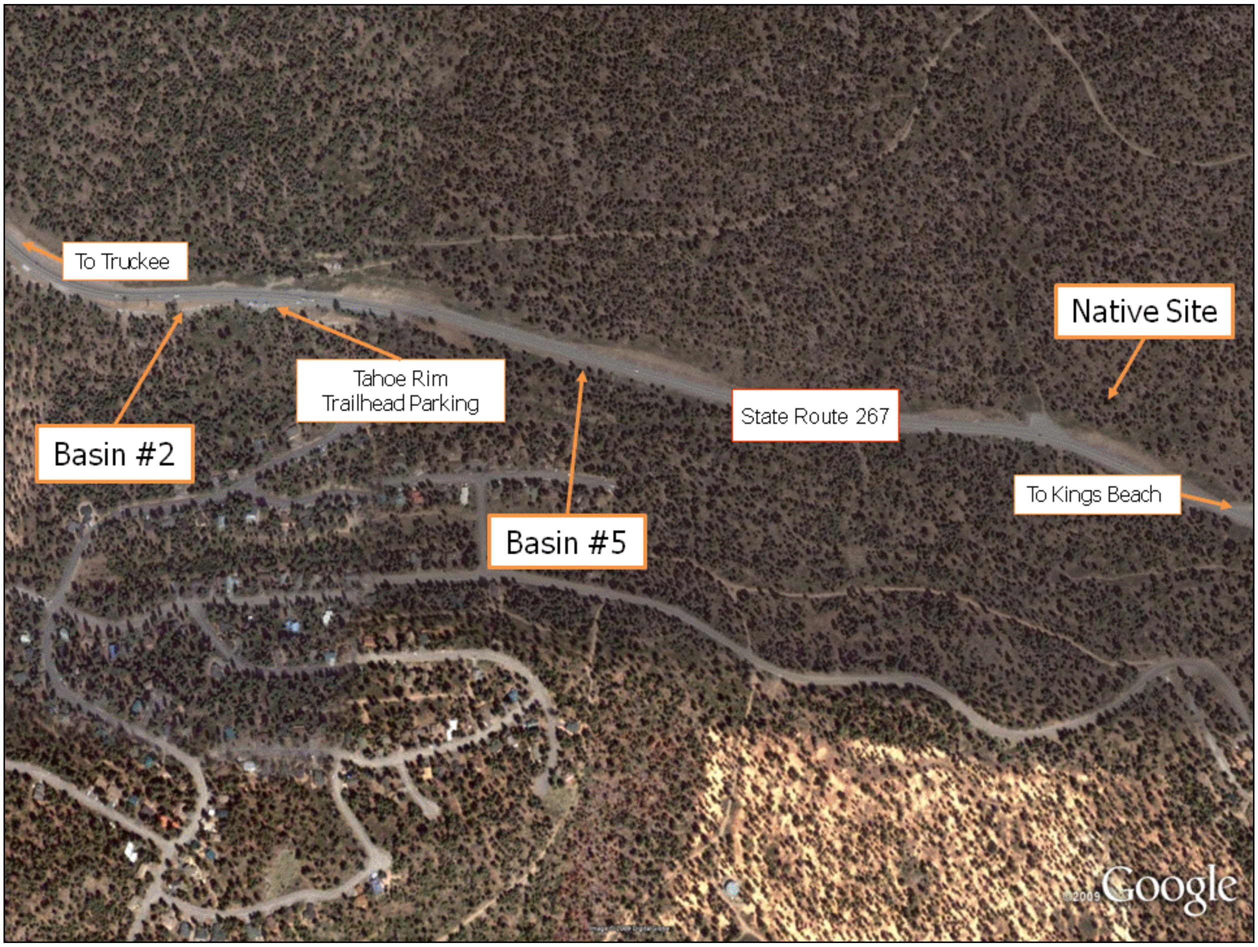


Figure 2. Satellite image showing the location of the Brockway Summit Basins #2, #5, and the native reference plot (labeled as Native Site).

Purpose

The project's monitoring objectives are outlined below. The following treatment definitions are included to aid understanding of these objectives.

Full Treatment: includes soil loosening by tilling or ripping, incorporation of an organic amendment such as compost, addition of fertilizer and native seed, and application of native mulch.

Partial Treatment: includes soil loosening by tilling or ripping, incorporation of an organic amendment such as compost, no fertilizer, addition of native seed, and application of native mulch and/or erosion control blanket (EC blanket).

Surface Treatment: does not include the incorporation of organic matter into the soil. This treatment may include surface fertilizing, seeding, or hydroseeding and is similar to Caltrans Erosion Control Type D (EC Type D).

The monitoring data was studied and analyzed to investigate:

1. the erosion control differences between full treatment and surface treatments
2. the effect of an erosion control blanket (EC blanket) on erosion control

Site Description

Basins

In 2004, a series of detention basins (including Basin #2) with road access were constructed along the down slope side of SR 267. In 2007, an addition set of basins were constructed down slope of the 2004 construction. The basins were constructed by cutting into the fill slopes from the original road construction. The test plots at each basin are located above the basin floor, on the fill slope (Figure 2).

Media Filter Basin #2 (Basin #2)

There are two test plots at Basin #2, located on a steep south-facing fill slope that is approximately 25 degrees. The site elevation is approximately 6,992 feet (2,131 m) above mean sea level (AMSL). The soil originated from volcanic parent material and is classified as a sandy loam, with approximately 13% clay, 17% silt, and 70% sand. The soil is rocky, with 35-40% coarse fragments greater than 0.5 inches (1.3 cm) in diameter. The plots have very little canopy cover and the solar exposure ranges from 87% to 96% during the summer months. Surrounding vegetation consists of a mixed conifer and shrub community. The dominant tree species include white fir (*Abies concolor*), Jeffrey pine (*Pinus jeffreyi*), and incense cedar (*Calocedrus decurrens*). In addition, some sugar pine (*Pinus lambertiana*) are present. The shrub community includes greenleaf manzanita (*Arctostaphylos patula*), tobacco brush (*Ceanothus velutinus*), huckleberry oak (*Quercus vaccinifolia*), and bitter cherry (*Prunus emarginata*).

Hold and Release Detention Basin #5 (Basin #5)

There is one test plot at Basin #5, which is located on a steep south-facing slope that is approximately 30 degrees. The site elevation is approximately 6,903 ft (2,104 m) above mean sea level (AMSL). The soil originated from volcanic parent material and rocky, with 35% coarse fragments greater than 0.5 inches (1.3 cm) in diameter. The plots have very less than 5% cover and the solar exposure ranges from 43 to 83% during the summer months. Surrounding vegetation consists of a mixed conifer and shrub community. The dominant tree species include white fir (*Abies concolor*), Jeffrey pine (*Pinus jeffreyi*), and incense cedar (*Calocedrus decurrens*). In addition, some sugar pine (*Pinus lambertiana*) are present. The shrub community includes greenleaf manzanita (*Arctostaphylos patula*), tobacco brush (*Ceanothus velutinus*), huckleberry oak (*Quercus vaccinifolia*), and bitter cherry (*Prunus emarginata*). Weeds are not a problem at this plot, which slopes away and downhill from the basin. However, weeds proliferated just above the basin at the nearby fill slope, and removal was necessary in September 2008.

Native Reference Plot

The native reference plot is located on southwest facing slope above the SR 267 cut slope. The slope angle is gentle (10 degrees) and the elevation is approximately 6,771 ft (2,063 m) AMSL. The soil parent material is volcanic in origin and has approximately 15% composition by rocks greater than 0.5 inches (1.3 cm) in diameter. The canopy cover is approximately 15% and the vegetation consists of squaw carpet (Ceanothus prostratus), greenleaf manzanita (*Arctostaphylos patula*), and huckleberry oak (*Quercus vaccinifolia*; Figure 3)

Figure 3. Brockway Summit native reference plot. Squaw carpet (*Ceanothus prostratus*), greenleaf manzanita (*Arctostaphylos patula*), and huckleberry oak (*Quercus vaccinifolia*) are the dominant species.

Treatments

Media Filter Basin #2 (Basin #2)

During the 2004 basin construction project, Basin #2 received four different treatments, two of which will be presented in this report. The two different restoration treatments included a full treatment with soil loosening (referred to as tilled plot) and a surface treatment without soil loosening (referred to as the untilled plot; Figure 4). In 2005, a failure, which was a result of a concentrated flow from SR 267, was noted and repaired. The two test areas were not located near the failure and failures have not occurred at any of monitored test plots since 2005. After treatment, utility work was conducted at an unknown location at the basins. Wheatgrass was seeded after the disturbance from the utility work. The treatments are presented in detail below and in Figure 4 and Table 3. Photos from before and after construction are shown in Figure 5, Figure 6, Figure 7, Figure 8, Figure 9, Figure 10, Figure 11, and Figure 12.

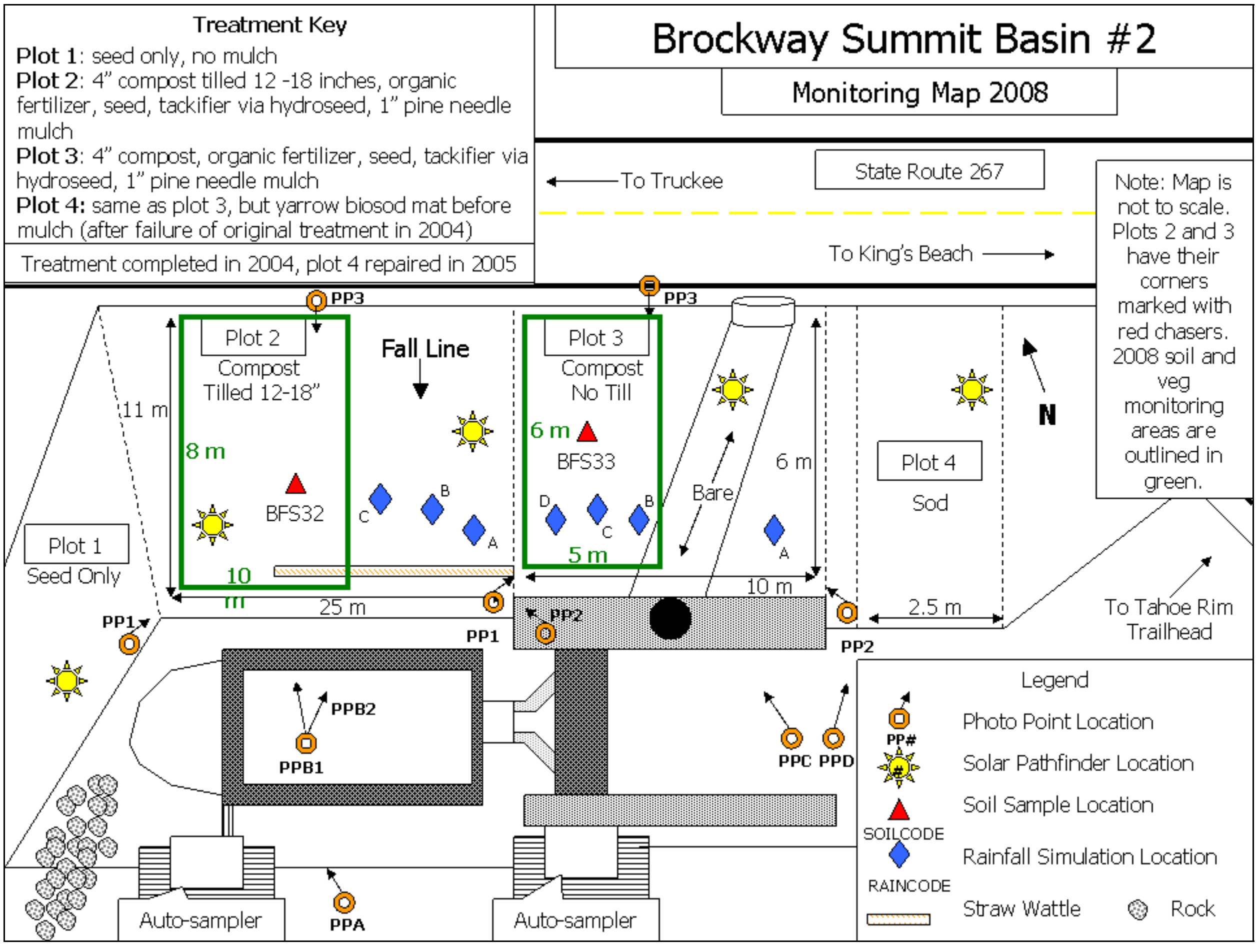


Figure 4. Map of the Brockway Summit Basin #2 with treatment key. Rainfall simulation, photos points, soil samples, and Solar Pathfinder locations are marked. Plots #1 and 4 were not monitored in 2008.

Figure 5. One of the basins, pre-treatment, 2004.

Figure 6. One of the basins, post-treatment, 2004.

Figure 7. Basin #2, plot 2, tilled treatment, 2006.

Figure 8. Basin #2, plot 3, untilled treatment, 2006.

Figure 9. Basin #2, plot 2, tilled treatment, 2007.

Figure 10. Basin #2, plot 3, untilled treatment, 2007.

Figure 11. Basin #2, plot 2, tilled treatment, 2008.

Figure 12. Basin #2, plot 3, untilled treatment, 2008.

Soil Loosening

At Basin #2, the only difference in treatment at plots 2 and 3 was soil loosening. Plot 2 was tilled 12 to 18 inches (30-46 cm) with a backhoe, while plot 3 did not receive any tilling treatments.

Amendment – Screened Compost

Approximately 4 inches (10 cm) of screened, fine compost was applied to both plots. The specified rate was 2,230 lbs/acre (2,500 kg/ha). The compost was spread on plot 2 before soil loosening or seeding occurred, and on plot 3 after seeding. Compost was defined as one of the following for this project, though actual material quality or composition was not documented:

- green material consisting of chipped, shredded, or ground vegetation; or clean processed recycled wood products
- class A, exceptional quality biosolids compost, conforming to the requirements in United States Environmental Protection Agency (EPA) regulation 40 CFR, Part 503 c
- any combination of the above green material and biosolids compost

The compost did not contain paint, petroleum products, herbicides, fungicides, or other chemical residues harmful to plant or animal life. Other deleterious material did not exceed more than 0.1% by volume. The compost was thermophilically processed for 15 days and was maintained at a minimum internal temperature of 55 C. The compost was screened at a maximum size of 0.5 inches (1.3 cm).

Biosol

Both plots were treated with Biosol organic fertilizer at a rate of 535 lbs/acre (600 kg/ha). The Biosol was applied in two steps with hydroseeding equipment. The first application was after compost incorporated at plot 2 and after compost application at plot 3. The first application included seed and 714 lbs/acre (800 kg/ha) of fiber. The second application followed the pine needle mulch application at both plots and included 714 lbs/acre of fiber and 134 lbs/acre (150 kg/ha) of stabilizing emulsion.

Seeding

The seed mix in Table 1 was applied at approximately 36 lbs/acre (40 kg/ha) at both plots, by a hydroseed application, which included 714 lbs/acre (800 kg/ha) of fiber and 134 lbs/acre (150 kg/ha) of stabilizing emulsion. This step followed compost incorporation at plot 2 and preceded compost application at plot 3. The exact seed rate is unknown because the seed mix varied from the specification and not all changes were recorded.

Table 1. Native seed mix #1 composition for plots 2 and 3 at Basin #2.

Common Name	Scientific Name	Seed Rate (lbs/acre)	% Pure Live Seed
Yarrow	*Achillea millefolium*	1.8	5
Western needlegrass	*Achnatherum occidentale*	2.7	8
Common sagebrush	*Artemisia tridentata*	0.9	3
Mountain brome	*Bromus carinatus*	8.9	25
Rabbitbrush	*Chrysothamnus nauseosus*	0.9	3
Elongated hairgrass	*Deschampsia elongata*	1.8	5
Squirreltail	*Elymus elymoides*	8.9	25
Nude buckwheat	*Eriogonum nudum*	0.9	3
Spanish lotus	*Lotus purshianus*	2.7	8
Silvery lupine	*Lupinus argenteus*	1.8	5
Green stipuled lupine	*Lupinus fulcratus*	1.8	5
Ryberg's penstomen	*Penstomen rybergii*	1.8	5
Antelope bitterbursh	*Purshia tridentata*	0.9	3
TOTALS		**35.7**	**100**

Mulch

One inch (2.5 cm) of native pine needle mulch was applied following the first hydroseeding, but before the second hydroseed application.

Hold and Release Detention Basin #5 (Basin #5)

A series of hold and release detention basins were constructed in 2007, downhill of the media filter basins constructed in 2004. The treatments are presented in detail below and in Figure 13 and Table 3. Photos from before and after construction of this are shown in Figure 14 and Figure 15. Basin #5, which was monitored for this study, will be referred to as the erosion control (EC) blanket till plot.

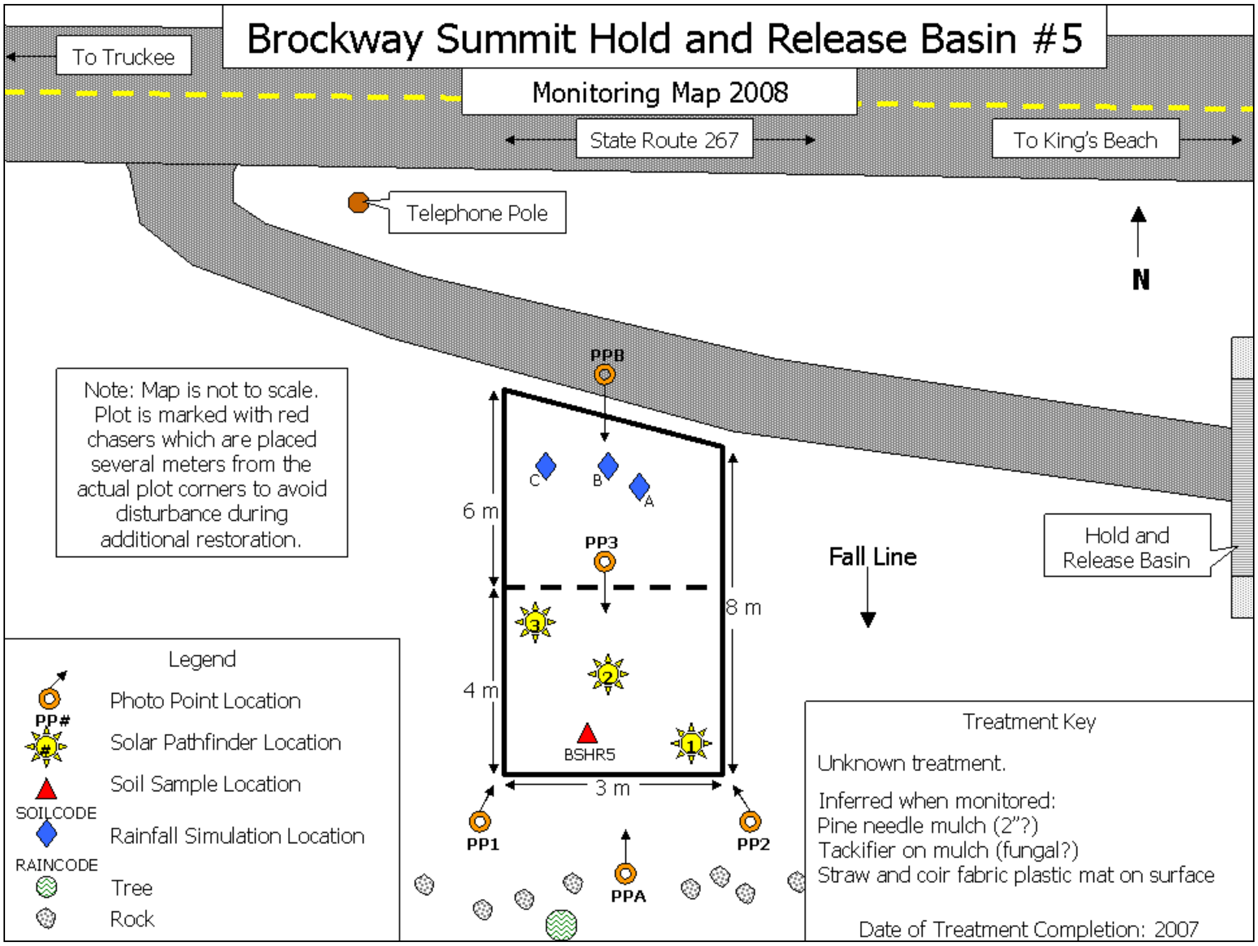


Figure 13. Map of the Brockway Summit Basin #5 with treatment key. Rainfall simulation, photos points, soil samples, and Solar Pathfinder locations are marked.

Figure 14. Basin #5, removal of erosion control blanket for monitoring purposes, 2008.

Figure 15. Basin #5, monitoring area and rainfall simulator, 2008.

Soil Loosening

The compost blend was incorporated during soil loosening. It was reputed to be evenly distributed in the top 12 to 18 inches (30-45 cm); however, it was incorporated least 22 inches (56 cm), as evidenced by penetrometer depth to refusal (DTR) readings in 2008. Penetrometer DTRs were not verified directly following treatment; however, the site specifications stated that the DTRs could not exceed 200 psi in the top 12 inches (30 cm). It is not known what type of equipment was used for the compost blend incorporation and soil loosening.

Amendment – Compost Blend

The compost blend used at Basin #5 was to be certified by United States Composting Council's Seal of Testing Assurance program. It was to be derived from any of or a mixture of the following feedstock materials, though actual material quality or composition was not documented:

- green material consisting of chipped, shredded, or ground vegetation; or clean processed recycled wood products
- biosolids
- manure
- mixed food waste

The compost blend did not contain paint, petroleum products, herbicides, fungicides or other chemical residues harmful to animal life or plant growth. The size of the material differed from that used at Basin #3 and was coarser. It will be called a compost blend in this report. When sieved, 100% of the material passed though a 3 inch (7.5 cm) sieve, 90-100% of the material passed through a 1 inch (2.5 cm) sieve, 65-100% of the material passed through a 0.8 inch (20 mm sieve), and 0-75% of the material passed through a 0.2 inch (6 mm) sieve. The maximum length was 6 inches (15 cm).

The compost blend was applied to 4 inches (10 cm) before any other erosion control measures were applied.

Fertilizer

Fertilizer was not applied at Basin #5.

Seed

Seed was applied at 46 lbs/acre (54 kg/ha) with the composition shown in Table 2. Hydroseed equipment was used to apply all seed, following incorporation of the compost blend. In addition to the seed, 714 lbs/acre (800 kg/ha) of fiber was included.

Table 2. Native seed mix #2 composition for Basin #5.

Common Name	Scientific Name	Seed Rate (lbs/acre)	% Pure Live Seed
Yarrow*	*Achillea millefolium*	1.8	3.9
Western needlegrass*	*Achnatherum occidentale*	2.7	5.8
Mountain brome*	*Bromus carinatus*	8.9	19.4
Tufted hairgrass*	*Deschampsia cespitosa*	4.5	9.7
Elongated hairgrass*	*Deschampsia elongata*	1.8	3.9
Squirreltail*	*Elymus elymoides*	8.9	19.4
Nude buckwheat*	*Eriogonum nudum*	0.9	1.9
Meadow barley*	*Hordeum brachyantherum*	8.9	19.4
Spanish lotus	*Lotus purshianus*	2.7	5.8
Brewer's lupine	*Lupinus breweri*	1.8	3.9
Gray's lupine	*Lupinus grayi*	1.8	3.9
Ryberg's penstomen*	*Penstomen rybergii*	1.8	3.9
Bittery cherry	*Prunus emarginata*	0.9	1.9
Antelope bitterbrush*	*Purshia tridentata*	0.1	0.2
Wax currant	*Ribes cereum*	0.2	0.5
Mule ears*	*Wyethia mollis*	0.2	0.5
TOTALS		**46**	**100**

*Seed was collected from the Northern Sierra or the Brockway Summit region, at an elevation of not less than 4,000 ft (1,220 m)

Mulch

After the first hydroseed application of native seed and fiber, native pine needle mulch was applied by hand to a depth of 1 inch (2.5 cm). Cover point sampling in 2008 verified that 1 inch (2.5 cm) was applied. After the mulch application, the hydroseeding equipment was used for the second time to apply a mixture of 714 lbs/acre (800 kg/ha) of fiber with 134 lbs/acre (150 kg/ha) of stabilizing emulsion.

Erosion Control Blanket

An erosion control blanket (EC blanket) was placed on top of the mulch layer after the second hydroseed application. The EC blanket was machine produced and consisted of a mat of 50-70% straw and 30-50% coconut fiber with lightweight biodegradable netting on the top and bottom. The EC blanket had a consistent thickness and the straw and fiber were evenly distributed throughout. The EC blanket was rolled out in strips of approximately 6.6 by 82 ft (2 by 25 m) and secured with wooden stakes. As observed during monitoring in 2008, the EC blanket was less than 1 inch (2.5 cm) thick.

Table 3. Treatments for Brockway Summit Basin #2 and Basin #5

Basin/Plot	Plot Name	Amendment	Soil Loosening	Biosol Rate (lbs/acre)	Seed Type	Seed Rate (lbs/acre)	Mulch
Basin #2, Plot 2	Till	4" Compost	12-18"	535	Native Seed Mix #1	35.7	1" Pine Needles
Basin #2, Plot 3	Untilled	4" Compost	None	535	Native Seed Mix #1	35.7	1" Pine Needles
Basin #5, Plot 1	EC Blanket Till	4" Compost Blend	12-18"	None	Native Seed Mix #2	46	1" Pine Needles

Monitoring Methods

Monitoring was conducted at both plots at Basin #2 in August 2006, July 2007, and September 2008. The native reference plot was monitored in 2007 only, and Basin #5 was monitoring in 2008 only. In the text, both English and metric units will be given; however, tables will contain one or the other.

Rainfall Simulation

In 2006, 2007, and 2008, rainfall simulation was conducted at the till and no till plots at Basin #2. In 2008, rainfall simulation was conducted the EC blanket till plot. Rainfall simulation was not conducted at the native plot.

The rainfall simulator "rains" on a square plot from a height of 3.3 feet (1 m; Figure 16 and Figure 17). The rate of rainfall is controlled, and runoff is collected from a trough at the bottom of a 6.5 ft^2 (0.6 $m^{2)}$ frame that has been pounded into the ground. The volume of water collected is measured and the volume of infiltration is calculated by subtracting the volume of runoff from the total volume of water applied to the plot. If runoff is not observed during the first 30 minutes (in 2006 and 2007) or the first 45 minutes (in 2008), the simulation is halted. The collected runoff samples are then analyzed for the amount of sediment they contain. This measurement is presented as the average steady state sediment yield and is hereafter referred to as "sediment yield". The steady state infiltration rate is calculated and will hereafter be referred to as "infiltration rate".

Before rainfall simulations, in the area of the frames, a cone penetrometer is used to record the depth to refusal (DTR), which is an index for soil density. The 2006 DTR pre-rainfall values were recorded at a maximum pressure of 250 psi (1,724 kPa), while the 2007 and 2008 DTR values were recorded at 350 psi (2,413 kPa). Soil moisture is measured in each frame prior to and following (2008 only) rainfall simulations. After rainfall simulation, at least three holes are dug with a trowel to determine the depth to wetting front, which shows how deeply water infiltrated into the soil. In 2007 and 2008, at least nine holes were dug to measure the depth to wetting front.

In 2006 and 2007, differing rainfall rates were applied to different plots depending on their propensity to runoff. The initial rainfall rate applied to the test plots was 2.8 in/hr (72 mm/hr). If runoff was not observed, the rainfall rate was increased to 4.7 in/hr (120 mm/hr) until runoff was observed or all the water was infiltrated. In 2008, 4.7 in/hr (120 mm/hr) was applied to all plots, so that data from the plots could be more easily compared. The initial rainfall rate of 2.8 in/hr (72 mm/hr) is more than twice the intensity of the 20 year, 1 hour 'design storm' for the local area.

Figure 16. Rainfall simulator and frame.

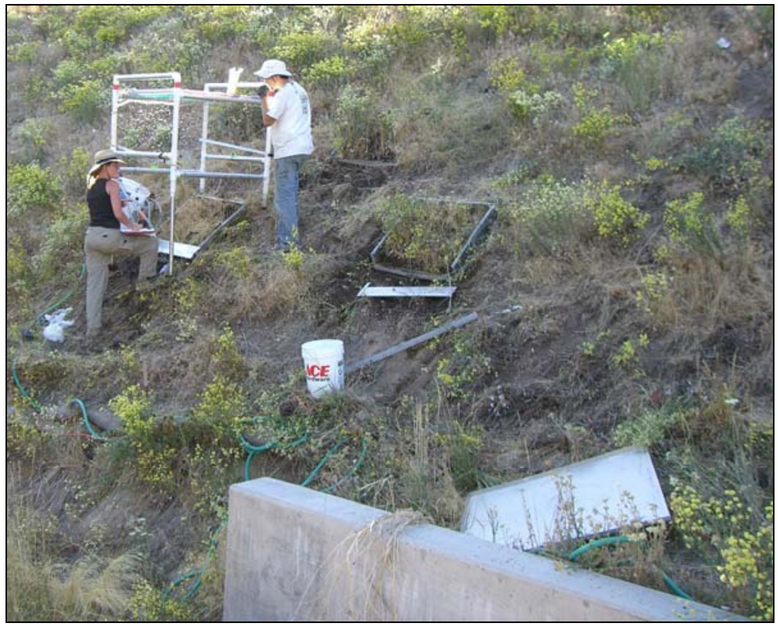


Figure 17. Rainfall simulator in use with frames at Basin #2 in 2007.

Cover

Cover monitoring was conducted at Basin #2 in 2006, 2007, and 2008, at the native reference plot in 2007, and at Basin #5 in 2008.

Cover is measured using the statistically defensible cover point method along randomly located transects.[1] The cover pointer consists of a metal rod with a laser pointer mounted 3.3 feet (1 m) high. After the rod is leveled in all directions, the button on the laser pointer is depressed, and two cover measurements are recorded (Figure 18 and Figure 19):

- the first hit cover, which is the first object intercepted starting from a height of 3.3 ft (1 m) above the ground
- the ground cover hit, which is the low-lying vegetation or soil below the first hit cover, at the ground level

The first hit cover measures the foliar cover by plants (leaves and stems). It does not measure the part of the plant rooted in the ground. The first hit vegetation is then moved aside and a ground cover hit measures the presence of litter/mulch, basal (or rooted) plant cover, rock and woody debris, and/or bare ground. Total ground cover represents any cover other than bare ground. Mulch cover is an important variable in erosion reduction through

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[1] Hogan, M. 2003. Luther Pass Monitoring Report: Plant and Soil Cover Monitoring for Evaluating Sediment Source Control Success in the Lake Tahoe Basin. Lahontan Regional Water Quality Control Board, South Lake Tahoe, CA.

sediment source control because treatments with cover by pine needle mulch have been shown to reduce sediment yields substantially.[2]

Figure 18. Cover pointer in use along transects.

Figure 19. Cover pointer rod with first hit and ground cover hit (second hit) by the laser pointer. The laser pointer hits are circled in red. The first cover hit is a native grass and the ground cover hit is pine needle mulch.

Foliar and ground level plant cover is recorded by species and then organized into cover groups based on four categories: life form (herbaceous/woody), perennial/annual, native/alien (2007 and 2008), and seeded/volunteer (2007 and 2008). Perennial herbaceous species includes seeded grasses, native grasses and forbs, and any non-native perennial species. Annual herbaceous species include native annuals such as groundsmoke (*Gayophytum sp.*) and invasive species such as cheatgrass (*Bromus tectorum*). Woody species includes any tree or shrub species, either native or introduced. Each species is then classified based on whether it is native to the Tahoe area, and whether it was seeded during treatment. Data is presented on the amount of cover by species. An ocular estimate of cover at each plot is also recorded and includes many species not hit using cover point sampling. The species lists, as well as the ocular estimates of cover by species, are presented in Appendix A.

Soil and Site Physical Conditions

Penetrometer Depth to Refusal (DTR) and Soil Moisture

In 2006, 2007, and 2008, penetrometer depth to refusal (an index for soil density) and soil moisture were measured along the same transects as the cover point data for all monitored plots. A cone penetrometer with a ½ inch diameter tip is pushed straight down into the soil until a maximum pressure of 350 pounds per square inch (2,413 kPa) is reached (Figure 20 and Figure 21). Although the rainfall frame maximum pressure was 250 psi in 2006, the

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[2] Grismer, M.E., and M.P. Hogan. 2004. Simulated rainfall evaluation of revegetation/mulch erosion control in the Lake Tahoe Basin: 1. Method assessment. Land Degradation & Development 15:573-588.

maximum pressure for DTRs measured on transects was 350 for all years, including 2006. The depth at which that pressure is reached is recorded as the depth to refusal (DTR).

Cone penetrometer DTR measurements are used as an index for soil density. Soils with higher DTRs are generally less dense than those with lower DTRs. A denser soil is less likely to allow infiltration. Rainfall simulations conducted on roadcuts in Oregon found increased infiltration rates in soils with penetrometer depths to refusal (DTRs) greater than 4 inches (10 cm).[3]

It is most informative to compare penetrometer DTR measurements collected in soils that have similar moisture levels. When soil moisture content increases, the resistance of the soil to the penetrometer decreases and DTR readings are deeper. Therefore, only penetrometer readings at the same soil moisture can be compared. A hydrometer was used to measure volumetric soil moisture content adjacent to the penetrometer readings at a depth of 4.7 inches (12 cm; Figure 22).

Figure 20. Photo of a cone penetrometer dial, showing pressure applied in pounds per square inch.

Figure 21. Photo of conducting cone penetrometer readings along transects.

Solar Exposure

In 2006, solar exposure measurements were taken at Basin #2. In 2007, measurements were taken at the native reference plot and at Basin #5 in 2008. These measurements are taken using a Solar Pathfinder (Figure 23). Since there was no change in solar obstructions, the solar pathfinder data was not collected again more than once at any area. Solar input affects evaporation rates and soil temperature, which may affect time of seed germination, germination rate, rate of plant growth, and soil microbial activity. Therefore, this is an important variable to consider when monitoring plant growth and soil development.

[3]Grismer, M.E. 2006. Simulated Rainfall Evaluation at Sunriver and Mt. Bachelor Highways, Oregon. Unpublished.

Figure 22. Conducting soil moisture readings along transects.

Figure 23. Solar pathfinder in use.

Soil Nutrient Analysis

Successful re-vegetation requires that nutrient capital be stored in the soil for release over time. Sufficient organic matter and a functioning microbial community are necessary to provide a long-term source of nitrogen for plants. Previous studies of soil nutrient levels at revegetation sites throughout the Tahoe area found that sites with high plant cover had significantly higher soil nutrients over the long-term than soils with lower plant cover levels.[4] Total Kjeldahl nitrogen and organic matter were used as indicators of soil health in this study. Total Kjeldahl nitrogen (TKN) is a measure of readily available nitrogen. Only three soil sub-samples were taken from each plot; therefore, differences in TKN and organic matter values may be a result of the variability within a plot.

In 2006, 2007, and 2008, soil samples were taken from both plots at Basin #2. In 2007, the native reference plot was sampled, and in 2008, the plot at Basin #5 was sampled. Three soil sub-samples at each plot were collected from the mineral soil beneath any mulch layer to a depth of 12 inches (30 cm; Figure 24). These sub-samples were combined and sieved to remove any material larger than 0.08 inches (2 mm) in diameter, and sent to A&L Laboratories in Modesto, California for the S3C nutrient suite (macro and micronutrients), total Kjeldahl nitrogen (TKN), and organic matter analysis.

[4]Claassen, V.P., and M.P. Hogan. 2002. Soil Nutrients Associated with Revegetation of Disturbed Sites in the Lake Tahoe Basin. Restoration Ecology 10:195-203.

Figure 24. Soil sub-sample collection.

Results and Discussion

Rainfall Simulation

Trends by Treatment Level

In 2006, 2007, and 2008, the sediment production at the untilled plot ranged from 0 to 30 lbs/acre/in (0 to 13 kg/ha/cm), while the sediment production at the tilled plot ranged from 0 to 107 lbs/acre/in (0 to 47 kg/ha/cm; Figure 25, Figure 26, and Figure 27). On average, the sediment production at the tilled plot was 3.6 times greater than that at the untilled plot (three-year average of 46 lbs/acre/in or 20 kg/ha/cm compared to a three-year average of 13 lbs/acre/in or 6 kg/ha/cm). This result is inconsistent with trends observed over three years in the Caltrans Demonstration and Development Program. Soil loosening generally results in an increase in infiltration and reduction in sediment yield. In this case, the tilled plot had penetrometer DTRs that were similar to that of the untilled plot. This indicates that any loosening gained by tilling did not persist two years following treatment. It is likely that the soil re-compacted because the screened compost amendment was not coarse enough to aid in maintaining a low density soil. Another potential reason for this re-compaction may be the heavy use of salt on that portion of the roadway. Salt reduces soil aggregation by dispersing soil structure.

It is difficult to determine why the tilled plot produced more sediment than the untilled plot, when both had similar DTRs.

In 2008, the sediment production at the EC blanket till plot was 991 lbs/acre/in (437 kg/ha/cm), which ranged from 22 to 78 times higher than at the tilled and untilled plots (Figure 27). Several different factors could have contributed to this high sediment yield. It is possible that the lack of re-compaction indicates a loose, unstructured soil. Loose, recently tilled soils sometimes produce high sediment yields directly following treatment.[5] Over time, usually one season, sediment yields decrease and infiltration rates increase as soils begin to

[5] Unpublished results from Homewood Mountain Resort and the Resort at Squaw Creek research.

aggregate. It is possible that the presence of the EC blanket did not allow this natural process to occur, especially when linked to the lack of vegetation, which also plays an important role in soil aggregation.

It is also possible that the hydroseed application of fiber and emulsifying solids created a transmissive layer that sheds water, thus increasing runoff and negatively affecting the site's ability to control erosion. Although the fiber and emulsifying solids were applied at Basin #2, these plots were not monitored one year following treatment. It is possible that any negative effects decrease over time and are not detected in the second year after treatment. It will be important to continue to monitor this site to determine the exact causes of this sediment increase.

In 2006, 2007, and 2008, infiltration rates were similar between the tilled and untilled plots and ranged from 3.7 to 4.5 in/hr (94 to 114 mm/hr; Figure 26, and Figure 27). In 2008, the infiltration rate at the EC blanket till plot was 3.8 in/hr (97 mm/hr; Figure 27).

Trends by Year

From 2006 to 2008, sediment yield exhibited an inconsistent but increasing trend over time, which was more evident at the tilled plot than the untilled plot. The sediment yield increased from 30 lbs/acre/in (13 kg/ha/cm) in 2006 to 107 lbs/acre/in (47 kg/ha/cm) in 2008 at the tilled plot (although it decreased to zero in 2007). From 2006 to 2008, sediment yield increased from zero in 2006 to 30 lbs/acre/in (13 kg/ha/cm) in 2008. These increasing sediment trends may indicate that the applied treatments are not sufficient to reduce erosion in the long term. Infiltration rates increased over time because the rate at which rainfall was applied increased from 2006 to 2008.

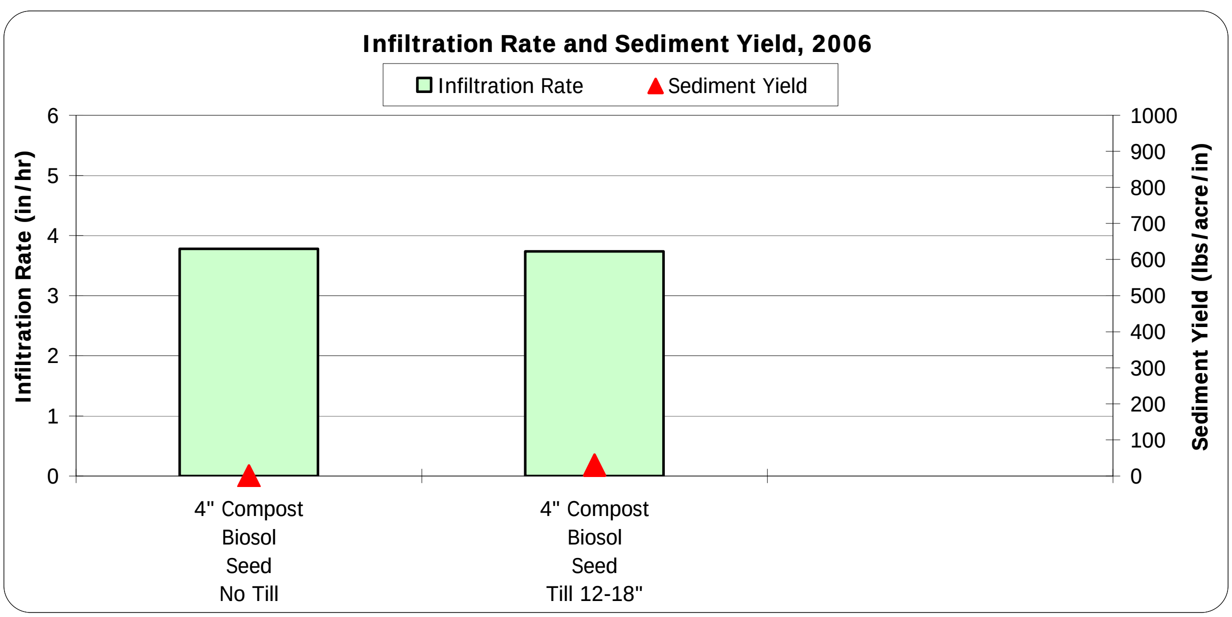

Figure 25. Infiltration Rate and Sediment Yield, 2006. No sediment was produced at the no till plot and 30 lbs/acre/in (13 kg/ha/cm) of sediment was produced at the till plot.

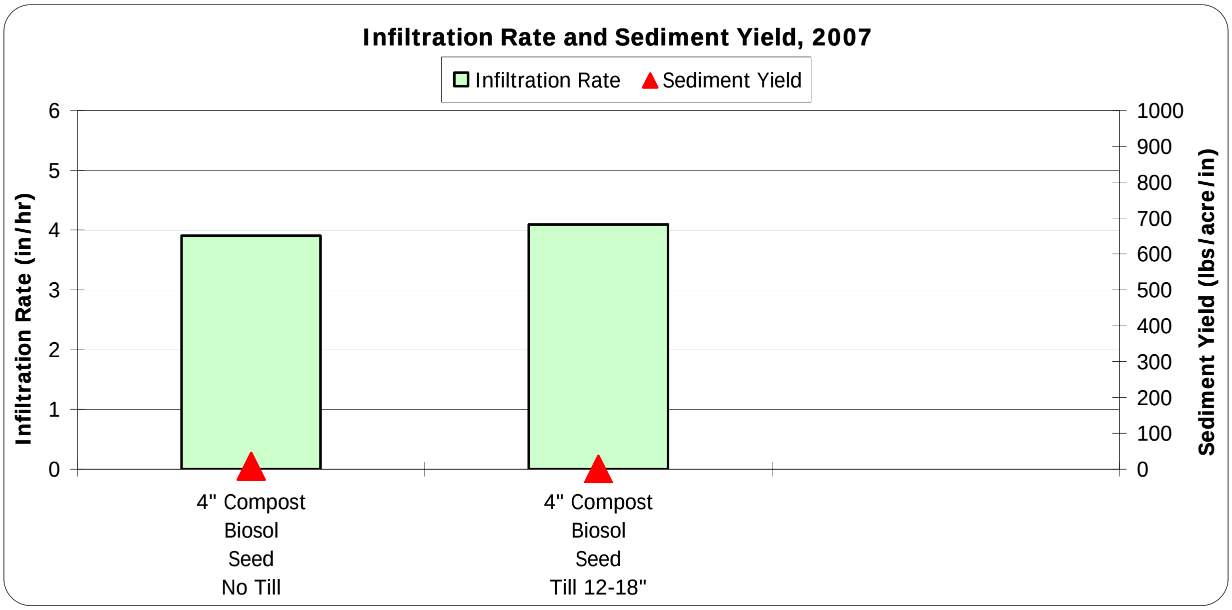

Figure 26. Infiltration Rate and Sediment Yield, 2007. Sediment yield was 7.7 lbs/acre/in (3.4 kg/ha/cm) at the no till plot and zero at the till plot.

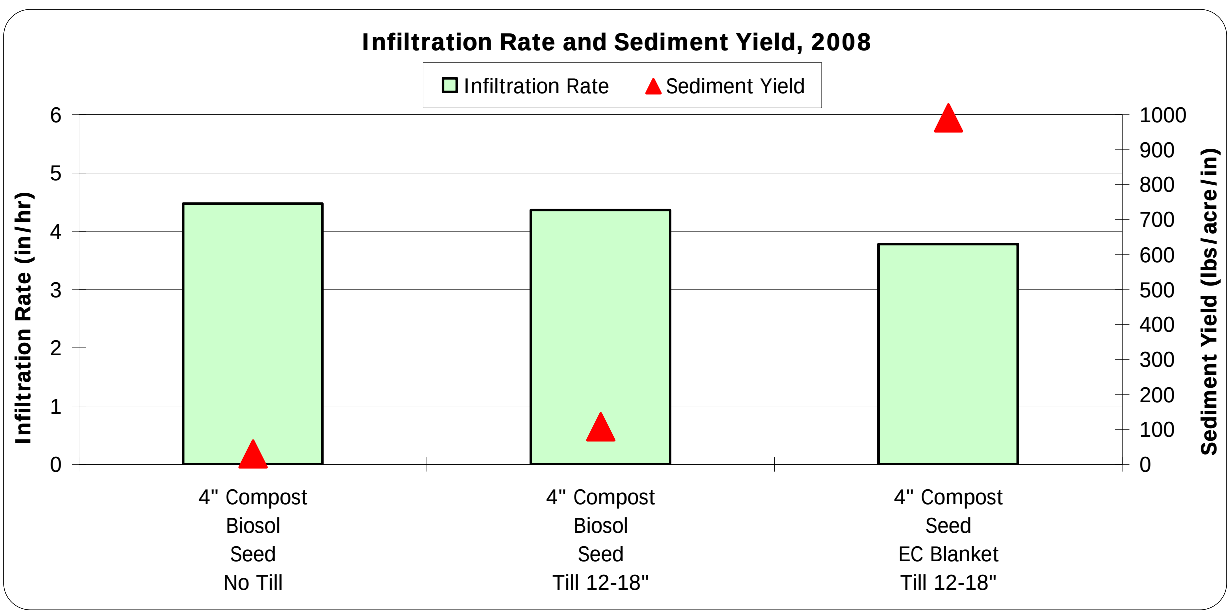

Figure 27. Infiltration Rate and Sediment Yield, 2008. The sediment yield at the no till plot was 4.7 lbs/acre/in (2.1 kg/ha/cm), compared to 190 lbs/acre/in (83.4 kg/ha/cm) at the till plot and 991 lbs/acre/in (437 kg/ha/cm) at the EC blanket till plot.

Soil Moisture

In 2006, 2007, and 2008, the soil moisture was similar for the tilled and untilled plots and ranged from 3 to 6% (Figure 28). These soil moisture levels are comparable to the soil moisture level at the native plot, 6%. In 2008, the soil moisture at the EC blanket till plot was 10%, which is slightly higher than the moisture levels at the other treatment plots and that native plot. The soil moisture levels measured at all plots are similar enough to allow comparison of penetrometer DTRs.

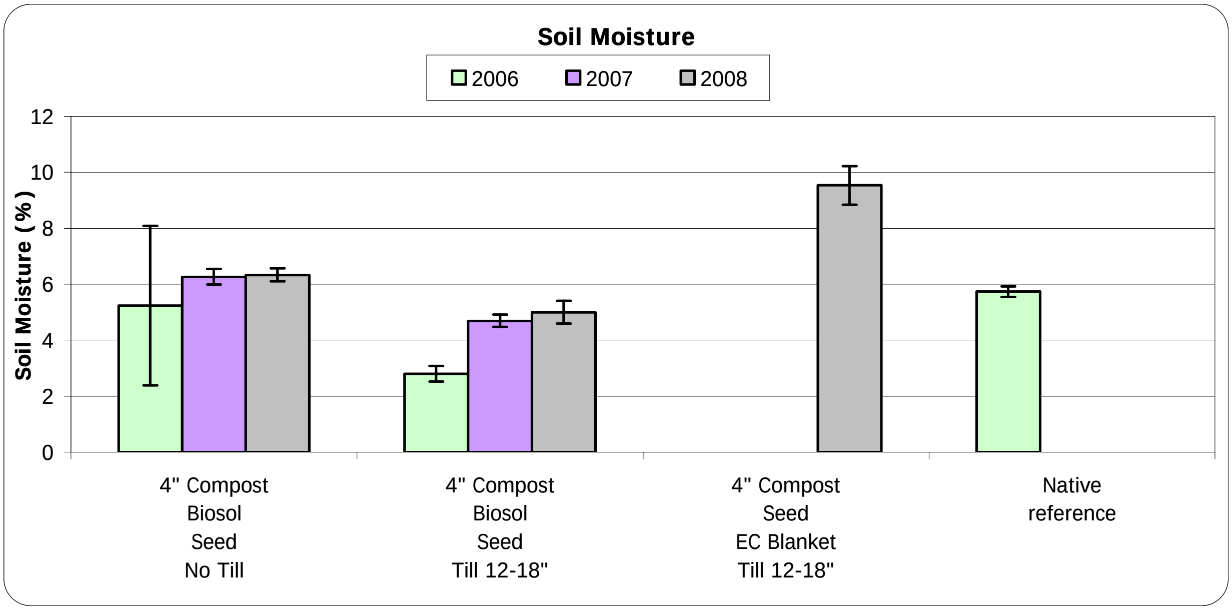

Figure 28. Soil Moisture. The soil moisture ranged from 3 to 6% at the tilled and untilled plots, and was 6% at the native plot and 10% at the EC blanket till plot.

Penetrometer Depth to Refusal (DTR)

Trends by Treatment Level

In 2006, 2007, and 2008, penetrometer DTRs were similar between the tilled and untilled plots and ranged from 5 to 8 inches (13-20 cm; Figure 29). In 2008, both plots had DTRs of 6 inches. In this case, tilling did not affect DTR two to four years following treatment.

The penetrometer DTR at the native plot (8 inches or 20 cm) ranged from 1.2 to 1.5 times higher than the three-year average DTRs at the tilled (6 inches or 15 cm) and untilled (7 inches or 18 cm) plots. The discrepancy between the DTR at the native plot and the tilled and untilled plots indicates the need for a coarser amendment to sustain deeper penetrometer DTRs after tilling.

The penetrometer DTR at the EC blanket till plot was 22 inches (56 cm), which is 3.2 to 3.9 times higher than the three-year average DTRs at the tilled (6 inches or 15 cm) and untilled (7 inches or 18 cm) plots, and 2.6 times higher than the DTR at the native plot (8 inches or 20 cm). This indicates little re-compaction occurred one year following treatment.

Trends by Year

From 2006 to 2008, penetrometer DTRs remained consistent at the tilled and untilled plots. The tilled plot, which was loosened to 12 to 18 inches (30-46 cm) re-compacted drastically between construction in 2004 and sampling in 2006. This re-compaction is most likely a result of the use of a screened compost amendment, which did not aid in maintaining loose soil over time. Unlike coarse amendments, such as tub grindings or woodchips, fine amendments allow for less pore space in soils, thereby increasing the chances for re-compaction.

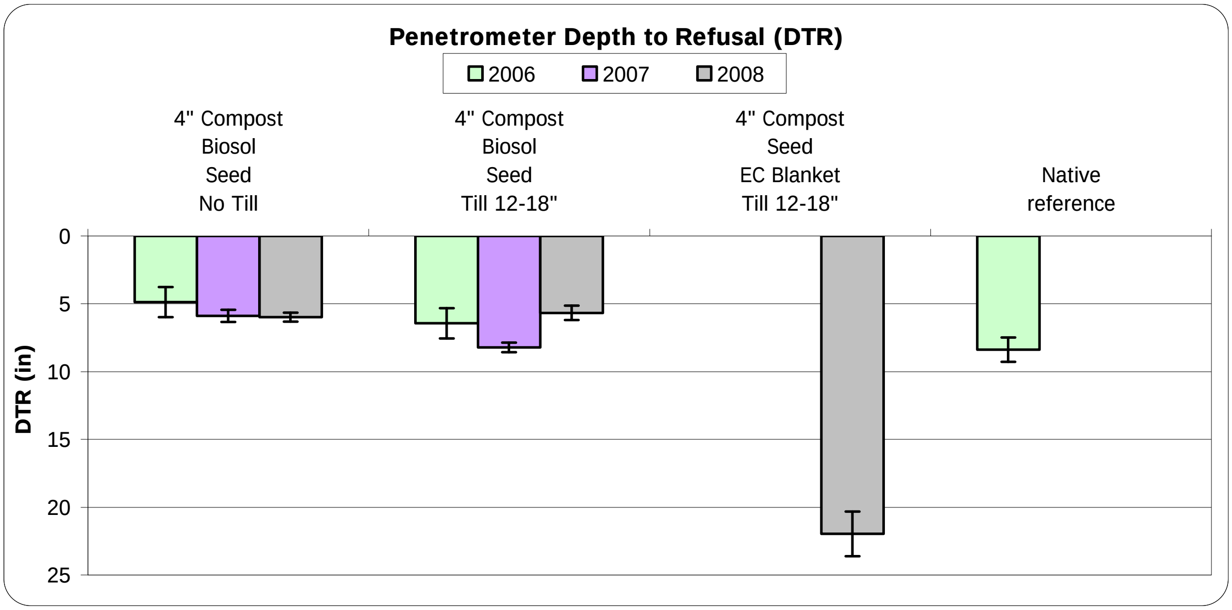

Figure 29. Penetrometer Depth to Refusal (DTR). In 2006, 2007, and 2008, penetrometer DTRs were similar between the tilled and untilled plots and ranged from 5 to 8 inches (13-20 cm). In 2008, the penetrometer DTR at the EC blanket till plot was 22 inches (56 cm). In 2006, the DTR at the native plot was 8 inches (20 cm).

Cover

Ground Cover by Mulch and Bare Soil

Trends by Treatment Level

It is unlikely that the use of tilling affected the cover by mulch. However, the use of the EC blanket may have an effect over time.

Trends by Year

In 2006, 2007, and 2008, mulch cover at the tilled and untilled plots was variable, but generally increased over time (Figure 30). In 2006, the mulch cover was 68% at both plots, and increased to 88% at the untilled plot and to 94% at the tilled plot. The increase in mulch cover over time may be related to the increase in plant cover over time (Figure 31). As plant cover increases, the plants that decompose over the winter contribute to the mulch layer as plant litter the following spring. As mulch cover increased over time, the amount of bare soil decreased.

In 2008, mulch cover at the EC blanket till plot (after blanket removal) was 87%. In 2006, the mulch cover was 52% at the native plot; however, the native plot did not have any bare soil. The remaining cover was by low-lying plants.

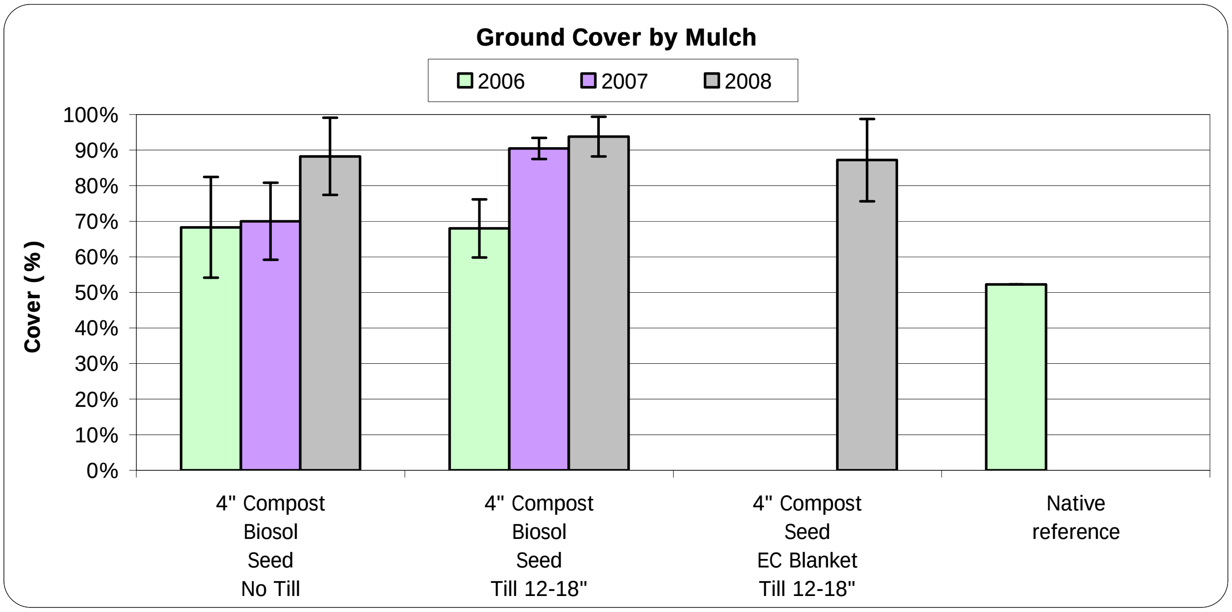

Figure 30. Ground Cover by Mulch. Mulch cover increased over time at the tilled and untilled plots.

Plant Cover and Composition

Trends by Treatment Level

Since both the tilled and untilled plots had similar plant cover and DTRs over the three-year period, it is unlikely that the use of tilling affected foliar plant cover.

Trends by Year

From 2006 to 2008, foliar plant cover at the tilled and untilled plots increased from 41% at the untilled plot and 53% at the tilled plot to near native levels (63%; Figure 31). Although the total foliar cover it similar to native levels, it is important to consider the plant composition, which does not reflect a native plant community (Figure 32, Figure 33, and Figure 34).

In 2008, plant cover was not present at the EC blanket till plot, most likely because the mulch layer, in addition to the thick blanket, did not allow sunlight to reach and germinate the seeds.

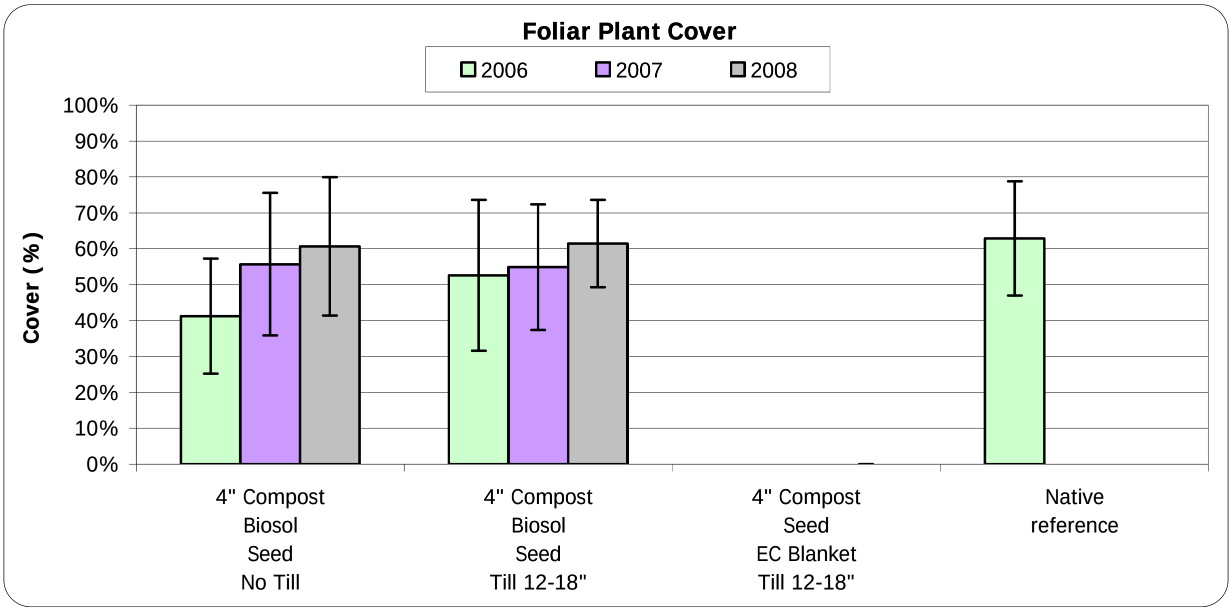

Figure 31. Foliar Plant Cover. From 2006 to 2008, foliar plant cover at the tilled and untilled plots increased from 41% at the untilled plot and 53% at the tilled plot to near native levels (63%). There was no foliar plant cover at the EC blanket till plot.

In 2006, the native species mountain brome (*Bromus carinatus*) and squirreltail (*Elymus elymoides*) dominated at the tilled and untilled plots (Figure 32). In 2007, the composition changed dramatically, with cheatgrass dominating at both plots, and very little seeded cover present (Figure 33). In 2008, cheatgrass was still the dominant species at both plots; however, other seeded species such as buckwheat and squirreltail increased (Figure 34). Decreases in cheatgrass populations have been observed over time as native plant cover increases at other sites in the Brockway Summit area. The increase in buckwheat from 2007 to 2008 may indicate a trend toward increasing native plant cover.

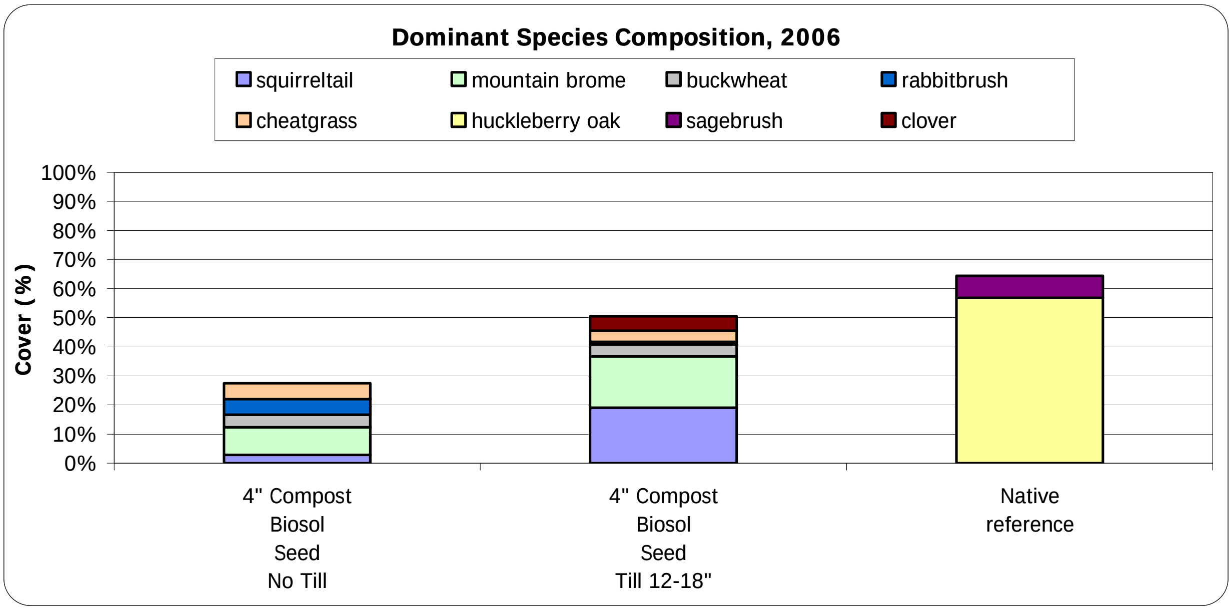

Figure 32. Dominant Species Composition, 2006. The seeded species mountain brome and squirreltail dominated at the tilled and untilled plots with compost. Huckleberry oak dominated at the native plot. Buckwheat was either sulphur flower buckwheat or nude buckwheat.

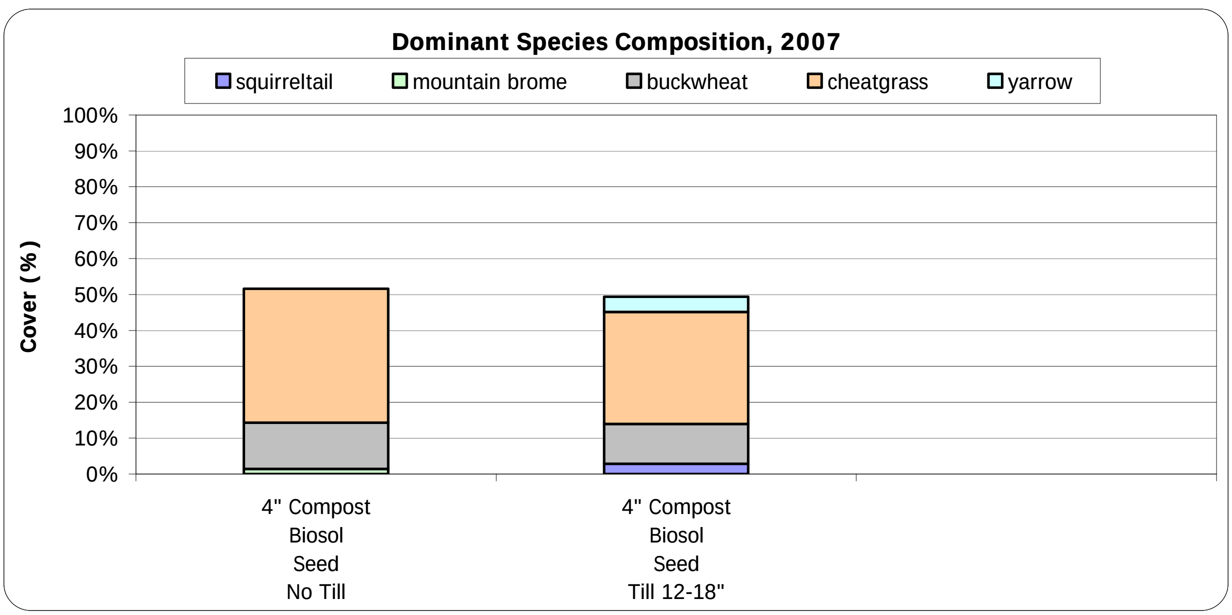

Figure 33. Dominant Species Composition, 2007. Cheatgrass dominated at both plots in 2007. Buckwheat was either sulphur flower buckwheat or nude buckwheat.

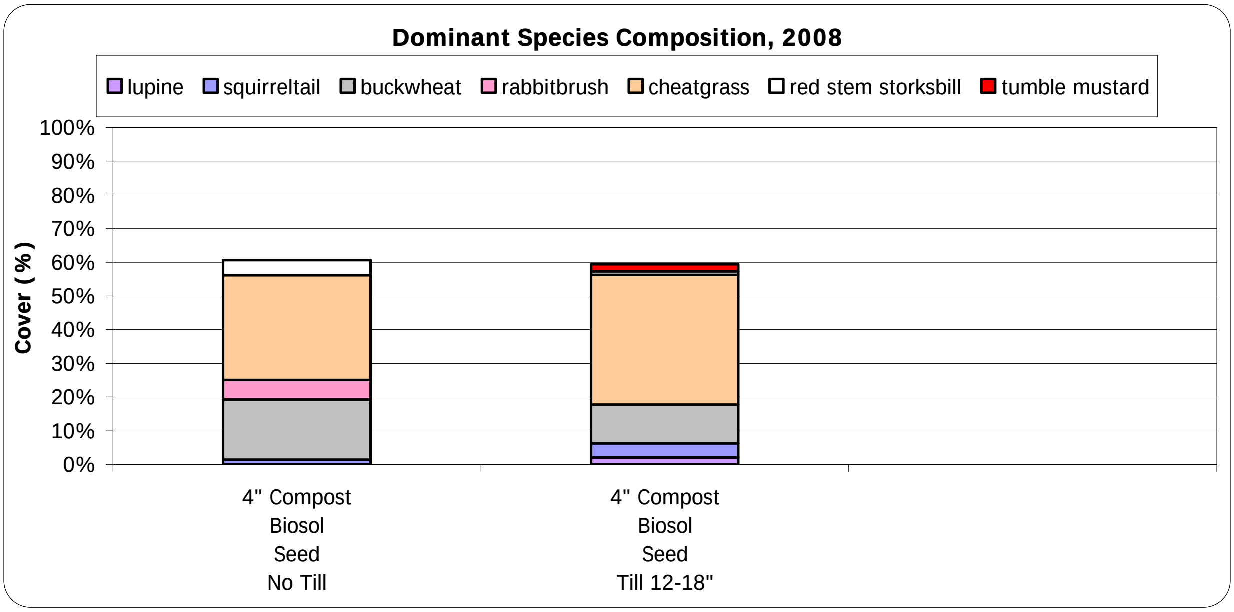

Figure 34. Dominant Species Composition, 2008. Although cheatgrass still dominated in 2008, other seeded species, such as buckwheat, increased in cover. Buckwheat was either sulphur flower buckwheat or nude buckwheat.

Soil Nutrients

Trends by Treatment Level

From 2006 to 2008, total Kjeldahl nitrogen (TKN) was similar at the tilled and untilled plots with compost. In 2006, TKN at the tilled and untilled plots ranged between 1,544 and 1,571 ppm, respectively. In 2008, TKN at the tilled and untilled plots ranged between 1,953 to 2,059 ppm, respectively (Figure 35). In 2008, the TKN at the EC blanket till plot was 1,844 ppm. In 2008, all plots had TKN levels that were higher than that of the native reference plot, 1,638 ppm. The TKN at the tilled and untilled plots was 1.2 to 1.3 times higher than at the native reference plot and the TKN at the EC blanket till plot was similar to that at the native reference plot.

In 2008, the organic matter at the tilled plot (4.2%) was 1.6 times lower than at the native reference plot and the organic matter at the untilled plot (4.0%) was 1.7 times lower than the organic matter at the native reference plot. The low organic matter levels at the tilled and untilled plots indicate that another amendment should be considered in place of or in addition to the screened compost. In 2008, the organic matter at the EC blanket till plot was 6.3%, which was similar to the organic matter level at the native reference plot, 6.6%.

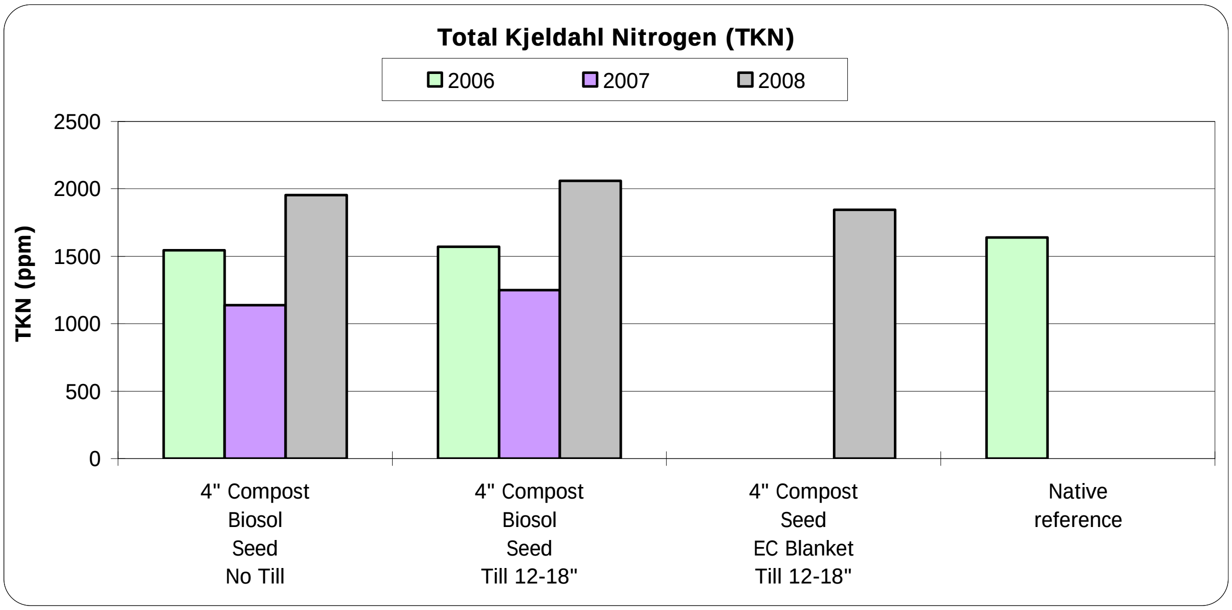

Figure 35. Total Kjeldahl Nitrogen (TKN). TKN showed an increasing trend over time. TKN levels at the treatment plots were higher by 1.2 to 1.3 times or similar to that of the native reference plot.

Trend by Year

From 2006 to 2008, both the tilled and untilled plots showed an increasing TKN trend from 1,544 and 1,571 ppm in 2006 to 1,953 to 2,059 ppm in 2008, respectively (Figure 35). A decrease in TKN was measured in 2007 at both the tilled (1,138 ppm) and untilled (1,250 ppm) compost plots. It is unclear why this decrease occurred.

From 2006 to 2008, the organic matter at the tilled and untilled treatment plots showed a slight increasing trend, from 3 to 4.2% the untilled plot and from 3.8 to 4% at the tilled plot (Figure 36). As with TKN, a decrease in organic matter was observed at the tilled and untilled plots in 2007; however, it is unclear why this decrease occurred.

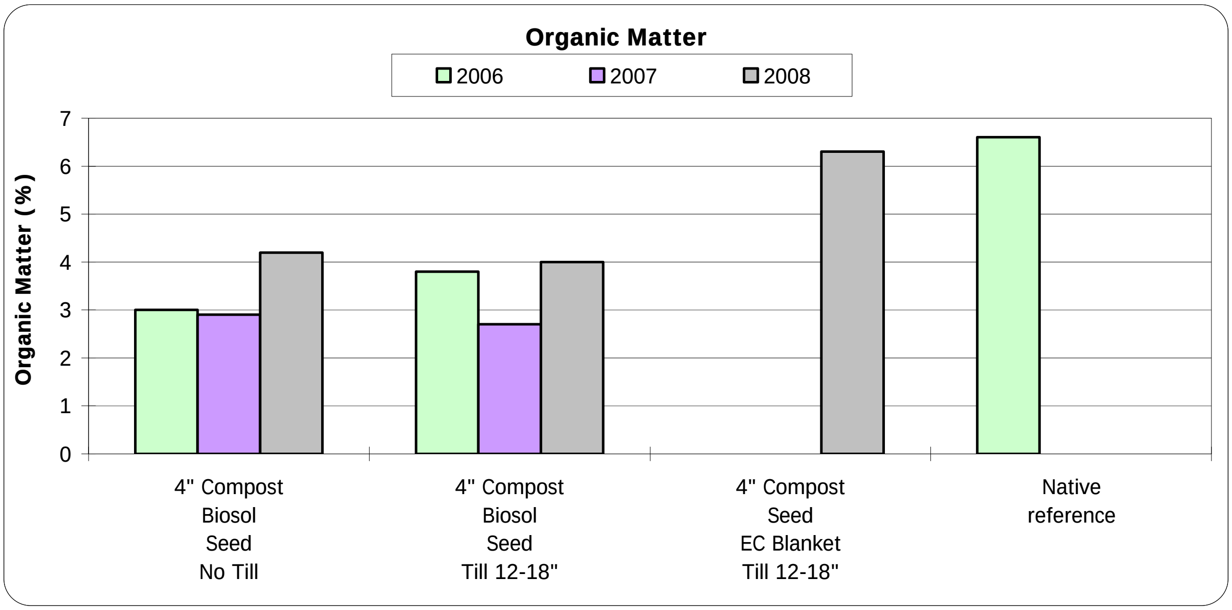

Figure 36. Organic Matter. Organic matter content ranged from 2.9 to 4.2% at the no till plot, 2.7 to 4% at the till plot, was 6.3% at the EC blanket till plots and 6.6% at the native reference plot.

Recommendations

These recommendations are for sites with rocky soils on volcanic parent material, with slope angles between 25 and 30 degrees and variable solar exposures, at approximately 6,900 feet (2,131 m) AMSL:

Tilling: 18 inches (46 cm)

Amendment: 7 inches (18 cm) compost with 25% fines and 75% coarse overs at a nitrogen equivalent of approximately 1,908 lbs/acre (2,139 kg/ha)

Biosol: 2,000 lbs/acre (2,250 kg/ha)

Seed: 46 lbs/acre (52 kg/ha) seed with the following composition:

squirreltail: 30%
mountain brome: 30%
Western needlegrass 20%
nude buckwheat 10%
native forbs and shrubs: 10%

Mulch: 2 to 3 inches (5-8 cm) of pine needles with 99% cover

Full Treatment versus Surface Treatment

Full treatment is recommended over surface treatment; however, the variation of full treatment applied at Basin #2 or Basin #5 is not recommended. At Basin #2, an increase in the depth of amendment and proportion of woody material in the amendment is recommended to prevent re-compaction after treatment. The tilled plot at Basin #2 re-compacted to the same penetrometer DTR as the untilled plot after two years and was functionally similar. Sediment production exhibited an increasing trend at Basin #2, which may be avoided by amending with a coarser organic material. In addition to possible prevention of re-compaction and reduced sediment yields, the coarser amendment may encourage native, perennial plant growth by allowing penetration of deep roots into the soil.

At Basin #5, an erosion control blanket was used in addition to the full treatment (minus fertilizer). This variation of full treatment that was not successful in sediment source control. Possible reasons for the high sediment yield include the rainwater interaction with the fiber and emulsion products, the lack of vegetation, and the lack of re-established soil structure. The EC blanket also may not allow enough sunlight to penetrate to encourage plant growth. Lack of plant growth may also be a result of the exclusion of fertilizer. Further study over the long-term is necessary to determine which components of the hydroseeding and EC blanket systems are negatively impacting sediment source control.

The surface treatment untilled plot Basin #2 exhibited low sediment yields over the three years sampled; however, the penetrometer DTRs remained low and may not be sufficient for long-term sediment source control. In addition, surface compost application can be associated to increased nutrients in runoff.

Tilling Depth

Soil loosening by tilling is recommended to 18 inches (46 cm) with 7 inches (18 cm) of amendment. Eighteen inches (46 cm) is recommended over the applied 12 to 18 inches (30-46 cm) because a consistent amendment concentration cannot be established with a variable tilling depth. The recommended amendment concentration is 39% of the total volume of soil tilled. The range of amendment concentrations generally recommended for volcanic soils is 30-40%. A concentration in the higher range is recommended for this site, since re-compaction has occurred at Basin #2.

Amendment Type and Depth

A 25% screened compost (1.75 inches or 4.4 cm) and 75% coarse overs (5.25 inches or 13.3 cm) blend is recommended at a total depth of 7 inches (18 cm). A reduction in the depth of screened compost from 4 inches to 1.75 inches (10 to 4.4 cm) may reduce the weed population, which can thrive on readily available nutrients. The addition of coarse overs may reduce soil densities over the long-term and prohibit re-compaction.

Biosol Rate

Biosol is recommended at a rate of 535 lbs/acre (600 kg/ha). This application provided sufficient nutrients for plant development two years following sampling.

Seed Mix and Rate

A native grass, forb, and shrub seed mix is recommended at a rate of 46 lbs/acre (52 kg/ha) with the following composition:

squirreltail: 30%
mountain brome: 30%

Western needlegrass 20%
nude buckwheat 10%
native forbs and shrubs: 10%

The seed mix was modified from the original mix to include a higher proportion of squirreltail and mountain brome (from 10 to 30%), which were present during the first year of sampling, then decreased. It is possible if these two species were seeded at higher rates, long-term success may ensue. Western needlegrass was also increased as it was observed throughout the Basin #2 plots. It originally composed only 5.8% of the seed mix and was increased to 20%. Nude buckwheat was increase from 1.9% of the mix to 10%. Buckwheat persisted in varying quantities during all years sampled and may establish earlier if seeded at this higher rate.

Mulch Type and Depth

Pine needle mulch is recommended at a 2 to 3 inch (5-8 cm) depth instead of the applied 1 inch (2.5 cm) because at Basin #2, two years following treatment, mulch cover decreased to less than 70% at both the till and no till plots.

Appendix A

Species list and ocular estimates for the Brockway Basin #2, 2006. Ocular estimates are presented below the plot descriptions. “T” indicates a species present in trace amounts.

Lifeform	Family	Scientific name	Common name	Annual/ Perennial	Native/ Alien	Noxious	Phenology	In seed mix? (excluding sod plot)	Seed only (%)	Basin 2 Plot 2 Tilled (%)	Basin 2 Plot 3 No till (%)	Sod (%)	Native reference (%)
Forb	Asteraceae	*Achillea millefolium*	yarrow	Perennial	Native		Flower	x	< 5	< 5	< 5	80	
Forb	Brassicaceae	*Alyssum alyssoides*	small alyssum	Annual	Alien		Seed			T			
Forb	Asteraceae	*Antennaria rosea*	pussy toes	Perennial	Native		Flower		< 5				
Forb	Brassicaceae	*Arabis sparsiflora*	elegant rockcress	Perennial	Native		Seed				T		
Forb	Chenopodiaceae	*Chenopodium album*	goosefoot	Annual	Alien		Seed				T		
Forb	Asteraceae	*Cirsium vulgare*	bull thistle	Annual	Alien	Invasive	Flower		T				
Forb	Brassicaceae	*Descurainia sophia*	herb Sophia	Annual	Alien	Invasive	Seed		T				
Forb	Polygonaceae	*Eriogonum nudum*	nude buckwheat	Perennial	Native		Flower	x	5		10 - 15		
Forb	Polygonaceae	*Eriogonum umbellatum*	sulphur flower buckwheat	Perennial	Native		Flower		10	13	25 - 30		
Forb	Geraniaceae	*Erodium cicutarium*	red stem storksbill	Annual	Alien		Seed			10	< 5		
Forb	Brassicaceae	*Hesperis matronalis*	dame's rocket	Perennial	Alien		Flower				T		
Forb	Asteraceae	*Lactuca serriola*	devil's lettuce	Annual	Alien		Veg.		T	T	T		
Forb	Brassicaceae	*Lepidium campestre*	English pepperweed	Annual	Alien	Invasive	Seed		T	< 5	< 5	T	
Forb	Fabaceae	*Lotus purshianus*	Spanish lotus	Perennial	Native		Flower	x	T	< 5	T		
Forb	Fabaceae	*Lupinus breweri*	Brewer's lupine	Perennial	Native		Seed	x	< 5	T			
Forb	Fabaceae	*Lupinus grayii*	Gray's lupine, Sierra lupine	Perennial	Native		Seed	x		T			
Forb	Fabaceae	*Medicago sativa*	alfalfa	Perennial	Alien		Flower			< 5			
Forb	Fabaceae	*Melilotus albens*	white sweetclover	Annual	Alien		Flower			5	< 5		
Forb	Scrophulariaceae	*Penstemon sp.*	penstemon	Perennial	Native		Dead	x			T		
Forb	Hydrophyllaceae	*Phacelia hastata*	silverleaf phacelia	Perennial	Native		Flower			T			
Forb	Poaceae	*Poa bulbosa*	bulbous bluegrass	Perennial	Alien		Seed			T			
Forb	Polygonaceae	*Polygonum douglasii*	Douglas knotweed	Annual	Native		Flower			T	5 - 10		
Forb	Asteraceae	*Sonchus asper*	prickly sows ear	Annual	Alien		Flower					T	
Forb	Scrophulariaceae	*Verbascum thapsus*	mullen	Annual	Native	Invasive	Flower				T		
Graminoid	Poaceae	*Achnatherum occidentale*	Western needlegrass	Perennial	Native		Seed	x	< 5				
Graminoid	Poaceae	*Elytrigia intermedia*	pubescent wheatgrass	Perennial	Alien		Seed				5		
Graminoid	Poaceae	*Bromus carinatus*	mountain brome	Perennial	Native		Flower	x	10	30	10 - 15	5 - 10	
Graminoid	Poaceae	*Bromus tectorum*	cheatgrass	Annual	Alien	Invasive	Seed			10	30	< 5	
Graminoid	Poaceae	*Deschampsia elongata*	elongated hairgrass	Perennial	Native		Seed	x	T				
Graminoid	Poaceae	*Elymus elymoides*	squirreltail	Perennial	Native		Flower	x	20	55		< 5	
Graminoid	Poaceae	*Elymus glaucus*	blue wildrye	Perennial	Native		Seed				10		
Schrub	Rhamnaceae	*Ceanothus prostratus*	Squaw carpet	Perennial	Native								X
Shrub	Brassicaceae	*Arabis holboellii*	Holboel's rockcress	Perennial	Native		Seed		T				
Shrub	Ericaceae	*Arctostaphylos patula*	greenleaf manzanita	Perennial	Native								X

Lifeform	Family	Scientific name	Common name	Annual / Perennial	Native / Alien	Noxious	Phenology	In seed mix? (excluding sod plot)	Seed only (%)	Basin 2 Plot 2 Tilled (%)	Basin 2 Plot 3 No till (%)	Sod (%)	Native reference (%)
Shrub	Asteraceae	*Artemisia tridentata*	common sagebrush	Perennial	Native			x					
Shrub	Asteraceae	*Chrysothamnus nauseosus*	rubber rabbitbrush	Perennial	Native		Flower	x			T		
Shrub	Asteraceae	*Purshia tridentata*	antelope bitterbrush	Perennial	Native			x					
Shrub	Fagaceae	*Quercus vacinifolia*	huckleberry oak	Perennial	Native		Veg.		T				X
Tree	Pinaceae	*Abies concolor*	white fir	Perennial	Native		Veg.						

Species list and ocular estimates for the Brockway basins, 2007. Ocular estimates are presented below the plot descriptions. “T” indicates a species present in trace amounts.

Lifeform	Family	Scientific name	Common name	Annual/ Perennial	Native/ Alien	Noxious	In seed mix?	Basin 2 Plot 2 Tilled (%)	Basin 2 Plot 3 No till (%)	Compost Till (Basin #1)	Compost No Till (Basin #1)
Forb	Asteraceae	*Achillea millefolium*	yarrow	Perennial	Native		x	<5	10	<5	<5
Forb	Asteraceae	*Antennaria rosea*	pussy toes	Perennial	Native			T		<5	
Forb	Brassicaceae	*Descurainia sophia*	herb Sophia	Annual	Alien	Invasive		T		T	
Forb	Polygonaceae	*Eriogonum nudum*	nude buckwheat	Perennial	Native		x		<5	5	
Forb	Polygonaceae	*Eriogonum umbellatum*	sulphur flower buckwheat	Perennial	Native			30	15	20	15
Forb	Fabaceae	*Lotus purshianus*	Spanish lotus	Perennial	Native		x				
Forb	Fabaceae	*Lupinus breweri*	Brewer's lupine	Perennial	Native		x				
Forb	Fabaceae	*Lupinus grayii*	Gray's lupine, Sierra lupine	Perennial	Native		x			<5	<5
Forb	Fabaceae	*Medicago sativa*	alfalfa	Perennial	Alien			T			
Forb	Fabaceae	*Melilotus alba*	white sweetclover	Annual	Alien	Of concern		T			
Forb	Scrophulariaceae	*Penstemon sp.*	penstemon	Perennial	Native		x				
Forb	Brassicaceae	*Sisymbrium altissimum*	tumble mustard	Annual	Alien					T	T
Graminoid	Poaceae	*Achnatherum occidentale*	Western needlegrass	Perennial	Native		x	T		T	
Graminoid	Poaceae	*Elytrigia intermedia*	pubescent wheatgrass	Perennial	Alien					T	
Graminoid	Poaceae	*Bromus carinatus*	mountain brome	Perennial	Native		x	T	<5	T	<5
Graminoid	Poaceae	*Bromus tectorum*	cheatgrass	Annual	Alien	Invasive		45	40	40	55
Graminoid	Poaceae	*Deschampsia elongata*	elongated hairgrass	Perennial	Native		x				
Graminoid	Poaceae	*Elymus elymoides*	squirrel'stail	Perennial	Native		x	10	5	10	T
Graminoid	Poaceae	*Elymus glaucus*	blue wildrye	Perennial	Native					T	<5
Shrub	Brassicaceae	*Arabis holboellii*	Holboel's rockcress	Perennial	Native			T			
Shrub	Asteraceae	*Artemisia tridentata*	common sagebrush	Perennial	Native		x				
Shrub	Asteraceae	*Chrysothamnus nauseosus*	rubber rabbitbrush	Perennial	Native		x		<5		
Shrub	Asteraceae	*Purshia tridentata*	antelope bitterbrush	Perennial	Native		x				

Of concern = not listed by the California Invasice Plant Council (CIPC), but listed for other areas with the United States Department of Agriculture (USDA)

Species list and ocular estimates for Brockway Basin #2 and #5, 2008. Ocular estimates are presented below the plot descriptions. “T” indicates a species present in trace amounts.

Lifeform	Family	Scientific name	Common name	Annual / Perennial	Native / Alien	Noxious	Phenology	In seed mix?	% in seed mix	Basin 2 Plot 2 Tilled (%)	Basin 2 Plot 3 No till (%)	In seed mix?	% in seed mix	Basin 5 EC Blanket Till (%)
Forb	Asteraceae	*Achillea millefolium*	yarrow	Perennial	Native			Yes	5	T	1	Yes	3.9	T
Forb	Asteraceae	*Antennaria rosea*	pussy toes	Perennial	Native					T				
Forb	Chenopodiaceae	*Chenopodium album*	goosefoot	Annual	Alien					T	T			
Forb	Capparaceae	*Cleome serrulata*	Rocky Mountain bee plant	Annual	Native						T			
Forb	Brassicaceae	*Descurainia sophia*	herb Sophia	Annual	Alien	Invasive				T				
Forb	Polygonaceae	*Eriogonum nudum*	nude buckwheat	Perennial	Native			Yes	3	25	10	Yes	1.9	
Forb	Geraniaceae	*Erodium cicutarium*	red stem storksbill	Annual	Alien	Invasive				T	T			T
Forb	Onagraceae	*Gayophytum sp*	goundsmoke	Annual	Native						T			
Forb	Brassicaceae	*Lepidium campestre*	English pepperweed	Annual	Alien					T	T			
Forb	Fabaceae	*Lotus purshianus*	Spanish lotus	Perennial	Native			Yes	8			Yes	5.8	
Forb	Fabaceae	*Lupinus argenteus*	silver lupine	Perennial	Native			Yes	5					
Forb	Fabaceae	*Lupinus breweri*	Brewer's lupine	Perennial	Native							Yes	3.9	
Forb	Fabaceae	*Lupinus fulcratus*	green stipuled lupine	Perennial	Native			Yes	5					
Forb	Fabaceae	*Lupinus grayi*	Gray's lupine	Perennial	Native							Yes	3.9	
Forb	Fabaceae	*Lupinus lepidus*	Culberton's lupine	Perennial	Native					T				
Forb	Scrophulariaceae	*Penstemon rydbergii*	Rydberg's penstemon	Perennial	Native			Yes	5			Yes	3.9	
Forb	Brassicaceae	*Sisymbrium altissimum*	tumble mustard	Annual	Alien					T				
Forb	Asteraceae	*Tragopogon dubius*	false salsify	Annual	Alien					T				
Forb	Asteraceae	*Wyethia mollis*	mule ears	Perennial	Native							Yes	.5	
Graminoid	Poaceae	*Achnatherum occidentale*	Western needlegrass	Perennial	Native			Yes	8	T		Yes	5.8	
Graminoid	Poaceae	*Bromus carinatus*	Mountain brome	Perennial	Native			Yes	25			Yes	19.4	
Graminoid	Poaceae	*Bromus tectorum*	cheatgrass	Annual	Alien	Invasive				40	30			
Graminoid	Poaceae	*Deschampsia cespitosa*	tufted hairgrass	Perennial	Native							Yes	9.7	
Graminoid	Poaceae	*Deschampsia elongata*	elongated hairgrass	Perennial	Native			Yes	5			Yes	3.9	
Graminoid	Poaceae	*Elymus elymoides*	squirreltail	Perennial	Native			Yes	25	1	T	Yes	19.4	T
Graminoid	Poaceae	*Elymus glaucus*	blue wildrye	Perennial	Native						T			
Graminoid	Poaceae	*Elytrigia intermedia*	intermediate wheatgrass	Perennial	Alien					T	T			
Graminoid	Poaceae	*Hordeum brachyantherum*	meadow barley	Perennial	Native							Yes	19.4	
Graminoid	Poaceae	*Hordeum vulgare*	barley	Annual	Alien					T				
Shrub	Asteraceae	*Artemisia tridentata*	common sagebrush	Perennial	Native			Yes	3					
Shrub	Asteraceae	*Chrysothamnus nauseosus*	rubber rabbitbrush	Perennial	Native			Yes	3		1			
Shrub	Rosaceae	*Prunus emarginata*	bitter cherry	Perennial	Native							Yes	1.9	
Shrub	Rosaceae	*Purshia tridentata*	antelope bitterbrush	Perennial	Native			Yes	3			Yes	.2	
Shrub	Grossulariaceae	*Ribes cereum*	wax currant	Perennial	Native							Yes	.5	
TOTAL COVER (transects)										62%	61%			0%
TOTAL COVER (ocular estimate)										69%	43%			0%

Brockway Summit Test Plots Site Report

May 2009

Introduction

This report will present monitoring results and erosion control treatment recommendations for a series of 13 test plots and a native reference plot, collectively referred to as the Brockway Summit test plots. The plots are located in Placer County on State Route (SR) 267, just north of the north shore of Lake Tahoe (Figure 1). The slope that the test plots are located on was treated in 1998 as part of a Caltrans erosion control project and the test plots were constructed in 2005 and monitored in 2006, 2007, and 2008 (Figure 2). These plots are representative of Caltrans roadside conditions in the Lake Tahoe area; therefore, the monitoring results from these plots will be applicable Basin-wide and throughout the Sierra Nevada.

Figure 1. Satellite map of the Brockway Summit project area location. The project area is just north of Lake Tahoe in Placer County.

Figure 2. Satellite map of the plot locations in the Brockway Summit area: the test plots and the native reference plot.

Purpose

The project's monitoring objectives are outlined below. The following treatment definitions are included to aid understanding of these objectives.

Full Treatment: includes soil loosening by tilling or by hand, incorporation of an organic amendment such as compost blend or tub grindings, addition of fertilizer and native seed, and application of native mulch.

Surface Treatment: does not include soil loosening or the incorporation of organic matter into the soil. This treatment may include surface fertilizing, seeding, or hydroseeding and is similar to Caltrans Erosion Control Type D (EC Type D).

The monitoring data was studied and analyzed to investigate:

1. the erosion control differences between full treatment and surface treatment plots

2. the effect of hand tilling to 9 inches (15 cm) compared to machine tilling to 18 inches (46 cm) on infiltration, sediment yield, penetrometer depth to refusal (DTR), and plant cover
3. the effect of the 25% compost blend, tub grindings, and a mix of the 25% compost blend and tub grindings as amendments on infiltration, sediment yield, penetrometer DTR, plant cover, and soil nutrient status
4. the effect of different fertilizer (Biosol) rates on soil nutrient status and plant cover
5. the effect of different seed rates on plant cover

Site Description

Test Plots

The test plots are located at an elevation of 6,900 feet (2,125 m) above mean sea level (AMSL), and they face west to southwest. The average slope is 28 degrees and the soil is shallow, highly consolidated, and derived from volcanic parent material. Surrounding soils are classified as Umpa, Jabu, Tahoma, and Fugawee, though the existing substrate shows little resemblance to mature surrounding soils. Soil testing conducted in 2007 classified the soil as a sandy loam with 72% sand, 12-16% silt, and 11-15% clay. The canopy cover is zero and the solar exposure is 98% in August.

The dominant plants in the plots are and buckwheat (*Eriogonum* sp.) and cheatgrass (*Bromus tectorum*). Surrounding vegetation consists of a mixed conifer shrub community. The dominant trees are white fir (*Abies concolor*), Jeffrey pine (*Pinus jefferyi*), incense cedar (*Calocedrus decurrens*), and sugar pine (*Pinus lambertiana*). The shrub community is dominated by green leaf manzanita (*Arctostaphylos patula*), *Ceanothus* species, huckleberry oak (*Quercus vaccinifolia*), and bitter cherry (*Prunus emarginata*).

Native Reference Plot

The native reference plot is located uphill of the test plots at an approximate elevation of 7,000 feet AMSL and a southwest aspect. The slope angle, 10 degrees, is gentler than that of the test plots. The soil is derived from volcanic parent material and is classified as Umpa, Jabu, Tahoma, and Fugawee. The canopy cover is approximately 15% and the solar exposure in August ranges between 53 and 82%, depending on canopy cover.

The vegetation in the plots consists of green leaf manzanita (*Arctostaphylos patula*), huckleberry oak (*Quercus vaccinifolia*), and squaw carpet (*Ceanothus prostrates*). The surrounding vegetation is the same as described for the test plots.

Treatments

1998

The slopes surrounding SR 267 were cut and graded during the installation of SR 267. In 1998, these slopes were laid back to reduce the over-steepened slope angle. After re-grading, a surface treatment was applied that included an application of 0.25 inches (0.63 cm) of compost, organic fertilizer (Biosol), and seed. A 0.5 inch (1.3 cm) layer of pine needles was used for mulch. This treatment was applied to plot BC, which is one of the 13 Brockway Summit test plots (Figure 3 and Table 1).

2005 Test Plot Construction

In 2005, 12 full treatment test plots, in addition to the one existing plot (BC), were constructed in an area that was treated in 1998 (Figure 3). Each plot is 10 by 10 ft (3 by 3 m) with a buffer of 3.3 ft (1 m) between plots. Detailed treatment information is presented below and in Table 1 and photos are shown in Figure 4, Figure 5, Figure 6, Figure 7, and Figure 8.

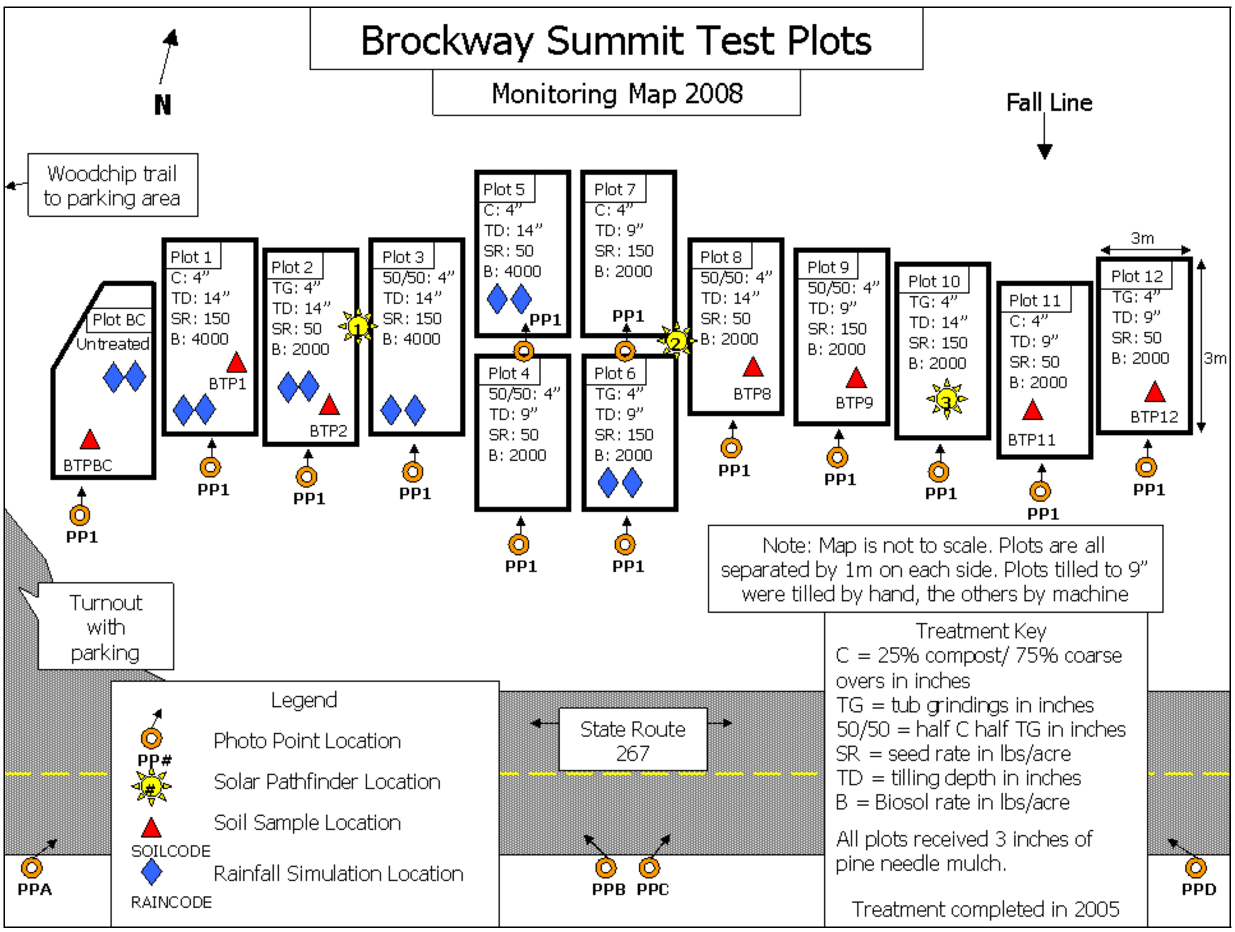

Figure 3. Layout and 2008 monitoring locations for Brockway Summit test plots.

Table 1. Treatments for plots 1-12 in 2005 and plot BC in 1998.

Plot	Tilling depth (in)	Tilling method	Biosol (lbs/acre)	25% compost blend (in)	Tub grindings (in)	25% compost blend + tub grindings (in)	Seed rate (lbs/acre)	Pine needle mulch (in)
1	14	Backhoe	4,000	4			150	3
2	14	Backhoe	2,000		4		50	3
3	14	Backhoe	4,000			4	150	3
4	9	Hand Till	2,000			4	50	3
5	14	Backhoe	4,000	4			50	3
6	9	Hand Till	2,000		4		150	3
7	9	Hand Till	2,000	4			150	3
8	14	Backhoe	2,000			4	50	3
9	9	Hand Till	2,000			4	150	3
10	14	Backhoe	2,000		4		150	3
11	9	Hand Till	2,000	4			50	3
12	9	Hand Till	2,000		4		50	3
BC			unknown	0.25 (surface application)			unknown	0.5

Figure 4. The Brockway Summit test plots in 2006 (top), 2007 (middle), and 2008 (bottom). Cheatgrass decreased over time.

Figure 5. Plot 4, hand tilled to 9 inches with 50/50 mix of 25% compost blend and tub grindings, July 2007. Cover by cheatgrass is 49%, as measured by cover point.

Figure 6. Plot 4, hand tilled to 9 inches with 50/50 mix of 25% compost blend and tub grindings, August 2008. Cover by cheatgrass decreased by 8 times to 6%, as measured by cover point.

Figure 7. Plot 11, hand tilled to 9 inches with 25% compost blend, July 2007. Cheatgrass cover is 42% as measured by cover point.

Figure 8. Plot 11, hand tilled to 9 inches with 25% compost blend, August 2008. Cheatgrass cover decreased by 5 times to 8%, as measured by cover point.

Soil Loosening

Test plots 1-12 were either tilled by hand with picks to a depth of 9 inches (23 cm) or tilled using a mini-excavator to a depth of 14 inches (36 cm; Figure 9 and Figure 10). During tilling, tub grindings and/or the 25% compost blend were incorporated into the soil. The soil was not loosened at plot BC.

Amendments

The 25% compost blend, tub grindings, or a fifty-fifty mix of the 25% compost blend and tub grindings was spread evenly across the surface of plots 1-12 to a depth of 4 inches (10 cm). Both amendments are described in detail below.

Tub Grindings

Type 1 tub grindings were obtained from the local landfill site and are composed of only raw trees, not processed construction wood. Type 1 tub grindings often include root material with attached soil and often posses more nutrients than woodchips. Tug grindings have a high surface area and are longer, narrower, and coarser than woodchips. The tub grindings were spread to a depth of 4 inches (10 cm) on plots 2, 6, 10, and 12, which provided an approximate nitrogen content of 190 lbs/acre (210 kg/ha).

25% Compost Blend

Integrated Tahoe Blend 25% was obtained from Full Circle Compost in Minden, Nevada. It will be referred to as the 25% compost blend in this report. This blend contains 25% humus fines of 3/8 inch (1 cm) or smaller and 75% compost wood overs. Wood overs (referred to in this report as coarse overs) are the woody material remaining after the composting process that do not pass through a 3/8 inch diameter screen, and range in size from 3/8 of an inch to 3 inches (1-7.6 cm). The Integrated Tahoe Blend 25% was spread to a depth of 4 inches (10 cm) on plots 1, 5, 7, and 11, which provided a nitrogen equivalent of approximately 2,500 lbs/acre (2,800 kg/ha). Screened compost from an unknown source was applied to plot BC during treatment in 1998.

Tub Grindings and 25% Compost Blend (50/50)

Tub grindings and the 25% compost blend were mixed in equal proportions and applied at a depth of 4 inches (10 cm) on plots 3, 4, 8, and 9. This mixture provided approximately 1,350 lbs/acre (1,520 kg/ha) of nitrogen equivalent.

Figure 9. Tilling by mini excavator to 18 inches.

Figure 10. Hand tilling to 9 inches by the CCCs.

Fertilizer

Following the incorporation of amendments at the full treatment plots, Biosol, a slow release fertilizer, was applied and raked approximately 1 inch (2.5 cm) into the soil at a rate of either 2,000 lbs/acre (2,241 kg/ha) or 4,000 lbs/acre (4,483 kg/ha). Plots 1, 3, and 5 received 4,000 lbs/acre (4,483 kg/ha) and plots 2, 4, and 6-12 received 2,000 lbs/acre (2,241 kg/ha; Table 1 and Figure 3). The type and rate of fertilizer applied at plot BC is unknown.

Seeding

At the plots 1-12, suitable native perennial grasses, forbs, and shrubs were seeded at a rate of either 50 lbs/acre (56 kg/ha) or 150 lbs/acre (168 kg/ha). The lower seed rate was applied at plots 2, 4, 5, 8, 11, and 12 while the higher seed rate was applied at plots 1, 3, 6, 7, 9, and 10 (Table 2). Seed rate and type are unknown for plot BC. The seed was raked into the soil surface to 0.25 inches (0.6 cm) to ensure contact.

Table 2. Grass, forb, and shrub seed mix for plots 1-12.

Common Name	Scientific Name	Pure Live Seed (%)
Yarrow	*Achillea millefolium*	5%
Western needlegrass	*Achnatherum occidentale*	16%
Mountain brome	*Bromus carinatus*	24%
Elongated hairgrass	*Deschampsia elongate*	5%
Blue wildrye (Stanislaus 5000)	*Elymus glaucus*	24%
Nude buckwheat	*Eriogonum nudum*	5%
Spanish lotus	*Lotus purshianus*	7%
Silver lupine	*Lupinus argenteus*	5%
Green stipuled lupine	*Lupinus fulcratus*	5%
Antelope bitterbrush	*Purshia tridentata*	5%

Mulch

Pine needle mulch was spread evenly by hand to achieve a depth 3 inches (8 cm) on all full treatment test plots (1-12). Plot BC received 0.5 inches (1.3 cm) of pine needle mulch (Table 2).

Monitoring Methods

The Brockway test plots were monitored in 2006, 2007, and 2008. In the text, both English and metric units will be given; however, tables will contain one or the other.

Rainfall Simulation

In 2006, rainfall simulation was conducted at the untreated plot (BC) and test plots 1, 2, and 3. In 2007, rainfall simulation was conducted on test plots 1, 2, 3, 5, and 6. In 2008, rainfall simulation was conducted at plots BC, 1, 2, 3, 5 and 6 (Figure 3).

The rainfall simulator "rains" on a square plot from a height of 3.3 feet (1 m; Figure 11 and Figure 12). The rate of rainfall is controlled, and runoff is collected from a trough at the bottom of a 6.5 ft^2 (0.6 m^2) frame that has been pounded into the ground. The volume of water collected is measured and the volume of infiltration is calculated by subtracting the volume of runoff from the total volume of water applied to the plot. If runoff was not observed during the first 30 minutes (in 2006 and 2007), or the first 45 minutes (in 2008), the simulation is halted. The collected runoff samples are then analyzed for the amount of sediment they contain. This measurement is presented as the average steady state sediment yield and is hereafter referred to as "sediment yield". The average steady state infiltration rate is then calculated and will hereafter be referred to as "infiltration rate".

A cone penetrometer is used to record the depth to refusal (DTR), which is an index for soil density, in the area of the frame before rainfall simulation. The 2006 DTR pre-rainfall values were recorded at a maximum pressure of 250 psi (1,724 kPa), while the 2007 and 2008 DTR values were recorded at 350 psi (2,413 kPa).

Soil moisture is measured in each frame prior and following (2008 only) rainfall simulations. After rainfall simulation, at least three holes are dug with a trowel to determine the depth to the wetting front, which shows how deeply the water infiltrated into the soil. In 2007 and 2008, at least nine holes were dug to measure the depth to wetting.

In 2006 and 2007, the rainfall rates applied to the plots were based on their propensity to runoff (3.8 or 4.7 in/hr or 9.6 or 120 mm/hr). In 2008, the only rate applied was 4.7 in/hr (120 mm/hr). All rates are in excess of the 20-year, one hour 'design storm' rate of 0.7 to 1.0 in/hr (18 to 25 mm/hr) for the Truckee-Tahoe area. The design storm rate is used to design most storm water routing plans.

Figure 11. Rainfall simulator and frame.

Figure 12. Rainfall simulation at the surface treatment plot. There was a high percentage of bare ground at this plot.

Cover

Cover point monitoring was conducted at each test plot (1-12) in 2006, 2007, and 2008 and at plot BC in 2007 and 2008.

Cover is measured using the statistically defensible cover point method along randomly located transects.[1] The cover pointer consists of a metal rod with a laser pointer mounted 3.3

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[1] Hogan, M. 2003. Luther Pass Monitoring Report: Plant and Soil Cover Monitoring for Evaluating Sediment Source Control Success in the Lake Tahoe Basin. Lahontan Regional Water Quality Control Board, South Lake Tahoe, CA.

ft (1 m) above the ground. After the rod is leveled in all directions, the button on the laser pointer is depressed and two cover measurements are recorded (Figure 13 and Figure 14):

- the first hit cover, which is the first object intercepted from a height of 3.3 ft (1 m) above the ground
- the ground cover hit, which is the low-lying vegetation or soil below the first hit cover, at the ground level

The first hit cover measures the foliar cover by plants (leaves and stems). It does not measure the part of the plant rooted in the ground. The first hit vegetation is then moved aside and a ground cover hit measures the presence of litter/mulch, basal (or rooted) plant cover, rock and woody debris, and/or bare ground. Total ground cover represents any cover other than bare ground.

Figure 13. Cover point montoring is data collected along transects.

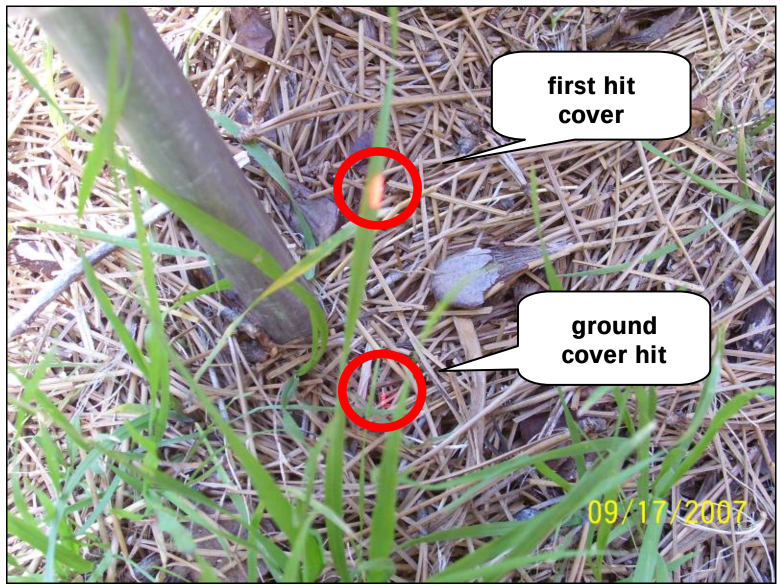

Figure 14. Cover point monitoring rod with first hit and ground cover hit by the laser pointer. The laser pointer hits are circled in red. The first cover hit is a native grass and the ground cover hit is pine needle mulch.

Foliar and ground level plant cover is recorded by species and then organized into cover groups based on four categories: life form (herbaceous/woody), perennial/annual, native/alien (2007 and 2008), and seeded/volunteer (2007 and 2008). Perennial herbaceous species includes seeded grasses, native grasses and forbs, and any non-native perennial species. Annual herbaceous species include native annuals such as groundsmoke (*Gayophytum sp.*) and invasive species such as cheatgrass (*Bromus tectorum*). Woody species include any native or introduced trees and shrubs. Each species is classified based on whether it was native to the Tahoe area and whether it was seeded during treatment.

In this report, data is also presented on the percentage of cover by species. An ocular estimate of cover at each plot was also recorded and includes many species not detected in the cover point sampling. The species lists, as well as the ocular estimates of cover by species, are presented in Appendix A.

Soil and Site Physical Conditions

Penetrometer Depth to Refusal and Soil Moisture

In 2006, 2007, and 2008, penetrometer depth to refusal (DTR) and soil moisture were measured along the same transects as the cover point data for all plots. To measure DTR, a cone penetrometer with a ½ inch diameter tip is pushed straight down into the soil until a maximum pressure of 350 pounds per square inch (2,413 kPa) is reached (Figure 15 and Figure 16). Although the rainfall frame maximum pressure was 250 psi in 2006, the maximum pressure for DTRs measured on transects was 350 psi for all years, including 2006. The depth at which that pressure is reached is recorded as the DTR.

Cone penetrometer DTR measurements are used as an index for soil density. Soils with higher DTRs are generally less dense than those with lower DTRs. A denser soil is less likely to allow infiltration. Rainfall simulations conducted on roadcuts in Oregon found increased infiltration rates in soils with penetrometer depths to refusal (DTRs) greater than 4 inches (10 cm).[2]

It is most informative to compare penetrometer DTR measurements collected in soils that have similar moisture levels. When soil moisture content increases, the resistance of the soil to the penetrometer decreases and DTR readings are deeper. Therefore, only penetrometer readings at the same soil moisture are comparable. A hydrometer was used to measure volumetric soil moisture content adjacent to the penetrometer readings at a depth of 4.7 inches (12 cm; Figure 17).

Figure 15. Cone penetrometer dial, showing pressure applied in pounds per square inch.

Figure 16. Conducting cone penetrometer readings along transects.

[2] Grismer, M.E. 2006. Simulated Rainfall Evaluation at Sunriver and Mt. Bachelor Highways, Oregon. Unpublished.

Solar Exposure

In 2006, solar exposure measurements were taken at three locations at the test plots and at three locations at the native reference plot. These measurements were taken using a Solar Pathfinder (Figure 18). Since there was no change in solar obstructions, data was not collected in 2007 or 2008. Solar input affects evaporation rates and soil temperature, which may affect time of seed germination, germination rate, rate of plant growth, and soil microbial activity. Therefore, it is an important variable to consider when monitoring plant growth and soil development.

Figure 17. Conducting soil moisture readings along transects.

Figure 18. Solar Pathfinder in use.

Soil Nutrient Analysis

Successful re-vegetation requires that nutrient capital be stored in the soil for release over time. Sufficient organic matter and a functioning microbial community are necessary to provide a long-term source of nitrogen for plants. Previous studies of soil nutrient levels at revegetation sites throughout the Tahoe area found that sites with high plant cover had significantly higher soil nutrients over the long term than soils with lower plant cover levels.[3] Total Kjeldahl nitrogen and organic matter were used as indicators of soil health in this study. Total Kjeldahl nitrogen (TKN) is a measure of readily available nitrogen. Three soil samples were taken from each plot; therefore, differences in TKN and organic matter values may be a result of the variability within a plot.

In 2006, soil samples were collected from plots BC, 1, 2, 3, and the native reference plot. In 2007, samples were taken from 1, 2, 8, 9, and 11. In 2008, samples were taken from plots BC, 1, 2, 8, 9, 11, and 12 (Table 1 and Figure 3). Three soil samples at each plot were collected from the mineral soil beneath the mulch layer to a depth of 12 inches (30 cm; Figure 19). These sub-samples were combined and sieved to remove any material larger than 0.08 inches (0.2 cm) in diameter. Samples were sent to A&L Laboratories (Modesto, CA) to

[3]Claassen, V.P., and M.P. Hogan. 2002. Soil Nutrients Associated with Revegetation of Disturbed Sites in the Lake Tahoe Basin. Restoration Ecology 10:195-203.

be analyzed for the S3C nutrient suite (macro and micronutrients), total Kjeldahl nitrogen (TKN), and organic matter analysis.

Figure 19. Soil sub-sample collection.

Statistical Analysis

Statistical tests were used to determine significant differences between treatments. The type of test employed depended on the number of variables tested and the normality of the sample. An Analysis of Variance (ANOVA) was used to investigate whether there were any significant differences in plant cover, soil moisture, or penetrometer DTR among plots with different treatments. An ANOVA sorts data by groups. In this case, data was sorted by amendment type, tilling depth, or year. ANOVA is typically used with three or more groups.

If a difference was detected using the ANOVA test, the Mann-Whitney test or Tukey test was sometimes used to further investigate differences between two sub-groups or sample sets within the larger group. The Mann-Whitney is a non-parametric test that can be applied to data sets with non-normal distributions. Non-normal distributions are common within small data sets. Some of the sample sizes at the Brockway Summit test plots were small (n=3), making it necessary to use a non-parametric test. The surface treatment plot could not be included in the statistical analysis because it did not have a replication.

Results and Discussion

Rainfall Simulation

Trends by Treatment Level

From 2006 to 2008, the surface treatment plot produced, on average, 680 times more sediment than the full treatment plots. The two-year average sediment yield for the surface treatment plot was 352 lbs/acre/in (155 kg/ha/cm), while the three-year average for the full treatment plots was 0.51 lbs/acre/in (0.22 kg/ha/cm; Figure 20, Figure 21, and Figure 22). Over three years, twenty-three out of twenty-four simulations at the full treatment plots did not produce any sediment. It is unclear why one frame did produce a small amount of sediment (6.2 lbs/acre/in or 2.7 kg/ha/cm).

On average, infiltration rates were 1.5 times higher for the full treatment plots (4.5 in/hr or 114 mm/hr) compared to the surface treatment plot (3 in/hr or 76 mm/hr; Figure 20, Figure 21, and Figure 22). Higher infiltration rates are expected when sediment yields are low.

Trends by Amendment Type

The only sediment produced at the full treatment plots was at plot 2, which was amended with tub grindings. It is unlikely that the sediment production was related to the amendment type as this was not observed more than once in three years of sampling.

Trends by Tilling Depth

The only sediment produced at the full treatment plots was at plot 2, which was tilled to 14 inches with a backhoe. It is unlikely that the sediment production was related to the tilling depth, as deeper tilling usually facilitates infiltration.

Trends by Year

Sediment production was consistent over the three years sampled at the full treatment plots. Sediment production was variable at the surface treatment plot and decreased between 2006 and 2008, from 431 to 273 lbs/acre/in (190 to 120 kg/ha/cm). This decrease coincided with an increase in the rainfall application rate from 2.8 in/hr (72 mm/hr) to 4.7 in/hr (120 mm/hr). This suggests an improvement over time occurred at the surface treatment plot. A slight increase in penetrometer depth to refusal (DTR) was observed between 2006 and 2008 (Figure 28). Often, areas with deeper penetrometer DTRs exhibit higher infiltration rates and lower sediment yield than plots with shallower DTRs. Although it is not known why the penetrometer DTR deepened, the lower sediment yield may be a result of this increase.

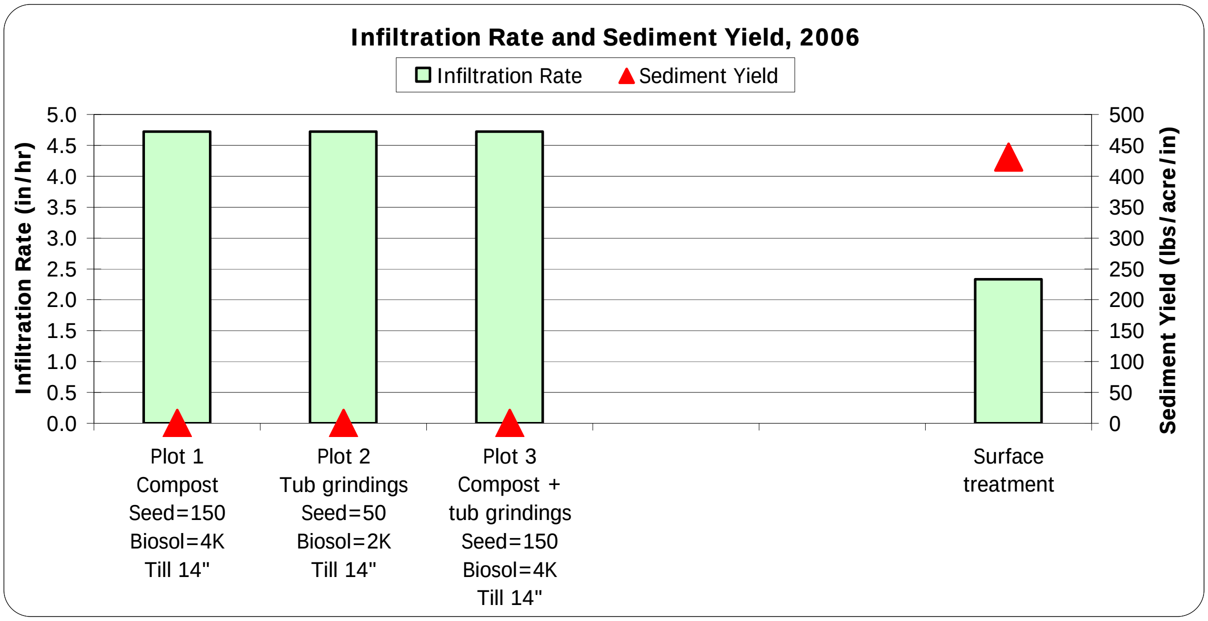

Figure 20. Infiltration Rate and Sediment Yield, 2006. The full treatment plots did not produce any sediment and had infiltration rates of 4.7 in/hr (120 mm/hr), while the surface treatment plot produced 431 lbs/acre/in (190 kg/ha/cm) of sediment and had an infiltration rate 2.3 in/hr (58 mm/hr). Compost=25% compost blend.

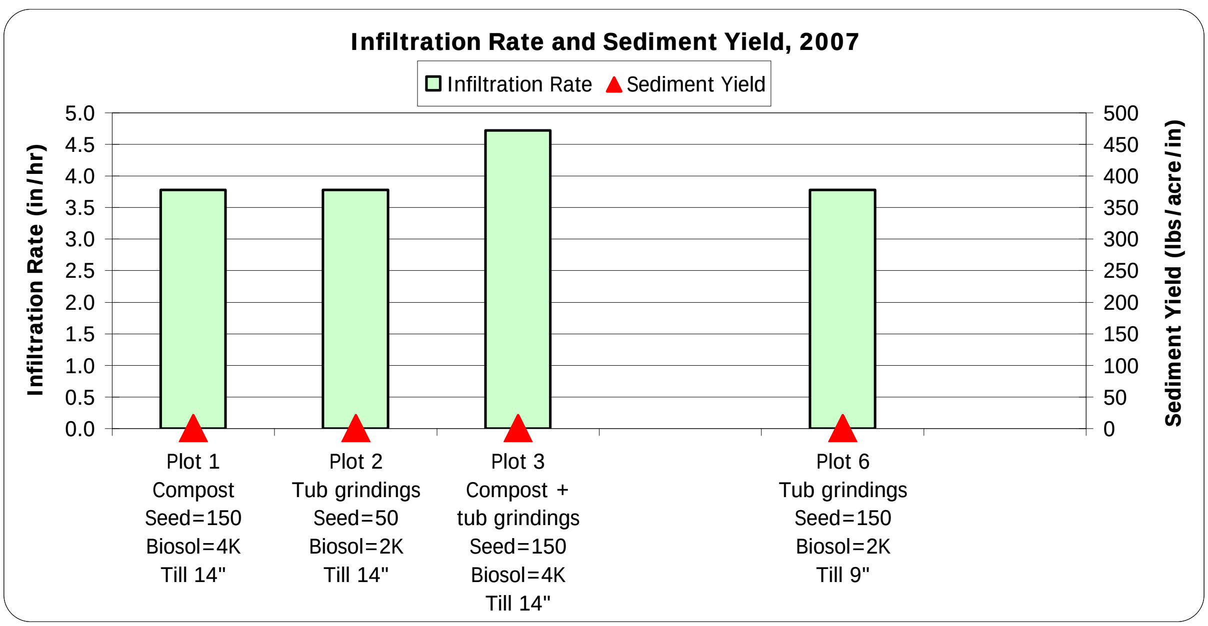

Figure 21. Infiltration Rate and Sediment Yield, 2007. Only full treatment plots were tested in 2007; none produced any sediment. Infiltration rates ranged from 3.8-4.7 in/hr (97-120 mm/hr). The higher infiltration rates reflect higher applied rainfall rates. All plots infiltrated 100% of the applied rainfall. Compost=25% compost blend.

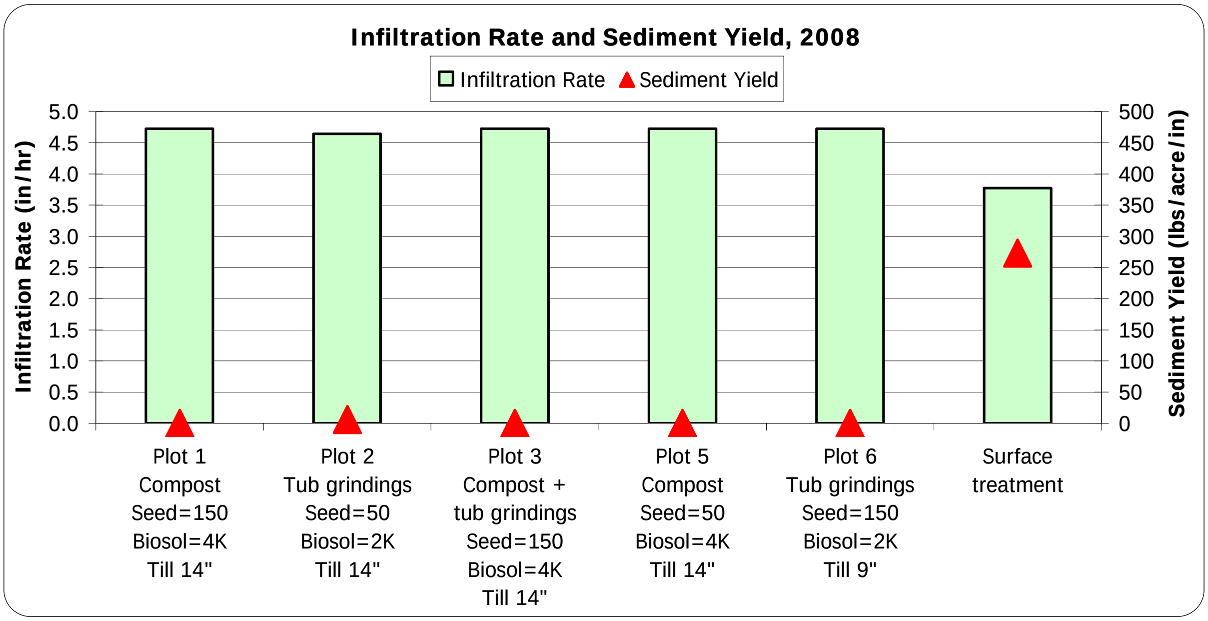

Figure 22 Infiltration Rate and Sediment Yield, 2008. The full treatment plot sediment yields ranged from 0-6.2 lbs/acres/in (0-2.7 kg/ha/cm), while the surface treatment sediment yield was on average 220 times higher, at 273 lbs/acre/in (120 kg/ha/cm). The infiltration rate for the full treatment plots was 4.7 in/hr (120 mm/hr) compared to 3.7 in/hr (94 mm/hr) for the surface treatment plot. Compost=25% compost blend.

Soil Moisture

Significant differences, which are elaborated upon below, were found between the soil moisture levels at some plots. This does not allow for comparison of penetrometer DTRs across all plots and years.

Trends by Amendment Type

The soil moisture was not significantly different over time for plots tilled to 9 inches or 14 inches and amended with tub grindings (8%) or the 25% compost blend and tub grindings (5%); Figure 23, Figure 24, and Table 3). However, soil moisture was significantly different for the 25% compost blend plots tilled to 9 inches between 2006 (average of 4%) and 2007 (average of 7%) and 2006 and 2008 (average of 8%; Figure 23 and Table 3). It was not significantly different for plots tilled to 9 inches between 2007 (average of 7%) and 2008 (average of 8%; Figure 23 and Table 3).

The soil moisture at the 25% compost blend plots tilled to 14 inches was significantly different between 2006 (average of 4%) and 2007 (average of 7%) and between 2007 (average of 7%) and 2008 (average of 6%; Figure 24 and Table 3). However, soil moisture for plots tilled to 14 inches was not significantly different between 2006 (average of 4%) and 2008 (average of 6%; Figure 24 and Table 3).

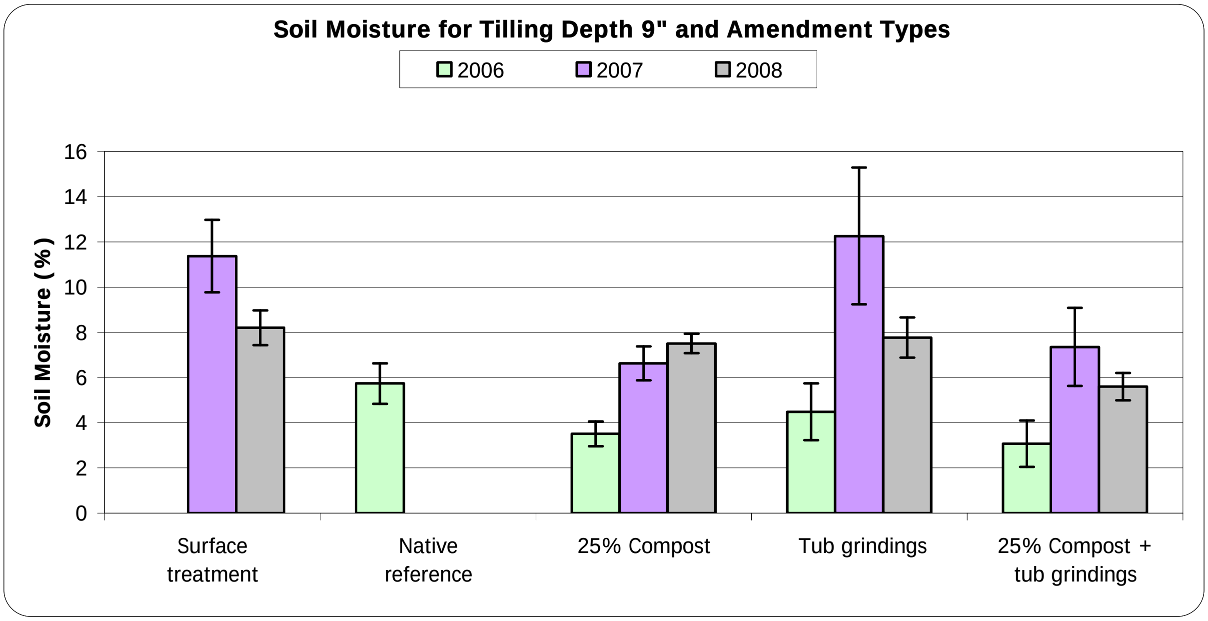

Figure 23. Soil Moisture for Tilling Depth 9 inch and Amendment Types. Soil moisture was not collected at the surface treatment plot in 2006 or the native reference plot in 2007 or 2008.

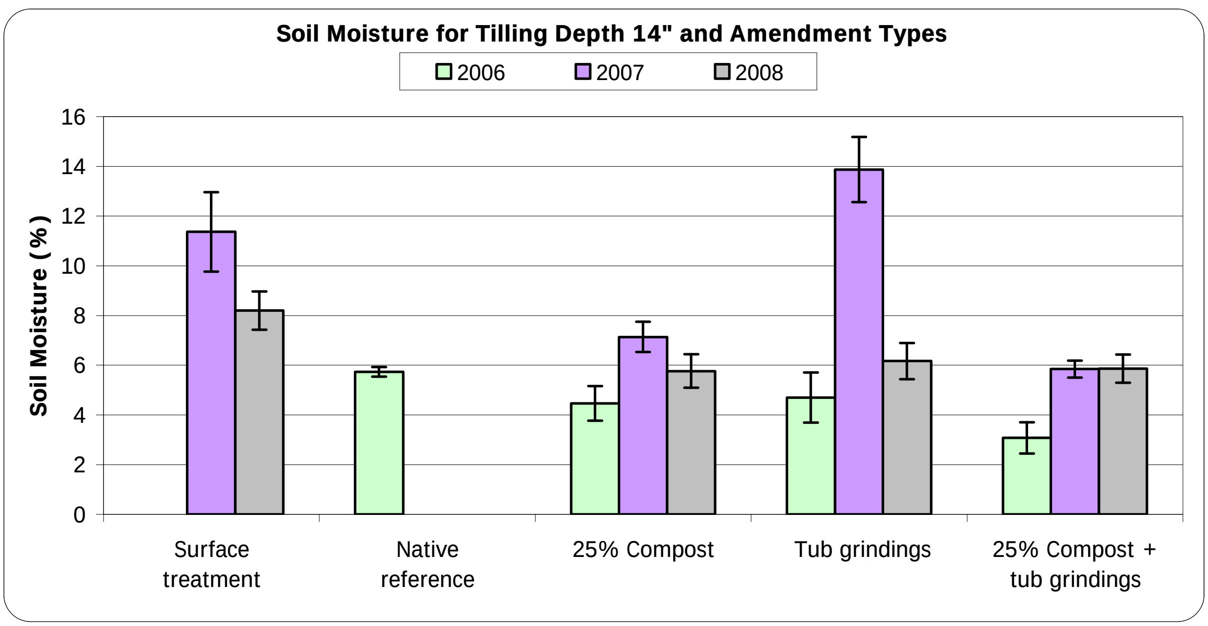

Figure 24. Soil Moisture for Tilling Depth 14 inch and Amendment Types. Soil moisture was not collected at the surface treatment plot in 2006 or the native reference plot in 2007 or 2008

Trends by Tilling Depth

Soil moisture for the 9 inch till depth plots was significantly lower in 2006 (4%) compared to 2007 (9%) and 2008 (7%; Figure 25 and Table 3). Soil moisture for the 14 inch till depth plots was significantly lower in 2006 (4%) compared to 2007 (9%), but not significantly different between 2006 and 2008 (6%; Figure 25 and Table 3). Soil moisture for plots tilled to 9 inches or 14 inches was not significantly different between 2007 and 2008 (Figure 25 and Table 3). The average soil moisture for the 9 inch till depth plots in 2007 was 9%, compared to 7% in 2008. The average soil moisture for the 14 inch till depth plots in 2007 was 9%, compared to 6% in 2008. Therefore, penetrometer depths for all treatment types cannot be compared over all years. However, all treatment types can be compared between 2007 and 2008 and within each year.

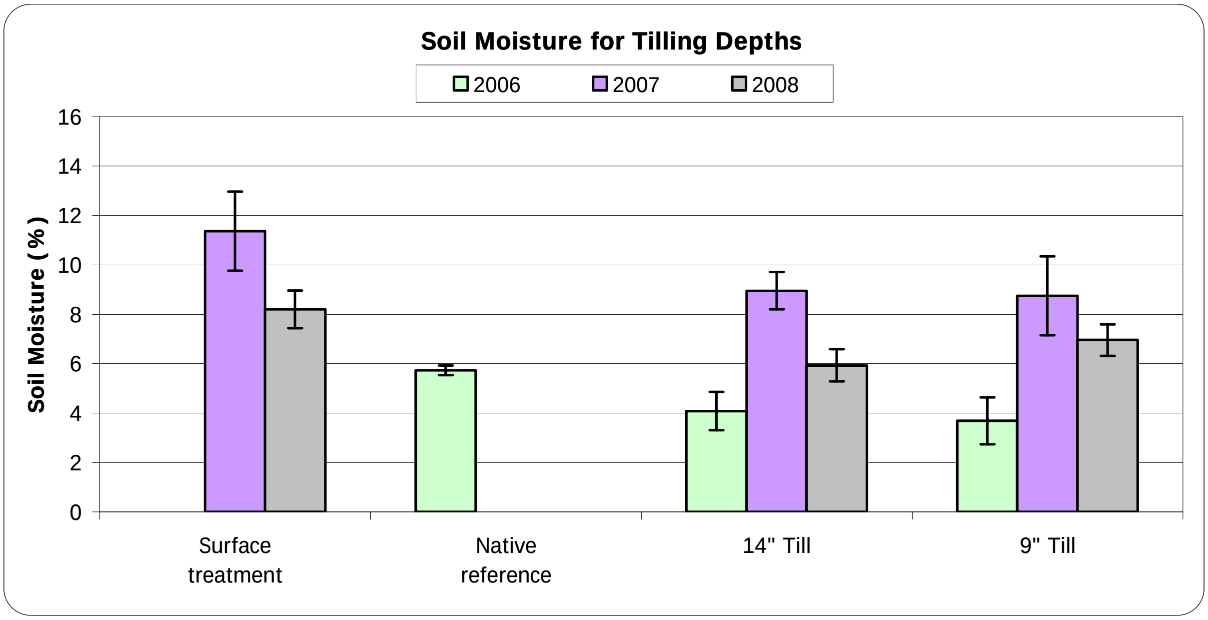

Figure 25. Soil Moisture for Tilling Depths. Significant differences were found between soil moisture levels for each tilling depth each year, therefore penetrometer depths cannot be compared over time, only within each year, where no significant differences were found. Soil moisture was not collected at the surface treatment plot in 2006 or the native reference plot in 2007 or 2008. The error bars represent the standard deviation above and below the mean.

Penetrometer Depth to Refusal (DTR)

Trends by Treatment Level

The 9 inch till depth plots had a three-year average DTR (6.9 inches or 18 cm) that was 1.6 times higher than the three-year average DTR for the surface treatment plot (4.4 inches or 11 cm). The 14 inch till depth plots had a three-year average DTR (10.6 inches or 27 cm) that was 2.4 times higher than the three-year average DTR for the surface treatment plot (4.4 inches). The DTRs for both the 9 inch (6.9 inches or 18 cm) and 14 inch (10.6 inches or 27 cm) tilling plots were similar to the DTR for the native reference plot (8.4 inches or 21 cm). Either tilling depth is feasible option for maintaining low density soil with penetrometer DTRs similar to those at the native reference plot; however, the 14 inch till depth exhibited deeper DTRs than the 9 inch till plot.

Trends by Amendment Type

Penetrometer DTRs did not vary consistently over time with amendment type for each tilling depth. Only statistically significant differences are presented. In 2006, the DTR at the

9 inch till depth plots with tub grindings (average of 11.4 inches or 29 cm) was on average 1.7-2.0 times significantly higher than the DTR at the 9 inch till depth plots with the 25% compost blend (average of 5.8 inches or 15 cm; Figure 26 and Table 3). In 2007, the DTR for the 14 inch till depth plots with tub grindings (average of 14.4 inches or 37 cm) ranged from 1.6 to 1.8 times significantly higher than the DTR at the 25% compost blend plots (average of 8.8 inches or 22 cm) or the 25% compost blend and tub grindings plots (average of 8.1 inches or 21 cm; Figure 27 and Table 3). Coarse amendments, such as tub grindings, may help reduce soil re-compaction over time, compared to amendments composed of finer material, such as compost.

No significant differences were found in 2008 between different amendment types, suggesting neither of the differences present in earlier years will persist over the long term. This may be a result of the coarser material, which was present in earlier years, breaking down over time and becoming finer. Finer material may not provide the same benefits in terms of deep penetrometer DTRs that coarse material can.

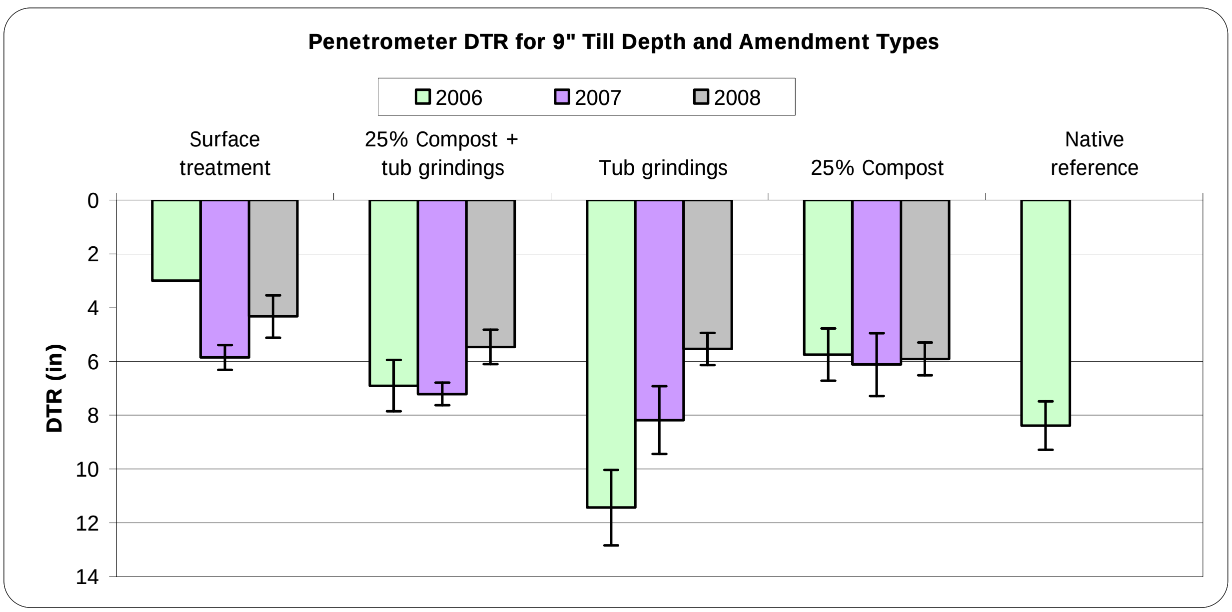

Figure 26. Penetrometer DTR for 9 inch Till Depth and Amendment Types. In 2006, the DTR at the 9 inch till depth plots with tub grindings (average of 11.4 inches or 29 cm) was on average 2 times significantly higher than the DTR at the 9 inch till depth plots with the 25% compost blend (average of 5.8 inches or 15 cm). The error bars represent the standard deviation above and below the mean.

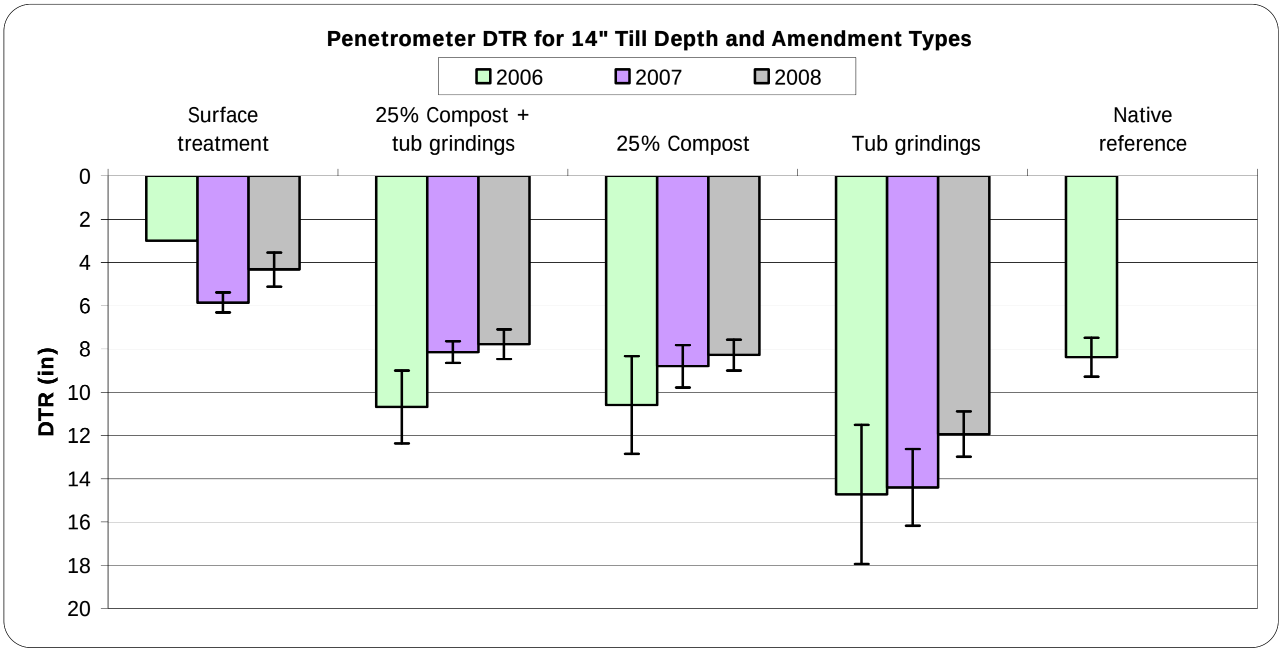

Figure 27. Penetrometer DTR for 14 inch Till Depth and Amendment Types. In 2007, the DTR for the 14 inch till depth plots with tub grindings ranged from 1.6 to 1.8 times significantly higher than the DTR at the 25% compost blend only (average of 8.8 inches or 22 cm) or the 25% compost blend and tub grindings plots (average of 8.1 inches or 21 cm). The error bars represent the standard deviation above and below the mean.

Trends by Tilling Depth

In 2006, 2007, and 2008, penetrometer depths were significantly deeper at the 14 inch till depth plots than the 9 inch till depth plots (Figure 28 and Table 3). The three-year average for the 14 inch till depth plots (10.6 inches or 27 cm) was 1.5 times higher than the three-year average for the 9 inch till depth plots (6.9 inches or 18 cm).

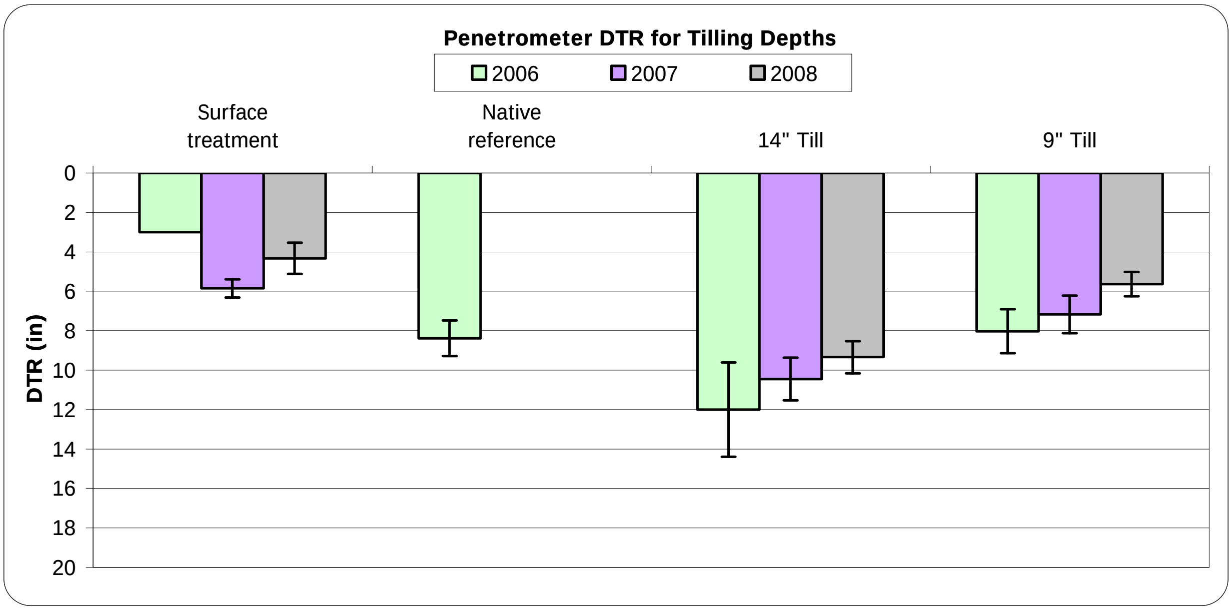

Figure 28. Penetrometer DTR by Tilling Depth. From 2006 to 2008, the penetrometer DTR was significantly higher by 1.5 times on average for the plots tilled to 14 inches (three-year average DTR of 10.6 inches) compared to plots tilled to 9 inches (three-year average DTR of 6.9 inches). The average DTRs for the 9 inch and 14 inch till depth plots were significantly higher by 1.6 to 2.4 times compared to the average DTR for the surface treatment plot (4.4 inches). The error bars represent the standard deviation above and below the mean.

Trends by Year

Penetrometer depths did not vary significantly over time for any tilling depth or amendment type for which soil moistures were not significantly different (Figure 26, Figure 27, and Figure 28). Penetrometer depths were not compared for treatment types that had significantly different soil moistures. Although significant differences were not found, penetrometer DTRs at the test plots showed a decreasing trend over time (Figure 26, Figure 27, and Figure 28). This change over time may be related to the thick, undefined mulch layer at the test plots, which can result in variable penetrometer DTR readings. The penetrometer DTR is read at the soil and mulch interface, which was hard to resolve at the test plots. This trend may also be a result of decreasing DTRs that while not currently statistically significant, could become so if the trend is maintained during subsequent samplings.

Cover

Mulch Cover

Trends by Treatment Level

Ground cover by mulch for treatment plots with all amendment types has not degraded over time and has remained over 80% for all three years. Ground cover by mulch cover was 4.9-5.2 times higher at the treated plots, which had three-year averages ranging from 84 to 93% when compared to the surface treatment plot, which had an average two-year average of 16% (Figure 29). Mulch cover is an important variable in erosion reduction through sediment source control because treatments with cover by pine needle mulch have been shown to reduce sediment yields substantially.[4]

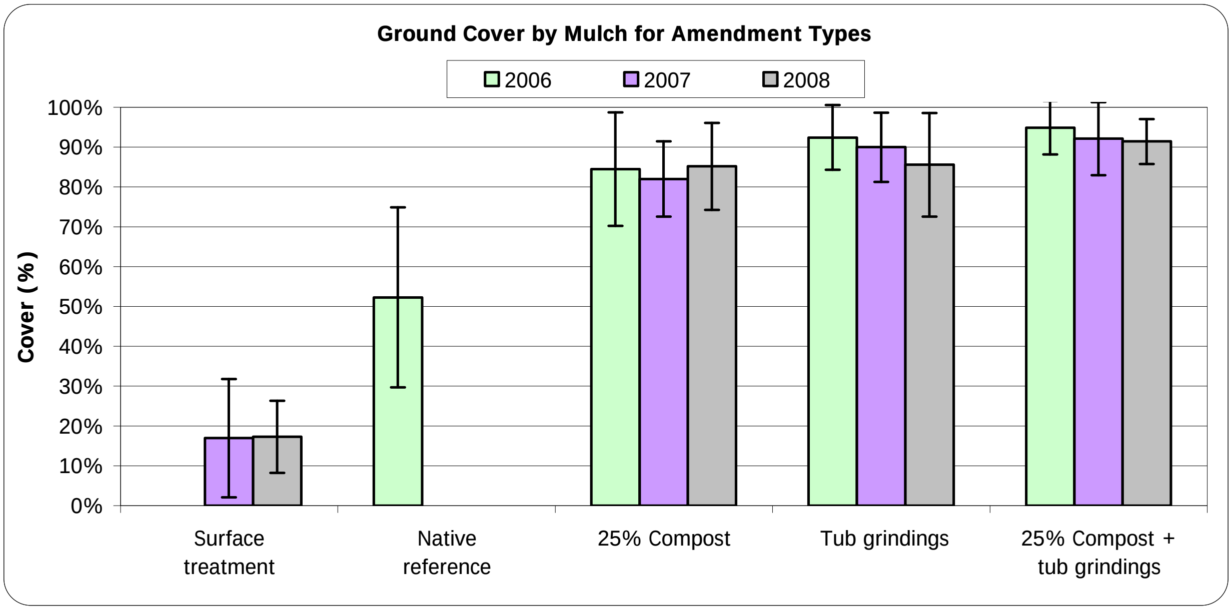

Figure 29. Ground Cover by Mulch for Amendment Types. The ground cover by mulch has remained over 80% at all the full treatment plots (25% compost blend, tub grindings, and 25% compost blend + tub grindings) over the three-year sampling period, while the two-year average mulch cover for the surface treatment plot was 5.0-5.6 times lower than at the full treatment plots, with a two-year average of 16%. The error bars represent the standard deviation above and below the mean.

Bare Soil

Trends by Treatment Level

The percent of bare soil was 10-117 times higher at the surface treatment plot compared to the full treatment plots (Figure 30). The surface treatment plot had a two-year average of 63% bare soil, compared to three-year average ranging from 0.5 to 6% at the fully treated plots. The native reference plot did not have any bare soil when sampled in 2006.

[4] Grismer, M.E., and M.P. Hogan. 2004. Simulated rainfall evaluation of revegetation/mulch erosion control in the Lake Tahoe Basin: 1. Method assessment. Land Degradation & Development 15:573-588.

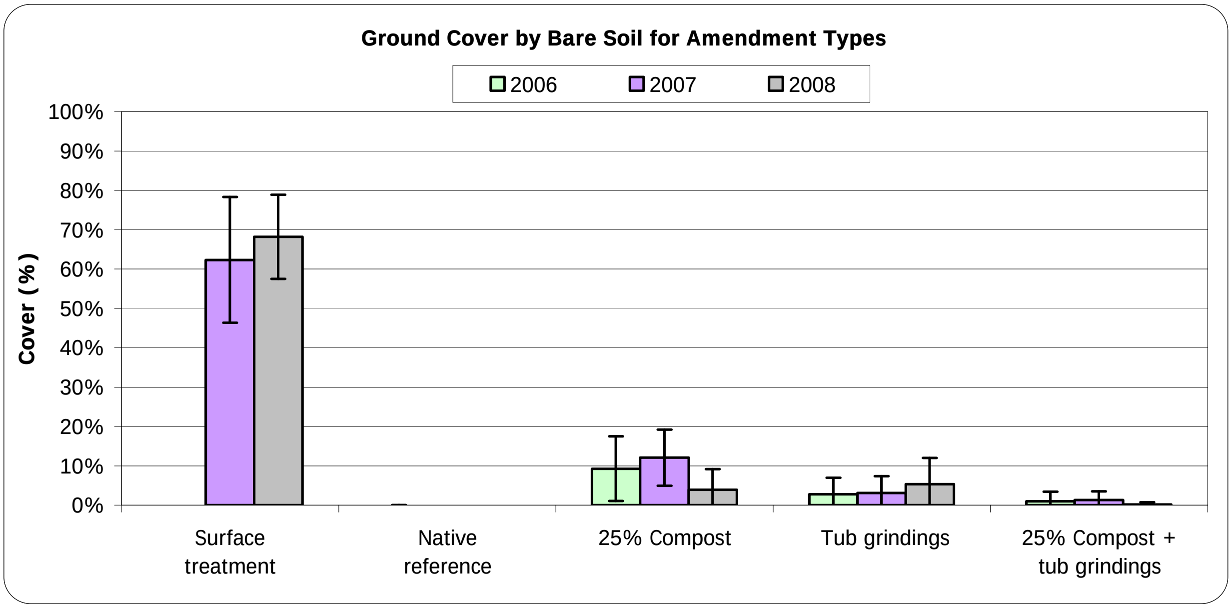

Figure 30. Ground Cover by Bare Soil for Amendment Types. Full treatment plots (25% compost blend, tub grindings, and 25% compost blend+ tub grindings), which had a three-year averages ranging from 0.5-6.0% bare cover, had 10-117 times less bare soil when compared to the surface treatment plot, which had a two-year average of 63% bare soil. The error bars represent the standard deviation above and below the mean.

Plant Cover and Composition

Trends by Treatment Level

For 2006, 2007, and 2008, foliar plant cover was 5.5 times higher at the full treatment plots amended with the 25% compost blend (three-year average of 34%) and 25% compost blend and tub grindings (three-year average of 34%) compared to the surface treatment plot (two-year average of 5%; Figure 31). Cover was similar at the surface treatment plot and the full treatment plot amended with tub grindings (5%).

Trends by Amendment Type

For 2006, 2007, and 2008, the foliar plant cover at the plots amended with the 25% compost blend or the 25% compost blend and tub grindings was 2.6 to 11 times significantly higher when compared the plots amended with tub grindings (Figure 31 and Table 3). The foliar cover ranged from 21to 51% at the 25% compost blend plots, from 23 to 49% at the 25% compost blend and tub grindings plots, and from 3.5 to 8.1% at the tub grindings plots.

In 2007 and 2008, amendment type did not significantly affect seeded plant cover (no graph, Table 3).

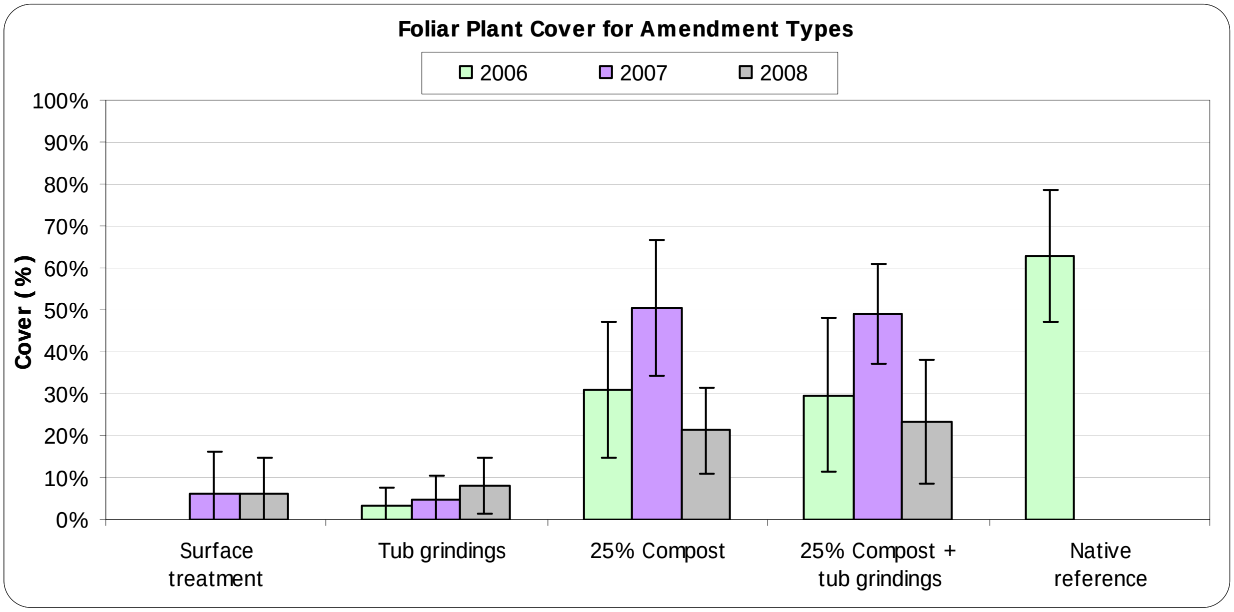

Figure 31. Foliar Plant Cover for Amendment Types. For all three years, the foliar cover at the plots amended with the 25% compost blend or the 25% compost blend and tub grindings was 2.6 to 11 times significantly higher when compared the plots amended with tub grindings. The foliar cover ranged from 21-51% at the 25% compost blend plots, from 23-49% at the 25% compost blend and tub grindings plots, and from 3.5 to 8.1% at the tub grindings plots. The error bars represent the standard deviation above and below the mean.

In 2007, the proportion of foliar cover by cheatgrass to foliar plant cover at the full treatment plots amended with the 25% compost blend or the 25% compost blend and tub grindings was significantly higher by 5.9-6.6 times compared to the full treatment plots amended with tub grindings (Figure 32 and Table 3). The proportion of cover by cheatgrass ranged from 78 to 94% at the 25% compost blend plots, from 58 to 100% at the 25% compost blend and tub grindings plots and from 0 to 34% at the tub grindings plots. Conversely, in 2008, the proportion of foliar cover by cheatgrass did not vary by amendment type.

Trends by Year

Foliar cover by cheatgrass was reduced significantly at the 25% compost blend and the 25% compost blend and tub grindings plots by 4.2-5.7 times between 2007 and 2008 from an average of 40-45% cover to an average of 8% (Figure 32, Figure 33, and Table 3). Foliar cover by cheatgrass did not decrease significantly between 2007 and 2008 at the plots amended with tub grindings. This suggests that although compost that contains amendments may initially increase cheatgrass cover, over time, cover by cheatgrass may decrease. The lower cover by cheatgrass could also be a result of the unusually dry spring in 2008. Less available water may have reduced overall cheatgrass populations (Figure 4).

From 2007 to 2008, seeded plant cover increased at all the test plots. In 2007, seeded cover ranged from 0.4 to 2.6%, while in 2008, seeded cover ranged from 6.7 to 9.7% (no graph). This increase may be related to the decrease in cheatgrass cover. Cheatgrass may have been out-competing the native, seeded species.

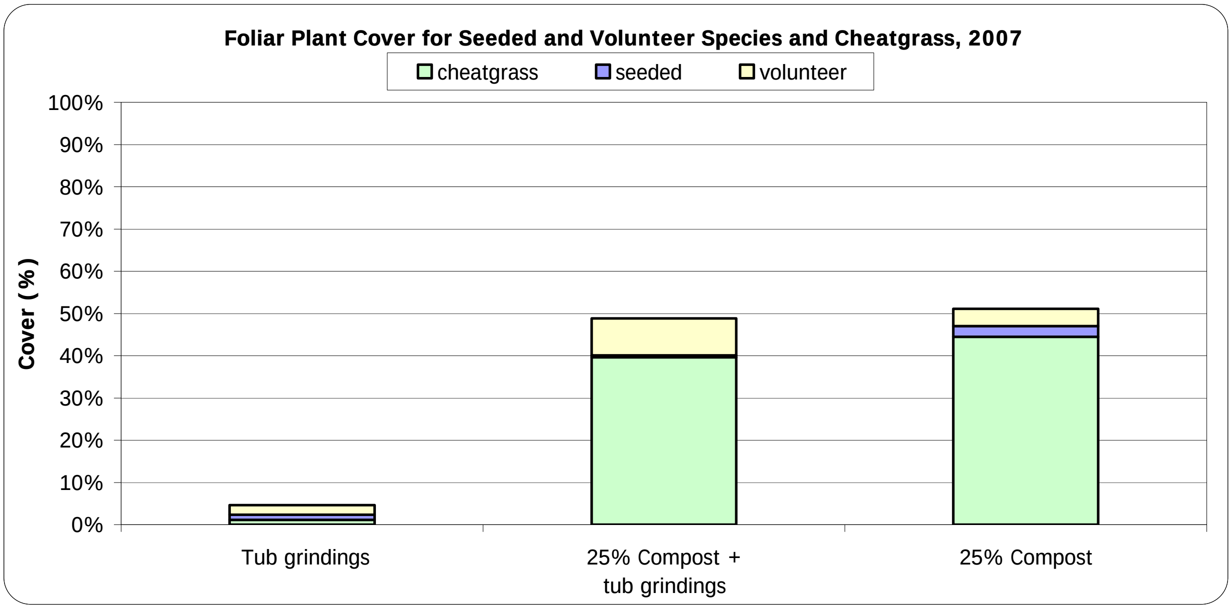

Figure 32. Foliar Plant Cover for Seeded and Volunteer Species and Cheatgrass, 2007. The proportion of foliar cover by cheatgrass compared to foliar plant cover at the 25% compost blend plots (78-94% of foliar cover) and the 25% compost blend and tub grindings plots (58-100% of foliar cover) was significantly higher by 5.9-6.6 times at the full treatment plots amended with tub grindings (0-34% of foliar cover).

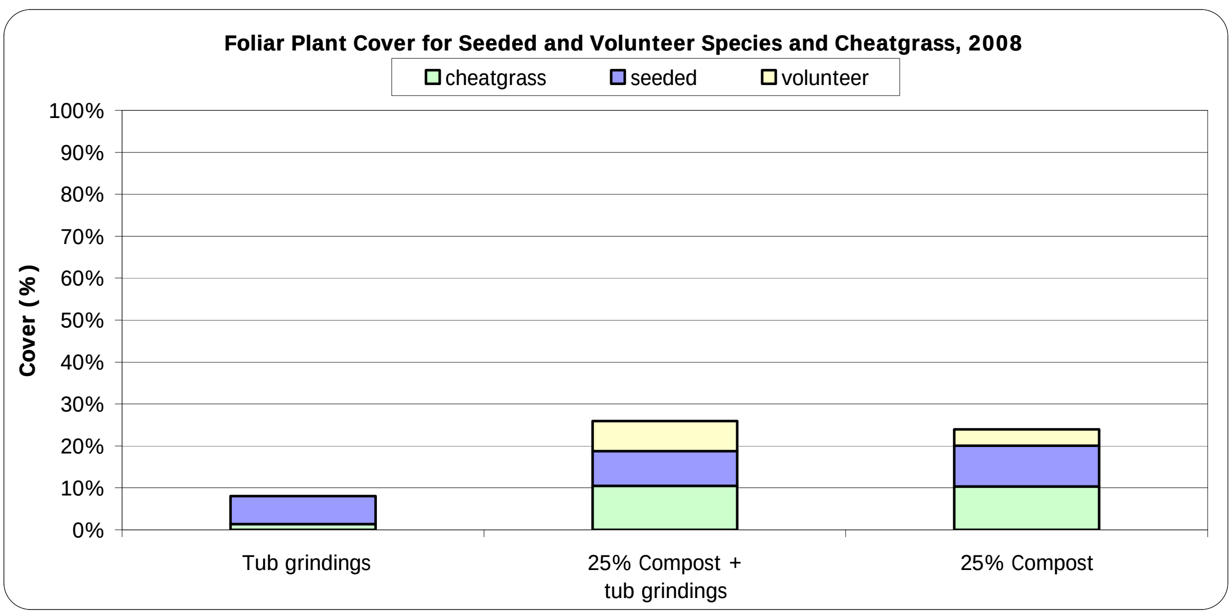

Figure 33. Foliar Plant Cover for Seeded and Volunteer Species and Cheatgrass, 2008. The proportion of cheatgrass did not vary by amendment type in 2008. Cheatgrass was reduced overall from an average of 40-45% cover across all full treatment plots in 2007 to an average of 8% cover in 2008.

Trends by Seed Rate

In 2007 and 2008, plots with higher seed rates had significantly higher cover by seeded species by 2.6-5.5 times (Figure 34 and Table 3). Seeded cover for individual plots ranged from 0 to 20% for the high seed rate plots and from 0 to 2.6% for the low seed rate plots. The two-year average for the high seed rate plots was 7.1%, while the two-year average for the low seed rate plots was 2.5%. Although this result is statistically significant, the vegetation levels are very low, making comparisons between the two seed rates difficult.

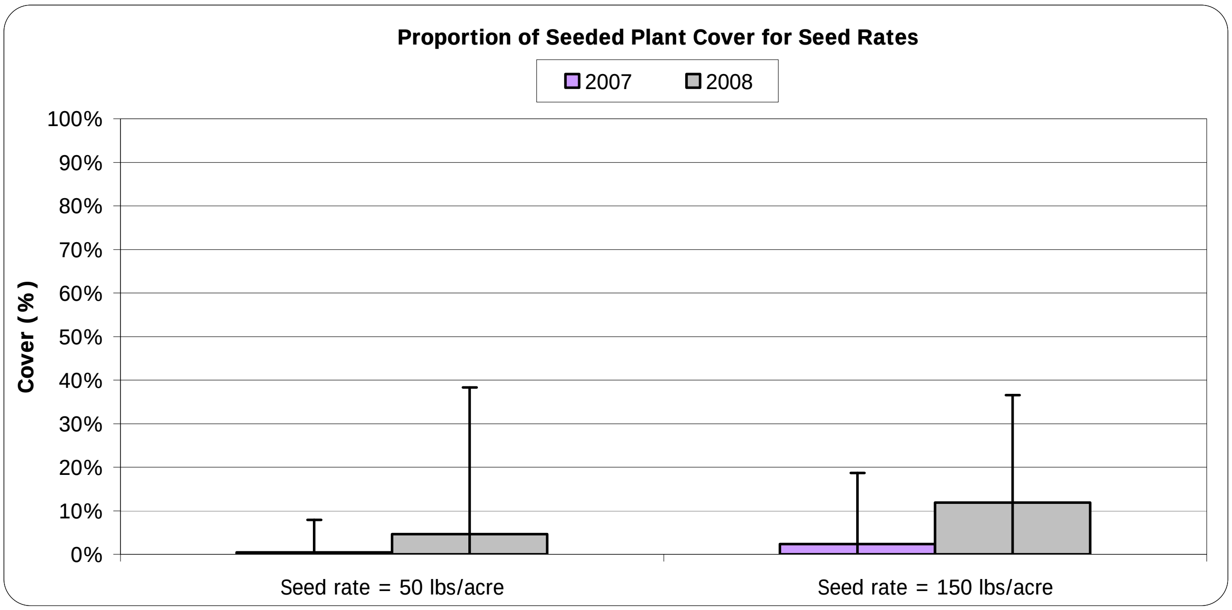

Figure 34. Proportion of Seeded Plant Cover for Seed Rates. In 2007 and 2008, plots with the seed rates of 150 lbs/acre (two-year average of 7.1% seeded cover) had significantly higher cover by seeded species by 2.6-5.5 times compared to plots with the 50 lbs/acre seed rate (two-year average of 2.5%). The error bars represent the standard deviation above and below the mean.

Trends by Biosol Rate

For 2006, 2007, and 2008, Biosol rate did not significantly affect foliar plant cover (Figure 35 and Table 3). Plant cover varied greatly between years at plots with different Biosol rates. In 2006, the plots with 4,000 lbs/acre of Biosol had an average of 20% foliar plant cover, compared with the 2,000 lbs/acre Biosol plots, which had an average of 22% foliar cover. In 2007, the plots with 4,000 lbs/acre of Biosol had an average of 61% foliar plant cover, compared with the 2,000 lbs/acre Biosol plots, which had an average of 26% foliar cover. In 2008, the plots with 4,000 lbs/acre of Biosol had an average of 24% foliar plant cover, compared with the 2,000 lbs/acre Biosol plots, which had an average of 16% foliar cover. The wide variation between cover levels for the two Biosol rates indicates if Biosol did have an effect, it was not consistent.

For 2006, 2007, and 2008, Biosol rate also did not significantly affect the proportion of annual plant cover in the plots (no graph, Table 3).

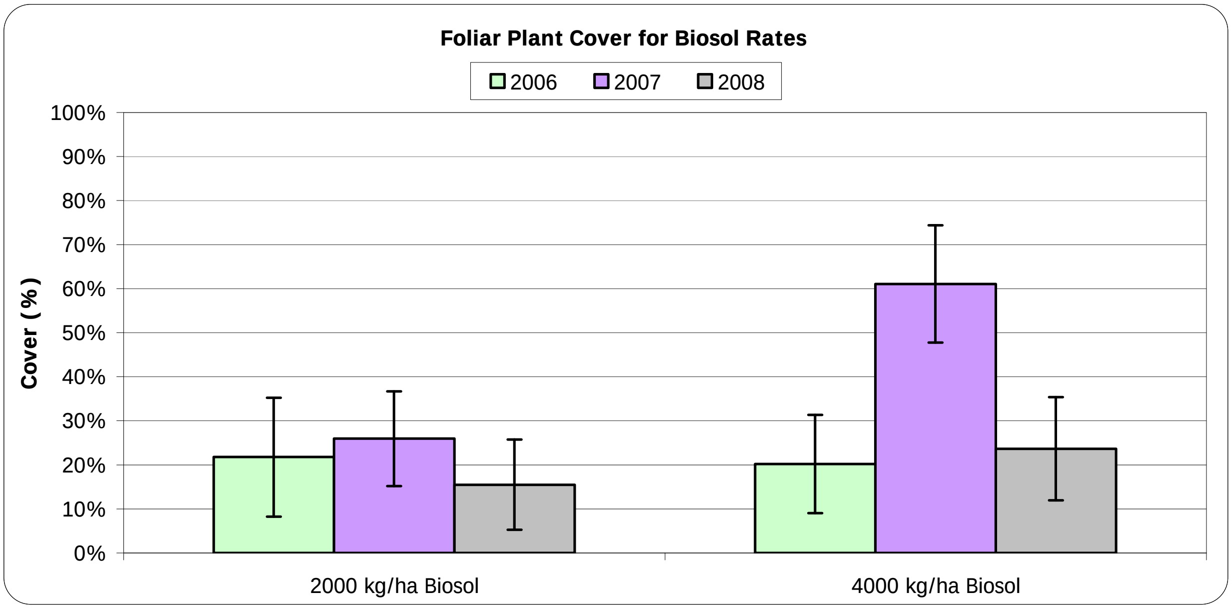

Figure 35. Foliar Plant Cover for Biosol Rates. For 2006, 2007, and 2008, Biosol rate did not significantly affect foliar plant cover. The error bars represent the standard deviation above and below the mean.

Soil Nutrients

Trends by Treatment Level

In 2008, TKN levels ranged from 1,197 to 2,069 ppm at the full treatment plots, compared to 580 ppm at the surface treatment plot and 1,638 at the native reference plot (Figure 36). In 2008, the average soil organic matter levels for all full treatment plots, which ranged from 6.3 to 6.7%, were higher than at the surface treatment plot (4.3%) and similar to the organic matter level of the native reference plot (6.6%; Figure 37). Both TKN and organic matter levels were low at the surface treatment plot compared to the native reference plot, while the full treatment plots were closer to the range of the native reference plot levels. This is mostly likely the result of the organic amendment addition at the full treatment test plots, which increased the nutrient levels.

Trends by Amendment Type

In 2008, the average TKN values for the 25% compost blend and the 25% compost blend and tub grindings full treatment plots (2,069 and 1,637 ppm respectively) were similar to or higher than the TKN at the native reference plot (1,638 ppm; Figure 36). The tub grindings plots had an average TKN that was lower than that of the native reference plot, 1,197 ppm. The 25% compost blend exhibited the highest nutrients levels, most likely because it this blend has the most available nutrients due to its lower carbon to nitrogen. Tub grindings, which have a higher carbon to nitrogen ratio compared to the other two amendments, had the lowest TKN, indicating that 4 inches (10 cm) of tub grindings are not sufficient to re-capitalize the soil to native reference levels.

Organic matter content was similar for all amendment types in 2008 (Figure 37).

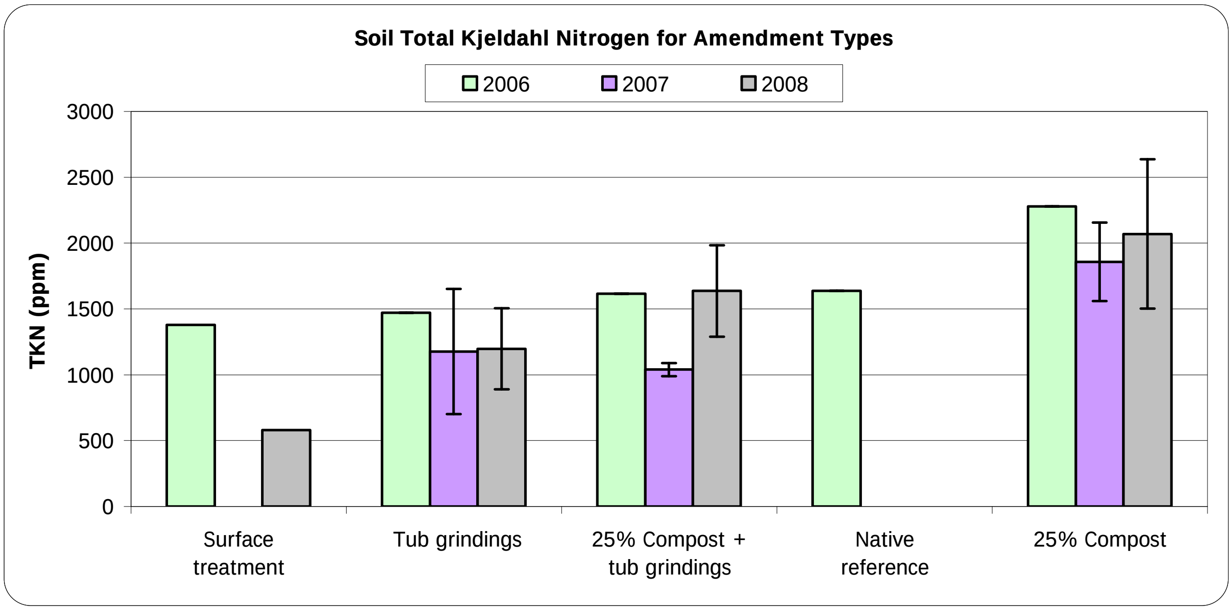

Figure 36. Soil Total Kjeldahl Nitrogen for Amendment Types. In 2008, the average TKN values for the 25% compost blend (average of 2,069 ppm) and the 25% compost blend and tub grindings (average of 1,637 ppm) were similar to the TKN for the native reference plot (1,638 ppm), while the plots with tub grindings had an average value of 1,197 ppm. The error bars represent the standard deviation above and below the mean. Lack of an error bar indicates an average value was not used.

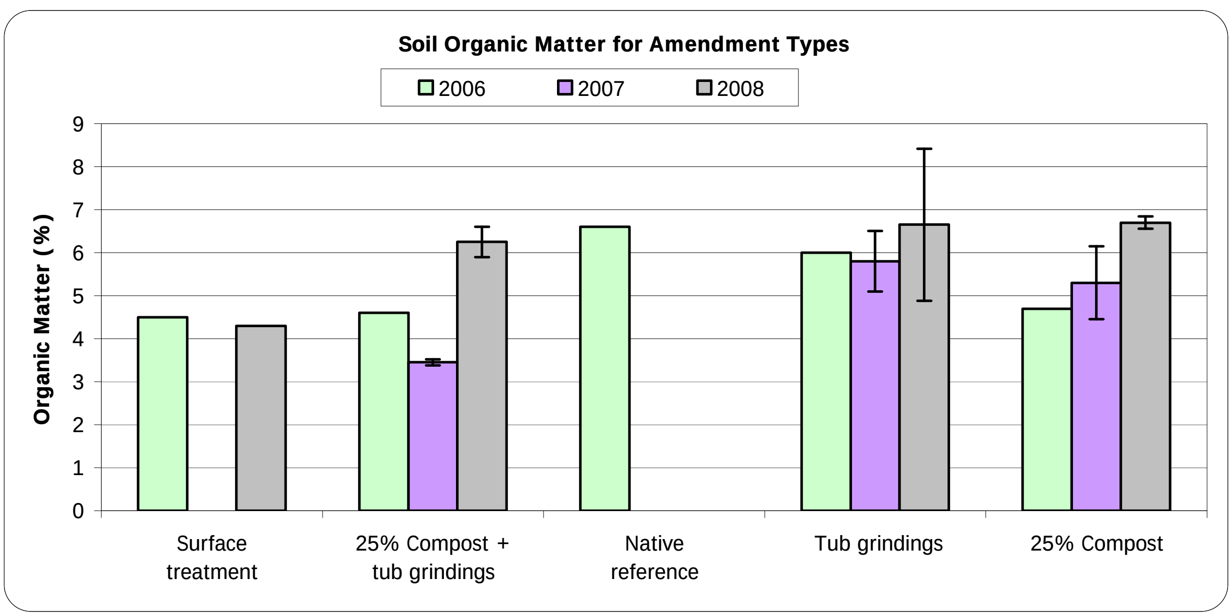

Figure 37. Soil Organic Matter for Amendment Types. In 2008, the average soil organic matter levels at the full treatment plots (6.3-6.7%) were higher than the surface treatment plot level (4.3%) and similar to the native level (average of 6.6%). The error bars represent the standard deviation above and below the mean. Lack of an error bar indicates an average value was not used.

Trends by Year

TKN decreased at most plots over time (Figure 37). From 2006 to 2008, TKN decreased by 800 ppm at the surface treatment plot, by 273 ppm at the plot with tub grindings, and by 209 ppm at the plot with the 25% compost blend and tub grindings. It increased slightly, 20 ppm, at the plot with the 25% compost blend. The TKN may have decreased over time because the nutrients may have been taken up by cheatgrass, which was present in large quantities.

Organic matter remained consistent at the surface treatment plot over two years, at 4.3-4.5% (Figure 36). The organic matter at the full treatment plots amended with the 25% compost blend, tub grindings, or the 25% compost blend and tub grindings showed a slight increasing trend over time, possibly a result of amendment breakdown over time.

Statistical Results

Statistical results are presented in the order in which they appear in the Results and Discussion section.

Table 3. Statistical Results. A probability of less than 0.1 is considered a significant.

Statistical Test	Factors	Variable	Year	Result	Test Statistics	Probability
ANOVA	Year (2006, 2007, 2008)	Soil Moisture for 9 inch Till Depth with Tub Grindings	N/A	No difference in soil moistures between years	F(2,3)=5.06	0.109
ANOVA	Year (2006, 2007, 2008)	Soil Moisture for 14 inch Till Depth with Tub Grindings	N/A	No difference in soil moistures between years	F(2,3)=4.12	0.138
ANOVA	Year (2006, 2007, 2008)	Soil Moisture for 9 inch Till Depth with 25% Compost Blend and Tub Grindings	N/A	No difference in soil moistures between years	F(2,3)=3.46	0.166
ANOVA	Year (2006, 2007, 2008)	Soil Moisture for 14 inch Till Depth with 25% Compost Blend and Tub Grindings	N/A	No difference in soil moistures between years	F(2,3)=3.60	0.159
Tukey	2006 and 2007	Soil Moisture for 9 inch Till Depth with 25% Compost Blend	N/A	Soil moisture higher in 2007 compared to 2006	q=6.43	0.040
Tukey	2006 and 2008	Soil Moisture for 9 inch Till Depth with 25% Compost Blend	N/A	Soil moisture higher in 2008 compared to 2006	q=8.22	0.021

Statistical Test	Factors	Variable	Year	Result	Test Statistics	Probability
Tukey	2007 and 2008	Soil Moisture for 9 inch Till Depth with 25% Compost Blend	N/A	No difference in soil moisture between 2007 and 2008	q=1.80	0.499
Tukey	2006 and 2007	Soil Moisture for 14 inch Till Depth with 25% Compost Blend	N/A	Soil moisture higher in 2007 compared to 2006	q=8.76	0.017
Tukey	2006 and 2008	Soil Moisture for 14 inch Till Depth with 25% Compost Blend	N/A	No difference in soil moistures between years	q=4.26	0.112
Tukey	2007 and 2008	Soil Moisture for 14 inch Till Depth with 25% Compost Blend	N/A	Soil moisture higher in 2007 compared to 2008	q=4.50	0.098
Tukey	2006 and 2007	Soil Moisture for 9 inch Till Depth	N/A	Soil moisture higher in 2007 compared to 2006	q=5.63	0.003
Tukey	2006 and 2008	Soil Moisture for 9 inch Till Depth	N/A	Soil moisture higher in 2008 compared to 2006	q=3.64	0.053
Tukey	2006 and 2007	Soil Moisture for 14 inch Till Depth	N/A	Soil moisture higher in 2007 compared to 2006	q=4.26	0.022
Tukey	2007 and 2008	Soil Moisture for 9 inch Till Depth	N/A	No difference in soil moistures between years	q=1.999	0.362
Tukey	2006 and 2008	Soil Moisture for 14 inch Till Depth	N/A	No difference in soil moistures between years	q=1.62	0.502
Tukey	2006 and 2007	Soil Moisture for 14 inch Till Depth	N/A	Soil moisture higher in 2007 compared to 2006	q=4.26	0.022
Tukey	2007 and 2008	Soil Moisture for 14 inch Till Depth	N/A	No difference in soil moistures between years	q=2.64	0.183
Tukey	25% Compost Blend and Tub Grindings	Penetrometer DTR for 9 inch Till Depth	2006	Deeper DTRs at plots with tub grindings	q=4.89	0.080
Tukey	25% Compost Blend and Tub Grindings	Penetrometer DTR for 14 inch Till Depth	2007	Deeper DTRs at plots with tub grindings	q=10.27	0.011
Tukey	25% Compost Blend+ Tub Grindings and Tub Grindings	Penetrometer DTR for 14 inch Till Depth	2007	Deeper DTRs at plots with tub grindings	q=11.46	0.008

Statistical Test	Factors	Variable	Year	Result	Test Statistics	Probability
Mann-Whitney	9 inch Till Depth and 14 inch Till Depth	Penetrometer DTR	2006	Deeper DTRs at 14 inch Till Depth Plots	U(6,6)=30	0.065
Mann-Whitney	9 inch Till Depth and 14 inch Till Depth	Penetrometer DTR	2007	Deeper DTRs at 14 inch Till Depth Plots	U(6,6)=30	0.065
Mann-Whitney	9 inch Till Depth and 14 inch Till Depth	Penetrometer DTR	2008	Deeper DTRs at 14 inch Till Depth Plots	U(6,6)=34	0.009
Tukey	25% Compost Blend and Tub Grindings	Foliar Plant Cover	2006	Higher foliar plant cover at plots with 25% compost blend	q= 4.89	0.018
Tukey	25% Compost Blend+ Tub Grindings and Tub Grindings	Foliar Plant Cover	2006	Higher foliar plant cover at plots with 25% compost blend + tub grindings	q=4.67	0.023
Tukey	25% Compost Blend and Tub Grindings	Foliar Plant Cover	2007	Higher foliar plant cover at plots with 25% compost blend	q= 6.07	0.005
Tukey	25% Compost Blend+ Tub Grindings and Tub Grindings	Foliar Plant Cover	2007	Higher foliar plant cover at plots with 25% compost blend + tub grindings	q=5.82	0.007
Tukey	25% Compost Blend and Tub Grindings	Foliar Plant Cover	2008	Higher foliar plant cover at plots with 25% compost blend	q=3.33	0.098
Tukey	25% Compost Blend+ Tub Grindings and Tub Grindings	Foliar Plant Cover	2008	Higher foliar plant cover at plots with 25% compost blend + tub grindings	q=3.82	0.057
ANOVA	Amendment Type	Seeded Plant Cover	2007	No difference in seeded cover	F(2,9)=1.47	0.280
ANOVA	Amendment Type	Seeded Plant Cover	2008	No difference in seeded cover	F(2,9)=0.175	0.843
Tukey	25% Compost Blend and Tub Grindings	Proportion of Cheatgrass Cover to Foliar Plant Cover	2007	Higher proportion of cheatgrass to foliar plant cover at plots with the 25% compost blend	q=9.50	0.000
Tukey	25% Compost Blend+ Tub Grindings and Tub Grindings	Proportion of Cheatgrass Cover to Foliar Plant Cover	2007	Higher proportion of cheatgrass to foliar plant cover at plots with 25% compost blend + tub grindings	q=8.30	0.001
Mann-Whitney	2007 and 2008	Cheatgrass Cover for 25% Compost Blend Plots	N/A	Higher cover by cheatgrass in 2007	U(4,4)=16,	p=0.029

Statistical Test	Factors	Variable	Year	Result	Test Statistics	Probability
Mann-Whitney	2007 and 2008	Cheatgrass Cover for 25% Compost Blend + Tub Grindings Plots	N/A	Higher cover by cheatgrass in 2007	U(4,4)=16,	p=0.029
Mann-Whitney	Seed Rate=150 lbs/acre and Seed Rate=50 lbs/acre	Cover by Seeded Species	2007	Higher cover by seeded species for seed rate=150 lbs/acre	U(6,6)=33.5	0.015
Mann-Whitney	Seed Rate=150 lbs/acre and Seed Rate=50 lbs/acre	Cover by Seeded Species	2008	Higher cover by seeded species for seed rate=150 lbs/acre	U(6,6)=30	0.065
Mann-Whitney	Biosol Rate = 2,000 lbs/acre and Biosol Rate = 4,000 lbs/acre	Foliar Plant Cover	2006	No difference in foliar plant cover	U(3,9) =14	1.000
Mann-Whitney	Biosol Rate = 2,000 lbs/acre and Biosol Rate = 4,000 lbs/acre	Foliar Plant Cover	2007	No difference in foliar plant cover	U(3,9)=23	0.100
Mann-Whitney	Biosol Rate = 2,000 lbs/acre and Biosol Rate = 4,000 lbs/acre	Foliar Plant Cover	2008	No difference in foliar plant cover	U(3,9)=20	0.282
Mann-Whitney	Biosol Rate = 2,000 lbs/acre and Biosol Rate = 4,000 lbs/acre	Proportion of Annual Plant Cover to Foliar Plant Cover	2006	No difference in proportion of annual plant cover	U(3,9) = 19	0.373
Mann-Whitney	Biosol Rate = 2,000 lbs/acre and Biosol Rate = 4,000 lbs/acre	Proportion of Annual Plant Cover to Foliar Plant Cover	2007	No difference in proportion of annual plant cover	U(3,9)=21	0.209
Mann-Whitney	Biosol Rate = 2,000 lbs/acre and Biosol Rate = 4,000 lbs/acre	Proportion of Annual Plant Cover to Foliar Plant Cover	2008	No difference in proportion of annual plant cover	U(3,9)=23	0.100

Recommendations

These recommendations are for sites with rocky soils on volcanic parent material, with slope angles of approximately 28 degrees, solar exposures of 98% during the summer months, and at 6,900 feet (2,103 m) AMSL:

Tilling: 14 inches (36 cm)

Amendment: 6 inches of tub grindings

Biosol: 2,000 lbs/acre (2,241 kg/ha)

Seed: 50 lbs/acre (56 kg/ha) seed with the following composition:

mountain brome: 24%
blue wildrye: 24%
Western needlegrass: 16%
squirreltail: 24% (not used in tests)
nude buckwheat: 5%
native forbs and shrubs: 7%

Mulch: pine needles, 3 inches (8 cm) and 99% cover

Full treatment versus Surface Treatment

Full treatment is recommended over surface treatment because full treatment plots exhibited:

- on average, 680 times less sediment than the surface treatment plot from 2006 to 2008 (0.51 lbs/acre/in or 0.22 kg/ha/cm compared to 352 lbs/acre/in or 155 kg/ha/cm)
- twenty-three out of twenty-four simulations over three years that did not produce any sediment
- low sediment yields that were steady over time (0-6.2 lbs/acre/in or 0-2.7 kg/ha/cm)
- on average, infiltration rates that were 1.5 times higher than at the surface treatment plot (4.5 in/hr or 114 mm/hr compared to 3 in/hr or 76 mm/hr)
- a three-year average DTR (10.6 inches or 27 cm) for the 14 inch till depth plots that was 2.4 times higher than the three-year average DTR for the surface treatment plot (4.4 inches or 11 cm)
- DTRs that were similar to that of the native reference plot (6.9 inches or 18 cm for the 9 inch till depth plot and 10.6 inches or 27 cm and for the 14 inch till depth plot compared to 8.4 inches or 21 cm for the native reference plot)
- ground cover by mulch that has not degraded over time and has remained over 80% for all three years

- ground cover by mulch cover that was 5.0-5.6 times higher (three year averages from 78 to 88%) when compared to the surface treatment plot (two-year average of 16%)
- bare soil that was on average 10-117 times lower than at the surface treatment plot (63% compared to 0.5-6% at the surface treatment plot)
- foliar plant cover was 5.5 times higher at the full treatment plots amended with the 25% compost blend (three-year average of 34%) and 25% compost blend and tub grindings (three-year average of 34%) compared to the surface treatment plot (two-year average of 5%)
- average soil organic matter levels that were similar to those at the native reference plot (range of 6.3-6.7% at the full treatment plots compared to 6.6%)
- TKN values in 2008 at plots amended with the 25% compost blend or the 25% compost blend and tub grindings that were similar to those at the native reference plot (2,069 and 1,637 ppm respectively compared to 1,638 ppm)
- decreases in TKN that were at most 273 ppm over time, compared to a decrease of 800 ppm at the surface treatment plot

Soil Loosening versus No Soil Loosening

Soil loosening is recommended over no soil loosening because plots with soil loosening exhibited:

- on average, 680 times less sediment than the no soil loosening plot from 2006 to 2008 (0.51 lbs/acre/in or 0.22 kg/ha/cm compared to 352 lbs/acre/in or 155 kg/ha/cm)
- twenty-three out of twenty-four simulations over three years that did not produce any sediment
- low sediment yields that were steady over time (0-6.2 lbs/acre/in or 0-2.7 kg/ha/cm)
- on average, infiltration rates that were 1.5 times higher than at the no soil loosening plot (4.5 in/hr or 114 mm/hr compared to 3 in/hr or 76 mm/hr)
- a three-year average DTR (6.9 inches or 18 cm) for the 9 inch till depth plots that was 1.6 times higher than the three-year average DTR for the no soil loosening plot (4.4 inches or 11 cm)
- a three-year average DTR (10.6 inches or 27 cm) for the 14 inch till depth plots that was 2.4 times higher than the three-year average DTR for the no soil loosening plot (4.4 inches or 11 cm)
- DTRs that were similar to that of the native reference plot (6.9 inches or 18 cm for the 9 inch till depth plot and 10.6 inches or 27 cm and for the 14 inch till depth plot compared to 8.4 inches or 21 cm for the native reference plot)

- ground cover by mulch that has not degraded over time and has remained over 80% for all three years
- ground cover by mulch cover that was 5.0-5.6 times higher (three year averages from 78-88%) when compared to the no soil loosening plot (two-year average of 16%)
- bare soil that was on average 10-117 times lower than at the no soil loosening plot (63% compared to 0.5-6% at the surface treatment plot)
- foliar plant cover was 5.5 times higher at the soil loosening plots amended with the 25% compost blend (three-year average of 34%) and 25% compost blend and tub grindings (three-year average of 34%) compared to the no soil loosening plot (two-year average of 5%)
- average soil organic matter levels that were similar to those at the native reference plot (range of 6.3-6.7% at the soil loosening plots compared to 6.6%)
- TKN values in 2008 at the soil loosening plots amended with the 25% compost blend or the 25% compost blend and tub grindings that were similar to those at the native reference plot (2,069 and 1,637 ppm respectively compared to 1,638 ppm)
- decreases in TKN that were at most 273 ppm over time, compared to a decrease of 800 ppm at the no soil loosening plot

Soil Loosening Method (Hand Tilling versus Machine Tilling)

Machine tilling is recommended over hand tilling for the following reasons:

- Amendments can be more evenly distributed with machine tilling. Amendments were observed on the surface of the hand tilling plots. A larger proportion of amendments may remain near the surface when hand tilling is employed.
- Tilling by hand may limit actual tilling depth because loosening deeper than 9 inches by hand may not be feasible. Tilling to 14 inches is recommended at this site (see below).

Amendment Type (25% Compost Blend versus 25% Compost Blend and Tub grindings)

Tub grindings applied to 6 inches and tilled to 14 inches are recommended for incorporation over the 25% compost blend or the 25% compost blend and tub grindings. The plots with tub grindings exhibited:

- initial penetrometer DTRs that were significantly higher in 2006 at the 9 inch hand till plots by an average 1.7-2.0 times (11.4 inches or 29 cm compared to an average of 5.8 inches or 15 cm at the plots with the 25% compost blend or the 25% compost blend and tub grindings)

- seeded plant cover over two years that was not significantly different than the seeded cover at plots with the 25% compost blend or the 25% compost blend and tub grindings
- significantly lower proportions of cover by cheatgrass to foliar plant cover in 2007 compared plots amended with the 25% compost blend or the 25% compost blend and tub grindings (0-34% compared to 78-94% and 58-100%, respectively)
- similar organic matter levels to plots amended with the 25% compost blend or the 25% compost blend and tub grindings (6.3 to 6.7%)
- similar organic matter levels to the native reference plot (6.6%)

Amendment Rate

Six inches of amendment, tilled by excavator to 14 inches are recommended. Four inches of amendment were applied to all of the full treatment test plots. The proportion of amendments at the 9 inch till depth plots was 64% (4 inches divided by 9 inches), compared to 29% at the 14 inch till depth plots. An intermediate proportion is recommended - 42% - which corresponds to 6 inches of amendment tilled to 14 inches for the following reasons:

- The increase in application depth from 4 to 6 inches may increase TKN, which was lower for the tub grindings plots (1,197 ppm) compared to the plots with the 25% compost blend (2,069 ppm) or the 25% compost blend and tub grindings (1,637 ppm).

Biosol Rate

Biosol is recommended at a rate of 2,000 lbs/acre (2,241 kg/ha) rather than 4,000 lbs/acre (4,483 kg/ha) for the following reason:

- for 2006, 2007, and 2008, Biosol rate did not significantly affect foliar plant cover or the proportion of annual plant cover; therefore the increased cost of doubling the Biosol rate is not necessary.

Seed Mix and Rate

An alternative to the tested mix of native grass, forb, and shrub seed is recommended at a rate 50 lbs/acre (56 kg/ha), rather than at 150 lbs/acre (168 kg/ha) with the following composition:

mountain brome: 24%
blue wildrye: 24%
Western needlegrass: 16%
squirreltail: 24% (not used in tests)
nude buckwheat: 5%
native forbs and shrubs: 7%

This mix is recommended for the following reasons:

- In 2007 and 2008, plots with higher seed rates had significantly higher cover by seeded species by 2.6-5.5 times (0-20% for the high seed rate plots and 0-2.6% for the low seed rate plots). However, since vegetation levels were low overall, average differences of less than 8% were measured between the high and low seed rates. The higher rate, which can increase cost appreciably, will not be recommended based on an 8% difference in plant cover.
- mountain brome, blue wildrye, and Western needlegrass, and nude buckwheat were present at most of the test plots and are therefore recommended as tested
- squirreltail was added to the recommended mix because it thrives at sites with similar characteristics

Mulch Type and Depth

Mulch composed of native pine needles should be applied at a depth of 3 inches (8 cm) and a ground cover of at least 99% for the following reasons. Plots with this application, compared to the 0.5 inch (1.3 cm) application at the surface treatment plot exhibited:

- ground cover by mulch that has not degraded over time and has remained over 80% for three years
- ground cover by mulch that was 5.0-5.6 times higher than at the plot with the 0.5 inch (1.3 cm) mulch application (78-88% compared to 16%)
- bare soil was 10-117 times lower than at the plot with the 0.5 inch (1.3 cm) mulch application (0.5-6% compared to 63%)

Appendix A

Species list and ocular estimates for the Brockway Summit Test plots, 2006. Ocular estimates, in percent, are presented below the plot numbers. “T” indicates trace amounts of cover. “X” indicates presence

Lifeform	Family	Scientific name	Common name	Annual / Perennial	Native / Alien	Invasive / Noxious	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10	Plot 11	Plot 12	Native
Forb	Brassicaceae	*Capsella bursa-pastoris*	shepherd's purse	Annual	Alien	Invasive								T					
Forb	Brassicaceae	*Descurainia Sophia*	herb Sophia	Annual	Alien	Invasive	< 5		T						T				
Forb	Geraniaceae	*Erodium cicutarium*	red stem storksbill	Annual	Alien														
Forb	Asteraceae	*Lactuca serriola*	devil's lettuce	Annual	Alien						T			T					
Forb	Polygonaceae	*Polygonum douglasii*	Douglas knotweed	Annual	Native		T												
Forb	Brassicaceae	*Sisymbrium altissimum*	tumble mustard	Annual	Alien		< 5			T	T	5 - 10		T			20		
Forb	Scrophulariaceae	*Verbascum thapsis*	mullen	Annual	Native	Invasive									T		T		
Forb	Brassicaceae	*Lepidium campestre*	English pepperweed	Annual	Alien						T		T	T	T				
Forb	Polemoniaceae	*Phlox gracilis*	slender phlox	Annual	Native						T								
Forb	Asteraceae	*Achillea millefolium*	yarrow	Perennial	Native		T		T		T								
Forb	Asteraceae	*Antennaria rosea*	pussy toes	Perennial	Native												5 - 10		
Forb	Polygonaceae	*Eriogonum nudum*	nude buckwheat	Perennial	Native						< 5		T						
Forb	Polygonaceae	*Eriogonum umbellatum*	sulphur flower buckwheat	Perennial	Native		T		T		< 5	T	T	T			T		
Forb	Onagraceae	*Gayophytum diffusum*	groundsmoke	Perennial	Native		< 5	T	< 5	< 10	20	T	< 5	T	5 - 10	T	< 5	T	
Forb	Fabaceae	*Lotus purshianus*	Spanish lotus	Perennial	Native						T	T	T						
Forb	Fabaceae	*Lupinus argenteus*	silver lupine	Perennial	Native		T	T	T		T	T							
Forb	Fabaceae	*Lupinus lepidus (culbertsonii)*	Culberton's lupine	Perennial	Native											T			
Forb	Onagraceae	*Oenethera sp.*	evening primrose	Perennial	Native		T						T						
Forb	Hydrophyllaceae	*Phacelia hastata*	silverleaf phacelia	Perennial	Native		T										T		
Graminoid	Poaceae	*Bromus tectorum*	cheatgrass	Annual	Alien	Invasive	30 - 40		30 - 40	40	25	25	50 - 60	80	30	< 5	25	T	
Graminoid	Poaceae	*Hordeum vulgare*	barley	Annual	Alien		5			T		T	T						
Graminoid	Poaceae	*Elytrigia intermedia*	intermediate wheatgrass	Perennial	Alien										5				
Graminoid	Poaceae	*Bromus carinatus*	mountain brome	Perennial	Native			< 5	T	T	< 5	T	< 5	< 5		< 5	< 5	T	
Graminoid	Poaceae	*Deschampsia elongata*	elongated hairgrass	Perennial	Native						T								
Graminoid	Poaceae	*Elymus elymoides*	squirreltail	Perennial	Native		< 5		< 5						T	T		T	
Graminoid	Poaceae	*Elymus glaucus*	blue wildrye	Perennial	Native		5		T		< 5			T	T	T			
Shrub	Ericaceae	*Arctostaphylos patula*	greenleaf Manzinita	Perennial	Native														x
Shrub	Rhamnaceae	*Ceanothus prostratus*	Squaw Carpet	Perennial	Native														x
Shrub	Fagaceae	*Quercus vacinifolia*	huckleberry oak	Perennial	Native														x
Tree	Pinaceae	*Pinus jefferyi*	Jeffrey pine	Perennial	Native								T	5 - 10			< 5		

Species list and ocular estimates for the Brockway Summit Test plots, 2007. Ocular estimates, in percent, are presented below the plot numbers. “T” indicates trace amounts of cover. “X” indicates presence

Lifeform	Family	Scientific name	Common name	Annual/ Perennial	Native/ Alien	Invasive/ Noxious	% in seed mix	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10	Plot 11	Plot 12	Plot BC
Forb	Asteraceae	*Achillea millefolium*	yarrow	Perennial	Native		4.82%			T										
Forb	Asteraceae	*Antennaria rosea*	pussy toes	Perennial	Native													<5		
Forb	Brassicaceae	*Arabis holboellii*	Holboel's rockcress	Perennial	Native						T									
Forb	Brassicaceae	*Capsella bursa-pastoris*	sheperd's purse	Annual	Alien	Invasive														
Forb	Brassicaceae	*Descurainia sophia*	herb Sophia	Annual	Alien	Invasive		T										T		
Forb	Polygonaceae	*Eriogonum nudum*	nude buckwheat	Perennial	Native		4.82%		T		<5	5-10	<5	<5		<5				
Forb	Polygonaceae	*Eriogonum umbellatum*	sulphur flower buckwheat	Perennial	Native			5-10		<5	5	5-10	5-10	5-10	5	5	T	<5	<5	
Forb	Geraniaceae	*Erodium cicutarium*	red stem storksbill	Annual	Alien									T						
Forb	Onagraceae	*Gayophytum diffusum*	groundsmoke	Perennial	Native				T	<5	T		T			T				T
Forb	Brassicaceae	*Isatis tinctoria*	dyer's woad	Annual	Alien	Noxious		5-10			T			<5						
Forb	Fabaceae	*Lotus purshianus*	Spanish lotus	Perennial	Native		7.24%													
Forb	Fabaceae	*Lupinus argenteus*	silver lupine	Perennial	Native		4.82%									T	T			
Forb	Fabaceae	*Lupinus lepidus (culbertsonii)*	Culberton's lupine	Perennial	Native															
Forb	Fabaceae	*Lupinus fulcratus*	green stipuled lupine	Perennial	Native		4.82%													
Forb	Hydrophyllaceae	*Phacelia hastata*	silverleaf phacelia	Perennial	Native			T	T											
Forb	Brassicaceae	*Sisymbrium altissimum*	tumble mustard	Annual	Alien									T				<5		
Forb	Scrophulariaceae	*Verbascum thapsis*	mullen	Annual	Native	Invasive											T			
Graminoid	Poaceae	*Achnatherum occidentale*	Western needlegrass	Perennial	Native		15.66%													
Graminoid	Poaceae	*Elytrigia intermedia*	intermediate wheatgrass	Perennial	Alien			T					T		5	5				
Graminoid	Poaceae	*Bromus carinatus*	mountain brome	Perennial	Native		24.12%	T	T	T	T			T			<5			
Graminoid	Poaceae	*Bromus tectorum*	cheatgrass	Annual	Alien	Invasive		55 - 60	T	40-45	65	50-60	T	70	70	30	<5	80	T	T
Graminoid	Poaceae	*Dactylis glomerata*	orchard grass	Perennial	Alien	Invasive						T								
Graminoid	Poaceae	*Deschampsia elongata*	elongated hairgrass	Perennial	Native		4.82%													
Graminoid	Poaceae	*Elymus elymoides*	squirreltail	Perennial	Native								T			T	T			
Graminoid	Poaceae	*Elymus glaucus*	blue wildrye	Perennial	Native		24.12%	T				T								
Shrub	Rosaceae	*Prunus emarginata*	bitter cherry	Perennial	Native				T											T
Shrub	Rosaceae	*Purshia tridentata*	antelope bitterbrush	Perennial	Native		4.82%													
Tree	Pinaceae	*Pinus jeffreyi*	Jeffrey pine	Perennial	Native									T	10			5	5-10	

Species list and ocular estimates for the Brockway Summit Test plots, 2008. Ocular estimates, in percent, are presented below the plot numbers. "T" indicates trace amounts of cover.

Lifeform	Family	Scientific name	Common name	Annual / Perennial	Native / Alien	Invasive / Noxious	In seed mix?	% in seed mix	Plot BC	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10	Plot 11	Plot 12
Forb	Asteraceae	*Achillea millefolium*	yarrow	Perennial	Native		X	4.82%				T				T					
Forb	Brassicaceae	*Arabis holboellii*	Holboel's rockcress	Perennial	Native													T			
Forb	Brassicaceae	*Descurainia sophia*	herb Sophia	Annual	Alien	Invasive				1										T	
Forb	Polygonaceae	*Eriogonum nudum*	nude buckwheat	Perennial	Native		X	4.82%		6	T	7	10	12	17	27	6	6	1	2	T
Forb	Onagraceae	*Gayophytum sp.*	groundsmoke	Annual	Native					T	T	T			T						
Forb	Brassicaceae	*Isatis tinctoria*	dyers woad	Perennial/ Biennial	Alien	Invasive				2						T					
Forb	Fabaceae	*Lotus purshianus var. purshianus*	Spanish lotus	Perennial	Native		X	7.24%													
Forb	Fabaceae	*Lupinus argenteus*	silver lupine	Perennial	Native		X	4.82%													
Forb	Fabaceae	*Lupinus lepidus*	Culberton's lupine	Perennial	Native					T	T	T									
Forb	Fabaceae	*Lupinus fulcratus*	green stipuled lupine	Perennial	Native			4.82%													
Forb	Onagraceae	*Oenothera elata*	evening primrose	Perennial	Native					T											
Forb	Hydrophyllaceae	*Phacelia hastata*	silverleaf phacelia	Perennial	Native						T										
Forb	Brassicaceae	*Sisymbrium altissimum*	tumble mustard	Annual	Alien															T	
Forb	Asteraceae	*Tragopogon dubius*	false salsify	Annual	Alien				T												
Graminoid	Poaceae	*Achnatherum occidentale*	Western needlegrass	Perennial	Native		X	15.66%		T								T			
Graminoid	Poaceae	*Bromus carinatus*	mountain brome	Perennial	Native		X	24.12%			T						T		T	T	T
Graminoid	Poaceae	*Bromus tectorum*	cheatgrass	Annual	Alien	Invasive			T	18		14	5	10	3		3	3	2	11	
Graminoid	Poaceae	*Deschampsia elongata*	elongated hairgrass	Perennial	Native			4.82%													
Graminoid	Poaceae	*Elymus elymoides*	squirreltail	Perennial	Native		X			T				T		T		T	T		
Graminoid	Poaceae	*Elymus glaucus*	blue wildrye	Perennial	Native		X	24.12%		T			T	T		T		T	T	T	
Graminoid	Poaceae	*Elytrigia intermedia*	intermediate wheatgrass	Perennial	Alien					T					T		T				
Shrub	Rosaceae	*Prunus emarginata*	bitter cherry	Perennial	Native				2	T	T										
Shrub	Rosaceae	*Purshia tridentata*	antelope bitterbrush	Perennial	Native		X	4.82%	1												
Tree	Cupressaceae	*Calocedrus decurrens*	incense cedar	Perennial	Native									T							
Tree	Pinaceae	*Pinus jeffreyi*	Jeffrey pine	Perennial	Native				3							T	7	T		T	2
TOTAL (transects)									6%	31%	0%	25%	14%	22%	20%	27%	29%	16%	8%	13%	4%
TOTAL (ocular estimate)									6%	28%	1%	22%	15%	22%	20%	28%	16%	10%	4%	14%	2%

Heavenly Valley Resort Canyon Test Plots Site Report

May 2009

Introduction

Monitoring results and erosion control treatment recommendations for a series 27 test plots at the Heavenly Valley Resort (Heavenly test plots) and a native reference plot will be presented in this report. Monitoring was conducted in 2004, 2005, 2006, 2007, and 2008, although the intensity of monitoring varied among years. The Heavenly Valley Mountain Resort spans the California and Nevada border area near the southeast corner of Lake Tahoe (Figure 1). The plots were installed in 2003 at the bottom of Betty's Bowl ski run, near the Canyon chairlift (Figure 2). The native reference plot is adjacent to Betty's Bowl ski run in a forested area. Although these plots are located at a ski area, rather than on a roadside, the monitoring results from the tests at these areas will be applicable to Caltrans roadside projects Basin-wide and throughout the Sierra Nevada.

Figure 1. Test and reference plots site location near the southeast shore of Lake Tahoe.

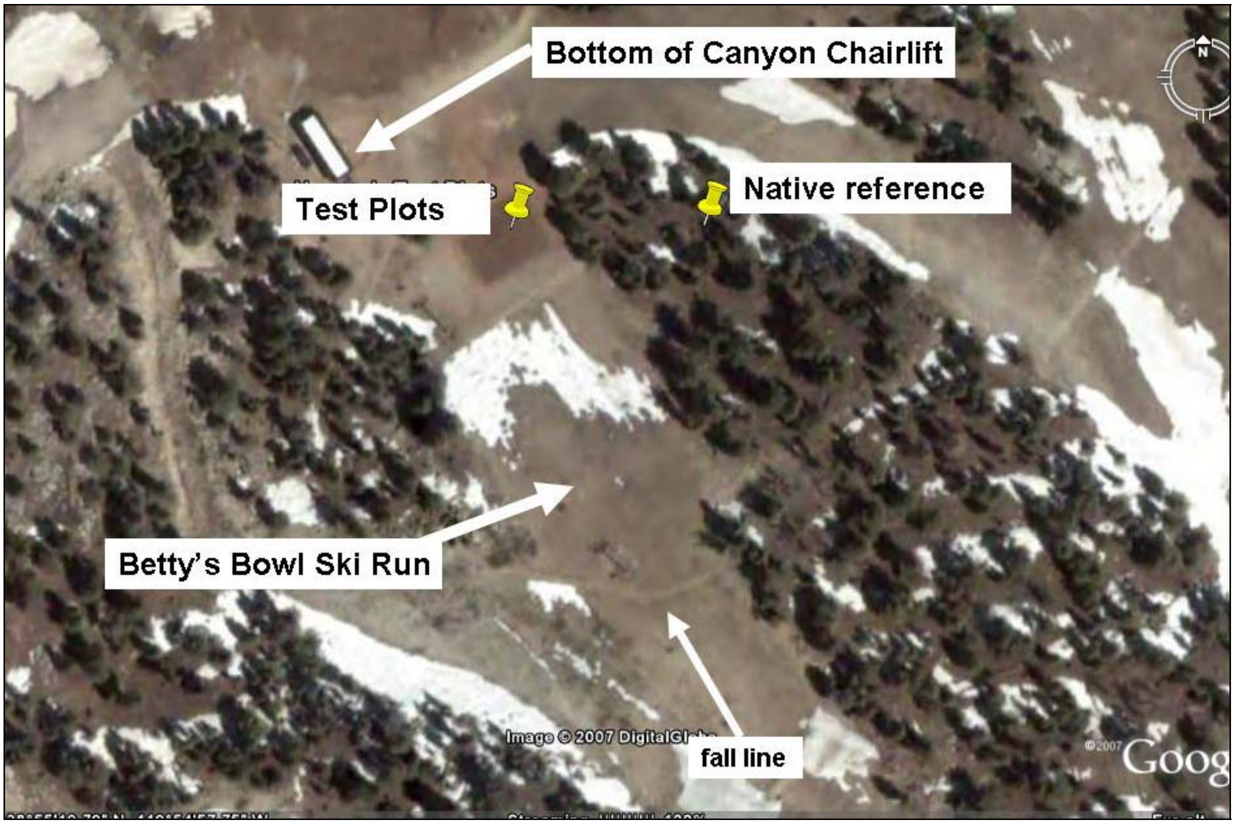

Figure 2. Test plot and reference site location at Heavenly Valley Resort.

Purpose

The project's monitoring objectives are outlined below. The following treatment definitions are included to aid understanding of these objectives.

Full Treatment: includes soil loosening by tilling, incorporation of an organic amendment such as compost, coarse overs or woodchips, addition of fertilizer and native seed, and application of native mulch.

Partial Treatment: variations of full treatment used in tests to isolate certain elements of full treatment (for example, the effects of varying amounts of Biosol fertilizer).

Surface Treatment: does not include the incorporation of organic matter into the soil. This treatment may include surface fertilizing, seeding, or hydromulching and is similar to Caltrans Erosion Control Type D (EC Type D).

The monitoring data was studied and analyzed to investigate:

1. the erosion control differences between full treatment and surface treatment plots
2. the erosion control differences between soil loosening plots with and without amendments
3. the effects of different types of organic matter (compost, woodchips, and coarse overs) on penetrometer depth to refusal (DTR), soil nutrient levels and availability, and plant growth

4. the effect of seeding on seeded plant cover
5. the effect of Biosol fertilizer on soil nutrients levels and plant cover

Site Description

Test Plots

The test plots are located at the bottom of Betty's Bowl, a north facing ski slope at Heavenly Ski Resort (Figure 3 and Figure 4). The site elevation is 8,562 feet (2,610 m) above mean sea level (AMSL) and the slope angle at the test plots is approximately 16 degrees. The solar exposure ranges from 78-91% during the summer.

At an unknown time before test plot installation, Betty's Bowl ski run was roughly graded and tree stumps and rocks were removed. Prior to treatment, the area exhibited rills and sheet erosion (Figure 5). Soils in the test area are derived from granitic parent material. Soil particle size analysis classified the soil as a sandy loam to sand with greater than 86% sand, 6% to 8% silt, and 5% clay. The soils have an average of 17% coarse material (greater than 0.5 inch or 1.3 cm diameter). Local native vegetation consists of a higher elevation mixed conifer forest with Western white pine (*Pinus monticola*), red fir (*Abies magnifica*) and lodgepole pine (*Pinus contorta*) as the dominant overstory species. The understory vegetation consists of forbs and grasses. In 2008, disturbance by small animals was noted throughout the test plot area. There was evidence of grazing as well as several animal burrows. During the winter of 2006-7, a gully formed upslope of the test plots and directed water downslope through plots 4, 10, 16, and 22. These plots were not sampled in 2007 because ground and plant cover disturbance was apparent at these plots (Figure 5). Plots 16 and 22 were monitored in 2008 as the disturbance was not longer apparent.

Figure 3. Heavenly Canyon test plots, 2007.

Figure 4. Heavenly Canyon test plots, 2008.

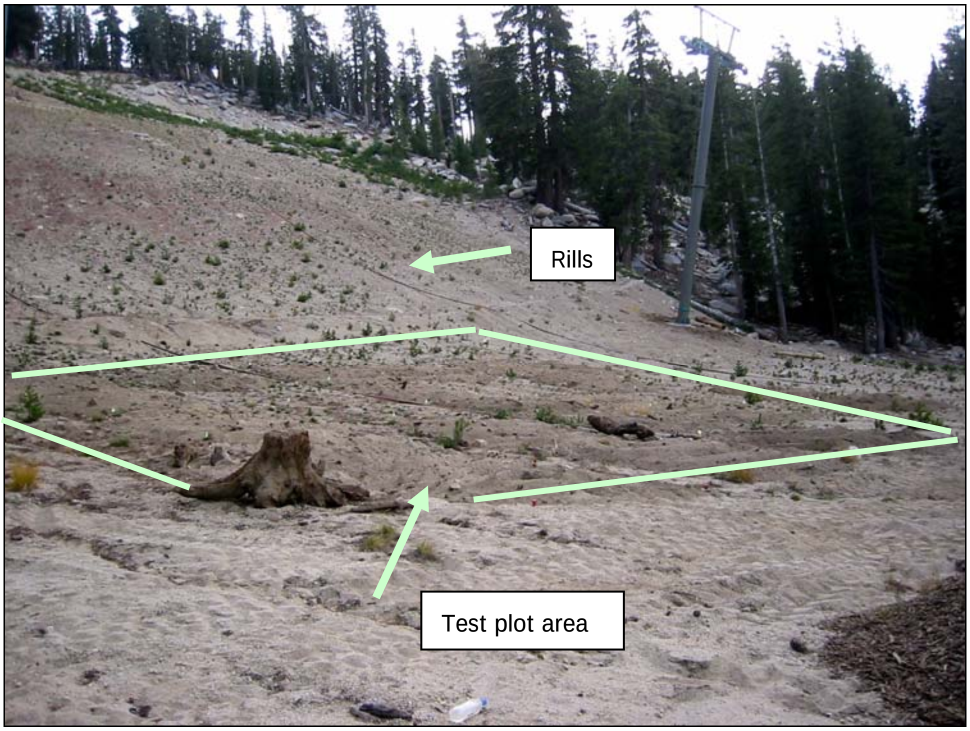

Figure 5. Test plots area following construction. Rills are apparent on the untreated slope above the plots, 2003.

Native Reference Plot

The native plot is located at the same elevation and aspect as the test plots and derives from the same parent material, with similar surrounding vegetation (Figure 6). The soil had approximately 30% coarse material greater than 0.5 inch (1.3 cm) diameter. The plot is in a forested, relatively undisturbed area that has a solar exposure of approximately 23%. The dominant understory species are: pioneer rockcress (*Arabis platysperma*), spike tritesum (*Tritesum spicatum*), and Ross's sedge (*Carex rosii*).

Figure 6. Heavenly Canyon native reference plot.

Treatment Overview

The test plot area consists of a grid of 18 full treatment plots, 6 partial treatment plots, and 6 untreated plots (with an existing surface treatment), for a total of 30 plots (Figure 7). Each plot is 3.3 ft by 3.3 ft (1 m by 1 m) and is buffered by 3.3 ft (1 m) on all sides. These treatments will be explained in detail below.

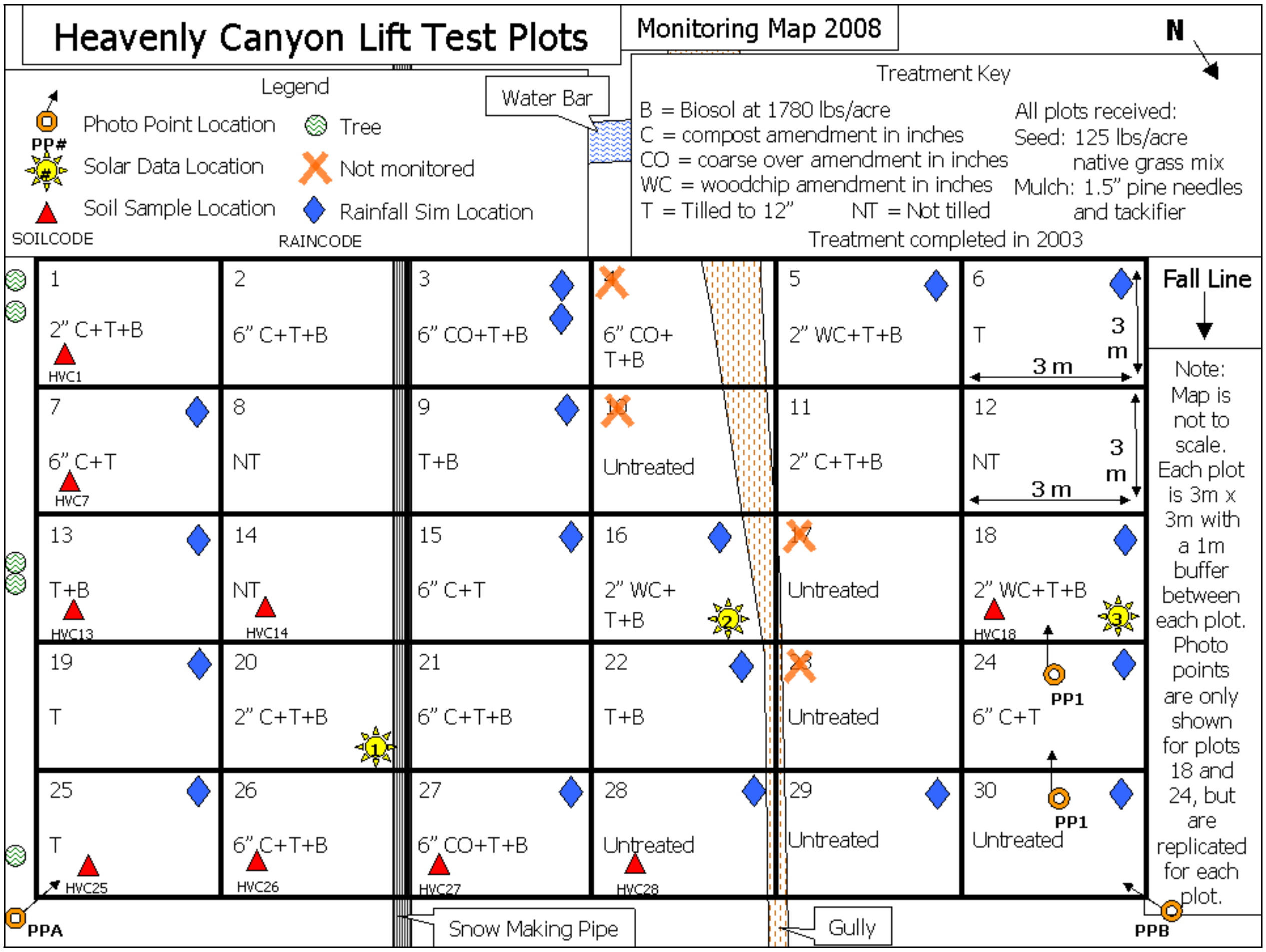

Figure 7. Map of the Heavenly Test Plots with treatment key. Rainfall simulation, photo points, soil sample, and Solar Pathfinder locations are marked. Rainfall markers indicate the treatment type sampled, not actual simulation locations.

Test Plot Treatments

Test plot treatments are presented in Table 1. Descriptions of these treatments can be found following the table.

Table 1. Heavenly Canyon Treatments.

Plots	Treatment Category	Amendment Type and Depth	Soil Loosening	Biosol Rate (kg/ha)	Seed Type	Seed Rate (lbs/acre)	Mulch Type and Depth
1, 11, 20	Full Treatment	2” Compost	12” Tilled	2,000	Native Grass Seed	125	1.5” Pine Needles
2, 21, 26	Full Treatment	6” Compost	12” Tilled	2,000	Native Grass Seed	125	1.5” Pine Needles
3, 4, 27	Full Treatment	6” Coarse overs	12” Tilled	2,000	Native Grass Seed	125	1.5” Pine Needles
5, 16, 18	Full Treatment	2” Woodchips	12” Tilled	2,000	Native Grass Seed	125	1.5” Pine Needles
6, 19, 25	Partial Treatment	None	12” Tilled	None	Native Grass Seed	125	1.5” Pine Needles
7, 15, 24	Partial Treatment	6” Compost	12” Tilled	None	Native Grass Seed	125	1.5” Pine Needles
8, 12, 14	Partial Treatment	None	None	None	Native Grass Seed	125	1.5” Pine Needles
9, 13, 22	Partial Treatment	None	12” Tilled	2,000	Native Grass Seed	125	1.5” Pine Needles
28, 29, 30	Surface Treatment	None	None	unknown	unknown	unknown	None

Soil Loosening

Soil loosening was conducted at all 12 of the full treatment plots (test groups: 1, 11, 20; 2, 21, 26; 3, 4, 27; and 5, 16, 18) and at 9 of the partial treatment plots (test groups: 6, 19, 25; 7, 15, 24; and 9, 13, 22; Table 1). All of these plots were tilled to at least 12 inches (30 cm) with a Woods backhoe attached to a Kubota 3830 tractor (Figure 10). Each plot was tilled with the tractor positioned on the uphill side of the slope to minimize down slope movement of soil and amendments. Due to logistical problems and the steepness of the slope, plots 1, 2, and 11 were tilled with a Gradall 43-foot reach forklift.

Amendments

Three different types of amendments (compost, wood chips, and coarse overs) were applied at two different rates and were incorporated to 12 inches (30 cm) at specific test plots (Table 1).

Compost

Screened compost, called the Integrated Tahoe Blend 100%, was obtained from Full Circle Compost in Minden, Nevada. Compost was applied at two depths at specific plots: 2 inches (5 cm) and 6 inches (15 cm; Table 1).

Coarse Overs

Coarse overs (also called wood overs) were obtained from Full Circle Compost in Minden, Nevada. Coarse overs are composted wood waste that remains after the composting process.

Coarse overs range in size from 3/8 to 3 inches (1-7.6 cm). Coarse overs were spread to a depth of 6 inches (15 cm) at specific plots (Table 1).

Woodchips

Woodchips were supplied by Heavenly Valley Resort and were most likely chipped on-site. Woodchips were spread to a depth of 6 inches (15 cm) at specific plots (Table 1).

Figure 8. From left to right, coarse overs, compost, and woodchips amendments.

Figure 9. Woodchip application with the Kubota 3830.

Fertilizer

Following incorporation of amendments, Biosol, a slow-release organic fertilizer, with a 6-1-3 nitrogen-phosphorous-potassium ratio, was applied on specific plots at a rate of 1,780 lbs/acre (2,000 kg/ha; Table 1). The Biosol was applied by hand after tilling (if applicable) and was raked into the soil surface to a depth of 1 inch (2.5 cm) at specific plots (Table 1). It is not known whether any fertilizer was applied to the surface treatment plots.

Seeding

After fertilizer was applied, all plots were seeded with native grass (Table 2). The grass seed was applied at 125 lbs/acre (140 kg/ha). The seed was lightly raked into the soil surface to a depth of ¼ inch (0.6 cm) to ensure adequate contact with the soil. The seed mix and rate applied to the surface treatment plot is unknown.

Table 2. Seed mix species composition.

Common Name	*Scientific Name*	% mix
Mountain brome	*Bromus carinatus*	29.01
Squirreltail	*Elymus elymoides*	26.56
Blue wildrye	*Elymus glaucus*	24.58
Western needlegrass	*Achnathrum occidentale*	12.62
Total		92.77*
*The remaining composition is unknown		

Mulch

Pine needle mulch was sourced from a Douglas County, Nevada Fire Department collection and retrieved from the Caltrans South Lake Tahoe snow storage yard. Approximately 40 cubic yards (30.5 m^3) were necessary to cover the applicable test plot at a 1.5 inch (4 cm) depth (Figure 11).

Tackifier

After the pine needle mulch was applied, a paddle agitator-equipped hydroseeder was used to apply two coats of tackifier to the entire treatment area. The tank was filled with water, one 50 lb (23 kg) bag of tackifier, and ½ a bale of wood fiber mulch.

Figure 10. Tilling using the Kubota tractor with a Wood's backhoe.

Figure 11. Applying mulch to test plots by hand.

Monitoring Methods

Monitoring at the Heavenly test plots has occurred each year since their construction in 2003. The level of detail in monitoring varied among years, but generally became more rigorous over time. The types of monitoring conducted during each year are presented in Table 3. In the text, both English and metric units will be given; however, tables will contain one or the other.

Table 3. Types of monitoring by year

Year	Soil and/or Vegetation Monitoring	Rainfall Simulation	Native Reference Monitoring
2004	No	5 of 9 treatment types	
2005	Penetrometer and soil moisture at selected plots in random locations	No	
2006	Penetrometer, soil moisture in random locations, ocular estimates of cover, soil samples at all plots	5 of 9 treatment types	Rainfall, penetrometer, soil moisture in random locations, cover, soil samples

Year	Soil and/or Vegetation Monitoring	Rainfall Simulation	Native Reference Monitoring
2007	Penetrometer, soil moisture, and cover on transects, ocular estimates of cover, soil samples at all plots except 4, 10, 16, 22, 28, 29, 30	8 of 9 treatment types	
2008	Penetrometer, soil moisture, and cover on transects, ocular estimates of cover, soil samples at all plots except 4, 10, 17, and 23.	9 of 9 treatment types	

Rainfall Simulation

Rainfall simulation was conducted in 2004, 2005, 2006, 2007, and 2008 on different plots within the treatment area, and at the native reference plot (Table 4). In 2004, three replications were conducted on each plot listed below. Rainfall simulation was not conducted at the native reference plot in 2004 or 2007. In 2005 and 2006, only one rainfall simulation was conducted on each plot, but three plots of each treatment were used to obtain three replicates of each treatment type (Table 4). In 2007, three replicates were conducted of each treatment type. In 2007, plots 4, 10, 16, and 22 were not monitored; therefore, other plots with the same treatments had more than one rainfall frame replication per plot.

Table 4. Rainfall simulation treatment types 2004-8.

Years Monitored	Treatment
2004	6" Compost, Seed=125 lbs/acre, Till 12 "
2004	2" Woodchips, Biosol=2,000 kg/ha, Seed=125 lbs/acre, Till 12"
2004	6" Coarse overs, Biosol=2,000 kg/ha, Seed=125 lbs/acre, Till 12"
2004, 2005, 2006, 2007, 2008	Seed=125 lbs/acre, Till 12"
2004, 2007, 2008	Seed=125 lbs/acre
2007, 2008	Biosol=2,000 kg/ha, Seed=125 lbs/acre, Till 12"
2007, 2008	6" Compost, Biosol=2,000 kg/ha, Seed=125 lbs/acre, Till 12"
2007, 2008	2" Compost, Biosol=2,000 kg/ha, Seed=125 lbs/acre. Till 12"
2008	Existing surface treatment

The rainfall simulator "rains" on a square plot from a height of 3.3 feet (1 m) (Figure 12 and Figure 13). The rate of rainfall is controlled, and runoff is collected from a trough at the bottom of a 6.5 ft^2 (0.6 m^2) frame that is pounded into the ground. The volume of water collected is measured; then the volume of infiltration is calculated by subtracting the volume of runoff from the total volume of water applied to the plot. If runoff was not observed during the first 30 minutes, the simulation was stopped. The average steady state infiltration rate was calculated and will hereafter be referred to as "infiltration rate". The collected runoff samples were then analyzed for the average steady state sediment yield (hereafter referred to as "sediment yield").

Before rainfall simulations, in the area surrounding the runoff frames, a cone penetrometer was used to record the depth to refusal (DTR) which is an index for soil density. In 2004 and 2005, the DTR was read at 100 psi (689 kPa), which is too low to compare to the current standard. These values were not used in this report. The 2006 DTR pre-rainfall values that were taken at a maximum pressure of 250 psi (1,724 kPa) and the 2007 and 2008 DTR values that were taken at 350 psi (2,413 kPa) are presented in this report. Soil moisture was also measured in each runoff frame prior to conducting the rainfall simulations. After rainfall simulation, at least three holes were dug with a trowel to determine the depth to wetting front, which shows how deeply the water infiltrated within the frame. In 2007 and 2008, at least nine holes were dug to measure the depth to wetting.

Different rainfall rates were applied to different plots depending on their propensity to runoff. In most cases, the initial rainfall rate applied to the test plots was 2.8 to 3.0 in/hr (70 to 75 mm/hr). If runoff was not observed, the rainfall rate was increased to 4.7 in/hr (120 mm/hr) until runoff was observed or all the water was infiltrated. In 2008, 4.7 in/hr was the only rate applied. The rainfall rate of 2.8 in/hr (70 mm/hr) is more than twice the intensity of the 20 year, 1 hour "design storm" for the local area.

Figure 12. Photo of the rainfall simulator and frame.

Figure 13. Photo of the rainfall simulator at the native reference site, 2006.

Cover

Two methods of measuring cover were conducted at the test plots: ocular estimation and cover point on transects. Cover point monitoring on transects is a statistically defensible method, while ocular estimates are subjective and vary by the observer. Ocular estimates tend to over estimate cover by 10% to 25%. These estimates cannot be directly compared with cover point values, but can be used to detect general differences among plots and treatments.

These two sets of photos illustrate the difference between plant cover values obtained from ocular estimates and cover point measurements (Figure 14, Figure 15, Figure 16, and Figure 17).

Figure 14. Plot 27, 6" Coarse overs in 2006. Ocular estimate of total cover is 52%.

Figure 15. Plot 27, 6" Coarse overs in 2007. Ocular estimate of total cover is 35%. Total cover as measured by cover point is 10%.

Figure 16. Plot 22, seed only, in 2006. Ocular estimate of total cover is 26.5%.

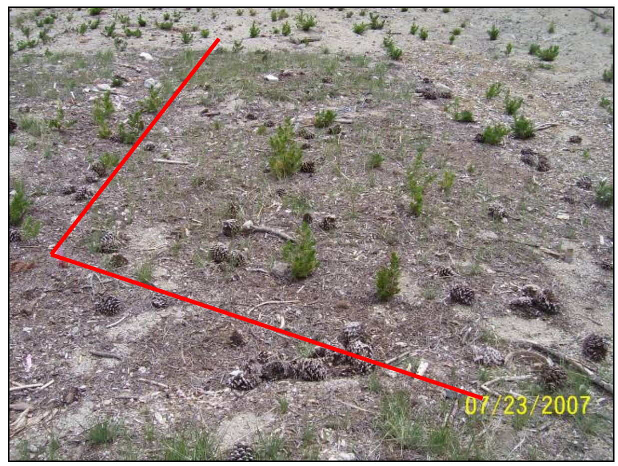

Figure 17. Plot 12, seed only, in 2007. Ocular estimate of total cover is 27%. Total cover as measure by cover point is 12%.

In 2007 and 2008, cover was measured using the cover point method along randomly located transects.[1] Cover point monitoring is a statistically defensible method of measuring plant and foliar cover (hereafter referred to as either "plant cover" or "foliar plant cover"), plant composition and mulch cover. The cover pointer consists of a metal rod with a laser pointer mounted 3.3 feet (1 m) high. After the rod is leveled in all directions, the button on the laser pointer is depressed and two cover measurements were recorded (Figure 18 and Figure 19):

- the first hit cover, which represents the first object intercepted starting from a height of 3.3 ft (1 m) above the ground and

[1] Hogan, M. 2003. Luther Pass Monitoring Report: Plant and Soil Cover Monitoring for Evaluating Sediment Source Control Success in the Lake Tahoe Basin. Lahontan Regional Water Quality Control Board, South Lake Tahoe, CA.

- the ground cover hit, which is the low lying vegetation or soil below the first hit cover, at the ground level

The first hit cover measures the foliar cover by plants (leaves and stems). It does not measure the part of the plant actually rooted in the ground. The ground cover hit measures whatever is lying on the ground or rooted in the ground (i.e. litter/mulch, bare ground, basal (or rooted) plant cover, rock, and woody debris). Total ground cover represents any cover other than bare ground.

Figure 18. Cover pointer in use along transects.

Figure 19. Cover pointer rod with first hit and ground cover hits by the laser pointer. The laser pointer hits are circled in red. The first cover hit is a native grass and the ground cover hit is pine needle mulch.

Plant cover both on the ground and foliar were recorded by species and then organized into cover groups based on four categories: lifeform (herbaceous/woody), perennial/annual, native/alien, and seeded/volunteer. Perennial herbaceous species includes seeded grasses, native grasses and forbs and any non-native perennial species. Annual herbaceous species included native annuals such as groundsmoke (*Gayophytum sp.)* and spurry buckwheat (*Eriogonum spergularium*). Few non-native annuals were present at this site. Woody species are any tree and shrub species of interest, whether native or introduced. Each species was then classified based on whether it is native to the Tahoe area and whether it was seeded during treatment. Data is also presented on the amount of cover by species. An ocular estimate of cover is also recorded and includes many species not hit using cover sampling. The species lists, as well as the ocular estimates of cover by species, are presented in Appendix A.

Soil and Site Physical Conditions

Penetrometer and Soil Moisture

In 2005 penetrometer measurement were conducted without soil moisture measurements at random plot locations. In 2006, penetrometer and soil moisture readings were taken at random locations in each plot. In 2007 and 2008, penetrometer readings were measured along the same transects as the cover point data.

The cone penetrometer, with a ½ inch diameter tip, is pushed straight down into the soil until a maximum pressure of 350 pounds per square inch (2,413 kPa) is reached (Figure 20 and Figure 21). Although the rainfall frame maximum pressure was 250 psi in 2006, the maximum pressure for DTRs measured on transects was 350 psi for all years, including 2006. The depth at which that pressure is reached is recorded as the depth to refusal (DTR).

Cone penetrometer DTR measurements are used as an index for soil density. A denser soil is less likely to allow infiltration. Rainfall simulations conducted on roadcuts in Oregon found increased infiltration rates in soils with penetrometer depths to refusal (DTRs) greater than 4 inches (10 cm).[2]

It is most informative to compare penetrometer DTR measurements collected in soils that have similar moisture levels. When soil moisture content increases, the resistance of the soil to the penetrometer decreases and DTR readings are deeper. Therefore, only penetrometer readings at the same soil moisture can be compared. A hydrometer was used to measure volumetric soil moisture content adjacent to the penetrometer readings at a depth of 4.7 inches (12 cm; Figure 22).

Figure 20. Cone penetrometer dial, showing pressure applied in pounds per square inch.

Figure 21. Conducting cone penetrometer readings along transects.

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[2] Grismer, M.E. 2006. Simulated Rainfall Evaluation at Sunriver and Mt. Bachelor Highways, Oregon. Unpublished.

Solar Pathfinder

Solar exposure measurements were taken using a Solar Pathfinder in 2006 (Figure 23). Since there was no change in solar obstructions at the test plots, the solar pathfinder data was not collected again in 2007 or 2008. Solar input affects evaporation rates and soil temperature, which may affect time of seed germination, germination rate, rate of plant growth, and soil microbial activity. Therefore, this is an important variable to consider when monitoring plant growth and soil development.

Figure 22. Conducting soil moisture readings along transects.

Figure 23. Solar pathfinder in use.

Soil Nutrient Analysis

Successful re-vegetation requires that nutrient capital be stored in the soil for release over time. Sufficient organic matter and a functioning microbial community are necessary to provide a long-term source of nitrogen for plants. Previous studies of soil nutrient levels at revegetation sites throughout the Tahoe area found that sites with high plant cover had significantly higher soil nutrients over the long-term than soils with lower plant cover levels.[3] Total Kjeldahl nitrogen and organic matter were used as indicators of soil health in this study. Total Kjeldahl nitrogen (TKN) is a measure of readily available nitrogen. Only three soil sub samples were taken from each plot; therefore, differences in TKN and organic matter values may be a result of the variability within a plot.

Soil samples were collected in 2003, 2006, 2007, and 2008. The treatments a which samples were collected are in Table 5. Three soil sub-samples at each plot were collected from the mineral soil beneath any mulch layer to a depth of 12 inches (30 cm; Figure 24). These sub-samples were combined and sieved to remove any material larger than 0.08 inches (2 mm) in diameter, and sent to A&L Laboratories in Modesto, California for the S3C nutrient suite (macro and micronutrients), total Kjeldahl nitrogen (TKN), and organic matter analysis.

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[3]Claassen, V.P., and M.P. Hogan. 2002. Soil Nutrients Associated with Revegetation of Disturbed Sites in the Lake Tahoe Basin. Restoration Ecology 10:195-203.

Table 5. Soil sample treatment types.

Years Sampled	Treatment
2003	Pre-treatment
2006	Native reference
2006, 2007, 2008	6" Coarse overs, Biosol=2,000 kg/ha, Seed=125 lbs/acre, Till 12"
2006, 2007, 2008	Seed=125 lbs/acre, Till 12"
2006, 2007, 2008	Biosol=2,000 kg/ha, Seed=125 lbs/acre, Till 12"
2006, 2007, 2008	6" Compost, Biosol=2,000 kg/ha, Seed=125 lbs/acre, Till 12"
2007, 2008	6" Compost, Seed=125 lbs/acre, Till 12 "
2007, 2008	2" Woodchips, Biosol=2,000 kg/ha, Seed=125 lbs/acre, Till 12"
2007, 2008	Seed=125 lbs/acre
2007, 2008	2" Compost, Biosol=2,000 kg/ha, Seed=125 lbs/acre. Till 12"
2008	Existing surface treatment

Figure 24. Soil sub-sample collection

Statistical Analysis

An analysis of variance test (ANOVA), which compares average values between two or more different groups, was used to resolve differences between plant and mulch cover values by treatment type, amendment type, and fertilizer (Biosol) application.

If a difference was detected using the ANOVA test, the Mann-Whitney test was sometimes used to further investigate differences between two sub-groups or sample sets within the larger group. The Mann-Whitney test is a non-parametric test that can be applied to data sets with non-normal distributions. Non-normal distributions are common within small data sets. At the Heavenly test plots, most of the treatments only have three replications.

Results and Discussion

Rainfall Simulation

Infiltration

Trends by Treatment Level

Over the five-year period from 2004 to 2008, the average percent infiltration at the full treatment plots (99%) and the partial treatment plots (96%) was 1.4 times higher than at the existing surface treatment plot, 70% (Figure 25). Higher infiltration rates are important for sediment source control treatments because lower infiltration rates are often associated with increased sediment yield.

The percent infiltration at the native reference plot was variable and was 86% in 2005 and 38% in 2006 (Figure 25). The low infiltration in both years may be a result of the hydrophobic mulch layer that is common throughout the Heavenly Resort, especially during the summer and early fall. Hydrophobic mulch does not allow simulation water to reach the soil, therefore producing runoff and sediment. Runoff collected is representative of water that moved laterally through the mulch, and not representative of the ability of the soil to infiltrate rainfall. Simulations should be repeated under more suitable condition to subsequent years so that soil infiltration rates collected at the test plot area can be compared to native conditions.

Trend by Soil Loosening

Over five years, percent infiltration was similarly high and did not vary widely with the type of treatment applied. Full treatment plots with amendments, tilling, Biosol, and seed had an average infiltration rate of 99%, while tilled plots without amendments had a five-year average infiltration rate of 96%. Untilled plots had a five-year average infiltration of 94%.

It is unclear why the untilled treatment plot, which had a similar treatment to the existing surface treatment plot, had a much higher percent infiltration. The untilled treatment received a mulch application, while the existing surface treatment did not; however, the mulch cover was similar between the two treatments in 2007 and 2008 (Figure 29). The existing surface treatment was treated prior to the untilled test plots, which may explain the difference.

Trends by Amendment Presence and Type

When comparing plots with and without amendments, average percent infiltration over time was slightly higher at plots with compost, seed, and tilling (96%), compared to plots with seed and tilling, but without compost or Biosol (92%). This difference is not large enough to suggest that amendment presence affects infiltration.

Full treatment plots amended with either woodchips or coarse overs exhibited similar percent infiltration, 99%, suggesting that amendment type does not affect infiltration.

Trends by Year

Percent infiltration was variable over time, neither increasing nor decreasing consistently. (Figure 25).

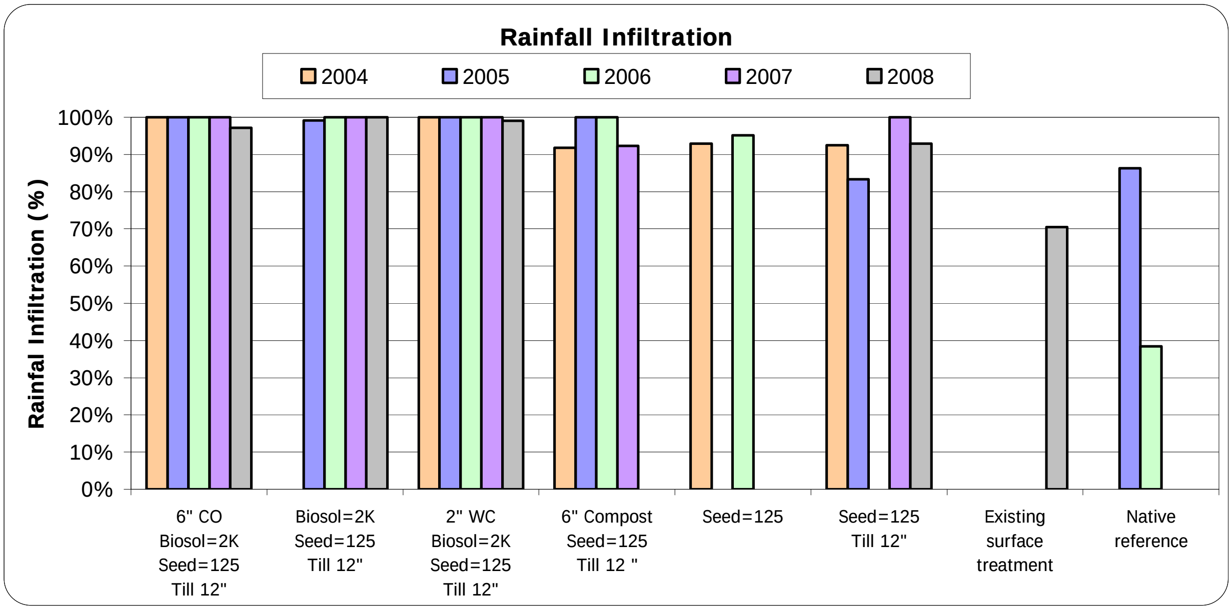

Figure 25. Rainfall Infiltration. The average percent infiltration at the treatment plots over five years was 97%, which was 1.4 times higher than the percent infiltration at the surface treatment plot in 2008, 70%. Data is sorted by decreasing average infiltration.

Sediment Yield

Trends by Treatment Level

Over the five years from 2004 to 2008, the sediment yield at the full treatment plots was an average of 8.5 lbs/acre/in (3.8 kg/ha/cm), which was 8 times lower than the sediment yield produced at the surface treatment plots in 2008, 68 lbs/acre/in (30 kg/ha/cm; Figure 26). This suggests that by implementing full treatment, sediment reductions are possible compared to surface treatment.

The average sediment yield at the native reference plot during the two years it was sampled was 28 lbs/acre/in (12 kg/ha/cm), which was 3.3 times higher than the sediment produced at the treated plots (Figure 26). This is most likely a result of the hydrophobic conditions discussed above.

Trends by Soil Loosening

Sediment yield did not vary widely and was similarly low among treated plots over the five sampling years. All full treatment plots with amendments (compost, woodchips, and coarse overs), tilling, Biosol, and seed had an average sediment yield of 8 lbs/acre/in (4 kg/ha/cm). Tilled plots without amendments had an average of 13 lbs/acre/in (6 kg/ha/cm; Figure 26). Untilled plots had an average sediment yield of 16 lbs/acre/in (7 kg/ha/cm).

Trends by Amendment Presence and Type

Over the five years, sediment yields between plots with and without amendments (seed and tilling included in treatment, but not Biosol) did not vary widely and ranged from an average of 17 to 21 lbs/acre/in (8 to 9 kg/ha/cm). This suggests that tilling alone may be sufficient to obtain sediment reductions.

Full treatment plots amended with either woodchips or compost exhibited similar sediment yields (0 to 8 lbs/acre/in or 0 to 4 kg/ha/cm). The sediment yield at the full treatment plots with coarse overs ranged from 0 to 39 lbs/acre/in (0 to 17 kg/ha/cm), which is higher than the woodchips or compost plots, but below the sediment yield at the surface treatment plots 68 lbs/acre/in (30 kg/ha/cm). This difference between the sediment yield at the coarse overs plots and woodchips and compost plots most likely does not indicate that amendment type affects infiltration.

Trends by Year

Sediment yield was variable at all plots, neither showing an increasing nor decreasing trend over time. Sediment yield ranged from zero to 67 lbs/acre/in (0-26 kg/ha/cm).

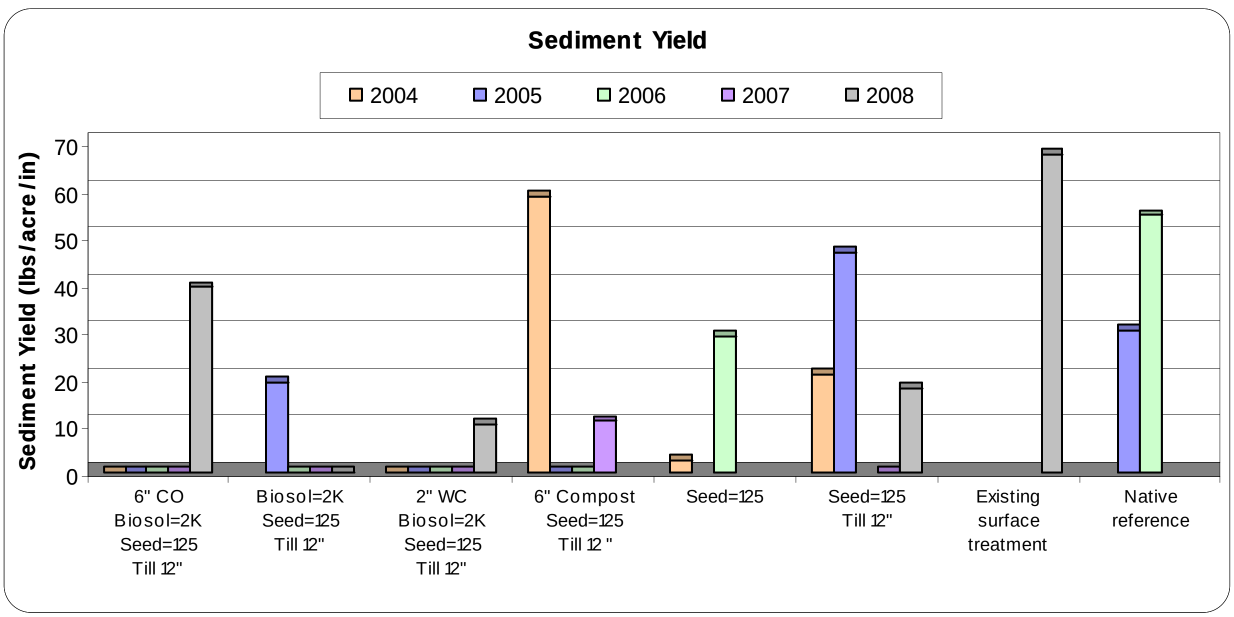

Figure 26. Sediment Yield. From 2004 to 2008, the average sediment yield at the full treatment plots was 8.5 lbs/acre/in (3.8 kg/ha/cm), which was 8 times lower than the sediment yield at the surface treatment plot in 2008, 68 lbs/acre/in (30 kg/ha/cm). Data is sorted to match Figure 25.

Soil Moisture

Soil moisture ranged between 3 and 6% for all treatment plots, for all years sampled. This narrow range allowed for comparison of penetrometer depth to refusal (DTR) across all years and treatments (Figure 27).

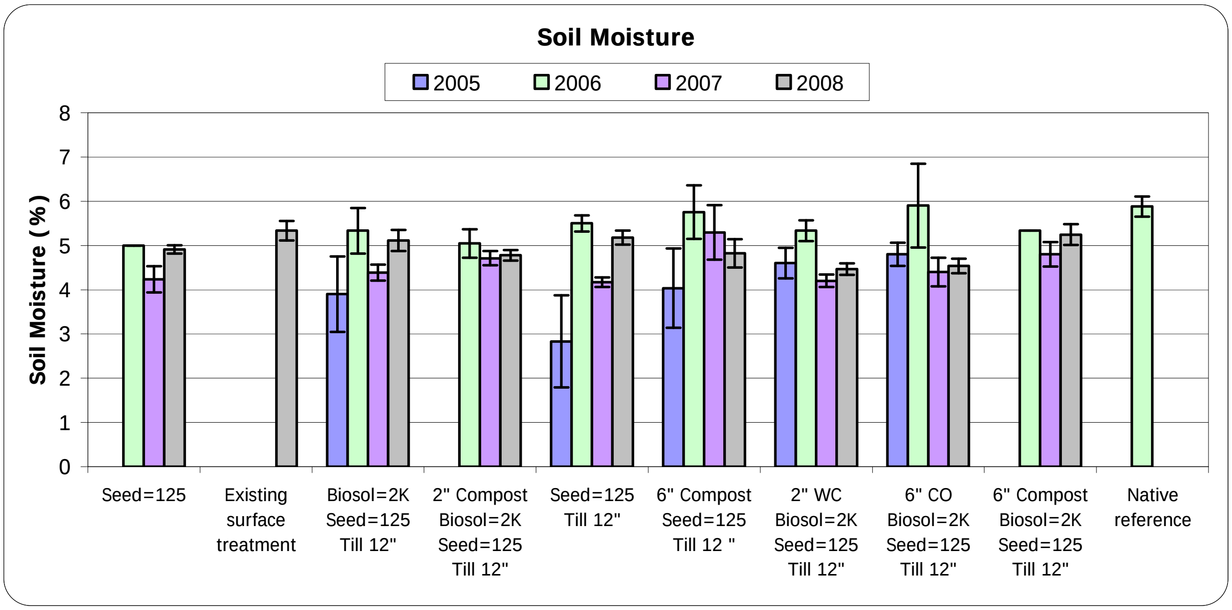

Figure 27. Soil Moisture. Soil moisture ranged from 3 to 6% for all treatment plots, allowing for comparison of penetrometer DTRs across all treatments and years. Error bars represent one standard deviation above and below the mean. Data is sorted to match Figure 28.

Penetrometer Depth to Refusal (DTR)

Trends by Treatment Level

For 2006, 2007, and 2008, the three-year average DTR for full treatment plots (15 inches or 38 cm) was deeper by 4.5 times when compared to the 2008 DTR at the plots with existing surface treatment (3.3 inches or 5 cm; Figure 28 and Table 4). In 2008, the DTR was significantly deeper at the full treatment plots compared to the surface treatment plots. This indicates that the full treatment plots, which included tilling treatments, maintain loose soil over time.

Trends by Soil Loosening

In 2006, 2007, and 2008, the three-year average DTR for all plots with tilling (15 inches or 37 cm) was 1.3 times deeper than the DTR at the native reference plot (12 inches or 29 cm). This indicates that the tilling treatments are more than adequate to reach native soil DTRs.

In 2006, 2007, and 2008, the three-year average DTR plots with soil loosening (15 inches or 38 cm) was significantly deeper by 8 times when compared to the three-year average of plots without soil loosening (2 inches or 5 cm; Figure 28 and Table 4).

Trends by Amendment Presence and Type

Amendment type or presence did not significantly affect penetrometer DTR for 2006, 2007, or 2008 (Figure 28 and Table 4). This indicates that amendments may not be crucial for maintaining deep penetrometer DTRs or low soil density; however, amendments can provide the nutrients essential for a sustainable soil conditions.

Trends by Year

Penetrometer DTR for tilled plots with or without amendments did not change significantly over time.

However, penetrometer DTR for the untilled plots increased significantly by 2 times from 1.3 inches (3.3 cm) in 2006 and 1.5 inches (3.8 cm) in 2007 to 3 inches (8 cm) in 2008 (Figure 28 and Table 4). Although this difference is statistically significant, penetrometer DTRs generally need to be deeper than 4 inches (10 cm) to impact infiltration and sediment yield positively.[4]

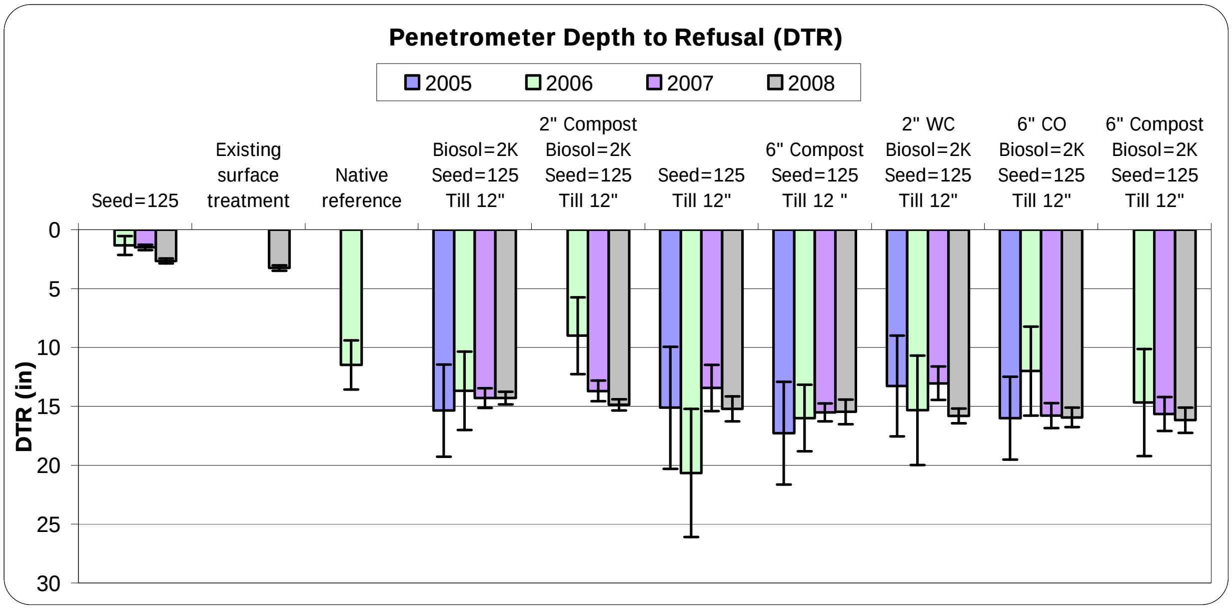

Figure 28. Penetrometer Depth to Refusal (DTR). Penetrometer DTRs did not change significantly over at plots with soil loosening; however, DTRs increased significantly by 2 times at the plots without soil loosening. Error bars represent one standard deviation above and below the mean. Data is sorted by increasing penetrometer DTR for 2008.

Cover

Ground Cover by Mulch and Bare Soil

Ground cover by mulch ranged from 72 to 96% from 2007 to 2008 among all plots and did not vary widely between treated and untreated plots. The ground cover by mulch ranged from 72 to 92% at the full treatment plots, compared to a similar proportion at the surface treatment plot, 88%

Trends by Year

Mulch cover exhibited a slight decreasing trend over time. The average mulch cover for all plots in 2007 was 87%, compared to an average mulch cover of 83% in 2008. This may be a result of the low water year in 2007.[5] Plant cover was lower in 2007, possibly because there

[4] Grismer, M.E. 2006. Simulated Rainfall Evaluation at Sunriver and Mt. Bachelor Highways, Oregon. Unpublished.

[5] Heavenly Valley Snotel data from: http://www.wcc.nrcs.usda.gov/snotel/snotel.pl?sitenum=518&state=ca

was less precipitation in 2007 compared to 2006 (ocular estimates) or 2008. Low plant cover in 2007 may have resulted in lower ground cover by plant litter in 2007, which reduces overall cover by mulch in the following season

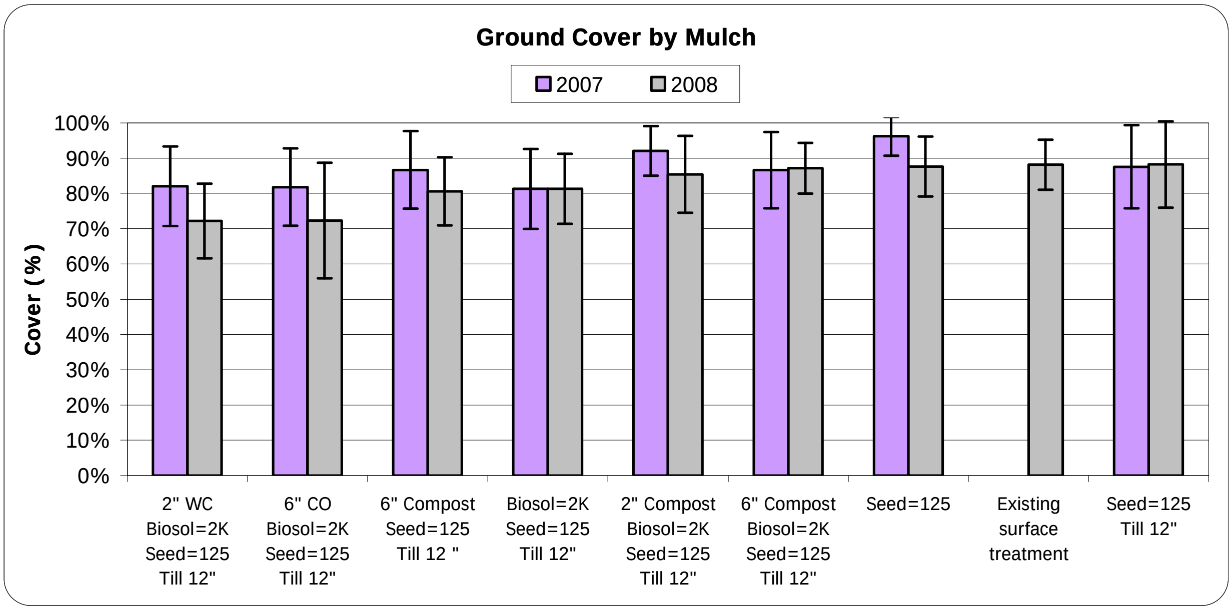

Figure 29. Ground Cover by Mulch. Mulch cover ranged between 72-96% for both years and showed a slight decreasing trend over time. Error bars represent one standard deviation above and below the mean. Data is sorted by increasing mulch cover for 2008.

Plant Cover and Composition

Trends by Soil Loosening

Although not statistically significant, plots that were tilled (two-year average of 19%), had plant cover that was higher by 1.8 times compared to untilled plots (two-year average of 11%; Figure 30). It is possible that the tilling allowed for deeper penetration of plant roots, which may have increased plant cover.

Trends by Amendment Type

In 2006 and 2007, neither foliar plant cover nor seeded plant cover varied significantly by amendment type or the presence of amendment (Figure 30 and Table 6). In 2008, all plots with 6 inches (15 cm) of compost (with and without Biosol) had plant cover (29%) that was significantly higher by 2.7 times compared to the plots with seed but without amendments or Biosol (11%; Figure 30 and Table 6). Although this trend was significant in 2008 only, the plot with 6 inches (15 cm) of compost and Biosol had the highest plant cover in 2007 and 2008. The combination of compost and Biosol over the long-term may have resulted in increased plant cover compared to plots with other amendments.

Trend by Amendment Presence

In 2006, 2007, and 2008, plant cover was not significantly different between plots with compost, tilling, seed, and Biosol compared to plots with tilling, seed, and Biosol but without compost (Figure 30 and Table 6). In 2006, 2007, and 2008, plant cover was not significantly different between plots with compost, tilling, and seed, compared to plots with tilling and seed but without compost (Figure 30 and Table 6).

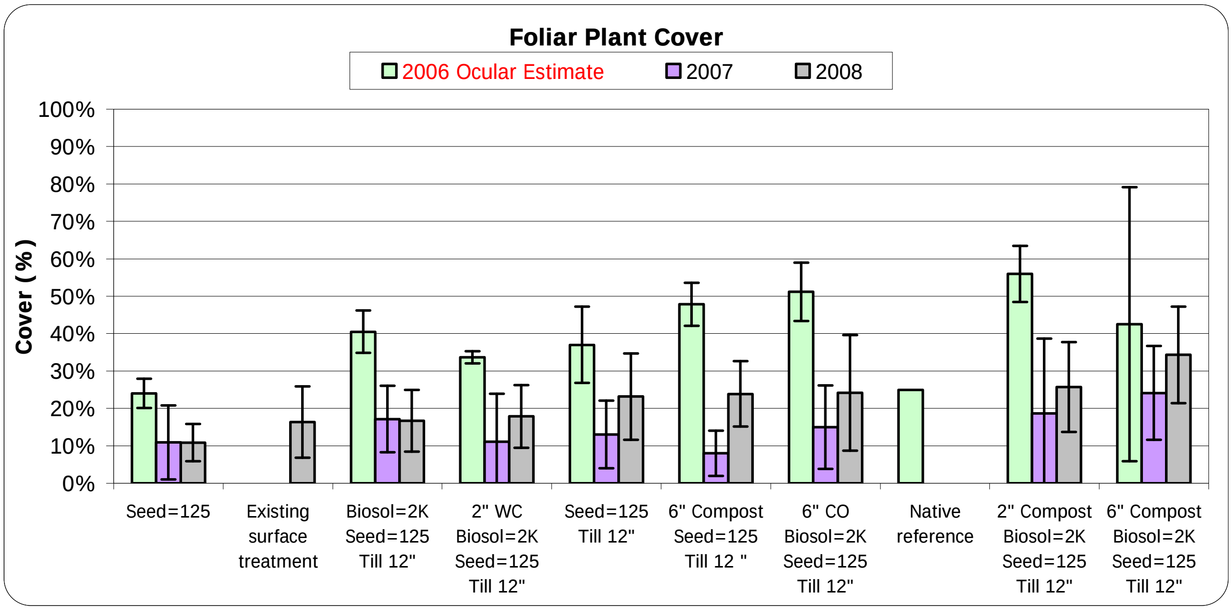

Figure 30. Foliar Plant Cover. Data from 2006 was ocularly estimated. Ocular estimates from 2006 cannot be compared directly to the cover point data from 2007 and 2008. From 2007 to 2008, foliar plant cover was 1.8 times higher at plots with tilling (two-year average of 19%), compared to plots without tilling (two-year average of 11%). In 2008, the plots with 6 inches (15 cm) of compost had plant cover (29%) that was significantly higher by 2.7 times compared to the plots with seed but without amendments or Biosol (11%). Error bars represent one standard deviation above and below the mean. Data is sorted by increasing foliar plant cover for 2008.

Trends by Biosol Presence

For two of the three years sampled, plant cover (in 2006 and 2008) and seeded plant cover (in 2007 and 2008) did not vary significantly with the use of Biosol (Figure 31 and Table 6). In 2007, plant cover was significantly higher by 2.3 times for plots with Biosol (17%) compared to those without Biosol (8%; Figure 31 and Table 6). Although statistically significant results were found, only three replications of the full treatment plot with Biosol were available for testing, while about a dozen full treatment plots with Biosol were tested. The low number of replications available for the full treatment plots with Biosol may have influenced the results. Further long-term study is necessary to determine whether Biosol use influences plant cover over the long-term. No significant differences were found during 2008 sampling, suggesting that the differences present in 2006 for seeded plant cover and 2007 for plant cover may not persist.

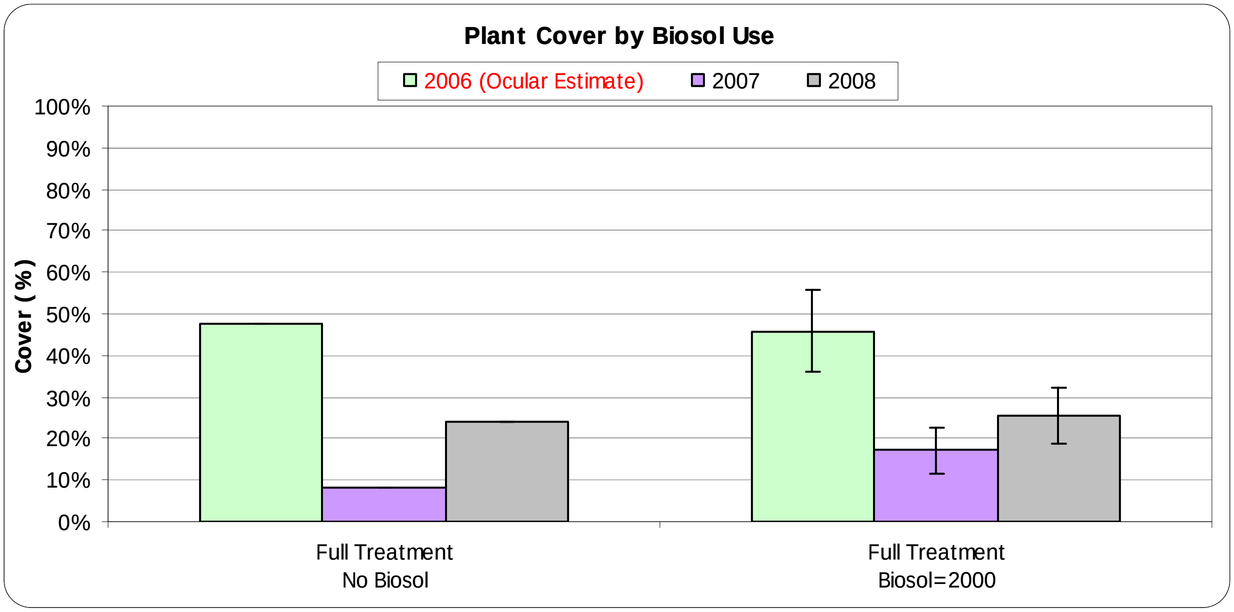

Figure 31. Plant Cover by Biosol Use. Ocular estimates from 2006 cannot be compared directly to the cover point data from 2007 and 2008. For two of the three years sampled (2006 and 2008), plant cover and seeded plant cover did not vary significantly with the use of Biosol. In 2007, plant cover was significantly higher by 2.3 times for plots with Biosol (17%) compared to those without Biosol (8%). Error bars represent one standard deviation above and below the mean.

Trends by Year

Plant cover for tilled plots with amendments was significantly higher by 1.8 times in 2008 (25%) than in 2007 (15%; Figure 30 and Table 6). This increase may be a result of the higher precipitation during the 2007-2008 water year (26 inches or 66 cm) compared to the 2006-2007 water year (22.1 inches or 56 cm).[6] Seeded plant cover for tilled plots with amendments or untilled plots that were seeded did not change significantly between 2007 and 2008. The increase in foliar plant cover, but not seeded plant cover, for tilled plots from 2007 to 2008 is a result of the change in plant composition between the two years (Figure 33, and Figure 34). The cover by groundsmoke, a native annual, increased between 2007 and 2008, but a corresponding increase was not observed for the native, perennial seeded species.

Plant cover was not significantly different in 2008 compared to 2007 for untilled plots with seed, but without amendments or Biosol (Figure 30 and Table 6). Plots without amendments and with lower nutrient levels may be less likely to respond to changing environmental conditions (Figure 35 and Figure 36).

Plant Composition Trends by Year

From 2006 to 2008, Western needlegrass, a native seeded grass, persisted as one of the dominant species (Figure 32, Figure 33, and Figure 34). In 2006, squirreltail, another native seeded grass, was co-dominant; however, squirreltail was present in small quantities in both 2007 and 2008 (Figure 32, Figure 33, and Figure 34). It is unclear why squirreltail exhibited a

[6] Heavenly Valley Snotel data from: http://www.wcc.nrcs.usda.gov/snotel/snotel.pl?sitenum=518&state=ca

decreasing trend over time. Mountain brome, a native seeded grass, was observed in small quantities in 2006 and decreased to trace amounts in 2007 and 2008 (Figure 32, Figure 33, and Figure 34). Mountain brome is often present in larger quantities directly following restoration, and then decreases over time.[7] Spurry buckwheat, a native annual, was present in small quantities in 2007, and increased markedly in 2008 (Figure 33 and Figure 34), possibly as a result of the higher water year from 2007-8.

The dominance of Western needlegrass through the low water years of 2006-2007 and 2007-2008, the decrease of squirreltail and mountain brome, and the absence of blue wildrye, indicates that Western needlegrass is better suited for the conditions at this Heavenly site compared to the other three seeded species.

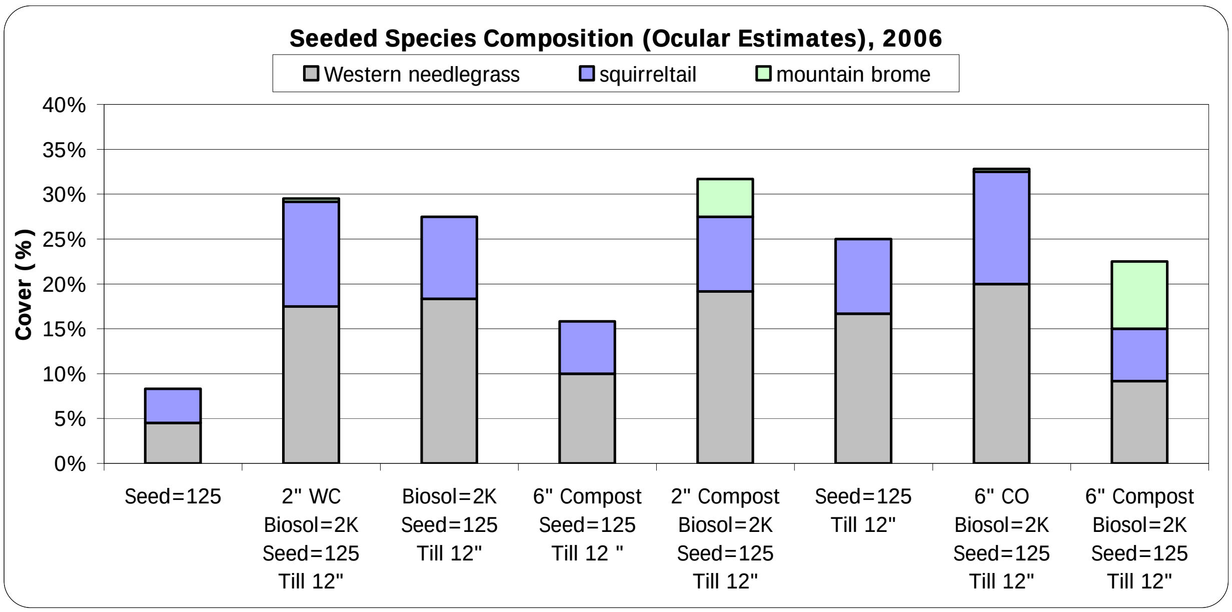

Figure 32. Seeded Species Composition (Ocular Estimates), 2006. Squirreltail and Western needlegrass were the dominant seeded species in 2006. Data is sorted to match Figure 34.

[7] Monitoring and Assessment of Erosion Control Treatments in and around the Lake Tahoe Basin, 2008-2009 Annual Report for Caltrans, Truckee Bypass Site Report. Unpublished.

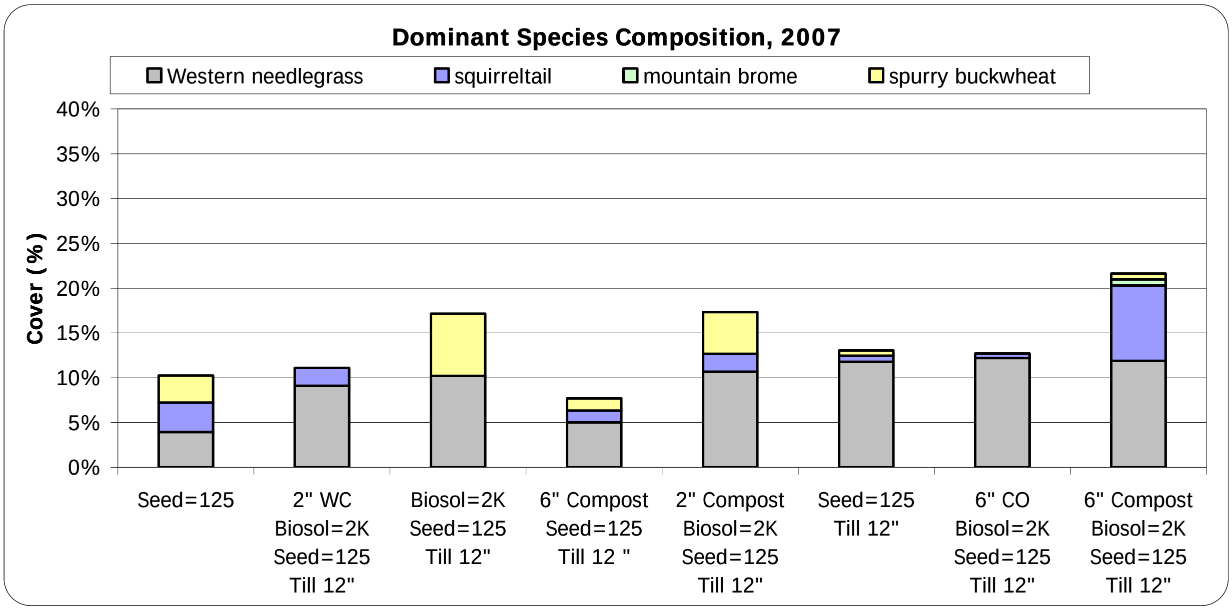

Figure 33. Dominant Species Composition, 2007. Western needlegrass was the dominant species in 2007. Cover by squirreltail may have decreased between 2006 and 2007. Data from 2006 was ocularly estimated, which cannot be compared directly to the cover point data collected in 2007. Data is sorted to match Figure 34.

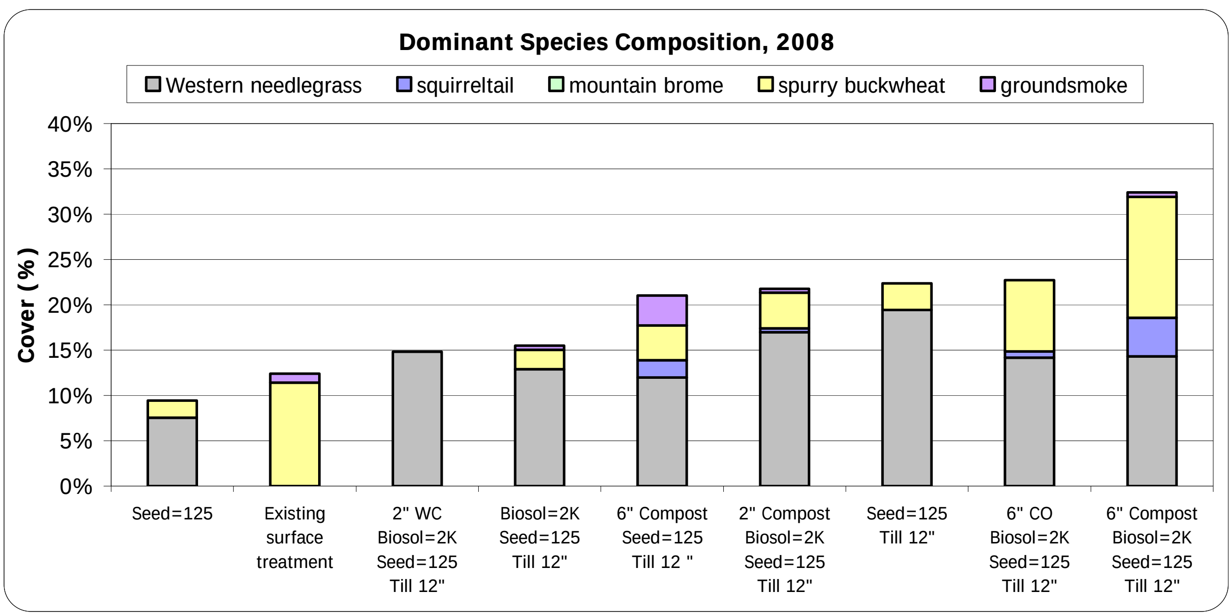

Figure 34. Dominant Species Composition, 2008. Western needlegrass and spurry buckwheat were the dominant species in 2008. Cover by Western needlegrass increased slightly from 2007 and cover by spurry buckwheat, a native annual also increased from 2007. Data is sorted by increasing cover by dominant species.

Soil Nutrients

Trends by Treatment Level

The soil total Kjeldahl nitrogen (TKN) at the full treatment plots (three-year average of 1,109 ppm), was higher by 1.3 times, compared to the TKN surface treatment plot in 2008 (863 ppm) and similar to that of the native reference plot (1,028 ppm). The organic matter content at the full treatment plots (three-year average of 3%) was higher by 1.6 times, compared to the organic matter content at the surface treatment plots (2%) and similar to that of the native reference plot (3.3%). Similar nutrients at the full treatment and native reference plots indicate that full treatment may move a site toward sustainable, native soil conditions.

Trends by Amendment Type

From 2006 to 2008, the TKN at plots amended with coarse overs (1,328-1,649 ppm) was up to 2.7 times higher than at the other full treatment plots with different amendments (610-1,254 ppm).

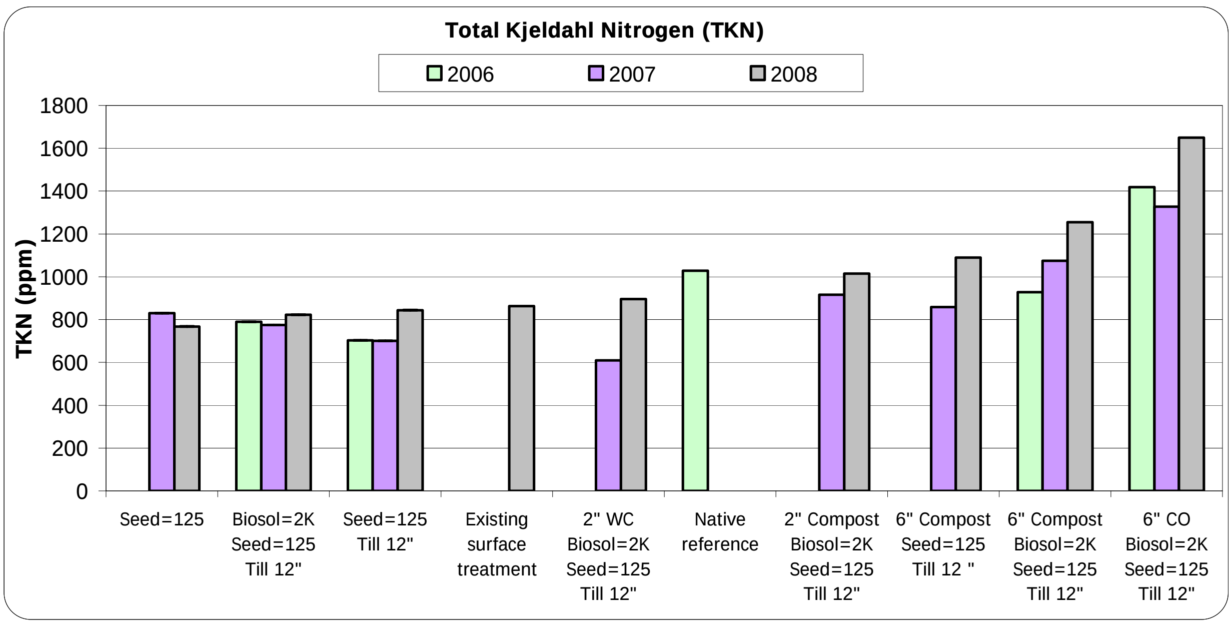

Figure 35. Total Kjeldahl Nitrogen (TKN). From 2006 to 2008, TKN levels at the full treatment plots (1,109 ppm) were similar to the TKN at the native reference plot (1,028 ppm). The TKN at plots amended with coarse overs (1,328-1649 ppm) was up to 2.7 times higher than at the other full treatment plots with amendments (610-1,254 ppm) TKN values increased from an average of 957 ppm in 2007 to an overall average of 1,180 ppm in 2008. Data is sorted by 2008 TKN.

From 2006 to 2008, the organic matter at plots amended with coarse overs (3.8-4.3%) was 1.3 to 2.3 times higher than at the other full treatment plots with amendments (1.9-3%).

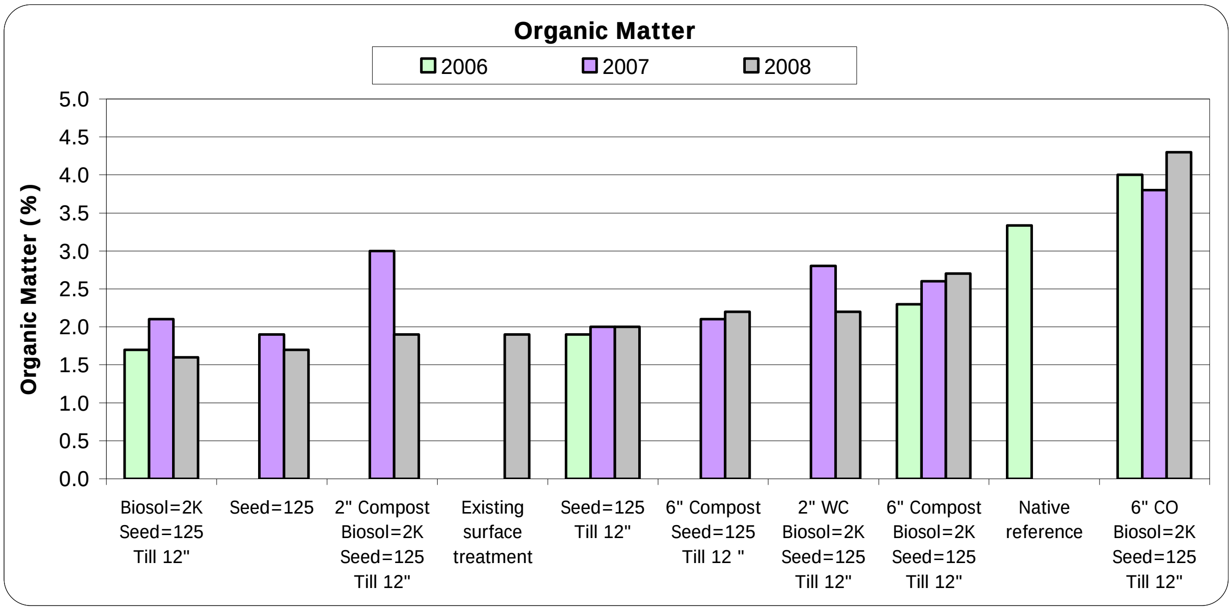

Figure 36. Organic Matter. From 2006 to 2008, The organic matter at the full treatment plots (3%) was similar to the organic matter at the native reference plot (3.3%). The organic matter at plots amended with coarse overs (3.8-4.3%) was 1.3 to 2.3 times higher than at the other full treatment plots with amendments (1.9-3%). Organic matter did not vary by more than 1.1% over time. Data is sorted by 2008 organic matter content.

Organic matter and TKN were most likely higher at the plots with 6 inches (15 cm) of coarse overs compared to the plots with 6 inches (15 cm) of compost because coarse overs have a higher carbon to nitrogen ratio; therefore, are still in the process of breaking down. It is likely that the compost broke down within the first few years and that measurable nutrients are not being released, while the coarse overs are still in the process of decomposing. It is likely that the woodchips would provide similar results to coarse overs after the first few years; however, the 2 inch (5 cm) application depth of woodchips cannot be compared to the 6 inch (15 cm) application depth of the coarse overs. It is possible that woodchips applied to a 6 inch (15 cm) depth or deeper may provide the higher level of nutrients desired in the long term.

Trends by Amendment Presence

From 2006 to 2008, TKN values at amended plots (three-year average of 1,086 ppm) were 1.4 times higher than plots without amendments (three-year average of 779 ppm; Figure 35). From 2006 to 2008, organic matter values at amended plots (three-year average of 2.8 ppm) were 1.5 times higher than plots without amendments (three-year average of 1.9 ppm; Figure 36). Regardless of the type of amendment incorporated, the use of amendments increased soil nutrients to near native levels. The TKN at the native reference plot was 1,028 ppm, while the organic matter at the native reference plot was 3.3%.

Trends by Biosol Presence

Plots with that were tilled with seed and Biosol had TKN values that ranged from 775 to 822 ppm while plots that were tilled with seed only had TKN values that ranged from 700 to 844 ppm (Figure 35). These ranges are similar, indicating that Biosol may not have a lasting effect on nutrient levels when applied at tilled plots with seed. Organic matter levels were also similar, ranging from 1.6 to 2.1% at plots with Biosol, and from 1.7 to 1.9% at plots without Biosol.

The plots with 6 inches (15 cm) of compost with Biosol had TKN values that ranged from 929 to 1,254 ppm, compared to the plots with 6 inches (15 cm) of compost without Biosol, at which TKN values ranged from 859 to 1,089 (Figure 35). The range for the plots with Biosol was slightly higher than the range for plots without Biosol, indicating that Biosol use in conjunction with compost application, tilling, and seeding may produce a lasting effect on soil TKN.

The organic matter levels were also slightly higher at the plots with 6 inches (15 cm) of compost with Biosol, ranging from 2.3 to 2.7%, compared to the organic matter level at the plots with 6 inches (15 cm) of compost without Biosol, 2.1-2.2%.

Trends by Year

All full treatment plots with amendments showed a slight increase from 2007 to 2008 from an overall average of 957 ppm to an overall average of 1,180 ppm. This increase may be linked with the increase in plant cover between 2007 and 2008 (Figure 30 and Figure 35). Organic matter remained fairly consistent over time and did not vary by more than 1.1% between 2006 and 2008 (Figure 36).

Table 6. Statistical Results. A probability of less than 0.1 is considered significant.

Statistical Test	Factors	Variable	Year	Result	Test Statistics	Probability
Mann-Whitney	Full Treatment and Existing Surface Treatment	Penetrometer DTR	2008	Deeper DTR at full treatment plots	U(14,3)=40	0.003
Mann-Whitney	Tilling and No Tilling	Penetrometer DTR	2006	Deeper DTR at tilled plots with seed	U(3,21)=63.1	0.001
Mann-Whitney	Tilling and No Tilling	Penetrometer DTR	2007	Deeper DTR at tilled plots with seed	U(3,18)=54	0.002
Mann-Whitney	Tilling and No Tilling	Penetrometer DTR	2008	Deeper DTR at tilled plots	U(20,6)=120	9x10-6
Mann-Whitney	Tilling with and without Amendments	Penetrometer DTR	2006	No difference in penetrometer DTR for plots tilled with or without amendments	U(15,6)=62.5	0.178

Statistical Test	Factors	Variable	Year	Result	Test Statistics	Probability
Mann-Whitney	Tilling with and without Amendments	Penetrometer DTR	2007	No difference in penetrometer DTR for plots tilled with or without amendments	U(13,5)=0.387	0.378
Mann-Whitney	Tilling with and without Amendments	Penetrometer DTR	2008	No difference in penetrometer DTR for plots tilled with or without amendments	U(14,6)=0.312	0.312
ANOVA	Amendment Type	Penetrometer DTR	2005	No difference in penetrometer DTR among amendment types	F(2,6)=1.65	0.269
ANOVA	Amendment Type	Penetrometer DTR	2006	No difference in penetrometer DTR among amendment types	F(3,11)=2.386	0.125
ANOVA	Amendment Type	Penetrometer DTR	2007	No difference in penetrometer DTR among amendment types	F(3,9)=1.637	0.249
ANOVA	Amendment Type	Penetrometer DTR	2008	No difference in penetrometer DTR among amendment types	F(3,10)=0.213	0.885
ANOVA	Year	DTR for Tilled Plots with Amendments	N/A	No difference in penetrometer DTRs	F(3,47)=1.706	0.179
ANOVA	Year	DTR for Tilled Plots without Amendments	N/A	No difference in penetrometer DTRs	F(3,19)=1.26	0.316
Tukey	2006 and 2008	Penetrometer DTR for Untilled Plots	N/A	Deeper penetrometer DTR in 2008	q=3.899	0.086
Tukey	2007 and 2008	Penetrometer DTR for Untilled Plots	N/A	Deeper penetrometer DTR in 2008	q=4.357	0.060
ANOVA	Amendment Type or No Amendment	Plant Cover	2006	No difference in plant cover	F(7,17)=1.63	0.194

Statistical Test	Factors	Variable	Year	Result	Test Statistics	Probability
ANOVA	Amendment Type and No Amendment	Plant Cover	2007	No difference in plant cover	F(6,14)=0.374	0.883
ANOVA	Amendment Type and No Amendment	Seeded Plant Cover	2006	No difference in seeded plant cover	F(7,17)=1.915	0.130
ANOVA	Amendment Type and No Amendment	Seeded Plant Cover	2007	No difference in seeded plant cover	F(6,14)=0.189	0.975
ANOVA	Amendment Type and No Amendment	Seeded Plant Cover	2008	No difference in seeded plant cover	F(6,16)=1.915	0.140
Mann-Whitney	Compost and No Amendment with seed	Plant Cover	2008	Higher plant cover at plots amended with compost	U(6,3)=18	0.024
Mann-Whitney	Amendment presence for plots with tilling, seed, and Biosol	Plant Cover	2006	No difference in plant cover	U(3,3)=5.00	1.00
Mann-Whitney	Amendment presence for plots with tilling, seed, and Biosol	Plant Cover	2007	No difference in plant cover	U(3,3)=0.00	0.100
Mann-Whitney	Amendment presence for plots with tilling, seed, and Biosol	Plant Cover	2008	No difference in plant cover	U(3,3)=5.00	1.00
Mann-Whitney	Amendment presence for plots with tilling and seed	Plant Cover	2006	No difference in plant cover	U(3,3)=6.00	0.700
Mann-Whitney	Amendment presence for plots with tilling and seed	Plant Cover	2007	No difference in plant cover	U(3,2)=5.00	0.400
Mann-Whitney	Amendment presence for plots with tilling and seed	Plant Cover	2008	No difference in plant cover	U(3,3)=9.00	0.100
Mann-Whitney	Biosol Rate for Full Treatment Plots	Seeded Plant Cover	2007	No difference between plots with 0 or 2,000 kg/ha of Biosol	U(3,10)=24.5	0.112

Statistical Test	Factors	Variable	Year	Result	Test Statistics	Probability
Mann-Whitney	Biosol Rate for Full Treatment Plots	Seeded Plant Cover	2008	No difference between plots with 0 or 2,000 kg/ha of Biosol	U(3,11)=21	0.555
Mann-Whitney	Biosol Rate for Full Treatment Plots	Seeded Plant Cover	2006	Higher plant cover at plots with 2,000 kg/ha of Biosol	U(3,12)=31.5	0.070
Mann-Whitney	Biosol Rate for Full Treatment Plots	Plant Cover	2007	Higher plant cover at plots with 2,000 kg/ha of Biosol	U(3,10)=26.5	0.049
Mann-Whitney	Biosol Rate for Full Treatment Plots	Plant Cover	2006	No difference between plots with 0 or 2,000 kg/ha of Biosol	U(3,12)=20	0.840
Mann-Whitney	Biosol Rate for Full Treatment Plots	Plant Cover	2008	No difference between plots with 0 or 2,000 kg/ha of Biosol	U(3,11)=19.5	0.769
Mann-Whitney	2007 and 2008	Plant Cover for Tilled and Amended Plots	N/A	Higher plant cover in 2008	U(13,14)=141	0.014
Tukey	2007 and 2008	Seeded Plant Cover for Tilled and Amended Plots	N/A	No difference in plant cover	q=2.313	0.243
Tukey	2007 and 2008	Seeded Plant Cover for Untilled Plots	N/A	No difference in seeded plant cover	q=0.528	0.927
Tukey	2007 and 2008	Plant Cover for Untilled Plots	N/A	No difference in plant cover	q=0.033	1.000

Recommendations

These recommendations are for a site with granitic parent material, a slope angle of 16 degrees, and a solar exposure of about 85% during the summer months. The approximate elevation should be 8,500 ft (2,618 m) and invasive plants should not be a present.

Tilling: 12 inches (30 cm)

Amendment: 6 inches (15 cm) of coarse overs

Biosol: 1,780 lbs/acre (2,000 kg/ha)

Seed: 125 lbs/acre (140 kg/ha) with the following composition:

Western needlegrass: 33.3%

squirreltail: 33.3%
mountain brome: 33.3%

Mulch: 2 inches (5 cm) of pine needles, 99% cover

Full Treatment versus Surface Treatment

Full treatment plot exhibited:

- average rainfall infiltration (99%) that was 1.4 times higher than the infiltration at the surface treatment plot, 70%
- sediment yield (2004-8 average of 8.5 lbs/acre/in or 3.8 kg/ha/cm) that was 8 times higher than the sediment yield produced at the surface treatment plot in 2008, 68 lbs/acre/in (30 kg/ha/cm)
- a the three-year average DTR (15 inches or 38 cm) that was deeper by 4.5 times when compared to the three-year average of the existing surface treatment plots (3.3 inches or 8 cm)
- ground cover by mulch ranged that from 72 to 92% from 2007 to 2008, compared to 88% at the existing surface treatment plot
- TKN (three-year average of 1,109 ppm) that was higher by 1.3 times, compared to the TKN surface treatment plot in 2008 (863 ppm) and similar to that of the native reference plot (1,028 ppm)
- organic matter content (three-year average of 3%) that was higher by 1.6 times, compared to the organic matter content at the surface treatment plots (2%) and similar to that of the native reference plot (3.3%)

Soil Loosening versus No Soil Loosening

Soil loosening is recommended over no soil loosening for the following reasons. Plots with soil loosening exhibited:

- percent infiltration over five years that was 99%, while tilled plots without amendments had a five-year average infiltration of 96% and untilled plots had a five-year average infiltration of 94%
- sediment yields that were similarly low among treated with or without soil loosening over the five sampling years
- a three-year average DTR plots from 2006 to 2008 (15 inches or 38 cm) that was significantly deeper by 8 times when compared to the three-year average of plots without soil loosening (2 inches or 5 cm)
- plant cover that was 1.8 times higher (two-year average of 19%) compared to untilled plots (two-year average of 11%)

Amendments versus No Amendments

It is recommended that amendments are incorporated to a depth of 12 inches (30 cm), rather than tilling without amendments. Plots with amendments exhibited:

- slightly higher percent infiltration (96%) at plots with compost, seed, and tilling, compared to 92% infiltration at plots with only seed and tilling
- sediment yields that were similar to the sediment yields at the plots without amendments (seed and tilling included in treatment, but not Biosol; average of 17 to 21 lbs/acre/in or 8-9 kg/ha/cm)
- penetrometer DTRs that were not significantly different than the DTRs at plots without amendments (average of 14.6-15.3 inches) and deeper than the DTR at the native reference plot (11.5 inches or 29 cm)
- plant cover and seeded plant cover was not significantly different than the cover at plots without amendments in 2006 and 2007
- plant cover from 2006 to 2008 that was not significantly different between plots with compost, tilling, seed, and Biosol compared to plots with tilling, seed, and Biosol but without compost
- plant cover from 2006 to 2008 that was not significantly different between plots with compost, tilling, and seed, compared to plots with tilling and seed but without compost
- TKN values from 2006 to 8 at amended plots (three-year average of 1,086 ppm) were 1.4 times higher than plots without amendments (three-year average of 779 ppm)
- from 2006 to 2008, organic matter values at amended plots (three-year average of 2.8 ppm) were 1.5 times higher than plots without amendments (three-year average of 1.9 ppm)

Amendment Type and Rate

Coarse overs, applied to a depth of 6 inches (15 cm) are recommended over woodchip or compost for the following reasons. Plots with coarse overs exhibited:

- penetrometer DTRs that were not significantly different from 2005 to 2008 from plots with other amendments
- foliar and seeded plant cover in 2006 and 2007 that was not significantly different than at plots with other amendments or plots without amendments
- soil TKN from 2006 to 2008 (1,328-1649 ppm) that was up to 2.7 times higher than the TKN at the other full treatment plots with amendments (610-1,254 ppm) and on average 1.7 times higher than the TKN at the surface treatment plot (863 ppm)
- soil TKN that was 1.4 times higher than the TKN at the native reference plot (1,028 ppm)

- organic matter from 2006 to 2008 (3.8-4.3%) that was 1.3 to 2.3 times higher than the organic matter at the other full treatment plots with amendments (1.9-3%) and on average 1.9 times higher than the organic matter at the surface treatment plot (1.9%)
- organic matter content (3.8-4.3%) that was 1.2 times higher than at the native reference plot (3.3%)

Biosol versus No Biosol

Biosol is recommended at a rate of 1,780 lbs/acre (2,000 kg/ha), for the following reasons. Plots with 1,780 lbs/acre (2,000 kg/ha) of Biosol exhibited:

- plant cover in 2007 that was significantly higher by 2.3 times (17%) compared to the plant cover at plots Biosol (8%; note that for two of the three years sampled, plant cover and seeded plant cover did not vary significantly with the use of Biosol)
- soil TKN values that ranged from 929 to 1,254 ppm at plots that included 6 inches (15 cm) of compost, compared to the plots with 6 inches (15 cm) of compost that did not include Biosol, at which TKN values ranged from 859 to 1,089 ppm
- organic matter levels at plots that included 6 inches (15 cm) of compost (2.3-2.7%) that were slightly higher than at the plots that included 6 inches (15 cm) of compost but did not include Biosol (2.1-2.2%)

Seed Rate and Composition

A native grass seed mix, at 125 lbs/acre (140 kg/ha) with the following composition is recommended:

Western needlegrass: 33.3%
squirreltail: 33.3%
mountain brome: 33.3%

This composition was modified from the tested composition for the following reasons:

- blue wildrye was removed from the tested mix, as this species was not observed during sampling in 2006-8
- Western needlegrass was increased from 12.6% to 33.3% because it thrived from 2006-8
- squirreltail and mountain brome were increased slightly to account for the removal of blue wildrye from the seed mix
- Although mountain brome was not observed in large quantities during sampling, it was included as approximately one third of the recommended seed mix. Mountain brome is often present during the first few seasons following treatment, before other

species, such as squirreltail become established.[8] The Heavenly Canyon plots were not monitored for vegetation during the first few years after establishment.

Mulch Cover and Depth

Mulch cover is recommended at 2 inches (5 cm) instead of the tested depth of 1.5 inches (3.8 cm). Mulch cover remained above 80% for most plots and above 72% for all plots.

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[8]Monitoring and Assessment of Erosion Control Treatments in and around the Lake Tahoe Basin, 2008-2009 Annual Report for Caltrans, Unpublished.

Appendix A

Species list and ocular estimates for the Heavenly Canyon test plots, 2006. Ocular estimates are presented below the plot numbers/letters. "T" indicated a species present in trace amounts.

Lifeform	Family	Scientific name	Common name	Annual/ Perennial	Native/ Alien	Noxious/ Invasive	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	N
Forb	Asteraceae	*Achillea millefolium*	Yarrow	Perennial	Native												T									T				T				
Forb	Brassicaceae	*Arabis platysperma*	pioneer rockcress	Perennial	Native						T						5										T							T
Forb	Polemoniaceae	*Collomia tinctoria*	tinted collomia	Annual	Native																			T										
Forb	Polygonaceae	*Eriogonum nudum*	nude buckwheat	Perennial	Native						T							T																
Forb	Polygonaceae	*Eriogonum spergulinum*	spurry buckwheat	Annual	Native								20	< 5				T	T		T				5	5 - 10		T	T	T	10	5 - 10	T	
Forb	Brassicaceae	*Erysimum capitatum*	Western wallflower	Perennial	Native													T										T						
Forb	Onagraceae	*Gayophytum diffusum*	groundsmoke	Perennial	Native		30	40	T	35	T	< 5	20	5 - 10	T		10		20	20	20	5 - 10		T	5	5 - 10		10	10	30	10	5 - 10	15	
Forb	Onagraceae	*Oenethera sp.*	evening primerose	Perennial	Native		T																											
Forb	Scrophulariaceae	*Penstemon newberryi*	pride of the mountain	Perennial	Native				T																		T	T						
Forb	Scrophulariaceae	*Penstemon sp.*	penstemon	Perennial	Native																								T				T	
Forb	Hydrophyllaceae	*Phacelia hastata*	silverleaf phacelia	Perennial	Native								T						T		T				T									
Forb	Scrophulariaceae	*Verbascum thapsis*	mullen	Annual	Native	Invasive		T					T				< 5																	
Graminoid	Poaceae	*Achnatherum occidentalis*	Western needlegrass	Perennial	Native		20	20	20	15	15	25 - 35	5	< 5	25 - 35		15 - 25	5 - 10	5	< 5	15 - 20	15		20 - 25	5 - 10	20		20 - 25		5 - 10	15	5 - 10	25	
Graminoid	Poaceae	*Elytrigia intermedia*	intermediate wheatgrass	Perennial	Alien					T							T		T								T							
Graminoid	Poaceae	*Bromus carinatus*	mountain brome	Perennial	Native		10 - 15	20 - 25	T															T					T					
Graminoid	Cyperaceae	*Carex rossii*	Ross' sedge	Perennial	Native									T						T														15
Graminoid	Cyperaceae	*Carex sp.*	sedge	Perennial	Native																										T	T		
Graminoid	Poaceae	*Dactyls glomerata*	orchard grass	Perennial	Alien	Invasive													T															
Graminoid	Poaceae	*Deschampsia elongate*	elongated hairgrass	Perennial	Native																													
Graminoid	Poaceae	*Elymus elymoides*	squirreltail	Perennial	Native				20	5 - 10	15	5 - 10	5 - 10	< 5	15		10	5 - 10	5	T	5	10		10	5 - 10	15	10	5 - 10		5	10	5 - 10	10	
Graminoid	Poaceae	*Elymus glaucus*	blue wildrye	Perennial	Native																													
Graminoid	Poaceae	*Festuca*	fescue sp.	Perennial	Native									T				T											T					
Graminoid	Poaceae	*Tritesum spicatum*	spike trisetum	Perennial	Native																													10
Shrub	Grossulariaceae	*Ribes cereum*	wax currant	Perennial	Native																													
Tree	Pinaceae	*Pinus contorta*	lodgepole pine	Perennial	Native							T		T	T		T	5 - 10		T						5			T					
Tree	Pinaceae	*Pinus monticola*	Western white pine	Perennial	Native																													T

Species list and ocular estimates for the Heavenly Canyon test plots, 2007. Ocular estimates are presented below the plot numbers. "T" indicated a species present in trace amounts.

Lifeform	Family	Scientific name	Common name	Annual / Perennial	Native / Alien	Noxious / Invasive	% in seed mix	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Forb	Asteraceae	*Achillea millefolium*	yarrow	Perennial	Native													T										T			T			
Forb	Brassicaceae	*Arabis platysperma*	pioneer rockcress	Perennial	Native																													
Forb	Polemoniaceae	*Collomia tinctoria*	tinted collomia	Annual	Native																													
Forb	Polygonaceae	*Eriogonum nudum*	nude buckwheat	Perennial	Native																													
Forb	Polygonaceae	*Eriogonum spergulinum*	spurry buckwheat	Annual	Native			5	T	<5	T	T	T	5	<5	<5	T	T	T	5	<5	<5	T	<5		5-10	10	5	T	T	T	T	10	<5
Forb	Brassicaceae	*Erysimum capitatum*	Western wallflower	Perennial	Native												T	10-15	T		T	T						5-10	T					T
Forb	Onagraceae	*Gayophytum diffusum*	groundsmoke	Perennial	Native			T	T	T	T	T	T	T	T	T	T	T		T	T	T				T	T	T		T	<5	T	T	<5
Forb	Onagraceae	*Oenothera sp.*	evening primerose	Perennial	Native																													
Forb	Scrophulariaceae	*Penstemon gracilentus*	penstemon	Perennial	Native																									T			T	T
Forb	Scrophulariaceae	*Penstemon newberryi*	pride of the mountain	Perennial	Native					T																		T	T		T			
Forb	Hydrophyllaceae	*Phacelia hastata*	silverleaf phacelia	Perennial	Native									T			T			T		T		T										
Forb	Scrophulariaceae	*Verbascum thapsis*	mullen	Annual	Native	Invasive								T				T																
Graminoid	Poaceae	*Achnatherum occidentale*	Western needlegrass	Perennial	Native		12.6	25	40	20	10	15-20	25-30	20	5-10	25-35	T	15-25	10	15	<5	15	15-20	T	25-35	5	25-30	30	25	T	10	20	5	20
Graminoid	Poaceae	*Elytrigia intermedia*	intermediate wheatgrass	Perennial	Alien														T	T														
Graminoid	Poaceae	*Bromus carinatus*	mountain brome	Perennial	Native		29.0	T	T	T	T						T													T				
Graminoid	Cyperaceae	*Carex multicostata*	sedge	Perennial	Native																											T	T	
Graminoid	Cyperaceae	*Carex rossii*	Ross' sedge	Perennial	Native										T						T													
Graminoid	Poaceae	*Dactylis glomerata*	orchard grass	Perennial	Alien	Invasive																												
Graminoid	Poaceae	*Deschampsia elongata*	elongated hairgrass	Perennial	Native																													
Graminoid	Poaceae	*Elymus elymoides*	squirreltail	Perennial	Native		26.5	10	10-15	20	5-10	<5	T	10	<5	5-15	T	10	5	5	<5	<5	5		5-10	10	10-15	10	5		<5	5	10-15	5
Graminoid	Poaceae	*Elymus glaucus*	blue wildrye	Perennial	Native		24.5																											
Graminoid	Poaceae	*Festuca trachyphylla*	hard fescue	Perennial	Native														T		T			T					T	T				
Graminoid	Poaceae	*Poa wheeleri*	Wheeler's bluegrass	Perennial	Native																													

Lifeform	Family	Scientific name	Common name	Annual / Perennial	Native / Alien	Noxious / Invasive	% in seed mix	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Graminoid	Poaceae	*Trisetum spicatum*	spike trisetum	Perennial	Native																													
Shrub	Ericaceae	*Arctostaphylos nevadensis*	pinemat manzanita	Perennial	Native																													
Shrub	Grossulariaceae	*Ribes cereum*	wax currant	Perennial	Native																													
Tree	Pinaceae	*Pinus contorta*	lodgepole pine	Perennial	Native												T													T				
Tree	Pinaceae	*Pinus monticola*	Western white pine	Perennial	Native								T	T	T	T	T	T	10		T				T		T			T	T			

Species list and ocular estimates for the Heavenly Canyon test plots, 2008. Ocular estimates are presented below the plot numbers. "T" indicated a species present in trace amounts.

Lifeform	Family	Scientific name	Common name	Annual / Perennial	Native / Alien	In seed mix?	% in seed mix	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Forb	Asteraceae	*Achillea millefolium*	yarrow	Perennial	Native													T													T						T
Forb	Asteraceae	*Antennaria rosea*	pussy toes	Perennial	Native																															T	
Forb	Polygonaceae	*Eriogonum nudum*	nude buckwheat	Perennial	Native									T			T																				
Forb	Polygonaceae	*Eriogonum spergulinum*	spurry buckwheat	Annual	Native			1	T	T	T			3	T		T	T	T	T	T	T	T	1	T	T	5	4		T	T	T	11	6	4	3	3
Forb	Brassicaceae	*Erysimum capitatum*	wall flower	Perennial	Native												T	8	T									4		T				T	1	T	
Forb	Onagraceae	*Gayophytum sp*	groundsmoke	Annual	Native					T	T	T		T	T		T	T	T	T	T	T		T			T	T		T	T	3	T	1	T	T	T
Forb	Scrophulariaceae	*Penstemon gracilentus*	slender penstemon	Perennial	Native			T																						T			T	T			
Forb	Scrophulariaceae	*Penstemon newberryi*	mountain pride	Perennial	Native					T												T	T				T	1	T		T						
Forb	Hydrophyllaceae	*Phacelia hastata*	silverleaf phacelia	Perennial	Native									1			T			T		T		T													
Forb	Brassicaceae	*Streptanthus tortuosus*	jewelweed, shieldplant	Annual/ Perennial	Native																																T
Graminoid	Poaceae	*Achnatherum occidentale*	Western needlegrass	Perennial	Native	x	12.6	22	32	11	11	5	12	11	5	10	T	14	5	10	5	10	8	T	10	9	21	26	20	T	15	11	7	8			
Graminoid	Poaceae	*Bromus carinatus*	mountain brome	Perennial	Native	x	29.0	T		T				T			T																				
Graminoid	Poaceae	*Bromus inermis ssp. inermis*	smooth brome	Perennial	Alien																														1		
Graminoid	Cyperaceae	*Carex multicostata*	many ribbed sedge	Perennial	Native																											T			1	T	T
Graminoid	Poaceae	*Elymus elymoides*	squirreltail	Perennial	Native	x	26.5	2	5	4	T		T	4		T	T	T		T						T	2	1		T	T	T	3	T			
Graminoid	Poaceae	*Elymus glaucus*	blue wildrye	Perennial	Native	x	24.5																														
Graminoid	Poaceae	*Elymus trachycaulus*	slender wheatgrass	Perennial	Native			T			T																	T			T		T			T	
Graminoid	Poaceae	*Festuca rubra*	red fescue	Perennial	Native						T				1	T																				T	1
Graminoid	Poaceae	*Festuca trachyphylla*	hard fescue	Perennial	Alien												T		T					T						T							
Graminoid	Poaceae	*Poa compressa*	compressed poa	Perennial	Alien										1																						
Graminoid	Poaceae	*Poa wheeleri*	Wheeler's bluegrass	Perennial	Native																								T								
Shrub	Ericaceae	*Arctostaphylos nevadensis*	pinemat manzanita	Perennial	Native																					T											
Shrub	Grossulariaceae	*Ribes cereum*	wax currant	Perennial	Native																														T		
Tree	Pinaceae	*Pinus contorta*	lodgepole pine	Perennial	Native												T				1											T			T		
Tree	Pinaceae	*Pinus jeffreyi*	Jeffrey pine	Perennial	Native														T						T												T

Lifeform	Family	Scientific name	Common name	Annual / Perennial	Native / Alien	In seed mix?	% in seed mix	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Tree	Pinaceae	*Pinus monticola*	western white pine	Perennial	Native								T		T	T	T	T	1		T			T			T			T					T		
TOTAL COVER (transects)								25	23	21	n/a	20	19	20	7	11	n/a	27	11	16	14	19	16	n/a	18	22	25	37	23	n/a	33	29	43	27	21	18	9
TOTAL COVER (ocular estimate)								26	37	16	12	5	12	18	7	11	5	23	7	11	6	11	8	3	10	10	28	35	20	4	16	15	22	16	13	5	5

Heavenly Gunbarrel Test Plots Site Report

May 2009

Introduction

Monitoring results and treatment recommendations for a series of three test plots in South Lake Tahoe at the Heavenly Ski Resort will be presented in this report (Figure 1). Monitoring was conducted in 2007 and 2008 at the Gunbarrel test plots, which are located at Heavenly Ski Resort on an open ski run near the top of the Gunbarrel ski lift. The test plots were constructed summer of 2006 (Figure 2). Although these plots are located at a ski area rather than on a roadside, the monitoring results from the tests at these areas will be applicable to Caltrans roadside projects Basin-wide and throughout the Sierra Nevada.

Figure 1. Satellite Map of the Heavenly Gunbarrel test plots location. The test plots are just south of Lake Tahoe, in California.

Figure 2. Satellite map of the test plot locations at Heavenly Ski Resort.

Purpose

The project's monitoring objectives are outlined below. The following treatment definitions are included to aid understanding of these objectives.

Full Treatment: includes soil loosening by tilling, incorporation of woodchips, addition of fertilizer and native seed, and application of native mulch.

Surface Treatment: does not include the incorporation of organic matter into the soil. This treatment includes "track-packing" with a Snowcat, seed, straw mulch, and irrigation.

The monitoring data was studied and analyzed to investigate:

1. the erosion control differences between full treatment and surface treatment plots
2. the effects of different fertilizer rates in terms of plant cover and nutrient cycling
3. the effects of irrigation on plant growth

Site Description

Test Plots and Surface Treatment Plot

The Gunbarrel test plots are located on a northeast facing ski slope at the Heavenly Ski Resort, in California (Figure 2). The site elevation is approximately 8,235 ft (2,510 m) above mean sea level (AMSL). The slope angle ranges between 15 and 20 degrees.

In 2000, prior to the construction of the test plots, the slope was track-packed with a Snowcat and treated with surface application of seed and straw mulch. Irrigation was installed, but was not run on a consistent schedule. The Gunbarrel test plots were built within this surface treatment area in the summer of 2006. The surface treatment plot that is referenced in this report refers to the area immediately adjacent to the test plots.

The soil parent material is granitic in origin. The soil is sandy and compacted, with up to 25% coarse fragments (rocks) greater than 0.5 inches (1.3 cm) in diameter in some areas. The site is an open ski run surrounded by patches of local native vegetation consisting of a red fir (*Abies magnifica*), western white pine (*Pinus monticola*), and Jeffrey pine (*Pinus jeffreyi*) canopy, with a few native bunchgrasses and forbs. The solar exposure is approximately 89% in the summer and there is no canopy cover over the test plots.

Treatment Overview

Of the four test plots, there are three plots (2B-2D) that received different variations of full treatment in 2006. These treatments are explained in detail below (Figure 3 and Table 1). Some of the treatment abbreviations in Figure 3 will be used throughout the report. The test plots were irrigated in 2008 only. Test plot 2A was destroyed in the spring of 2007 by water damage and was not used for monitoring.

The surface treatment was completed in 2000 and encompasses the area surrounding the test plots. This area was also irrigated in 2008 and most likely in the some of the years prior to the test plot construction.

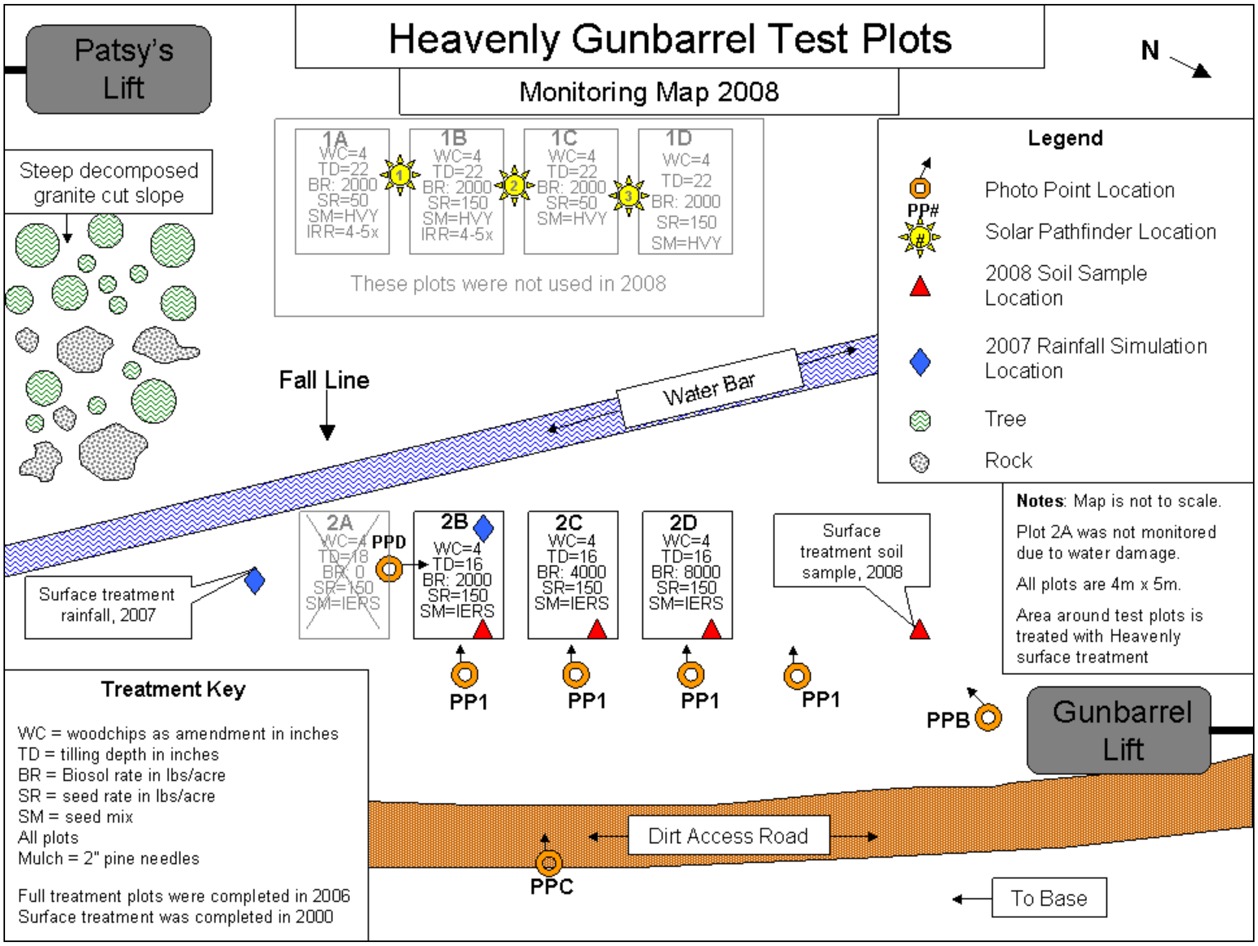

Figure 3. Map of Heavenly Gunbarrel test plots with treatment key. Rainfall simulation, photo points, soil samples, and Solar Pathfinder locations are marked. Some of the treatment abbreviations used on this map will be used throughout the report.

Test Plot Treatments

Test plot treatments are presented in Table 1. Descriptions of these treatments can be found following the table. Photos of the test plots before and after treatment are shown in Figure 4, Figure 5, Figure 6, and Figure 7.

Table 1. Heavenly Gunbarrel Treatments.

Plot Name	Amendment	Soil Loosening	Biosol Rate (lbs/acre)	Seed Type	Seed Rate	Mulch
Surface Treatment	None	None	None	Heavenly high elevation seed mix	Unknown	Unknown amount of straw
2B	4” Woodchips	16” Tilled	2,000	IERS	150 lbs/acre	2” Pine needles
2C	4” Woodchips	16” Tilled	4,000	IERS	150 lbs/acre	2” Pine needles
2D	4” Woodchips	16” Tilled	8,000	IERS	150 lbs/acre	2” Pine needles

Figure 4. Heavenly Gunbarrel test plots, pre-construction, August, 2006.

Figure 5. Heavenly Gunbarrel test plots, post-treatment, August, 2006.

Figure 6. Heavenly Gunbarrel test plots, one year following treatment, August, 2007.

Figure 7. Heavenly Gunbarrel test plot 2D (8,000 lbs/acre Biosol), two years following treatment, August, 2008.

Soil Loosening

Test plots 2B-2D were tilled to a depth of approximately 16 inches (41 cm) by an excavator using a bucket. The tilling depths were verified by penetrometer measurements directly after treatment.

The soil at the surface treatment area was not loosened; it was track-packed with a Snowcat.

Amendments

Woodchip amendment was incorporated at the full treatment test plots (2B-2D). The woodchips used were produced onsite at Heavenly. The woodchips consisted of fine chips with asymmetrical shapes and sizes. The woodchips were chipped the same summer that they were used. Further information on the source is not available. The woodchips were spread to depth of 4 inches (10 cm) at the plots and tilled to 16 inches (41 cm).

Fertilizer

Following incorporation of amendments at the full treatment plots, Biosol, a slow release fertilizer, was applied and raked approximately 1 inch (2.5 cm) into the soil at a rate of either 2,000 lbs/acre (2,241 kg/ha), 4,000 lbs/acre (4,483 kg/ha) or 8,000 lbs/acre (8,966 kg/ha; plots B, C, and D respectively).

The type and amount of fertilizer applied to the surface treatment area is unknown.

Seeding

At the test plots, suitable native perennial grasses, forbs, and shrubs were seeded at a rate of 150 lbs/acre (168 kg/ha; Figure 3, Table 2). The surface treatment plot was seeded with the Heavenly high elevation mix (Table 3) at an unknown rate.

Table 2. IERS Upland Seed Mix (plots 2B-2D)

Common Name	*Scientific Name*	% Pure Live Seed
Squirreltail	*Elymus elymoides*	30.5%
Mountain brome (Bromar)	*Bromus carinatus*	28.8%
Blue wildrye (Stan 5000)	*Elymus glaucus*	21.8%
Blue wildrye (Eldorado)	*Elymus glaucus*	6.1%
Antelope bitterbrush	*Purshia tridentata*	8.7%
Greenleaf manzanita	*Arctostaphylos patula*	1.3%
Sulphur flower buckwheat	*Eriogonum umbellatum*	1.3%
Wax currant	*Ribes cereum*	1.2%
Common sagebrush	*Artemisia tridentata*	.2%

Table 3. Heavenly High Elevation Mix (Surface Treatment)

Common Name	*Scientific Name*	% Pure Live Seed
Sheep fescue	*Festuca ovina*	25%
Hard fescue	*Festuca trachyphylla*	25%
Hybrid wheatgrass	*Agropyron smithii*	15%
Alpine bluegrass	*Poa alpina*	16%
Mountain brome	*Bromus carinatus*	10%
Blue wildrye	*Elymus glaucus*	5%
Prairie junegrass	*Koeleria cristata*	2%
Birdsfoot trefoil	*Lotus corniculatus*	2%

Mulch

Pine needle mulch was spread evenly by hand to achieve 99% cover at a depth of 2 inches (5 cm) on all full treatment test plots (2B-2D). Pine needle mulch was approximately one year old, dark in color, and partially decomposed.

The surface treatment plot received an unknown amount of straw mulch in 2000.

Monitoring Methods

Both the test plots and the surface treatment area were monitored in 2007 and 2008. In the text, both English and metric units will be given, however, tables will contain one or the other.

Rainfall Simulation

In 2007, rainfall simulation was conducted on test plot 2B and the surface treatment area. The rainfall simulator "rains" on a square plot from a height of 3.3 ft (1 m; Figure 8 and Figure 9). The rate of rainfall is controlled, and runoff is collected from a trough at the bottom of a 6.5 ft^2 (0.6 m^2) frame that has been pounded into the ground. The volume of water collected is measured and the volume of infiltration is calculated by subtracting the volume of runoff from the total volume of water applied to the plot. The collected runoff samples are then analyzed for the amount of sediment they contain. This measurement is presented as the average steady state sediment yield and is hereafter referred to as "sediment yield". The steady state infiltration rate is calculated and will hereafter be referred to as "infiltration rate".

Before rainfall simulations, in the area surrounding the frames, a cone penetrometer is used to record the depth to refusal (DTR), which is an idex for soil density. The 2007 DTR pre-rainfall values were recorded at a maximum pressure of 350 psi (2,413 kPa). Soil moisture is measured in each frame prior to and following rainfall simulations. After rainfall simulation, at least nine holes are dug with a trowel to determine the depth to wetting front, which shows how deeply water infiltrated into the soil.

In 2007, rainfall at a rate of 4.7 in/hr (120 mm/hr) was applied to both plots so that data from the plots could be more easily compared. This rate is in excess of the 20-year, one hour 'design storm' rate of 0.7 to 1.0 in/hr (18-25 mm/hr) for the Truckee-Tahoe area. The design storm rate is used to design most storm water routing plans.

Figure 8. Photo of the rainfall simulator and frame.

Figure 9. Photo of rainfall simulation at Heavenly Lower Ridge Run test plots, August 2007. The same system was used at Heavenly Gunbarrel.

Cover

Cover point monitoring was conducted at the test plots and the surface treatment plot in August of 2007 and August of 2008.

Cover is measured using the statistically defensible cover point method along randomly located transects.[1] The cover pointer consists of a metal rod with a laser pointer mounted 3.3 ft (1 m) high. After the rod is leveled in all directions, the button on the laser pointer is depressed, and two cover measurements are recorded (Figure 10 and Figure 11):

- the first hit cover, which is the first object intercepted starting from a height of 3.3 ft (1 m) above the ground
- the ground cover hit, which is the low-lying vegetation or soil below the first hit cover at the ground level

The first hit cover measures the foliar cover by plants (leaves and stems). It does not measure the part of the plant rooted in the ground. The first hit vegetation is then moved aside and a ground cover hit measures the presence of litter/mulch, basal (or rooted) plant

[1]Hogan, M. 2003. Luther Pass Monitoring Report: Plant and Soil Cover Monitoring for Evaluating Sediment Source Control Success in the Lake Tahoe Basin. Lahontan Regional Water Quality Control Board, South Lake Tahoe, CA.

cover, rock and woody debris, and/or bare ground. Total ground cover represents any cover other than bare ground.

Figure 10. Cover pointer in use along transects.

Figure 11. Cover pointer rod with first hit and ground cover hit by the laser pointer. The laser pointer hits are circled in red. The first cover hit is a native grass and the ground cover hit is pine needle mulch.

Foliar and ground level plant cover is recorded by species and then organized into cover groups based on four categories: life form (herbaceous/woody), perennial/annual, native/alien, and seeded/volunteer. Perennial herbaceous species includes seeded grasses, native grasses and forbs, and any non-native perennial species. Annual herbaceous species include native annuals such as groundsmoke (*Gayophytum sp.*) and invasive species such as English pepperweed (*Lepidium campestre*). Woody species includes any tree or shrub species, either native or introduced. Each species is then classified based on whether it is native to the Tahoe area and whether it was seeded during treatment. Data is presented on the amount of cover by species. An ocular estimate of cover at each plot is also recorded and includes many species not hit using cover point sampling. The species lists, as well as the ocular estimates of cover by species, are presented in Appendix A.

Soil and Site Physical Conditions

Penetrometer Depth to Refusal and Soil Moisture

In 2007 and 2008, penetrometer depth to refusal (an index for soil density) and soil moisture were measured along the same transects as the cover point data for all plots. A cone penetrometer with a ½ inch diameter tip is pushed straight down into the soil until a maximum pressure of 350 pounds per square inch (2,413 kPa) is reached (Figure 12 and Figure 13). The depth at which that pressure is reached is recorded as the depth to refusal (DTR).

Cone penetrometer DTR measurements are used as an index for soil density. A denser soil is less likely to allow infiltration. Rainfall simulations conducted on roadcuts in Oregon found increased infiltration rates in soils with penetrometer depths to refusal (DTRs) greater than 4 inches (10 cm).[2]

It is most informative to compare penetrometer DTR measurements collected in soils that have similar moisture levels. When soil moisture content increases, the resistance of the soil to the penetrometer decreases and DTR readings are deeper. Therefore, only penetrometer readings at the same soil moisture can be compared. A hydrometer was used to measure volumetric soil moisture content adjacent to the penetrometer readings at a depth of 4.7 inches (12 cm; Figure 14).

Figure 12. Photo of a cone penetrometer dial, showing pressure applied in pounds per square inch.

Figure 13. Photo of conducting cone penetrometer readings along transects.

Solar Exposure

In 2007, solar exposure measurements were taken at the Gunbarrel test plots. These measurements were taken using a Solar Pathfinder (Figure 15). Since there was no change in solar obstructions at the test plots, the solar exposure data was not collected in 2008. Solar input affects evaporation rates and soil temperature, which may affect time of seed germination, germination rate, rate of plant growth, and soil microbial activity. Therefore, this is an important variable to consider when monitoring plant growth and soil development.

[2] Grismer, M.E. Simulated Rainfall Evaluation at Sunriver and Mt Bachelor Highways, Oregon. Unpublished.

Figure 14. Conducting soil moisture readings along transects.

Figure 15. Solar pathfinder in use.

Soil Nutrient Analysis

Successful re-vegetation requires that nutrient capital be stored in the soil for release over time. Sufficient organic matter and a functioning microbial community are necessary to provide a long-term source of nitrogen for plants. Previous studies of soil nutrient levels at revegetation sites throughout the Tahoe area found that sites with high plant cover had significantly higher soil nutrients over the long term than soils with lower plant cover levels.[3] Total Kjeldahl nitrogen and organic matter were used as indicators of soil health in this study. Total Kjeldahl nitrogen (TKN) is a measure of readily available nitrogen. Only three soil sub-samples were taken from each plot; therefore, differences in TKN and organic matter values may be a result of the variability within a plot.

In 2007 and 2008, soil samples were taken from test plots 2B, 2C, and the surface treatment plot. In addition, a soil sample was taken from plot 2D in 2008 (Table 1 and Figure 3). Three soil sub-samples at each plot were collected from the mineral soil beneath any mulch layer to a depth of 12 inches (30 cm; Figure 16). These sub-samples were combined and sieved to remove any material larger than 0.08 inches (2 mm) in diameter, and sent to A&L Laboratories in Modesto, California for the S3C nutrient suite (macro and micronutrients), total Kjeldahl nitrogen (TKN), and organic matter analysis.

[3]Claassen, V.P., and M.P. Hogan. 2002. Soil Nutrients Associated with Revegetation of Disturbed Sites in the Lake Tahoe Basin. Restoration Ecology 10:195-203.

Figure 16. Soil sub-sample collection.

Results and Discussion

Rainfall Simulation

Trend by Treatment Level

Average steady state sediment yield was 20 times higher at the surface treatment plot (313 lbs/acre/in or 13.8 kg/ha/cm) compared to the full treatment plot with 2,000 lbs/acre (2,241 kg/ha) Biosol (16 lbs/acre/in or 0.71 kg/ha/cm; Figure 17). This full treatment plot exhibited an infiltration rate of 4.5 in/hr (113 mm/hr), which was 1.2 times higher than the infiltration rate exhibited by the surface treatment plot. The infiltration rate at the surface treatment plot was 3.9 in/hr (98 mm/hr; Figure 17).

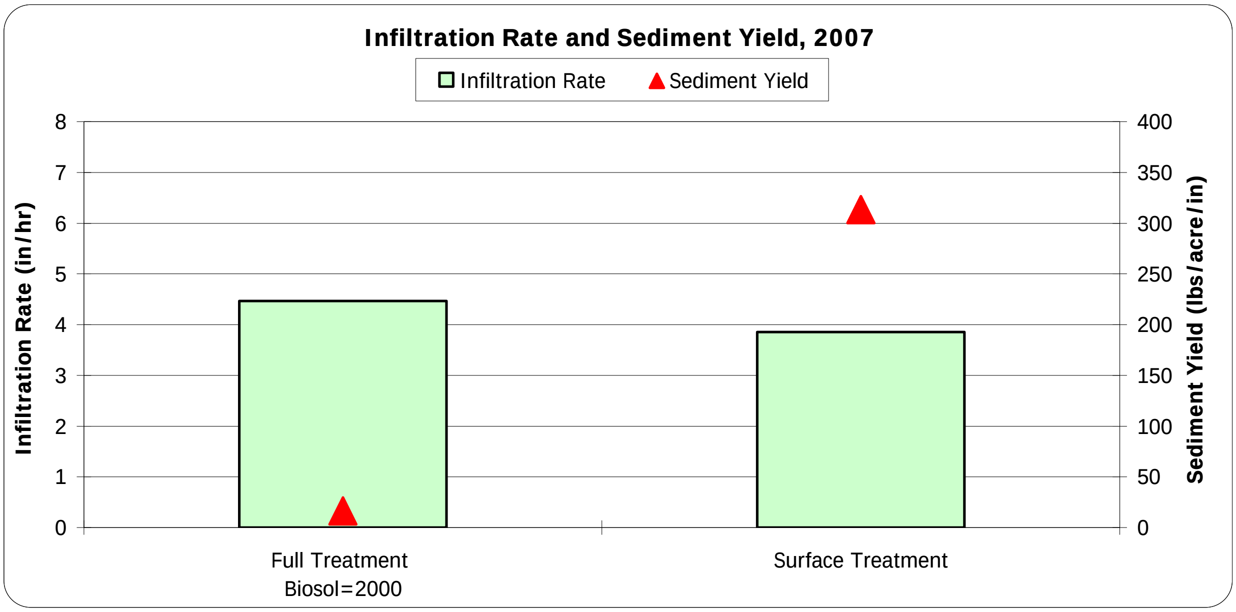

Figure 17. Infiltration Rate and Sediment Yield, 2007. The full treatment plot with 2,000 lbs/acre (2,241 kg/ha) Biosol produced 16 lbs/acre/in (7.1 kg/ha/cm) sediment and had high infiltration rates, 4.5 in/hr (113 mm/hr), while the sediment for the surface treatment plot was 313 lbs/acre/in (13.8 kg/ha/cm) with an infiltration rate of 3.9 in/hr (98 mm/hr).

Soil Moisture

Soil moisture ranged between 4.2 to 8.1% and was similar among treatments within each year (Figure 18). The average soil moisture for all plots in 2007 was 5.1%, while the average in 2008 was 7.1%. These similar moisture values allow for comparison of penetrometer depths over time and among treatments. Soil moisture increased slightly in all plots between 2007 and 2008, most likely due to irrigation in 2008.

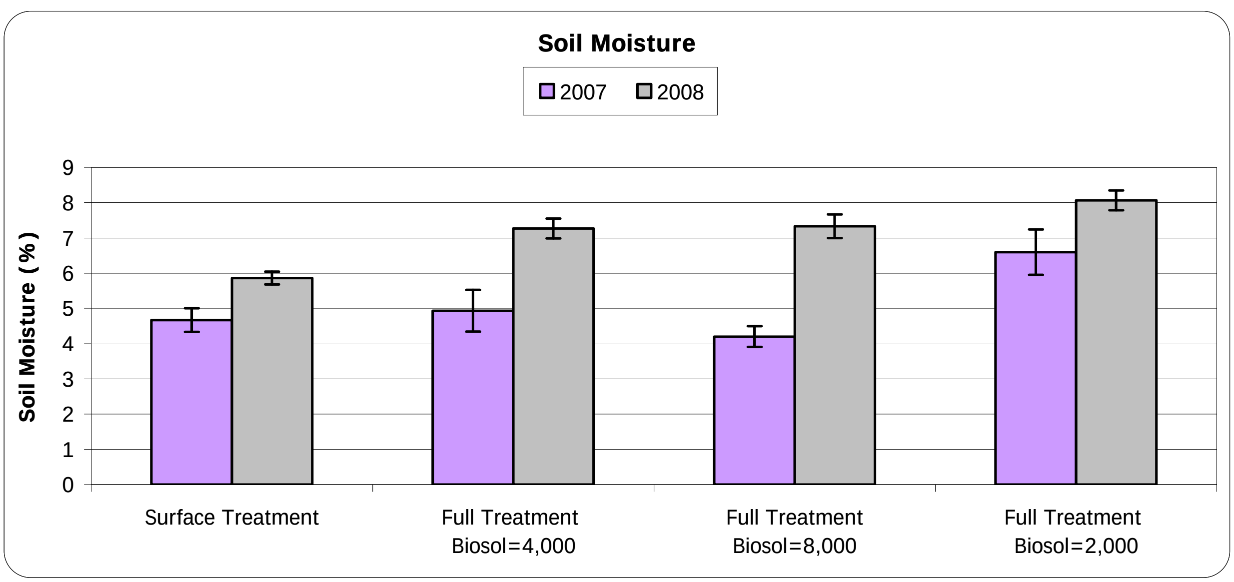

Figure 18. Soil Moisture. Soil moisture levels were similar across all plots within each year. The error bars represent one standard deviation above and below the mean. Data is sorted by increasing 2008 soil moisture.

Penetrometer Depth to Refusal

Trends by Treatment Level

The average soil density for the full treatment plots during 2007 and 2008 was 11.2 inches (28 cm), which was 3.4 times deeper compared to the surface treatment plot, which had a two-year average DTR of 3.3 inches (8.4 cm; Figure 19). Biosol rates did not affect DTR for either year.

Trends by Year

In 2008, the average DTR for the full treatment plots increased from 8.7 inches (22 cm) in 2007 to 13.7 inches (35 cm), which is 4.2 times deeper than the DTR at the surface treatment plot. The DTR at the surface treatment plot, 3.3 inches or 8.4 cm, did not change over time (Figure 19). A potential hypothesis for the increase in DTR at the full treatment plots from 2007 to 2008 is that the increase in soil moisture resulted in deeper DTRs. However, the extent of the impact of the soil moisture on DTR is difficult to determine. Although irrigation was applied in 2008, soil moisture and penetrometer DTR at the surface treatment area were similar in 2007 and 2008. Irrigation may not have increased the soil moisture in the surface treatment area because the compacted soil may have prevented deep infiltration (Figure 18 and Figure 19).

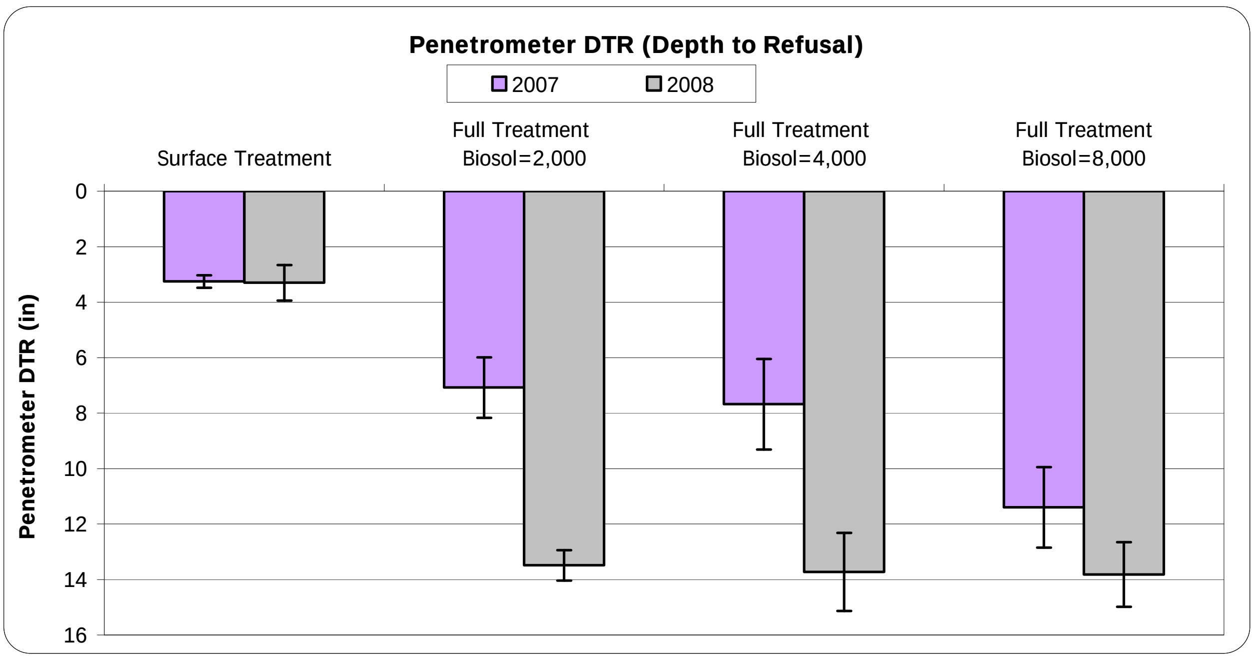

Figure 19. Penetrometer DTR. The average DTR for the full treatment plots was 8.7 inches (22 cm) in 2007 and 13.7 inches (35 cm) in 2008. The average DTR at the surface treatment plot was 3.3 inches (8.4 cm) both years. The penetrometer DTR in the full treatment plots was 2.7 times deeper in 2007 and 4.2 times deep in 2008 than the surface treatment plots over the same time. The error bars represent one standard deviation above and below the mean. Data is sorted by decreasing penetrometer DTR for 2008.

Cover

Ground Cover by Mulch and Bare Soil

Trend by Treatment Level

The mulch cover at the full treatment plots (two-year average of 77%) was on average 2.3 times higher than the mulch cover at the surface treatment plot (two-year average of 34%; Figure 20). The cover by bare soil was 2.7 times lower at the full treatment plots (two-year average of 16%) when compared to the bare cover at the surface treatment plot (two-year average of 44%; Figure 23).

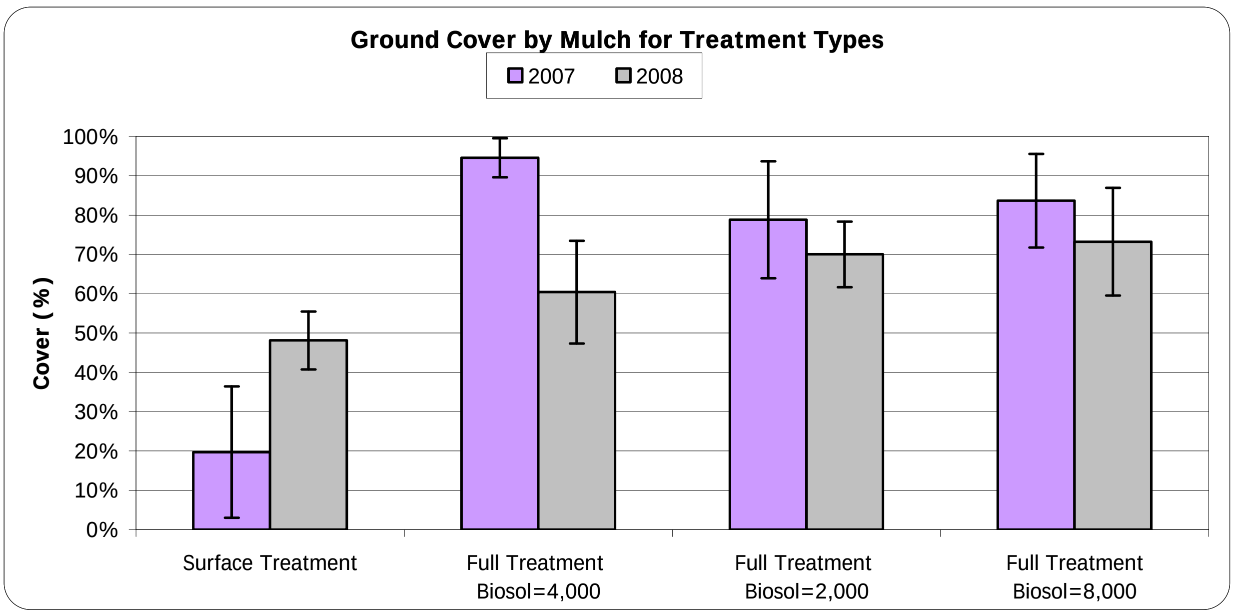

Figure 20. Ground Cover by Mulch for Treatment Types. Mulch cover decreased 1.3 times in the full treatment plots, from 86% in 2007 to 68% in 2008. Mulch increased in the surface treatment plots 2.4 times, from 20% in 2007 to 48% in 2008. The error bars represent one standard deviation above and below the mean. Data is sorted by increasing 2008 mulch cover.

Trends by Year

Mulch cover decreased 1.3 times in the full treatment plots, from 86% in 2007 to 68% in 2008 (Figure 20). The decrease in pine needle mulch cover may be a result of the type of irrigation applied. Heavenly uses a temporary high-flow overhead irrigation system with two Rain Bird impact heads. Each head sprays 30 to 50 gal/min (114-189 L/min). In September of 2008, rill formation was observed during irrigation (Figure 21 and Figure 22). The decrease in mulch cover may also be due to wind transport. This site is at a high elevation and is susceptible to high winds. Another possible cause for mulch loss is disturbance by gophers or other small animals. Animal holes were observed in the plots in 2007 and 2008 and are common throughout the Heavenly Resort. Gophers, for instance, are known to bury mulch with the castings from the burrows that they dig.

Mulch increased in the surface treatment plots 2.4 times, from 20% in 2007 to 48% in 2008. Two thirds of the mulch was plant litter and the remaining one third consisted of pine needles. Therefore, the increase was most likely a result of the plant litter accrued from the previous season.

Figure 21. Rills from irrigation, September, 2008.

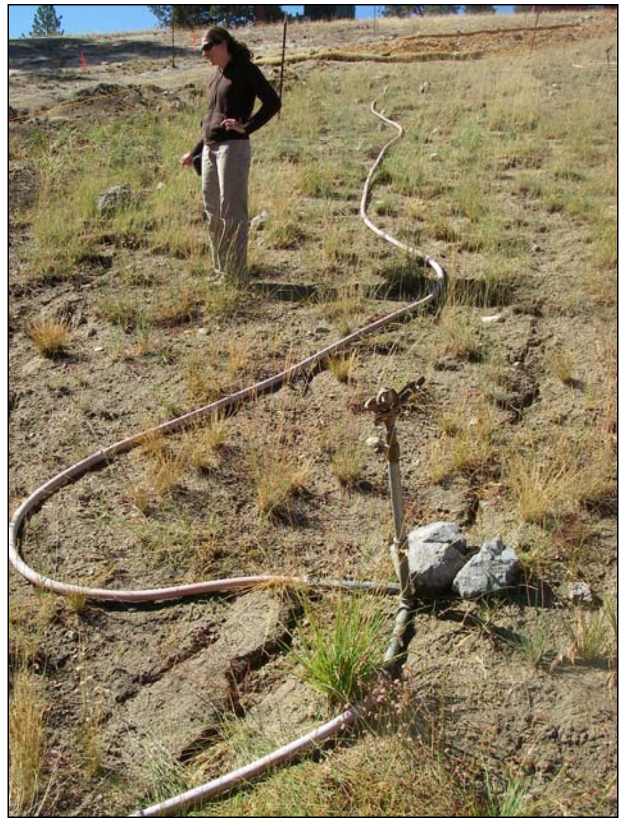

Figure 22. Rills from irrigation and irrigation set up, September, 2008.

The percent of bare soil increased in the full treatment plots by 1.6 times, from 13% in 2007 to 20% in 2008 (Figure 23). This may be because of the irrigation used in 2008. Evidence of water erosion was present in 2008 (Figure 21 and Figure 22). The cover by bare soil decreased in the surface treatment plots 1.5 times, from 53% in 2007 to 35% in 2008. This corresponds with the increase of plant litter mulch from 2007 to 2008 (Figure 23).

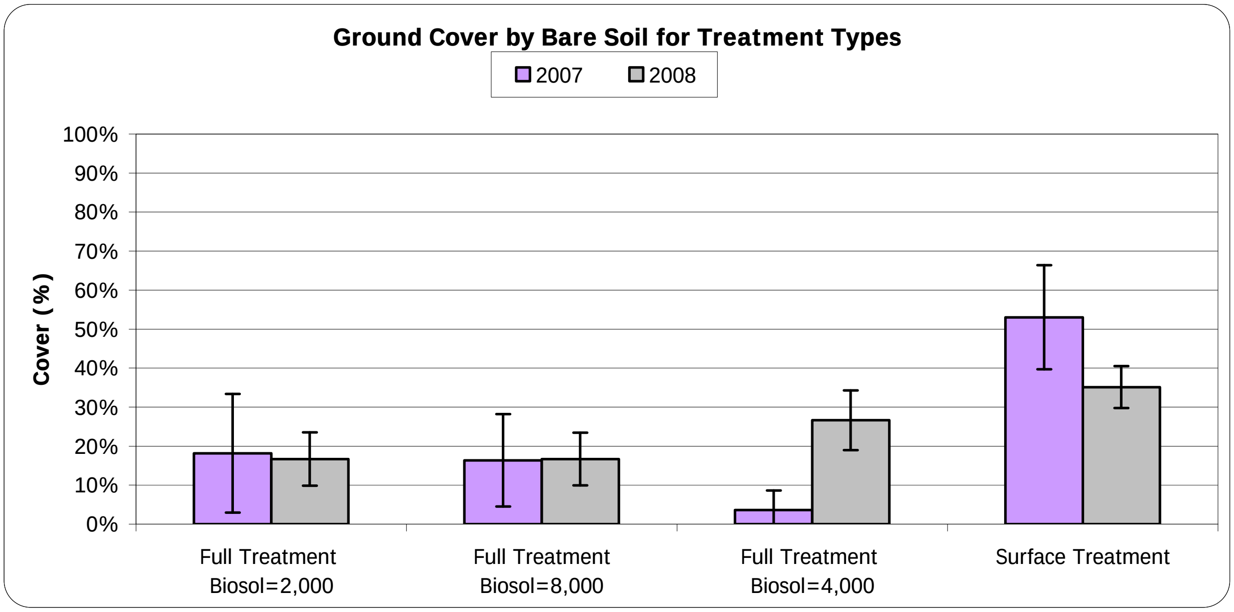

Figure 23. Ground Cover by Bare Soil for Treatment Types. The cover by bare soil increased in the full treatment plots 1.6 times, from 13% in 2007 to 20% in 2008. The cover by bare soil decreased in the surface treatment plots 1.5 times, from 53% in 2007 to 35% in 2008. The error bars represent one standard deviation above and below the mean. Data is sorted by increasing bare soil for 2008.

Plant Cover

Trends by Treatment Level

In 2007, plant cover was less than 1% at all the full treatment plots and was 9.1% at the surface treatment plot (Figure 24). These plots were not irrigated in 2006 or 2007. In 2008, the 2,000 lbs/acre (2,241 kg/ha) Biosol plot had 5% cover, the 4,000 lbs/acre (4,483 kg/ha) Biosol plot had 15% cover and the 8,000 lbs/acre (8,966 kg/ha) Biosol plot had 39% cover. The 8,000 lbs/acre (8,966 kg/ha) Biosol plot had 7.9 times higher plant cover than the 2,000 lbs/acre (2,241 kg/ha) Biosol plot. This indicates an increase in plant cover with increase in Biosol rate (Figure 24). In 2008, plant cover at the surface treatment plot was similar to that of the 4,000 (4,483 kg/ha) Biosol rate plot at 16% (Figure 24).

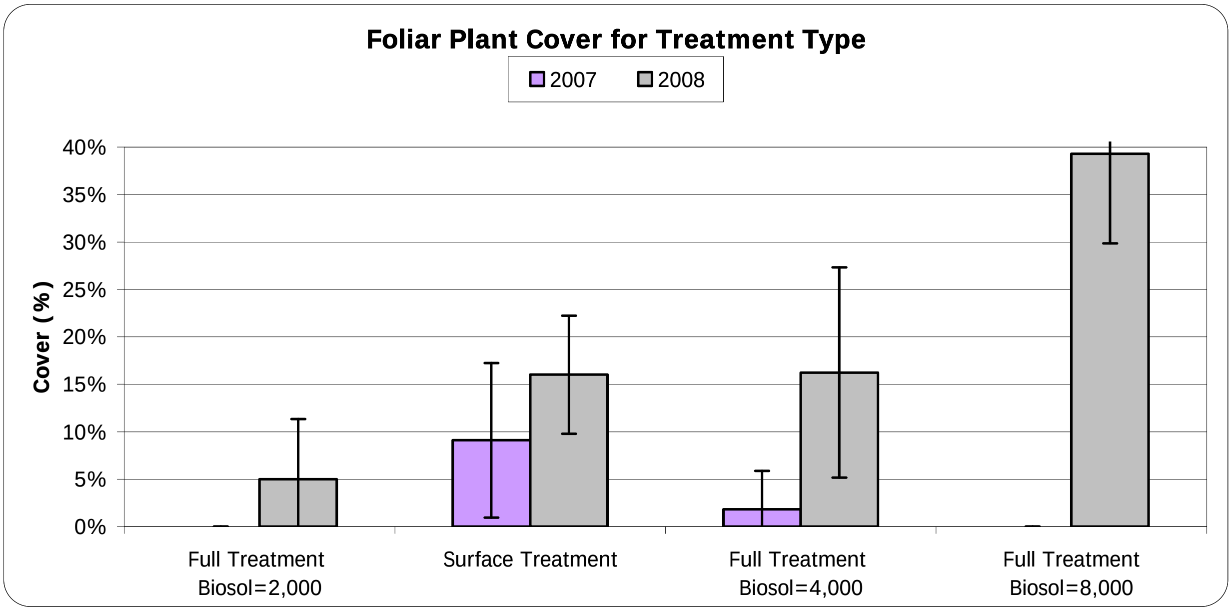

Figure 24. Foliar Cover by Treatment Type. Plant cover was zero in 2007 at the 2,000 and 8,000 lbs/acre (2,241 and 8,966 kg/ha) Biosol test plots. In 2008 cover increased with increasing Biosol rate. The error bars represent one standard deviation above and below the mean. Data is sorted by increasing foliar plant cover for 2008.

Trends by Year/Effect of Irrigation

Both the full treatment plots and the surface treatment plot exhibited an increase in plant cover between 2007 and 2008. The plant cover increased in the full treatment plots by 5-39 times from less than 1% in 2007 to 5-39% in 2008 (Figure 24). From 2007 to 2008, plant cover at the surface treatment plot increased 1.8 times. Cover increased from 9% in 2007 to 16% in 2008 (Figure 24). These increases may be a result of the irrigation that was applied in 2008, but not 2007.

Plant Composition

In 2007 and 2008, intermediate wheatgrass (*Elytrigia intermedia ssp. intermedia*) was the dominant grass at the surface treatment plot. This non-native grass was seeded in the surface treatment plot and exists in small quantities (between 1 and 4%) at the full treatment plots (Figure 25).

Although all of the full treatment plots received the same seed mix, seeded species composition varied among the full treatment plots. In 2008, the seeded native grass, mountain brome (*Bromus carinatus*) was dominant at the 2,000 lbs/acre (2,241 kg/ha) and 4,000 lbs/acre (4,483 kg/ha) Biosol test plots. The native, seeded grass squirreltail (*Elymus elymoides*) was dominant at the 8,000 lbs/acre (8,966 kg/ha) Biosol test plot. Blue wildrye (*Elymus glaucus*) composed 28% of the seed mix for the full treatment plots. There were no occurrences of blue wildrye in any of the full treatment plots over the two years of observations (Figure 25).

Of the plants recorded in the three full treatment plots and the surface treatment plots from 2007 to 2008, less than 5% of cover was volunteer (Figure 26 and Figure 27).

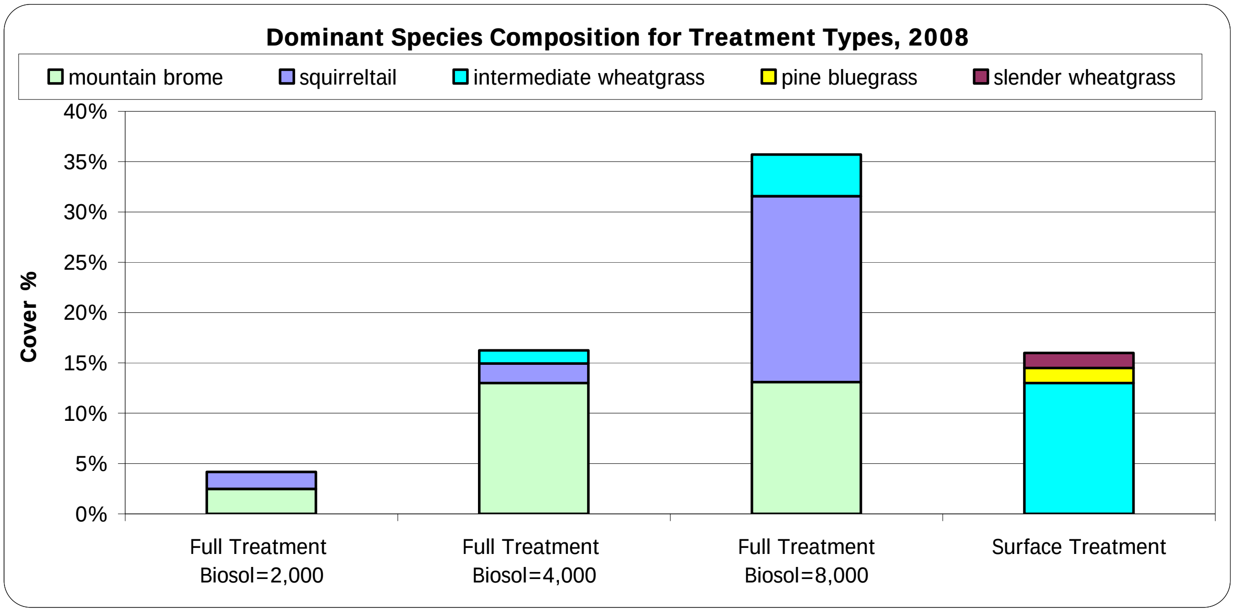

Figure 25. Dominant Species Composition by Treatment Type, 2008. Squirreltail was the dominant species at the full treatment plot with 8,000 lbs/acre (8,966 kg/ha) Biosol. Mountain brome was the dominant species at the full treatment plots with 2,000 and 4,000 lbs/acre (2,241 and 4,483 kg/ha) Biosol. Intermediate wheatgrass was the dominant species at the surface treatment plot.

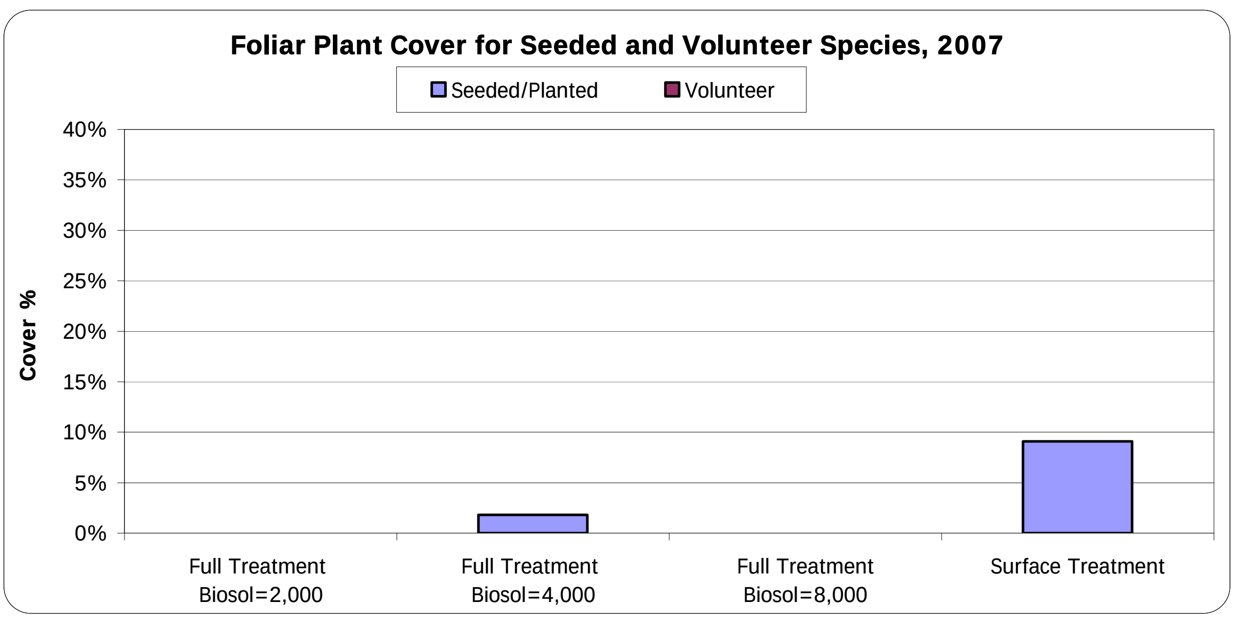

Figure 26. Foliar Plant Cover for Seeded and Volunteer Species, 2007. There was no plant cover at the 2,000 and 8,000 lbs/acre (2,241 and 8,966 kg/ha) Biosol test plots in 2007. There were no volunteer species observed on transects in any plot in 2007.

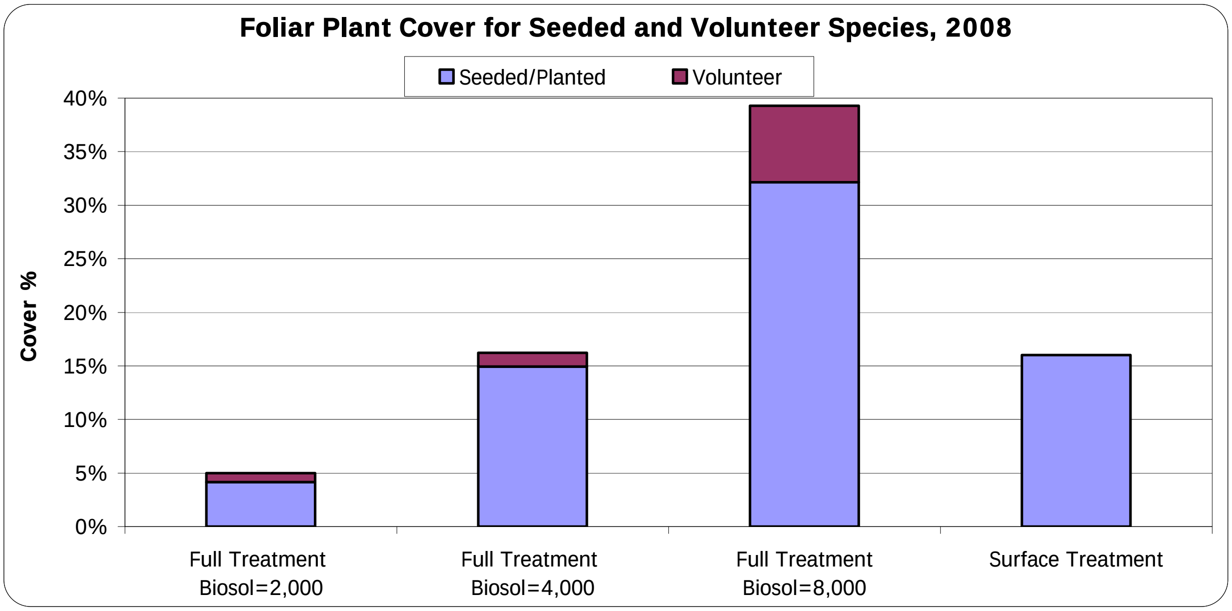

Figure 27. Foliar Plant Cover for Seeded and Volunteer Species, 2008. Seeded plant cover increased overall from 0-9% in 2007 to 4-39% in 2008 across all the plots. Volunteer species accounted for an overall average of less than 5% cover across all plots in 2008.

Soil Nutrients

Trends by Treatment Level

TKN at the full treatment plots ranged from 789 to 1,046 ppm from 2007 to 2008. Over the same time period, TKN at the surface treatment plot ranged from 546 to 593 ppm. The TKN at the Biosol plots was from 1.4 to 1.8 times higher than the surface treatment (Figure 28). In 2007, TKN was 1,046 ppm at the 4,000 lbs/acre (4,483 kg/ha) Biosol plot compared to 773 ppm at the 2,000 lbs/acre (2,241 kg/ha) Biosol plot. TKN was 1.4 times higher at the plot with 4,000 lbs/acre (4,483 kg/ha) Biosol. The only treatment difference between the two plots was the Biosol rate; all other variables were held constant (Figure 28).

Organic matter was 1.6 times higher at the full treatment plots over a two-year range (2.1-2.6%), compared to the surface treatment plot (1.4-1.5%; Figure 29). Organic matter was 2.6% at the 4,000 lbs/acre (4,483 kg/ha) Biosol plot compared to 1.9% at the 2,000 lbs/acre (2,241 kg/ha) Biosol plot. Organic matter was 1.4 times higher at the plot with 4,000 lbs/acre (4,483 kg/ha) Biosol (Figure 29).

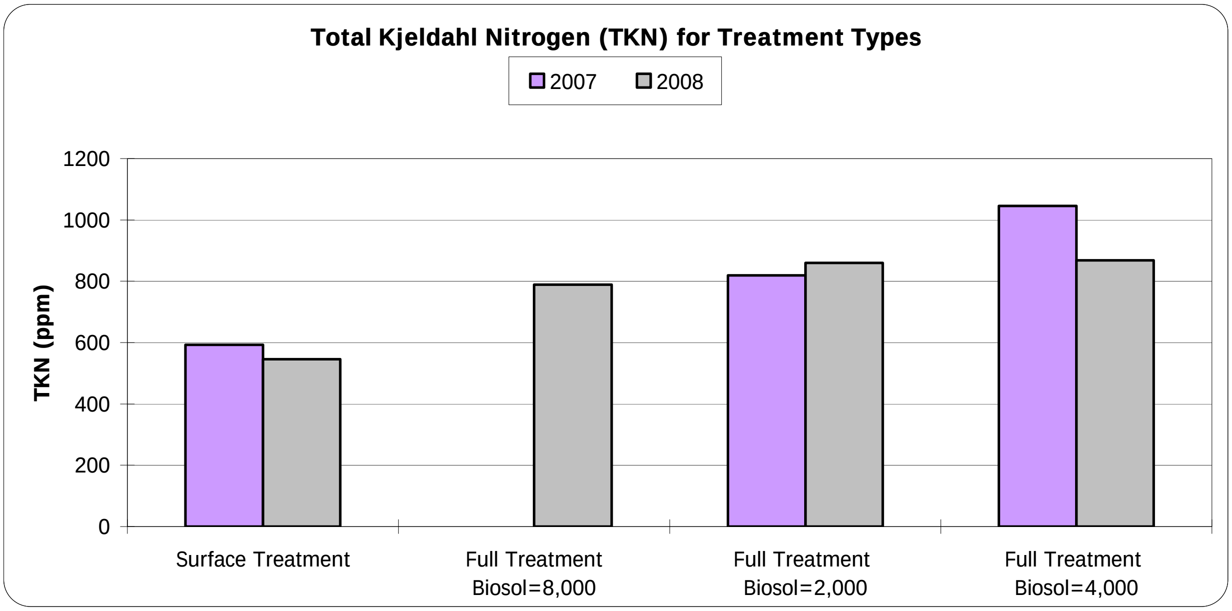

Figure 28. Total Kjeldahl Nitrogen for Treatment Types. Full treatment plots, with varying Biosol rates, had higher average TKN from 2007 to 2008 (886 ppm) compared to the surface treatment plot (570 ppm). Data is sorted by increasing TKN for 2008. The plot with 8,000 lbs/acre (8,966 kg/ha) Biosol was not sampled in 2007.

Trends by Year

In 2008, TKN was generally lower than in 2007 and similar across plots with differing Biosol rates (Figure 28). Additional TKN provided by the slow-releasing Biosol in 2007, one year following treatment, was not maintained in 2008. This may be a result of nutrient loss through extended irrigation or plant uptake.

In 2008, organic matter average of the full treatment plots was the same as in 2007 at 2.4 ppm (Figure 29). Organic matter levels remained consistent in each plot over a two-year period. This is possibly due to the slow breakdown and decomposition of the woodchip amendment. The woodchips used were fresh and may take several years to decompose.

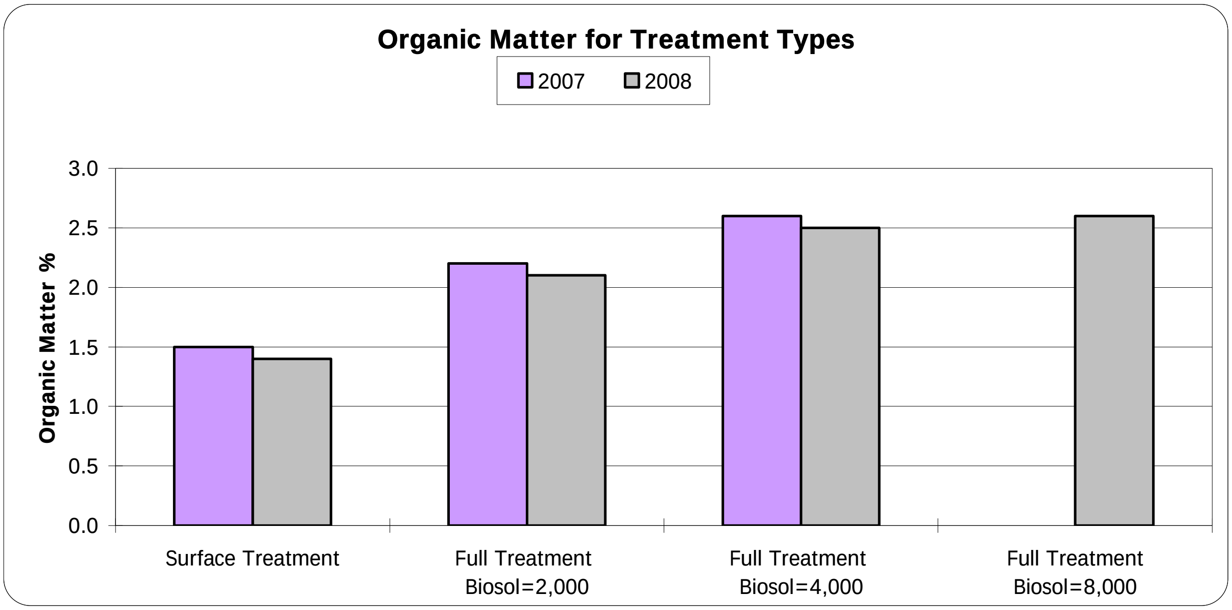

Figure 29. Organic Matter for Treatment Types. Organic matter was slightly higher at the full treatment plots over a two-year range (2.1-2.6%), compared to the surface treatment plot (1.4-1.5%). Data is sorted by increasing organic matter for 2008.

Recommendations

These recommendations are for sites with sandy soils on granitic parent material, with slope angles between 20 and 25 degrees, solar exposures of 89-98% during the summer months, at 8,235 ft (2,510 m) AMSL:

Tilling: 16 inches (41 cm)

Amendment: 4 inches (10 cm) woodchips

Biosol: 8,000 lbs/acre (8,966 kg/ha)

Seed: 150 lbs/acre (168 kg/ha) seed with the following composition:

squirreltail: 45%
mountain brome: 35%
blue wildrye: 10%
native forbs and shrubs: 10%

Mulch: pine needles, 2 inches (5 cm) and 99% cover

Irrigation: Low flow heads used daily for a short duration until germination has begun. Once seeds have germinated switch to irrigating two to three times a week for a longer duration to promote root growth.

Full treatment versus Surface Treatment

Full treatment is recommended over surface treatment because full treatment plots exhibited:

- sediment yield that was 20 times lower (16 lbs/acre/in or 0.7 kg/ha/cm) compared to the surface treatment plot (313 lbs/acre/in or 13.8 kg/ha/cm)
- infiltration rate that was 1.2 times higher than the infiltration rate exhibited by the surface treatment plot (4.5 in/hr or 113 mm/hr compared to 3.9 in/hr or 98 mm/hr)
- soil densities that were 3.4 times deeper than the surface treatment (11.2 inches or 28 cm compared to 3.3 inches or 8.4 cm)
- mulch cover was 2.3 times higher than mulch cover at the surface treatment plot (77% compared to 34%)
- cover by bare soil was 2.7 times lower compared to bare soil cover at the surface treatment plots (16% compared to 44%)
- foliar plant cover was higher by 2.5 times compared to the foliar plant cover at the surface treatment plots in 2008 (39% compared to 16%)
- TKN levels were 1.4 times higher than the surface treatment plot (789 ppm compared to 546 ppm)
- organic matter levels were 1.6 times higher than the surface treatment plot (2.4% compared to 1.5%)

Soil Loosening versus No Soil Loosening

Tilling is recommended to a depth of 16 inches (41 cm) for the following reasons. Plots with soil loosening exhibited:

- sediment yield that was 20 times lower (16 lbs/acre/in or 0.7 kg/ha/cm) compared to the surface treatment plot (313 lbs/acre/in or 13.8 kg/ha/cm)
- infiltration rate that was 1.2 times higher than the infiltration rate exhibited by the surface treatment plot (4.5 in/hr or 113 mm/hr compared to 3.9 in/hr or 98 mm/hr)
- soil densities that were 3.4 times deeper than the surface treatment (11.2 inches or 28 cm compared to 3.3 inches or 8.4 cm)
- mulch cover was 2.3 times higher than mulch cover at the surface treatment plot (77% compared to 34%)
- cover by bare soil was 2.7 times lower compared to bare soil cover at the surface treatment plots (16% compared to 44%)
- foliar plant cover was higher by 2.5 times compared to the foliar plant cover at the surface treatment plots in 2008 (39% compared to 16%)
- TKN levels were 1.4 times higher than the surface treatment plot (789 ppm compared to 546 ppm)
- organic matter levels were 1.6 times higher than the surface treatment plot (2.4% compared to 1.5%)

Amendment Type and Rate

Woodchips applied to a 4 inch (10 cm) depth and tilled in is recommended over no amendment for the following reasons. Plots with woodchips applied to a depth of 4 inches (10 cm) exhibited:

- sediment yield that was 20 times lower (16 lbs/acre/in or 0.71 kg/ha/cm) compared to the surface treatment plot (313 lbs/acre/in or 13.8 kg/ha/cm)
- infiltration rate that was 1.2 times higher than the infiltration rate exhibited by the surface treatment plot (4.5 in/hr or 113 mm/hr compared to 3.9 in/hr or 98 mm/hr)
- soil densities that were 3.4 times deeper than the surface treatment (11.2 inches or 28 cm compared to 3.3 inches or 8.4 cm)
- foliar plant cover was higher by 2.5 times compared to the foliar plant cover at the surface treatment plots in 2008 (39% compared to 16%)
- TKN levels were 1.4 times higher than the surface treatment plot (789 ppm compared to 546 ppm)
- organic matter levels were 1.6 times higher than the surface treatment plot (2.4% compared to 1.5%)

Biosol Rate

Biosol is recommended at a rate of 8,000 lbs/acre (8,966 kg/ha) for the following reasons. Plots with this application exhibited:

- foliar cover was 7.9 times higher than the 2,000 lbs/acre (2,241 kg/ha) Biosol plot in 2008 (39% compared to 5%)
- foliar cover was 2.5 times higher than the surface treatment plot in 2008 (39% compared to 16%)

Seed Rate and Mix

A native grass, forb, and shrub seed mix is recommended at a rate of 150 lbs/acre (168 kg/ha). Suggested species composition is:

squirreltail: 45%
mountain brome: 35%
blue wildrye: 10%
native forbs and shrubs: 10%

Changes are suggested from the applied mix for the following reasons:

- Squirreltail (*Elymus elymoides*) was increased from the tested application of 30.5% of the seed mix, because cover composition results indicated that squirreltail thrived in the plot with of 8,000 lbs/acre (8,966 kg/ha) Biosol.
- Blue wildrye was decreased from the tested application because no occurrences of blue wildrye were observed in any of the full treatment plots.

Mulch Cover and Depth

Mulch composed of native pine needles should be applied at a depth of 2 inches (5 cm) and a ground cover of at least 99% for the following reasons. Plots with this application exhibited:

- sediment yield production of 16 lbs/acre/in (0.71 kg/ha/cm) compared to the surface treatment plot 313 lbs/acre/in (13.8 kg/ha/cm)
- mulch cover was 2.3 times higher than mulch cover at the surface treatment plot (77% compared to 34%)
- cover by bare soil was 2.7 times lower compared to bare soil cover at the surface treatment plots (16% compared to 44%)

Irrigation

Daily use of low flow irrigation with water conserving heads (for example: MP rotator heads) at 4 gal/min (15 L/min), is recommended for a short duration to promote seed germination. Once the seeds have germinated, the irrigation frequency should be decreased to two to three times a week for longer durations to promote root growth. Irrigation is recommended for the following reasons:

- the increased plant growth from 2007 to 2008 is most likely a result of the use of irrigation in 2008

The tested irrigation system is not recommended because:

- the high flow overhead irrigation with two Rain Bird (brass) impact heads reached flow rates of 30 to 50 gal/min (114-189 L/min), which resulted in rill erosion

Appendix A

Species list and ocular estimates for Heavenly Gunbarrel test plots and surface treatment plot, 2008. Ocular estimates are presented below the plot numbers/letters. "T" indicates a species present in trace amounts.

Lifeform	Family	Scientific name	Common name	Annual/ Perennial	Native/ Alien	% in IERS Seed Mix	Plot 2B	Plot 2C	Plot 2D	% in Heavenly mix	Surface Treatment
Forb	Polygonaceae	*Eriogonum nudum*	nude buckwheat	Perennial	Native				T		
Forb	Polygonaceae	*Eriogonum spergulinum*	spurry buckwheat	Annual	Native				T		
Forb	Polygonaceae	*Eriogonum umbellatum*	sulphur flower buckwheat	Perennial	Native	1.3%					
Forb	Brassicaceae	*Erysimum capitatum*	wall flower	Perennial	Native				T		
Forb	Onagraceae	*Gayophytum sp*	groundsmoke	Annual	Native		T	T	T		
Forb	Brassicaceae	*Lepidium campestre*	English pepperweed	Annual	Alien				T		
Forb	Fabaceae	*Lotus corniculatus*	birdsfoot trefoil	Perennial	Alien					2%	
Graminoid	Poaceae	*Achnatherum occidentale*	Western needlegrass	Perennial	Native				T		
Graminoid	Poaceae	*Agropyron cristatum*	crested wheatgrass	Perennial	Alien				T		
Graminoid	Poaceae	*Bromus carinatus*	mountain brome	Perennial	Native	28.8%	5	11	15	10%	
Graminoid	Cyperaceae	*Carex douglasii*	Douglas sedge	Perennial	Native		T				
Graminoid	Poaceae	*Elymus elymoides*	squirreltail	Perennial	Native	30.5%	5	11	15		
Graminoid	Poaceae	*Elymus glaucus*	blue wildrye	Perennial	Native	27.9%				5%	
Graminoid	Poaceae	*Elymus trachycaulus*	slender wheatgrass	Perennial	Native						T
Graminoid	Poaceae	*Elytrigia intermedia ssp. intermedia*	intermediate wheatgrass or pubescent wheatgrass	Perennial	Alien			T	T		20
Graminoid	Poaceae	*Festuca ovina*	sheep fescue	Perennial	Alien					25%	
Graminoid	Poaceae	*Festuca rubra*	red fescue	Perennial	Native				T		
Graminoid	Poaceae	*Festuca trachyphylla*	hard fescue	Perennial	Alien					25%	
Graminoid	Poaceae	*Koeleria macrantha / Koeleria cristata*	prairie junegrass	Perennial	Native					2%	
Graminoid	Poaceae	*Poa alpina*	bluegrass	Perennial	Alien					16%	
Graminoid	Poaceae	*Poa secunda*	pine bluegrass	Perennial	Native						
Graminoid	Poaceae	*Pascopyrum smithii / Agropyron smithii*	western wheatgrass / hybrid wheatgrass	Perennial	Alien					15%	
Shrub	Ericaceae	*Arctostaphylos patula*	greenleaf manzanita	Perennial	Native	1.3%					
Shrub	Asteraceae	*Artemisia tridentata*	common sagebrush	Perennial	Native	.2%					
Shrub	Rosaceae	*Purshia tridentata*	antelope bitterbrush	Perennial	Native	8.7%	T	T	T		
Shrub	Grossulariaceae	*Ribes cereum*	wax currant	Perennial	Native	1.2%					
TOTAL PERCENT COVER (transects)							5	16	39		16
TOTAL PERCENT COVER (ocular estimate)							11	22	30		15

Homewood Wedding Road Site Report

May 2009

Introduction

Monitoring results and erosion control treatment recommendations for a series of 21 test plots at Homewood Mountain Resort will be presented in this report (Figure 1). The Wedding Road test plots were installed in 2007 as part of the road restoration of upper Wedding Road and monitored in 2008. The plots are located in Homewood, California, which is approximately six miles south of Tahoe City on State Route 89 in Placer County (Figure 2). Although located on a ski run, these plots are representative of Caltrans roadside conditions in the Lake Tahoe area, therefore the monitoring results from these plots will be applicable Basin-wide and throughout the Sierra Nevada.

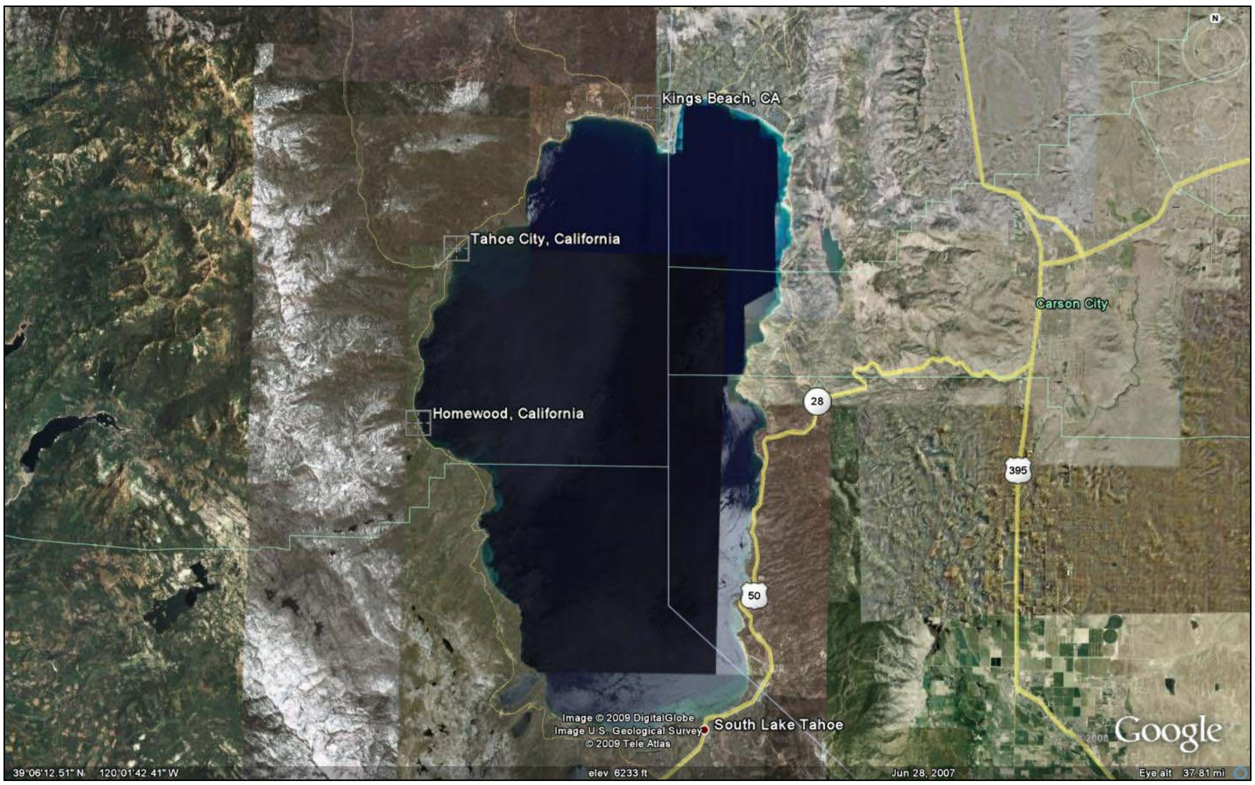

Figure 1. Satellite Map of the Homewood project area location. The project area is on the west shore of Lake Tahoe, in California.

Figure 2. Satellite map of the test plot location at Homewood Mountain Resort.

Purpose

The project's monitoring objectives are outlined below. The following treatment definitions are included to aid understanding of these objectives.

Full Treatment: includes soil loosening by tilling, incorporation of an organic amendment such as tub grindings, addition of fertilizer and native seed, and application of native mulch.

The monitoring data was studied and analyzed to investigate:

1. the effects of different seed rates and seed mixes on plant cover and composition

Site Description

The test plots are located on a north facing slope at an elevation of approximately 6,826 ft (2,080 m) above mean sea level (AMSL). The slope angle ranges between 10 and 18 degrees. The plots are located on the El Capitan ski run next to the upper third of the Quail chairlift. They are on the restored Wedding Road, which was formerly used in the summer to transport guest to weddings at the top of the Quail chairlift. The upper portion of Wedding Road was restored in 2007. The lower portion has not been restored.

The soil parent material is volcanic in origin and is very rocky, with up to 60% coarse fragments greater than 0.5 inches (1.3 cm) in diameter in some areas. The site is surrounded by local native vegetation consisting of a mixed red fir (*Abies magnifica*) and white fir (*Abies concolor*) forest with an understory of tobacco brush (*Ceanothus velutinus*), mountain whitethorn (*Ceanothus cordulatus*), currant (*Ribes* sp.), greenleaf manzanita (*Arctostaphylos patula*), and native grasses and forbs. The solar exposure ranges from approximately 38 to 100% in the summer and there is no canopy cover.

Treatment Overview

The 21 test plots consisted of replications (in all but one case) of different seed mix compositions or single species tests (Figure 3). Each treatment type and mix will be explained in detail below. An overview of the plot layout on Wedding Road is presented in Figure 3.

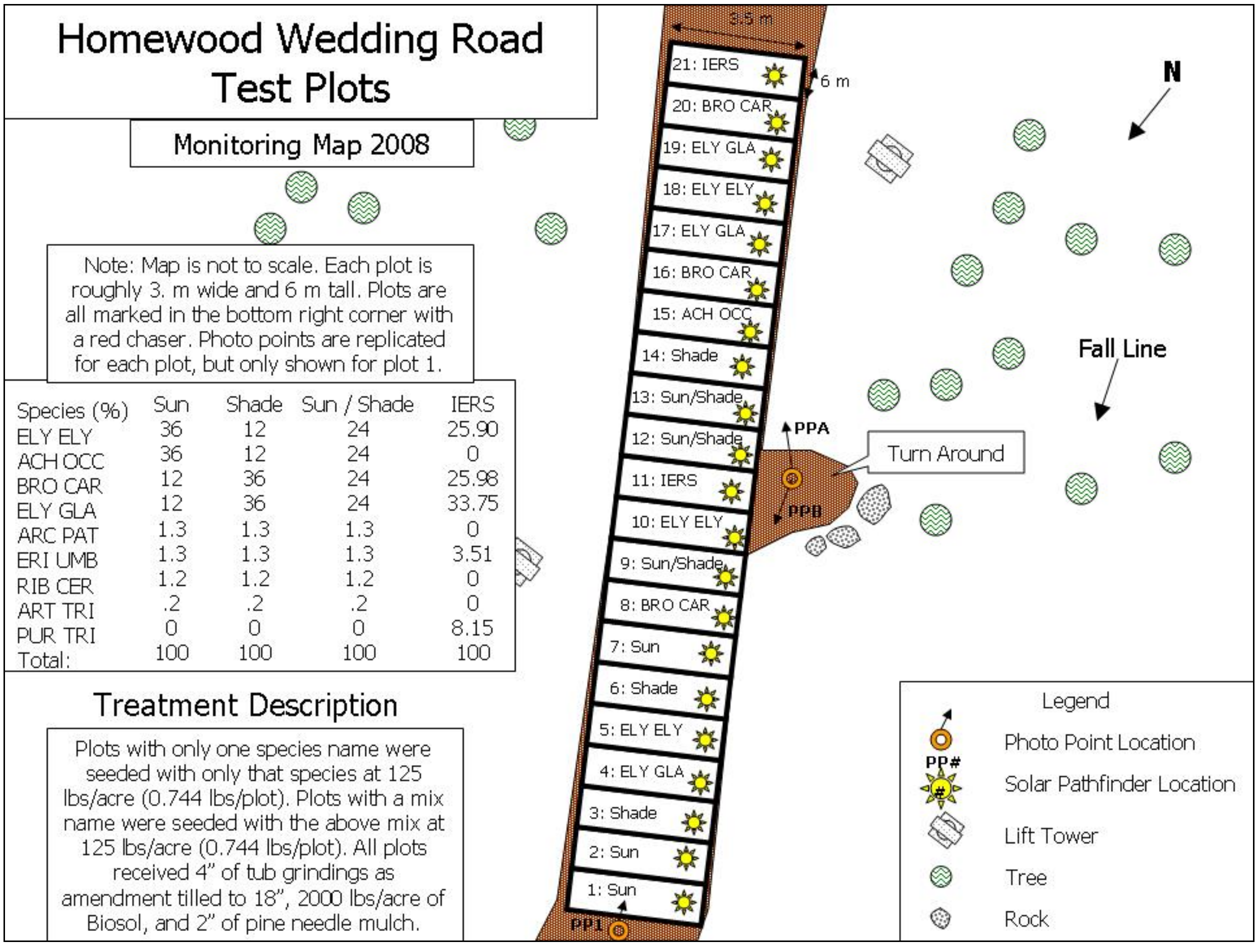

Figure 3. Map of the Wedding Road test plots with treatment description. Photo points and Solar Pathfinder locations are marked. Runoff simulation and soil sample location are just downhill of the test plots. The four seed mixes used are: IERS, Sun, Shade, and Sun/Shade. The four individual species used are ELY ELY (squirreltail), ACH OCC (western needlegrass), BRO CAR (mountain brome), and ELY GLA (blue wildrye). Other species in the mixes are; ARC PAT (greenleaf manzanita), ERI UMB (sulphur flower buckwheat), ART TRI (common sagebrush), and PUR TRI (antelope bitterbrush).

Test Plot Treatments

Test plot treatments are presented in Table 1. Descriptions of these treatments can be found following the table. Photos of the test plots before and after treatment are shown in Figure 4, Figure 5, Figure 6, and Figure 7.

Table 1. Homewood Wedding Road Treatments.

Plots	Plot Name	Amendment	Soil Loosening	Biosol Rate (lbs/acre)	Seed Type	Seed Rate (lbs/acre)	Mulch
1, 2, 7	Sun	4" Tub Grindings	18" Tilling	2,000	Sun	125	2" Pine Needles
3, 6, 14	Shade	4" Tub Grindings	18" Tilling	2,000	Shade	125	2" Pine Needles
4,17,19	ELY GLA	4" Tub Grindings	18" Tilling	2,000	Blue wildrye (*Elymus glaucus*)	125	2" Pine Needles
5, 10, 18	ELY ELY	4" Tub Grindings	18" Tilling	2,000	Squirreltail (*Elymus elymoides*)	125	2" Pine Needles
8, 16, 20	BRO CAR	4" Tub Grindings	18" Tilling	2,000	Mountain brome (*Bromus carinatus*)	125	2" Pine Needles
9, 12, 13	Sun/Shade	4" Tub Grindings	18" Tilling	2,000	Sun/Shade	125	2" Pine Needles
11, 21	IERS	4" Tub Grindings	18" Tilling	2,000	IERS	125	2" Pine Needles
15	ACH OCC	4" Tub Grindings	18" Tilling	2,000	Western needlegrass (*Achnatherum occidentale*)	125	2" Pine Needles

Figure 4. Wedding Road, pre-treatment, 2007.

Figure 5. Wedding Road, post-treatment, 2007.

Figure 6. Shade plot, #14, 1 year following treatment, 10% cover.

Figure 7. Mountain brome plot, #16, 1 year following treatment, 10% cover.

Soil Loosening

Four inches (10 cm) of tub grindings were applied to the length of Wedding Road and tilled into the soil to a depth of approximately 18 inches (46 cm) using the bucket of the excavator. The tilling depths were not verified by penetrometer measurements directly after treatment.

Amendments

One amendment type was used at the Wedding Road test plots, tub grindings.

Tub Grindings

Type 1 tub grindings were obtained from a local landfill and are composed of only raw trees, not processed construction wood that comprises some tub grindings. Type 1 tub grindings often include root material with attached soil and often possess more nutrients than woodchips. Tub grindings have a high surface area and are longer, narrower, and coarser than woodchips. The tub grindings were spread to a depth of 4 inches (10 cm) at each plot.

Fertilizer

Following incorporation of amendments, Biosol, a slow release fertilizer, was applied by hand and raked approximately 1 inch (2.5 cm) into the soil at a rate of 2,000 lbs/acre (2,241 kg/ha).

Seeding

After fertilizer, one of the seed mixes or a single species seed was spread by hand and lightly raked into the soil to ¼ inch (0.6 cm) at a rate of 125 lbs/acre (140 kg/ha). The four seed mixes and four single species use are presented in Table 2 and Table 3, along with their relative costs.

Table 2. Percent pure live seed (PLS) for Sun, Shade, Sun/Shade, and IERS seed mixes. Each mix was seeded at 125 lbs/acre.

Common Name	*Scientific Name*	Sun (% PLS)	Shade (% PLS)	Sun/Shade (% PLS)	IERS (% PLS)
Squirreltail	*Elymus elymoides*	36%	12%	24%	26%
Western needlegrass	*Achnatherum occidentale*	36%	12%	24%	0%
Mountain brome (Bromar)	*Bromus carinatus*	12%	36%	24%	26%
Blue wildrye	*Elymus glaucus*	12%	36%	24%	33.8%
Greenleaf manzanita	*Arctostaphylos patula*	1.3%	1.3%	1.3%	0%
Sulphur flower buckwheat	*Eriogonum umbellatum*	1.3%	1.3%	1.3%	3.5%
Wax currant	*Ribes cereum*	1.2%	1.2%	1.2%	0%
Common sagebrush	*Artemisia tridentata*	0.2%	0.2%	0.2%	0%
Antelope bitterbrush	*Purshia tridentata*	0%	0%	0%	8.2%
	Relative cost	$$$$	$$	$$$	$

Table 3. Single species used at the test plots. Each species was seeded at 125 lbs/acre.

Common Name	*Scientific Name*
Squirreltail	*Elymus elymoides*
Western needlegrass	*Achnatherum occidentale*
Mountain brome (Bromar)	*Bromus carinatus*
Blue wildrye	*Elymus glaucus*

Mulch

Mulch was spread evenly by hand to achieve 99% cover at a depth of 2 inches (5 cm) at each plot.

Monitoring Methods

The test plots were monitored in 2008. In the text, both English and metric units will be given; however, tables will contain one or the other.

Runoff Simulation

The runoff simulator is a 3.3 feet (1 m) wide PVC pipe with 50 evenly spaced holes that are one sixteenth inches (1.6 mm) in diameter (Figure 8). When water is pumped though the pipe and exits the holes, an even flow of water across the entire width of the pipe is produced, thereby simulating snowmelt runoff through sheet flow. Snowmelt can produce a significant amount of runoff and sediment, which can lead to severe erosion problems. A collection trough is installed 6 to 10 ft (2-3 m) down slope from the runoff pipe and all runoff is collected until steady state is reached.

The volume of water collected is measured and the volume of infiltration is calculated by subtracting the volume of runoff from the total volume of water applied to the plot. If runoff is not observed during the first 45 minutes, the simulation is halted. The collected runoff samples are then analyzed for the amount of sediment they contain. This measurement is presented as the average steady state sediment yield and is hereafter referred to as "sediment yield". The steady state infiltration rate is calculated and will hereafter be referred to as "infiltration rate".

The cone penetrometer is used to record the depth to refusal (DTR), which is an index of soil density, in the area of the frame before runoff simulations. The DTR values were recorded at 350 psi (2,413 kPa). Soil moisture is measured in each frame prior to and following runoff simulations. After the simulation, nine holes were dug to measure the depth to wetting front.

In 2007 and 2008, 5 L/min of water was applied, which corresponds to 4.4 in/hr (112 mm/hr).

Figure 8. The runoff simulator at Wedding Road. The PVC pipe is visible at the top of the photo and the collection frame is at the bottom.

Cover

Cover point monitoring was conducted in 2008 at each test plot. Cover is measured using the statistically defensible cover point method along randomly located transects.[1] The cover pointer consists of a metal rod with a laser pointer mounted 3.3 feet (1 m) high. After the rod is leveled in all directions, the button on the laser pointer is depressed and two cover measurements are recorded (Figure 9 and Figure 10):

[1] Hogan, M. 2003. Luther Pass Monitoring Report: Plant and Soil Cover Monitoring for Evaluating Sediment Source Control Success in the Lake Tahoe Basin. Lahontan Regional Water Quality Control Board, South Lake Tahoe, CA.

- the first hit cover, which is the first object intercepted starting from a height of 3.3 ft (1 m) above the ground
- the ground cover hit, which is the low-lying vegetation or soil below the first hit cover, at the ground level

The first hit cover measures the foliar cover by plants (leaves and stems). It does not measure the part of the plant rooted in the ground. The first hit vegetation is then moved aside and a ground cover hit measures the presence of litter/mulch, basal (or rooted) plant cover, rock and woody debris, and/or bare ground. Total ground cover represents any cover other than bare ground. Mulch cover is an important variable in erosion reduction through sediment source control because treatments with cover by pine needle mulch have been shown to reduce sediment yields substantially.[2]

Figure 9. Cover pointer in use along transects.

Figure 10. Cover pointer rod with first hit and ground cover hit by the laser pointer. The laser pointer hits are circled in red. The first cover hit is a native grass and the ground cover hit is pine needle mulch.

Foliar and ground level plant cover is recorded by species and then organized into cover groups based on four categories: life form (herbaceous/woody), perennial/annual, native/alien, and seeded/volunteer. Perennial herbaceous species includes seeded grasses, native grasses and forbs, and any non-native perennial species. Annual herbaceous species include native annuals and invasive species. Woody species includes any tree or shrub species, either native or introduced. Each species is then classified based on whether it is native to the Tahoe area and whether it was seeded during treatment. Data is presented on the amount of cover by species. An ocular estimate of cover at each plot is also recorded and includes many species not hit using cover point sampling. The species lists, as well as the ocular estimates of cover by species, are presented in Appendix A. In some areas where the

[2] Grismer, M.E., and M.P. Hogan. 2004. Simulated rainfall evaluation of revegetation/mulch erosion control in the Lake Tahoe Basin: 1. Method assessment. Land Degradation & Development 15:573-588.

grasses had not gone to seed, it was difficult to determine whether squirreltail or blue wildrye was present. When identification was not possible, the grass was categorized as *Elymus* sp.

Soil and Site Physical Conditions

Penetrometer Depth to Refusal and Soil Moisture

In 2008, penetrometer depth to refusal and soil moisture were measured along the same transects as the cover point data for all plots. A cone penetrometer with a ½ inch diameter tip is pushed straight down into the soil until a maximum pressure of 350 pounds per square inch (2,413 kPa) is reached (Figure 11 and Figure 12). The depth at which that pressure is reached is recorded as the depth to refusal (DTR).

Cone penetrometer DTR measurements are used as an index for soil density. Soils with higher DTRs are generally less dense than those with lower DTRs. A denser soil is less likely to allow infiltration. Rainfall simulations conducted on roadcuts in Oregon found increased infiltration rates in soils with penetrometer depths to refusal (DTRs) greater than 4 inches (10 cm).[3]

It is most informative to compare penetrometer DTR measurements collected in soils that have similar moisture levels. When soil moisture content increases, the resistance of the soil to the penetrometer decreases and DTR readings are deeper. Therefore, only penetrometer readings at the same soil moisture can be compared. A hydrometer was used to measure volumetric soil moisture content adjacent to the penetrometer readings at a depth of 4.7 inches (12 cm; Figure 13).

Figure 11. Photo of a cone penetrometer dial, showing pressure applied in pounds per square inch.

Figure 12. Photo of conducting cone penetrometer readings along transects.

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[3]Grismer, M.E. 2006. Simulated Rainfall Evaluation at Sunriver and Mt. Bachelor Highways, Oregon. Unpublished.

Solar Exposure

In 2007, solar exposure measurements were taken at each plot. These measurements are taken using a Solar Pathfinder (Figure 14). Since there was no change in solar obstructions at the test plots, the solar pathfinder data was not collected in 2008. Solar input affects evaporation rates and soil temperature, which may affect time of seed germination, germination rate, rate of plant growth, and soil microbial activity. Therefore, this is an important variable to consider when monitoring plant growth and soil development.

Figure 13. Conducting soil moisture readings along transects.

Figure 14. Solar pathfinder in use.

Soil Nutrient Analysis

Successful re-vegetation requires that nutrient capital be stored in the soil for release over time. Sufficient organic matter and a functioning microbial community are necessary to provide a long-term source of nitrogen for plants. Previous studies of soil nutrient levels at revegetation sites throughout the Tahoe area found that sites with high plant cover had significantly higher soil nutrients over the long term than soils with lower plant cover levels.[4] Total Kjeldahl nitrogen and organic matter were used as indicators of soil health in this study. Total Kjeldahl nitrogen (TKN) is a measure of readily available nitrogen. Only three soil sub samples were taken from each plot; therefore, differences in TKN and organic matter values may be a result of the variability within a plot.

Soil samples were collected in 2007 and 2008. Three soil sub-samples at each plot were collected from the mineral soil beneath any mulch layer to a depth of 12 inches (30 cm; Figure 15). These samples were combined and sieved to remove any material larger than 0.08 inches (2 mm) in diameter, and sent to A&L Laboratories in Modesto, California for the S3C nutrient suite (macro and micronutrients), total Kjeldahl nitrogen (TKN), and organic matter analysis.

[4]Claassen, V.P., and M.P. Hogan. 2002. Soil Nutrients Associated with Revegetation of Disturbed Sites in the Lake Tahoe Basin. Restoration Ecology 10:195-203.

Figure 15. Soil sub-sample collection.

Statistical Analysis

Statistical tests were used to determine significant differences between treatments. An Analysis of Variance (ANOVA) was used to investigate whether there were any significant differences in plant cover or seeded plant cover among plots with different seed applications.

Results and Discussion

Runoff Simulation

Pre-treatment runoff simulation resulted in a sediment yield of 20,780 lbs/acre/in (9,170 kg/ha/cm), which was the highest sediment yield observed during two seasons of runoff simulation at a variety of locations at Homewood (Figure 16). One year following treatment, sediment yield decreased to zero and the infiltration rate increased to 5.9 in/hr (150 mm/hr) from 4.0 in/hr (102 mm/hr; Figure 16).

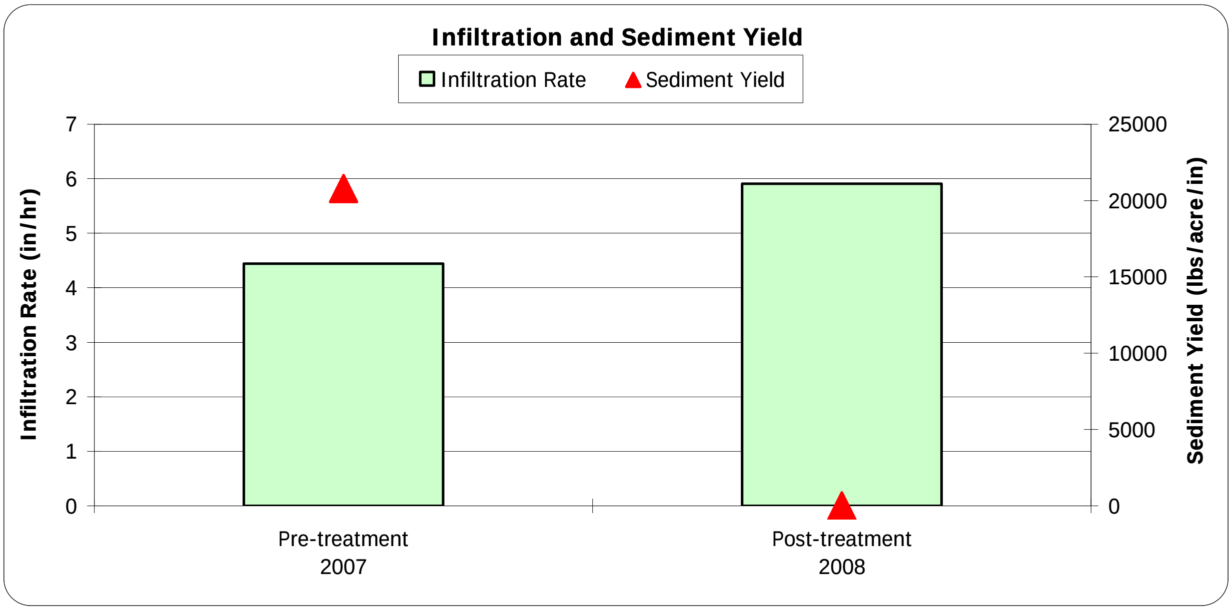

Figure 16. Infiltration and Sediment Yield. The sediment yield decreased by 20,780 lbs/acre/in (9,170 kg/ha/cm) and the infiltration rate increased by 01.9 in/hr (48 mm/hr) following treatment.

Soil Moisture

In 2008, the average soil moisture ranged between 5.5 and 6.5% (Figure 17). These similar values allow for comparison of penetrometer depths among treatments.

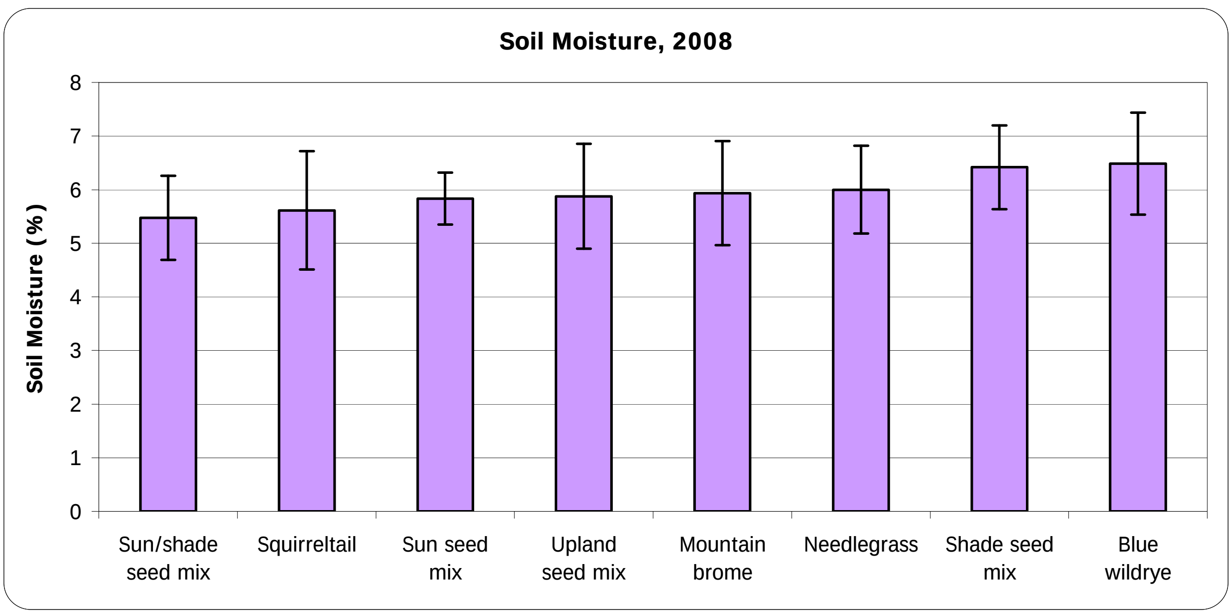

Figure 17. Soil Moisture. Soil moisture ranged between 5.5 and 6.5%.

Penetrometer Depth to Refusal (DTR)

Penetrometer DTR ranged from an average of 5.7 to 9.4 inches (14.5-24 cm) and did not vary significantly among plots with different seed treatments (Figure 18 and Table 4). The small differences in DTR are most likely a result of varied tilling depth during plot installation. The penetrometer DTRs are 1.9 to 3.3 times shallower than the tilling depth of 18 inches (46 cm). This may be a result of re-compaction over time or it is possible that the tilling depth of 18 inches (46 cm) was not achieved.

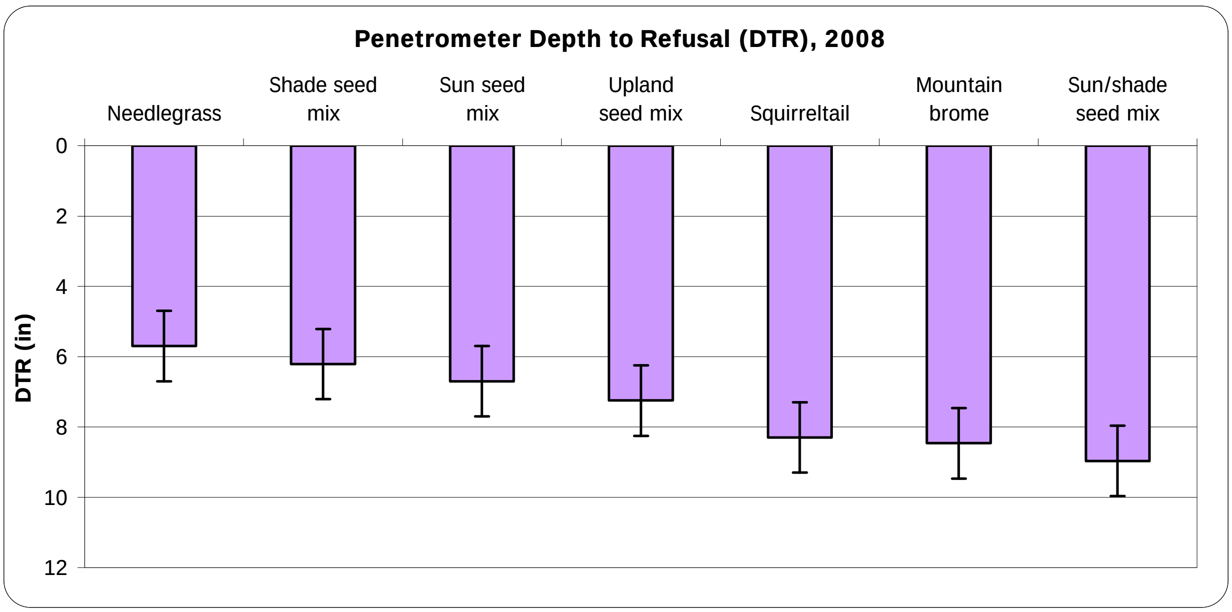

Figure 18. Penetrometer Depth to Refusal (DTR). Penetrometer DTR ranged from 5.7 to 9.4 inches (14.5-24 cm) and did not vary significantly among plots with different seed treatments.

Cover

Ground Cover by Mulch

Mulch cover was greater than 90% at all plots, while ground cover by bare soil was less than 3% for all plots (Figure 19). Treatments with considerable mulch cover have been shown to reduce sediment yields substantially.[5] The high mulch cover, in addition to the soil treatments, may be related to the large reduction in sediment yield.

[5] Grismer, M.E., and M.P. Hogan. 2004. Simulated rainfall evaluation of revegetation/mulch erosion control in the Lake Tahoe Basin: 1. Method assessment. Land Degradation & Development 15:573-588.

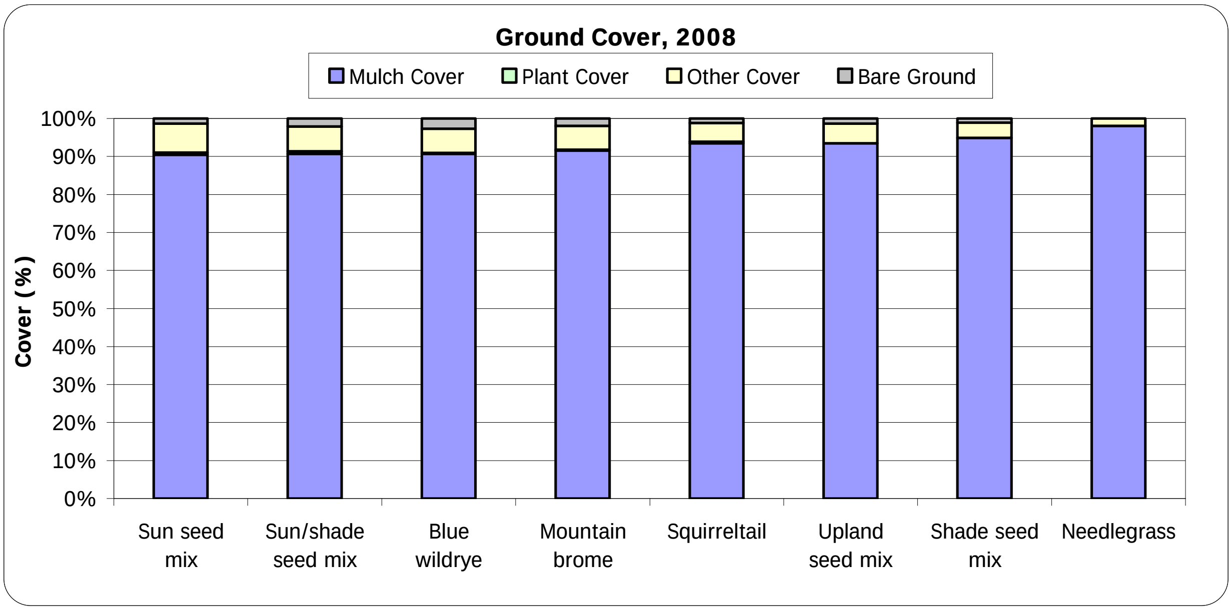

Figure 19. Ground Cover. Mulch cover was greater than 90% at all plots, while bare soil was less than 3% for all plots.

Plant Cover

Plant cover was highest at the plot seeded with needlegrass only (20%) compared to all other plots, which had cover that ranged from 6 to 13% (Figure 20). No significant differences in plant cover or seeded plant cover were found between plots with different seed mixes (excluding needlegrass).The needlegrass plot did not have three replications; therefore, statistical tests were not applied (Figure 20 and Table 4).

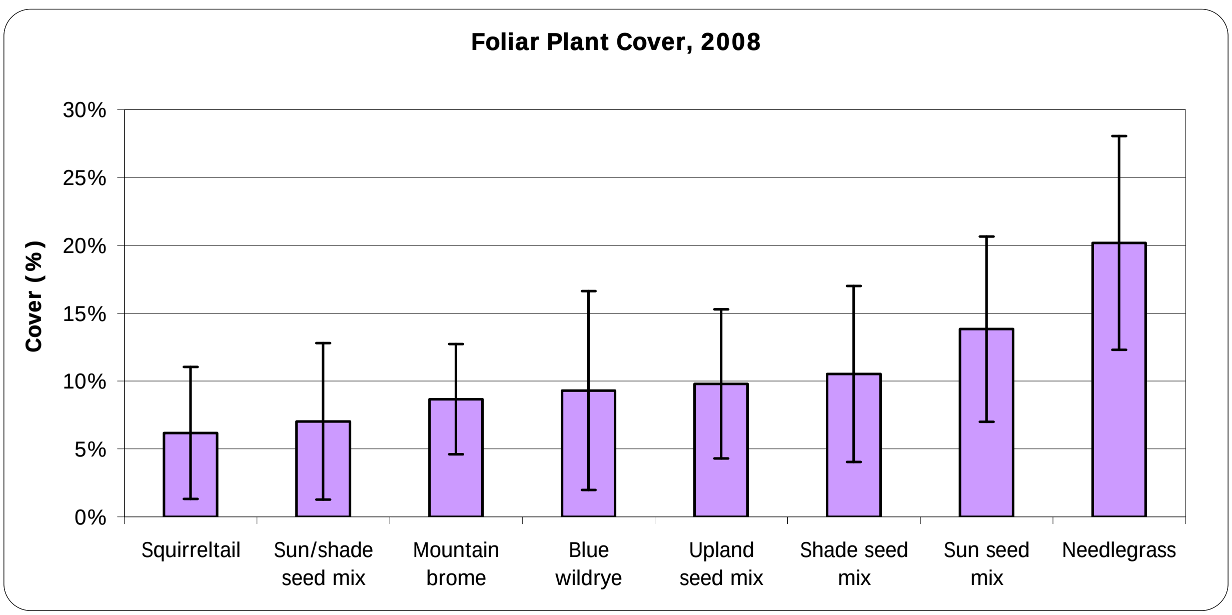

Figure 20. Foliar Plant Cover. No significant differences in plant cover were found between plots with different seed mixes (excluding needlegrass). Plant cover was highest at the plot seeded with needlegrass only (20%) compared to all other plots, which had cover that ranged from 6 to 13%.

Plant Composition

Plots with Seed Mixes

The sun and shade mixes produced similar amounts of cover (11 and 14%, respectively) with similar composition. Both plots had proportionally high amounts of needlegrass and *Elymus* sp, though different amounts of the two species were seeded (Figure 21). The sun/shade plot and the upland seed mix plots were both dominated by mountain brome. The seed mix for these plots contained less mountain brome (24%) than in the shade mix (36%), but the sun/shade plot and the upland plot produced more cover by mountain brome than the shade plot (Figure 21). It is unclear why plots with less mountain brome in the seed mix produced more cover by mountain brome.

Blue wildrye may not compete well with other grass species, as it was present in small quantities in plots where it was applied as part of a mix.

Plots with Individual Species

When Western needlegrass is seeded at 125 lbs/acre (140 kg/ha), it out-competes most volunteer species, as it composed 100% of seeded cover (Figure 21 and Figure 22). Only Western needlegrass was detected during cover point monitoring and just a few other species were present during ocular estimates (Appendix A).

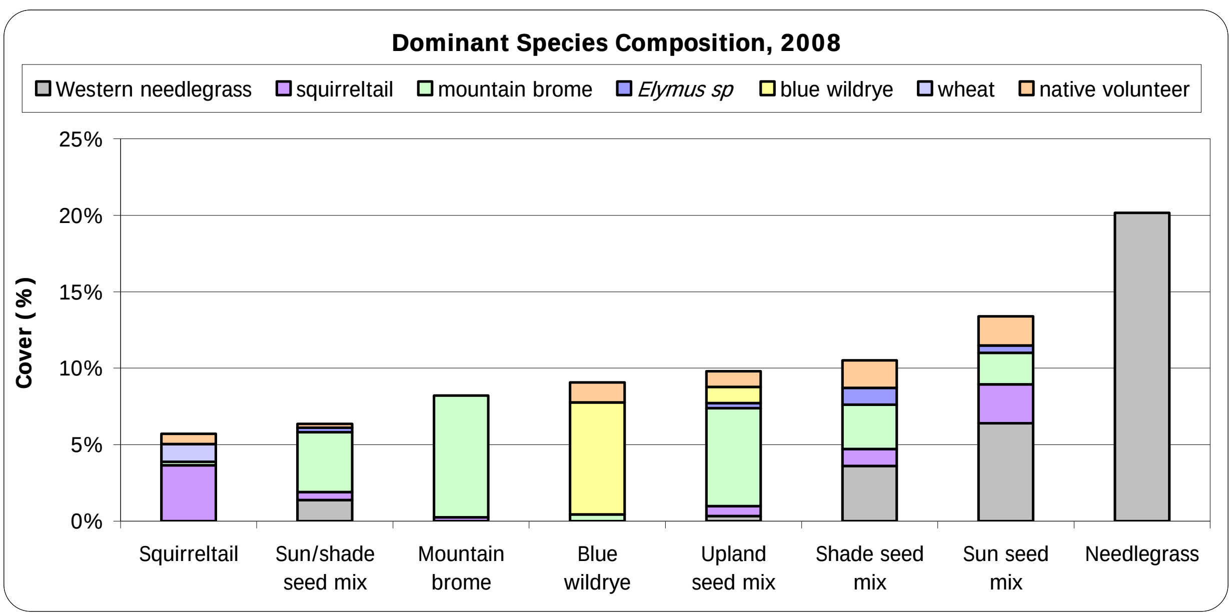

Figure 21. Dominant Species Composition. The Western needlegrass plots produced the highest cover and Western needlegrass was present at all plots in which it was seeded. Blue wildrye produced the least cover of all seeded species when seeded in a mix.

In the single-species squirreltail plot, approximately 60% of the cover was by squirreltail, while the remainder of the cover was dominated by a non-native wheatgrass species (Figure 21 and Figure 22). This indicates that squirreltail should be seeded in conjunction with other species to produce a higher cover by seeded species. Squirreltail has been observed to increase over time after low rates are observed during the first season after application.[6]

The blue wildrye single-species plot had 80% cover by the seeded species, while the mountain brome single-species plot had 95% cover by seeded species (Figure 22).

The combination of mountain brome (which produces higher cover during the first season), squirreltail (which produces some cover during the first season, but generally increases over time), and Western needlegrass (which produces high cover during the first season) may be best for sites with high solar exposure.

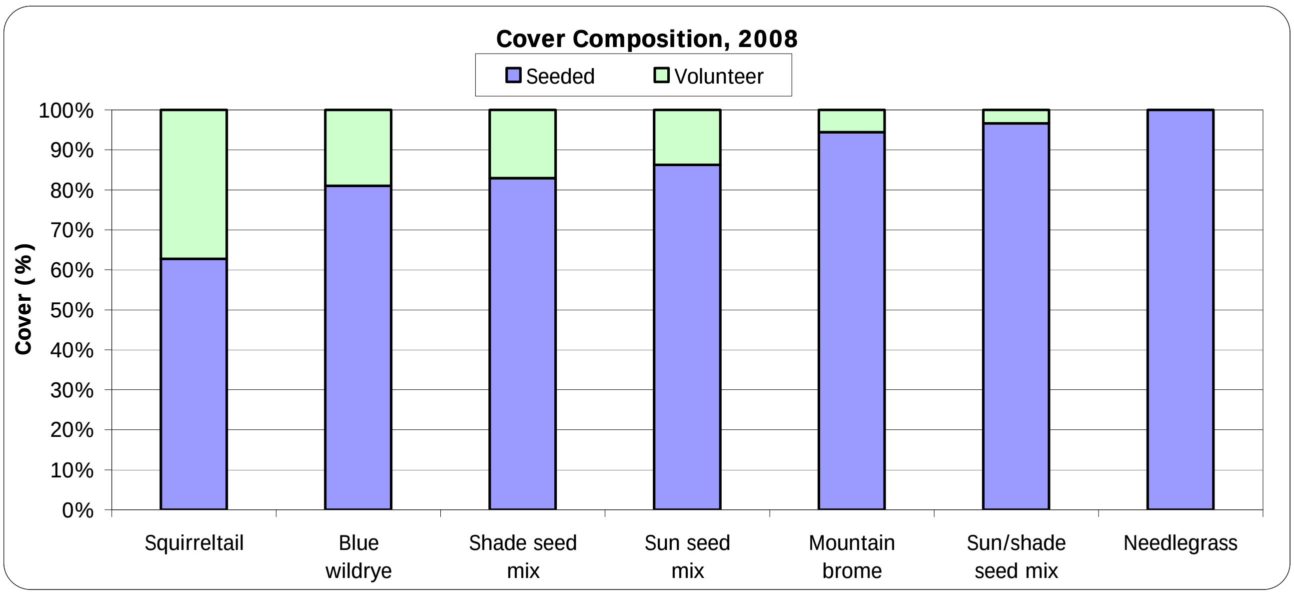

Figure 22. Cover composition. Seeded species composition was highest at the needlegrass plot, 100%, and lowest at the squirreltail plot, 63%.

Solar Exposure

The average solar exposure, as measured in June, was similarly high (84-97%) for all plots except for the sun seed mix and the shade seed mix (Figure 23). The solar exposure for the sun seed mix was 60%, while it was 63% for the shade seed mix. It is difficult to determine whether solar exposure affects plant composition. Generally, site with less solar exposure favor the species mountain brome or blue wildrye.[7] Neither were present in greater quantities at the sun or shade seed mix plots, compared to plots with higher solar exposures.

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[6] Monitoring and Assessment of Erosion Control Treatments in and around the Lake Tahoe Basin, 2008 Annual Report for Caltrans. Unpublished.

[7] Monitoring and Assessment of Erosion Control Treatments in and around the Lake Tahoe Basin, 2007 Annual Report for Caltrans. Unpublished.

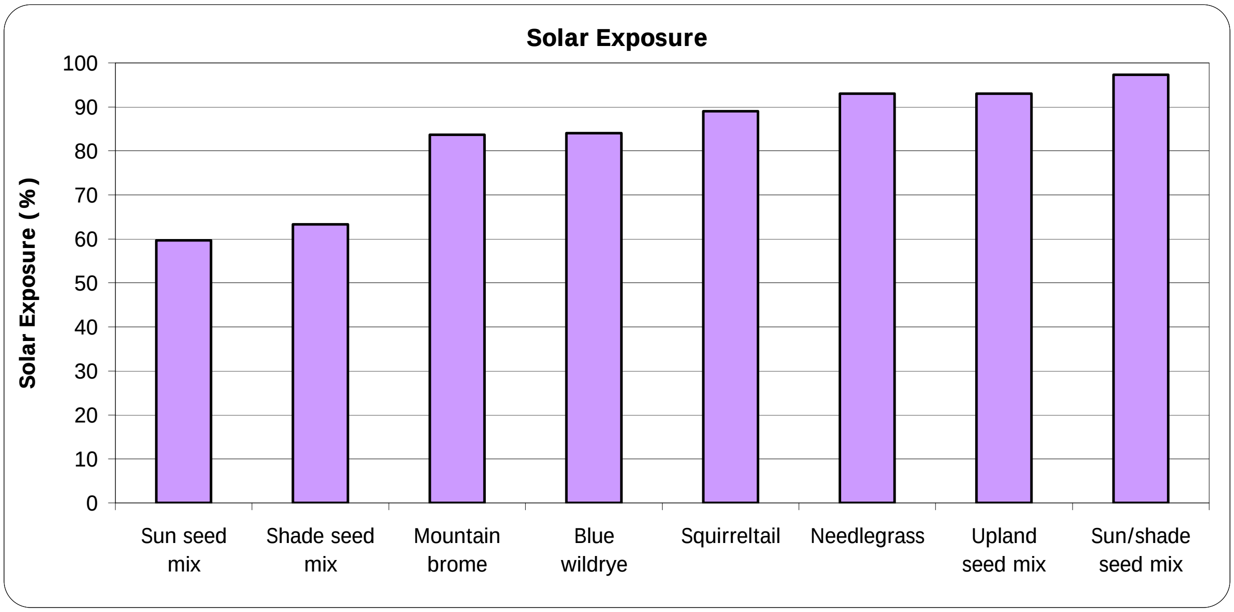

Figure 23. Solar Exposure. Average solar exposure, as measured in June, ranged from 84 to 97% for all plots except the sun seed mix and the shade seed mix, which ranged from 60-63%.

Soil Nutrients

Total Kjeldahl nitrogen (TKN) and organic matter levels were sufficient to promote plant growth at this site. The TKN at a nearby area that was treated in the same manner and timeframe as the seed rates plots was 1,768 ppm, while the organic matter was 6.4%.

Statistical Results

Statistical results are presented in the order in which they appear in the Results and Discussion section.

Table 4. Statistical results. A probability of less than 0.1 is considered significant.

Statistical Test	Factors	Variable	Year	Result	Test Statistics	Probability
ANOVA	Seed mix or single species	DTR	2008	No difference in DTR among different mixes or single species applications	F(6,13)=1.98	0.142
ANOVA	Seed mix or single species	Foliar Plant Cover	2008	No difference in foliar plant cover among different mixes or single species applications	F(6,13)=1.69	0.200
ANOVA	Seed mix or single species	Seeded Plant Cover	2008	No difference in seeded plant cover among different mixes or single species applications	F(6,13)=1.4	0.270

Recommendations

These recommendations are for sites with rocky soils on volcanic parent material, with slope angles between 10 and 18 degrees, variable solar exposures from 38 to 100%, and an elevation of approximately 6,826 ft AMSL (2,080 m). Recommended treatments that differ from test plot applications are discussed below the recommendations.

Tilling: 18 inches (46 cm)

Amendment: 7 inches (18 cm) of tub grindings

Biosol: 2,000 lbs/acre (2,241 kg/ha)

Seed: 125 lbs/acre (140 kg/ha) with the following composition:

Western needlegrass 12%
Squirreltail 12%
Mountain brome 36%
Blue wildrye: 36%
Native shrubs/forbs: 4%

Mulch: 2 inches (5 cm) of pine needle mulch spread to 99% cover

Amendment Type and Depth

Tub grindings are recommended at a depth of 7 inches (18 cm) instead of the applied depth of 4 inches (10 cm) because penetrometer DTRs were 1.9 to 3.3 times shallower than the tilling depth of 18 inches (46 cm). Additional application of a coarse amendment, such as tub grindings, may reduce the occurrence of soil re-compaction.

Seed Type and Rate

The shade seed mix is recommended at the tested rate, 125 lbs/acre (140 kg/ha) with the following species composition

Western needlegrass 12%
squirreltail 12%
mountain brome 36%
blue wildrye: 36%
native shrubs/forbs: 4%

All of the tested mixes produced seeded cover greater than 80% and would be suitable at this site. However, the shade seed mix had a greater diversity of seed compared to the upland mix, produced higher cover by seeded species than the sun/shade mix, and had a lower cost than sun mix. Therefore, the shade mix is recommended based on this first year of monitoring data.

Appendix A

Species list and ocular estimates of cover for the Homewood Wedding Road seed rate plots, 2008. Ocular estimates are presented below the plot numbers. "T" indicates a species present in trace amounts.

Lifeform	Family	Scientific name	Common name	Annual / Perennial	Native / Alien	Noxious / Invasive	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10	Plot 11	Plot 12	Plot 13	Plot 14	Plot 15	Plot 16	Plot 17	Plot 18	Plot 19	Plot 20	Plot 21
Forb	Amaranthaceae	*Amaranthus albus*	pigweed amaranth, tumbleweed	Annual	Alien						T																
Forb	Scrophulariaceae	*Collinsia parviflora*	blue-eyed mary	Annual	Native												T										
Forb	Polemoniaceae	*Collomia linearis*	narrow-leaved collomia	Annual	Native												T				T						
Forb	Boraginaceae	*Cryptantha watsonii*	Watson's cryptantha	Annual	Native		T	T				T	T				T	T		T							
Forb	Polygonaceae	*Eriogonum umbellatum*	sulphur flower buckwheat	Perennial	Native																						
Forb	Onagraceae	*Gayophytum sp*	groundsmoke	Annual	Native		1	T		1	2	1	T		T	T	T	T	T	1	T	1	T	2	T	T	1
Forb	Asteraceae	*Leucanthemum vulgare*	ox-eye daisy	Perennial	Alien	Invasive					T																
Forb	Fabaceae	*Medicago sp.*		Annual or Perennial	Alien									T													
Forb	Lamiaceae	*Monardella odoratissima*	mountain monardella	Perennial	Native		T																				
Forb	Hydrophyllaceae	*Nama lobbii*	Lobb's fiddleleaf	Perennial	Native				T		T	T								T			T				
Forb	Polemoniaceae	*Navarretia sinistra*	Alva Day's pincushionplant	Annual	Native					T		T					T										
Forb	Solanaceae	*Nicotiana attenuata*	coyote tobacco	Annual	Native					T																	
Forb	Onagraceae	*Oenothera sp*	evening primrose	Perennial	Native						T																
Forb	Scrophulariaceae	*Penstemon gracilentus*	slender penstemon	Perennial	Native					T	T			T													
Forb	Hydrophyllaceae	*Phacelia hastata*	silverleaf phacelia	Perennial	Native				T		T						T								T		
Forb	Rosaceae	*Potentilla glandulosa*	cinquefoil, glandular five finger	Perennial	Native					T	T	T															
Forb	Brassicaceae	*Sisymbrium altissimum*	tumble mustard	Annual	Alien																	T					
Forb	Asteraceae	*Taraxacum officinale*	dandelion	Annual	Alien	Of concern																		T			
Forb	Asteraceae	*Tragopogon dubius*	false salsify	Annual	Alien				T		T			T							T						
Graminoid	Poaceae	*Achnatherum occidentale*	Western needlegrass	Perennial	Native		5	4	2	T	T	T	1					T	3	2	18						
Graminoid	Poaceae	*Bromus carinatus*	mountain brome	Perennial	Native		3	3	2	T		1	1	11	5		4	4	3	4		10		T	T	9	6
Graminoid	Poaceae	*Elymus elymoides*	squirreltail	Perennial	Native			T	T			1	1	T	T	3	1			1		T		2			T
Graminoid	Poaceae	*Elymus glaucus*	blue wildrye	Perennial	Native					3													2		3		1

Lifeform	Family	Scientific name	Common name	Annual / Perennial	Native / Alien	Noxious / Invasive	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10	Plot 11	Plot 12	Plot 13	Plot 14	Plot 15	Plot 16	Plot 17	Plot 18	Plot 19	Plot 20	Plot 21
Graminoid	Poaceae	*Elymus sp.*	blue wildrye or squirreltail	Perennial	Native		3	1	T		2	2	3		1				T								1
Graminoid	Poaceae	*Triticum aestivum*	wheat	Annual	Alien																			T			
Shrub	Ericaceae	*Arctostaphylos nevadensis*	pinemat manzanita	Perennial	Native														T								
Shrub	Ericaceae	*Arctostaphylos patula*	greenleaf manzanita	Perennial	Native																						
Shrub	Asteraceae	*Artemisia tridentata*	common sagebrush	Perennial	Native																						
Shrub	Rhamnaceae	*Ceanothus velutinus*	tobacco brush or snow brush	Perennial	Native														T								
Shrub	Rosaceae	*Purshia tridentata*	antelope bitterbrush	Perennial	Native											T	T	T								T	T
Shrub	Grossulariaceae	*Ribes cereum*	wax currant	Perennial	Native			T		T			T														
Shrub	Grossulariaceae	*Ribes montigenum*	alpine prickly currant, gooseberry currant, mountain gooseberry	Perennial	Native						T	T		T		T							T	T	T		
Shrub	Salicaceae	*Salix lasiolepis*	arroyo willow	Perennial	Native			T																			
Tree	Pinaceae	*Abies concolor*	white fir	Perennial	Native						T	T				T		T		T			T				
TOTAL COVER (transects)							11%	19%	11%	14%	10%	11%	12%	9%	8%	3%	9%	7%	6%	10%	20%	10%	1%	6%	13%	7%	11%
TOTAL COVER (ocular estimate)							12%	9%	6%	4%	4%	3%	7%	12%	6%	3%	6%	4%	6%	7%	18%	11%	3%	4%	4%	9%	7%

Northstar Bearpaw Test Plots Site Report

May 2009

Introduction

Monitoring results and treatment recommendations for a series of six test plots at the Northstar-at-Tahoe ski resort (Northstar) will be presented in this report (Figure 1). The Northstar Bearpaw test plots are located in Placer County, California, just off State Route (SR) 267 between Truckee and King's Beach (Figure 1). The test plots are located on the Wood Cutter ski run (also known as Bearpaw), just south and parallel to the Bearpaw ski lift. The plots were constructed in 2005 and monitored from 2006 to 2008. The area surrounding the test plots was treated before 2005 and consists of a surface treatment. A monitoring plot was designated in this area for comparison with the full treatment test plots (Figure 3). This surface treatment plot was established in 2007 and monitored in 2007 and 2008. The native reference plot is located on the corner of Big Springs Drive and Overlook Place in a Northstar residential area. This area was both established and monitored in 2008. Although these plots are at a ski resort and not along a roadside, they are similar to roadside conditions in the Lake Tahoe area; therefore, the monitoring results from these plots will be applicable Basin-wide and throughout the Sierra Nevada.

Figure 1. Satellite Map of the Northstar Bearpaw test plots location. The test plots are located at the "Northstar Bearpaw Test Plots" label. The project area is just north of Lake Tahoe, in California.

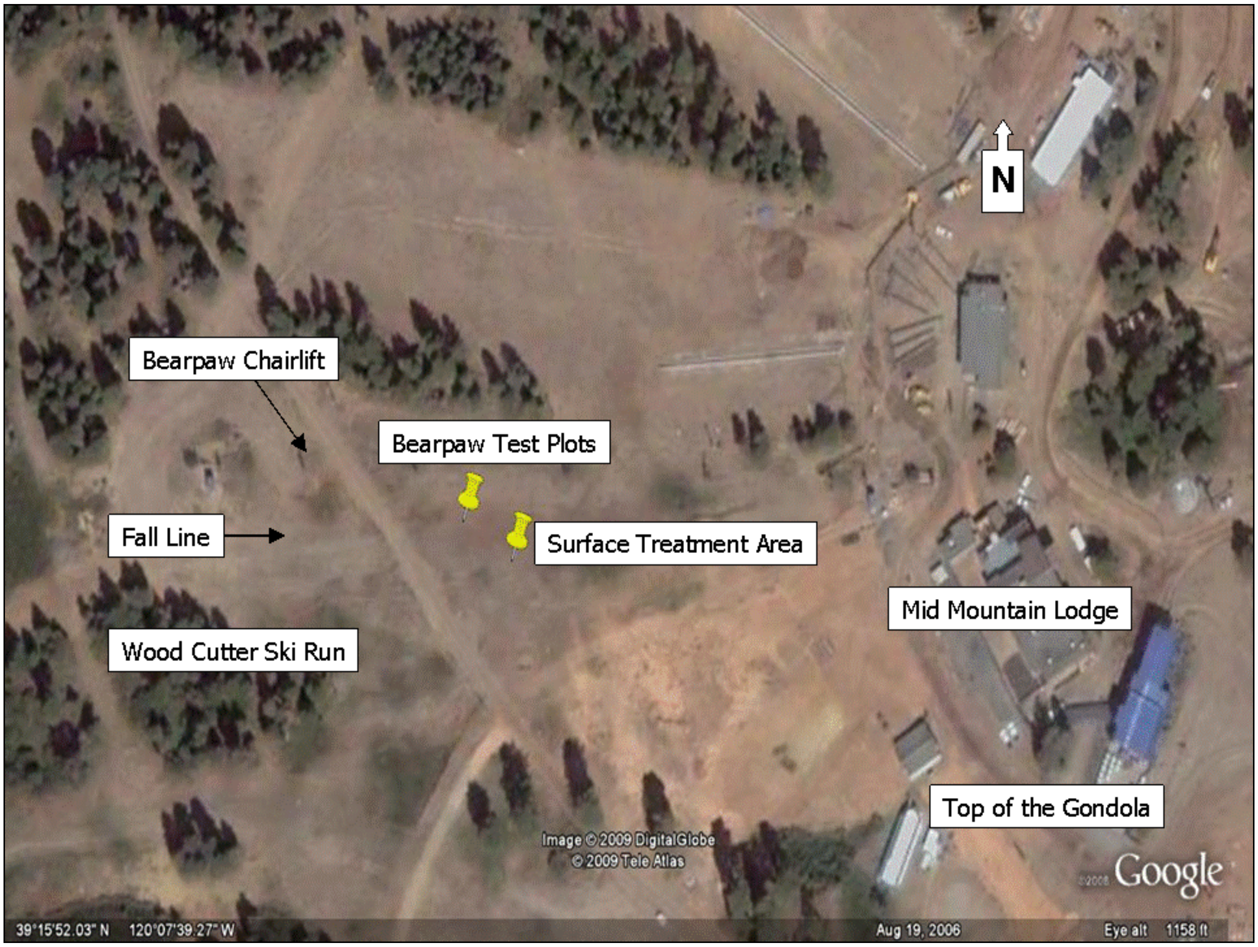

Figure 2. Satellite showing the location of the Northstar Bearpaw test plots and the surface treatment plot.

Purpose

The project's monitoring objectives are outlined below. The following treatment definitions are included to aid understanding of these objectives.

Full Treatment: includes soil loosening by tilling, incorporation of an organic amendment such as a compost blend, addition of fertilizer and native seed, and application of native mulch.

Surface Treatment: does not include the incorporation of organic matter into the soil. This treatment may include surface fertilizing, seeding, or hydromulching and is similar to Caltrans Erosion Control Type D (EC Type D).

The monitoring data was studied and analyzed to investigate:

1. the erosion control differences between full treatment and surface treatment plots
2. for full treatment plots, the effects of different tilling depths in terms of soil function, water holding capacity, infiltration, and nutrient availability

Site Description

Test Plots and Surface Treatment Plot

The test plots and the surface treatment plot are located on moderately sloped, north-east facing ski run at Northstar in Truckee, California (Figure 2). The site elevation is approximately 6,907 feet (2,105 m) above mean sea level (AMSL).

The test plots are located just south of and parallel to the Bearpaw lift. They are situated in an area that was disturbed during the replacement of a waterline. At the time of test plot construction in 2005, there was no remaining vegetation or topsoil along the waterline and the soil was highly compacted. The soil parent material is of volcanic origin. The soil is rocky with up to 50% coarse fragments greater than 0.5 inches (1.3 cm) in diameter in some areas. Surrounding vegetation consists of mule ears (*Wyethia mollis*) and wheatgrass (*Elytrigia intermedia*) with a white fir (*Abies concolor*) dominated forest nearby. All plots have no canopy cover and a solar exposure average between 95% and 100% during the summer months.

Native Reference Plot

The native reference plot is located near the Unit 7 test plots on the corner of Big Springs Drive and Overlook Place. The soil parent material is volcanic in origin with up to 65% coarse fragments. This plot was used for a native reference soil sample only.

Treatment Overview

The six test plots received different variations of full treatment in 2005 (Figure 3). These treatments are described in detail below (Table 1). None of the plots were irrigated.

The surface treatment plot is located next to the test plots. There is no further information available regarding treatment methods or date.

The native reference plot is undisturbed and was used as a soil nutrient reference for the full treatment plots. This plot is not included in Figure 3.

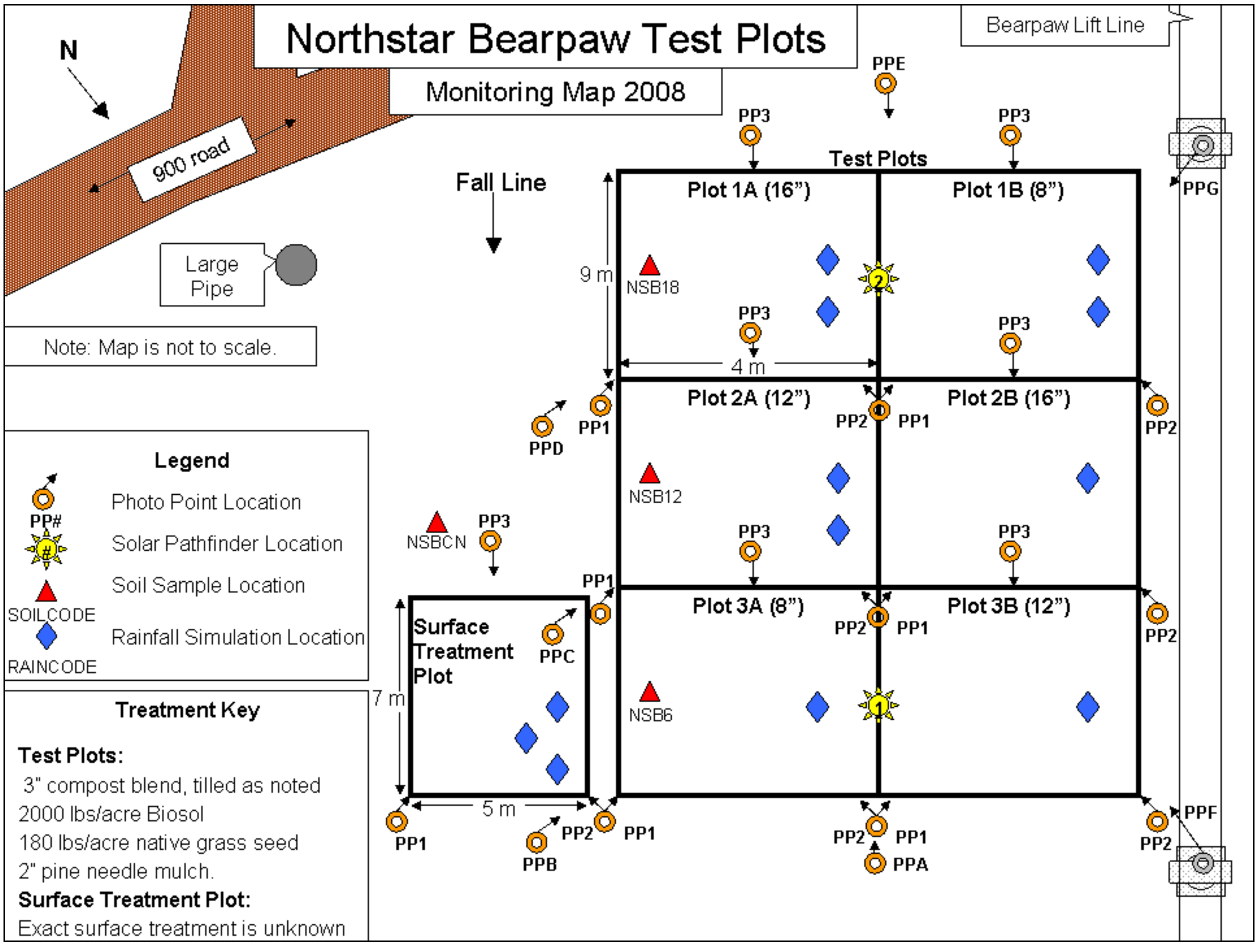

Figure 3. Monitoring and treatment map of Northstar Bearpaw test plots with treatment key. Rainfall simulation, photo points, soil sample, and Solar Pathfinder locations are marked.

Plot Treatments

Plot treatments are presented in Table 1. Descriptions of these treatments can be found following the table. Photos of the Bearpaw test plots before and after treatment are shown in Figure 4, Figure 5, Figure 6, Figure 7. A photo of the test plots taken from above is shown in Figure 8 and the surface treatment plot is shown in Figure 9.

Table 1. Northstar Bearpaw treatments.

Plot Name	Amendment	Soil Loosening	Biosol Rate (lbs/acre)	Seed Type	Seed Rate	Mulch
1A	3" Compost Blend	18" Tilled	2,000	Native grass seed mix	180 lbs/acre	2" Pine needles
1B	3" Compost Blend	6" Tilled	2,000	Native grass seed mix	180 lbs/acre	2" Pine needles
2A	3" Compost Blend	12" Tilled	2,000	Native grass seed mix	180 lbs/acre	2" Pine needles
2B	3" Compost Blend	18" Tilled	2,000	Native grass seed mix	180 lbs/acre	2" Pine needles
3A	3" Compost Blend	6" Tilled	2,000	Native grass seed mix	180 lbs/acre	2" Pine needles
3B	3" Compost Blend	12" Tilled	2,000	Native grass seed mix	180 lbs/acre	2" Pine needles
Surface Treatment	Unknown	None	Unknown	Unknown	Unknown	Unknown

Figure 4. Northstar Bearpaw test plots during construction, August, 2005.

Figure 5. Northstar Bearpaw test plots, July, 2006.

Figure 6. Northstar Bearpaw test plots, June, 2007.

Figure 7. Northstar Bearpaw test plots, August, 2008.

Figure 8. Northstar Bearpaw test plots, aerial view, one year following treatment, June, 2006.

Figure 9. Northstar surface treatment, next to test plots, August, 2007.

Soil Loosening

The Bearpaw plots were tilled to a depth of approximately 8 to 16 inches (20-41 cm) using an excavator bucket.

The surface treatment plot was not tilled.

Amendment

Northstar compost blend, which was produced onsite, was applied to the surface of all test plots to a depth of three inches (8 cm). It is not known for how long or at what temperature the compost was cured. This compost had a high percentage of woody material. It was incorporated into the soil during tilling.

Fertilizer

Following incorporation of amendments at the full treatment plots, Biosol, a slow release fertilizer, was applied and raked approximately 1 inch (2.5 cm) into the soil at a rate of 2,000 lbs/acre (2,241 kg/ha).

Seeding

A mix of suitable native perennial grasses were seeded at a rate of 180 lbs/acre (202 kg/ha; Figure 3 and Table 1). The surface treatment plot was seeded with an unknown seed mix at an unknown rate.

Table 2. Bearpaw test plots seed mix. Percent pure live seed is approximate.

Common Name	*Scientific Name*	% Pure Live Seed
Mountain brome (Bromar)	*Bromus carinatus*	43.0%
Blue wildrye	*Elymus glaucus*	32.4%
Squirreltail	*Elymus elymoides*	21.7%

Mulch

Mulch was spread evenly by hand to achieve 99% cover at a depth of 2 inches (5 cm) at the Bearpaw test plots.

Monitoring Methods

The Bearpaw test plots were monitored post-treatment in 2005, and subsequently in 2006, 2007, and 2008. The surface treatment plot was monitored in 2007 and 2008 only. Additionally, in 2008 monitoring was conducted at a native reference plot for soil nutrients.

In the text, both English and metric units will be given; however, tables will contain one or the other.

Rainfall Simulation

In 2007, rainfall simulation was conducted on the 8 inch (20 cm) and 16 inch (41 cm) till test plots as well as the surface treatment plot. In 2008, rainfall simulation was conducted on all test plots as well as the surface treatment plot (Figure 3).

The rainfall simulator "rains" on a square plot from a height of 3.3 feet (1 m; Figure 10 and Figure 11). The rate of rainfall is controlled, and runoff is collected from a trough at the bottom of a 6.5 ft^2 (0.6 m^2) frame that has been pounded into the ground. The volume of water collected is measured and the volume of infiltration is calculated by subtracting the volume of runoff from the total volume of water applied to the plot. If runoff is not observed during the first 45 minutes, the simulation is halted. The collected runoff samples are then analyzed for the amount of sediment they contain. This measurement is presented as the average steady state sediment yield and is hereafter referred to as "sediment yield". The steady state infiltration rate is calculated and will hereafter be referred to as "infiltration rate".

The cone penetrometer is used to record the depth to refusal (DTR; an index for soil density) in the area of the frames before rainfall simulations. The 2007 and 2008 DTR values were recorded at 350 psi (2,413 kPa). Soil moisture is measured in each frame prior to and following rainfall simulations. After rainfall simulation, at least three holes are dug with a trowel to determine the depth to wetting front, which shows how deeply water infiltrated into the soil. In 2007 and 2008, at least nine holes were dug to measure the depth to wetting front.

In 2007 and 2008, 4.7 in/hr (120 mm/hr) was applied to all plots, so that data from the plots could be more easily compared. The rainfall rate, 4.7 in/hr, is in excess of the 20-year, one hour 'design storm' rate of 0.7 to 1.0 in/hr (18-25 mm/hr) for the Truckee-Tahoe area. The design storm rate is used to design most storm water routing plans.

Figure 10. Photo of the rainfall simulator and frame.

Figure 11. Photo of rainfall simulation at similar ski run at Northstar, 2006.

Cover

Cover point monitoring was conducted at the test plots and the surface treatment plot in July of 2006 (test plots only), June of 2007, and August of 2008.

Cover is measured using the statistically defensible cover point method along randomly located transects.[1] The cover pointer consists of a metal rod with a laser pointer mounted 3.3 feet (1 m) high. After the rod is leveled in all directions, the button on the laser pointer is depressed and two cover measurements are recorded (Figure 12 and Figure 13):

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[1] Hogan, M. 2003. Luther Pass Monitoring Report: Plant and Soil Cover Monitoring for Evaluating Sediment Source Control Success in the Lake Tahoe Basin. Lahontan Regional Water Quality Control Board, South Lake Tahoe, CA.

- the first hit cover, which is the first object intercepted starting from a height of 3.3 ft (1 m) above the ground
- the ground cover hit, which is the low-lying vegetation or soil below the first hit cover, at the ground level

The first hit cover measures the foliar cover by plants (leaves and stems). It does not measure the part of the plant rooted in the ground. The first hit vegetation is then moved aside and a ground cover hit measures the presence of litter/mulch, basal (or rooted) plant cover, rock and woody debris and/or bare ground. Total ground cover represents any cover other than bare ground. Mulch cover is an important variable in erosion reduction through sediment source control because treatments with cover by pine needle mulch have been shown to reduce sediment yields substantially.[2]

Figure 12. Cover pointer in use along transects.

Figure 13. Cover pointer rod with first hit and ground cover hit by the laser pointer. The laser pointer hits are circled in red. The first cover hit is a native grass and the ground cover hit is pine needle mulch.

Foliar and ground level plant cover is recorded by species and then organized into cover groups based on four categories: life form (herbaceous/woody), perennial/annual, native/alien (2007 and 2008), and seeded/volunteer (2007 and 2008). Perennial herbaceous species includes seeded grasses, native grasses and forbs, and any non-native perennial species. Annual herbaceous species include native annuals such as knotweed (*Polygonum sp.*) and invasive species such as cheatgrass (*Bromus tectorum*). Woody species includes any tree or shrub species, either native or introduced. Each species is then classified based on whether it is native to the Tahoe area, and whether it was seeded during treatment. Data is presented on the amount of cover by species. An ocular estimate of cover at each plot is also recorded

[2] Grismer, M.E., and M.P. Hogan. 2004. Simulated rainfall evaluation of revegetation/mulch erosion control in the Lake Tahoe Basin: 1. Method assessment. Land Degradation & Development 15:573-588.

and includes many species not hit using cover point sampling. The species lists, as well as the ocular estimates of cover by species, are presented in Appendix A.

Soil and Site Physical Conditions

Penetrometer Depth to Refusal and Soil Moisture

In 2005, 2006, 2007, and 2008, penetrometer depth to refusal (DTR) and soil moisture were measured along the same transects as the cover point data for all plots. In 2005, DTR and soil moisture were taken directly after treatment. These results represent the tilling depths of the plots. A cone penetrometer with a ½ inch diameter tip is pushed straight down into the soil until a maximum pressure of 350 pounds per square inch (2,413 kPa) is reached (Figure 14 and Figure 15). The depth at which that pressure is reached is recorded as the depth to refusal.

Cone penetrometer DTR measurements are used as an index for soil density. Soils with higher DTRs are generally less dense than those with lower DTRs. A denser soil is less likely to allow infiltration. Rainfall simulations conducted on roadcuts in Oregon found increased infiltration rates in soils with penetrometer DTRs greater than 4 inches (10 cm).[3]

It is most informative to compare penetrometer DTR measurements collected in soils that have similar moisture levels. When soil moisture content increases, the resistance of the soil to the penetrometer decreases and DTR readings are deeper. Therefore, only penetrometer readings at the same soil moisture can be compared. A hydrometer was used to measure volumetric soil moisture content adjacent to the penetrometer readings at a depth of 4.7 inches (12 cm; Figure 16).

Figure 14. Photo of a cone penetrometer dial, showing pressure applied in pounds per square inch.

Figure 15. Photo of conducting cone penetrometer readings along transects.

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[3]Grismer, M.E. 2006. Simulated Rainfall Evaluation at Sunriver and Mt. Bachelor Highways, Oregon. Unpublished.

Solar Exposure

In 2006, solar exposure measurements were taken throughout the Bearpaw test plots. These measurements are taken using a Solar Pathfinder (Figure 17). Since there was no change in solar obstructions at the test plots, the solar pathfinder data was not collected again in 2007 or 2008. Solar input affects evaporation rates and soil temperature, which may affect time of seed germination, germination rate, rate of plant growth, and soil microbial activity. Therefore, this is an important variable to consider when monitoring plant growth and soil development.

Figure 16. Conducting soil moisture readings along transects.

Figure 17. Solar pathfinder in use.

Soil Nutrient Analysis

Successful re-vegetation requires that nutrient capital be stored in the soil for release over time. Sufficient organic matter and a functioning microbial community are necessary to provide a long-term source of nitrogen for plants. Previous studies of soil nutrient levels at revegetation sites throughout the Tahoe area found that sites with high plant cover had significantly higher soil nutrients over the long-term than soils with lower plant cover levels.[4] Total Kjeldahl nitrogen and organic matter were used as indicators of soil health in this study. Total Kjeldahl nitrogen (TKN) is a measure of readily available nitrogen. Only three soil sub-samples were taken from each plot; therefore, differences in TKN and organic matter values may be a result of the variability within a plot.

In 2006, 2007, and 2008, soil samples were taken from the test plots. Soil samples were taken from the surface treatment plot in 2007 and 2008 (Figure 3). In 2008, a soil sample was also taken from the native plot. Three soil sub-samples at each plot were collected from the mineral soil beneath any mulch layer to a depth of 12 inches (30 cm; Figure 18). These sub-samples were combined and sieved to remove any material larger than 0.08 inches (2 mm) in diameter, and sent to A&L Laboratories in Modesto, California for the S3C nutrient suite (macro and micronutrients), total Kjeldahl nitrogen (TKN), and organic matter analysis.

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[4]Claassen, V.P., and M.P. Hogan. 2002. Soil Nutrients Associated with Revegetation of Disturbed Sites in the Lake Tahoe Basin. Restoration Ecology 10:195-203.

Figure 18. Soil sub-sample collection.

Results and Discussion

Rainfall Simulation

Trends by Treatment Level

From 2007 to 2008, the surface treatment plot produced sediment ranging from 26 to 31 lbs/acre/in (12-14 kg/ha/cm), which was an average of 3.2 to 3.9 times higher than the two-year average sediment yield produced by the full treatment plots (8.0 lbs/acre/in or 3.5 kg/ha/cm; Figure 19 and Figure 20).

The full treatment plots exhibited infiltration rates that ranged from 4.5 to 4.7 in/hr (114-120 mm/hr), which was on average 1.2 times higher than the infiltration rates exhibited by the surface treatment plots, which ranged from 4.0 to 4.1 in/hr (102-104 mm/hr; Figure 19 and Figure 20).

Full treatment plots consistently demonstrated higher infiltration rates and lower sediment yields than the surface treatment plot.

Trends by Year

The sediment produced at the surface treatment plot was similar in 2007 and 2008. More simulations over time will indicate if this trend persists. From 2007 to 2008, three of five rainfall simulations conducted on full treatment plots did not produce any sediment. Sediment yield increased from zero in 2007 to an average of 13 lbs/acre/in (5.9 kg/ha/cm) in 2008 (Figure 19 and Figure 20). From 2007 to 2008, infiltration rate and sediment did not change at the 8 inch (20 cm) till plots. During both years, the 8 inch (20 cm) till plots infiltrated all applied water and did produce any sediment. There was an increase in the sediment yield and decrease in infiltration rate at the 16 inch (41 cm) till plots from 2007 to 2008. In 2007, simulations conducted on this treatment did not produce any sediment and infiltrated completely. In 2008, the sediment yield for this treatment was 30 lbs/acre/in (13 kg/ha/cm). The infiltration rate decreased slightly from 4.7 to 4.5 in/hr (120-114 mm/hr; Figure 19 and Figure 20). Although the infiltration rate was similar between years, and all or nearly all of the water infiltrated, the small volume of runoff produced a sediment yield similar to that of the surface treatment plot. More simulations over time will indicate if this is a trend. It is possible that the lower mulch cover at this plot in 2008 may have contributed to the higher sediment yield (Figure 23). Mulch cover is an important variable in erosion reduction through sediment source control because treatments with cover by pine needle mulch have been shown to reduce sediment yields substantially.[5]

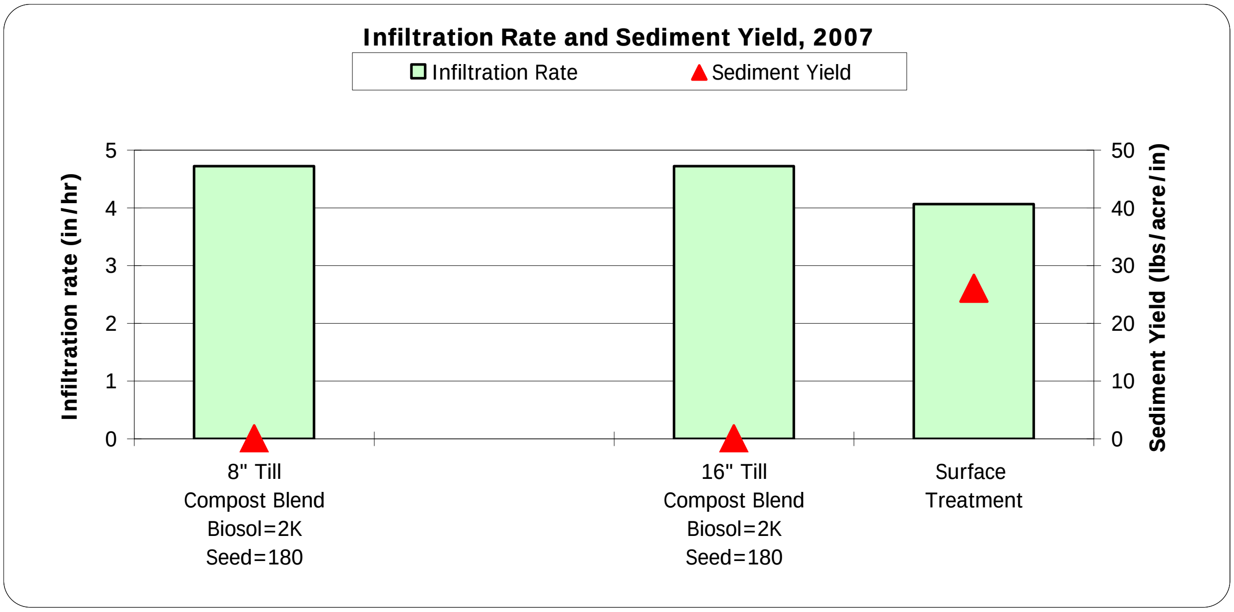

Figure 19. Infiltration Rate and Sediment Yield, 2007. The full treatment plots (8 and 16 inch or 20 and 41 cm) till did not produce any sediment and had high infiltration rates, 4.7 in/hr (120 mm/hr), while the sediment for the surface treatment plot was 26 lbs/acre/in (12 kg/ha/cm), and the infiltration rate was 4.1 in/hr (104 mm/hr). Rainfall simulation was not conducted at the 12 inch (30 cm) till plots in 2007.

[5] Grismer, M.E., and M.P. Hogan. 2004. Simulated rainfall evaluation of revegetation/mulch erosion control in the Lake Tahoe Basin: 1. Method assessment. Land Degradation & Development 15:573-588.

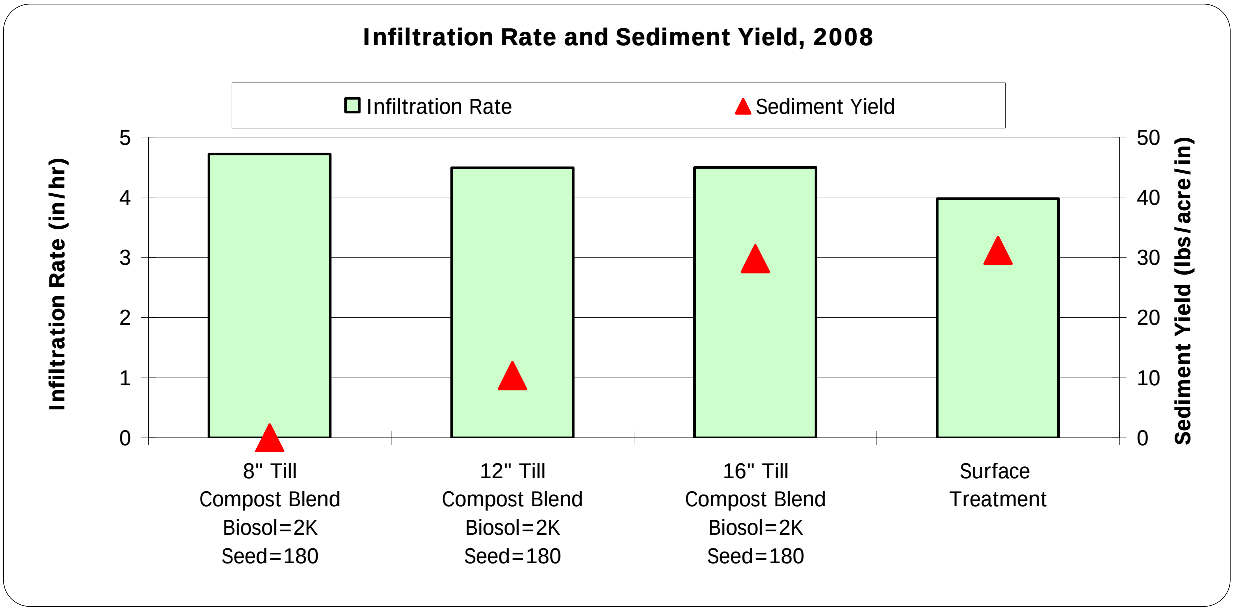

Figure 20. Infiltration Rate and Sediment Yield, 2008. The 8 inch (20 cm) till full treatment plots did not produce any sediment and had a high infiltration rate of 4.7 in/hr (120 mm/hr). The 12 and 16 inch (30 and 41 cm) till full treatment plots produced sediment that ranged from 10 to 30 lbs/acre/in (4.6-13 kg/ha/cm) and had infiltration rates of 4.5 in/hr (114 mm/hr). The sediment for the surface treatment plot was 31 lbs/acre/in (14 kg/ha/cm), and the infiltration rate was 4.0 in/hr (102 mm/hr).

Soil Moisture

Soil moisture was similar between the plots within each year. However, soil moisture levels in 2006 ranged from 15 to 17%, which was 2.4 to 4.5 times higher than soil moisture in any other year. Excluding 2006, soil moisture readings were between 3-7% at the plots with and without soil loosening, allowing for comparison of penetrometer DTRs (Figure 21). Soil moisture was collected in 2008 only at the surface treatment plot. In 2007, the soil moisture meter could not be inserted into the compacted soil without damaging the instrument.

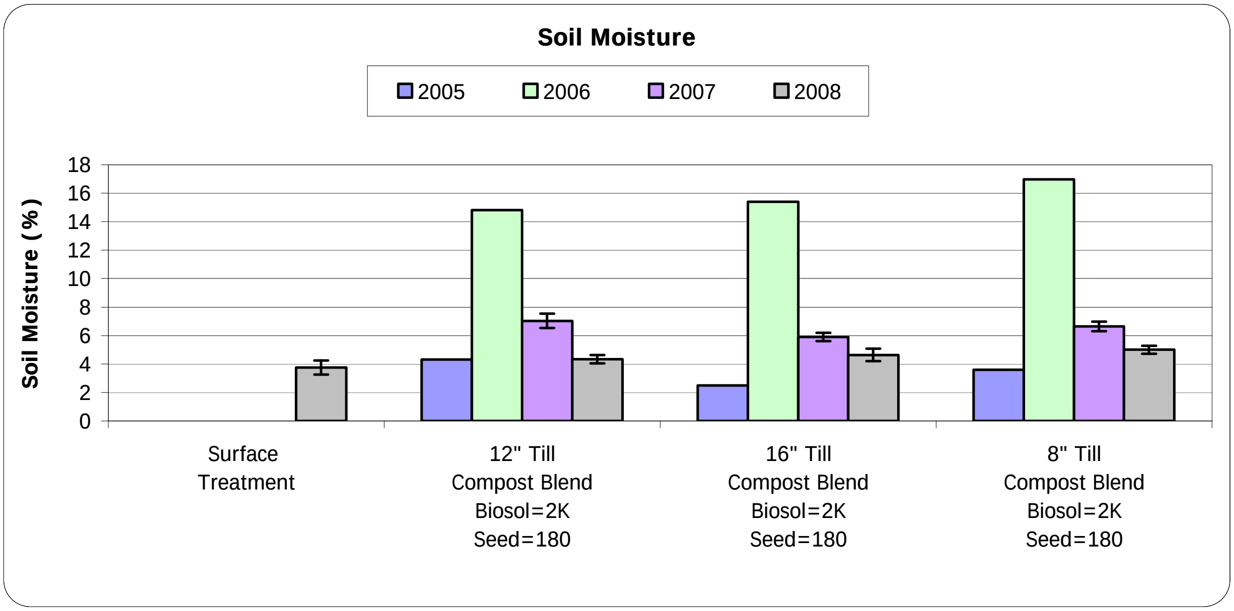

Figure 21. Soil Moisture. Soil moisture levels were similar across all plots, except in 2006. Soil moisture was sampled only in 2008 at the surface treatment plot. The error bars represent one standard deviation above and below the mean. Data is sorted by increasing 2008 soil moisture.

Penetrometer Depth to Refusal

Penetrometer readings are compared for 2005, 2007, and 2008. The 2006 penetrometer readings cannot be compared with data from other years because the soil moisture readings were not in the same range (Figure 21 and Figure 22).

Trends by Treatment Level

DTR readings at the surface treatment plot ranged from 1.6 to 2.0 inches (4.1 to 5.1 cm). The two-year average (1.8 inches or 4.6 cm) for the surface treatment plot DTR was 2.5, 4.1, and 3.5 times shallower than the 8, 12, and 16 inch (20, 30, and 41 cm) till plots respectively (two-year average of 4.4, 7.1, and 6.1 inches or 11, 18, and 16 cm; Figure 22). This suggests that tilling and addition of amendments to the soil may be necessary to maintain deeper DTRs.

Trends by Year

Penetrometer DTR decreased at all plots from 2007 to 2008, except at the 16 inch (41 cm) till plots, where DTRs were similar between 2007 and 2008 (6.1 to 6.2 inches or 16 cm; Figure 22). The 16 inch (41 cm) till plots exhibited the most re-compaction when compared to the 12 and 8 inch (30 and 20 cm) till plots from post treatment to 2008. Penetrometer DTR for the 16 inch (41 cm) till plots decreased 2.6 times from the original tilling depth of 16.3 inches (41.4 cm) in 2005 to 6.2 inches (16 cm) in 2008. Penetrometer DTR for the 12 inch (30 cm) till plots decreased 2.1 times from the original tilling depth of 12.5 inches (32 cm) in 2005 to 6.0 inches (15 cm) in 2008. Penetrometer DTR for the 8 inch (20 cm) till plots decreased 1.9 times from the original tilling depth of 7.6 inches (19 cm) in 2005 to 4.0 inches (10 cm) in 2008. Deeper tilling at the 12 and 16 inch (30 and 41 cm) till plots reduced the concentration of amendments in the tilled portion of the soil. There was a smaller proportion of woody material per depth at the 16 inch (41 cm) plot, which may have led to soil re-compaction. When coarse material is tilled into the soil at higher proportions, as in at the 8 inch (20 cm) till plot, some of this re-compaction may be avoided.

Soil re-compaction occurred within a shorter time at the 16 inch (41 cm) till plots compared to the 8 and 12 inch (20 and 30 cm) till plots. From 2006 to 2007, the DTR at the 16 inch (41 cm) till plot decreased 2.7 times from the post-treatment depth of 16 inches (41 cm) to 6.1 inches (16 cm) in 2007. From 2007 to 2008, the DTR remained steady at approximately 6 inches (15 cm). From 2006 to 2007, the DTR at the 8 and 12 inch (20 and 30 cm) till plots decreased by 1.5 and 1.6 times respectively. From 2007 to 2008, the DTR decreased by less, 1.2 to 1.4 times respectively. It is possible that the lower the concentration of amendments at the 12 and 16 inch (30 and 41 cm) till plots resulted in the higher level of compaction, sooner after treatment completion. The higher concentration of amendments at the 8 inch (20 cm) till plots may have delayed the re-compaction and it occurred more incrementally. More observations over time are necessary to determine whether all plots have completed settling and re-compacting. Higher concentrations of amendments may delay or eliminate soil re-compaction. Further testing is necessary to determine whether higher concentrations of amendments (not tested at this site) are appropriate for preventing re-compaction.

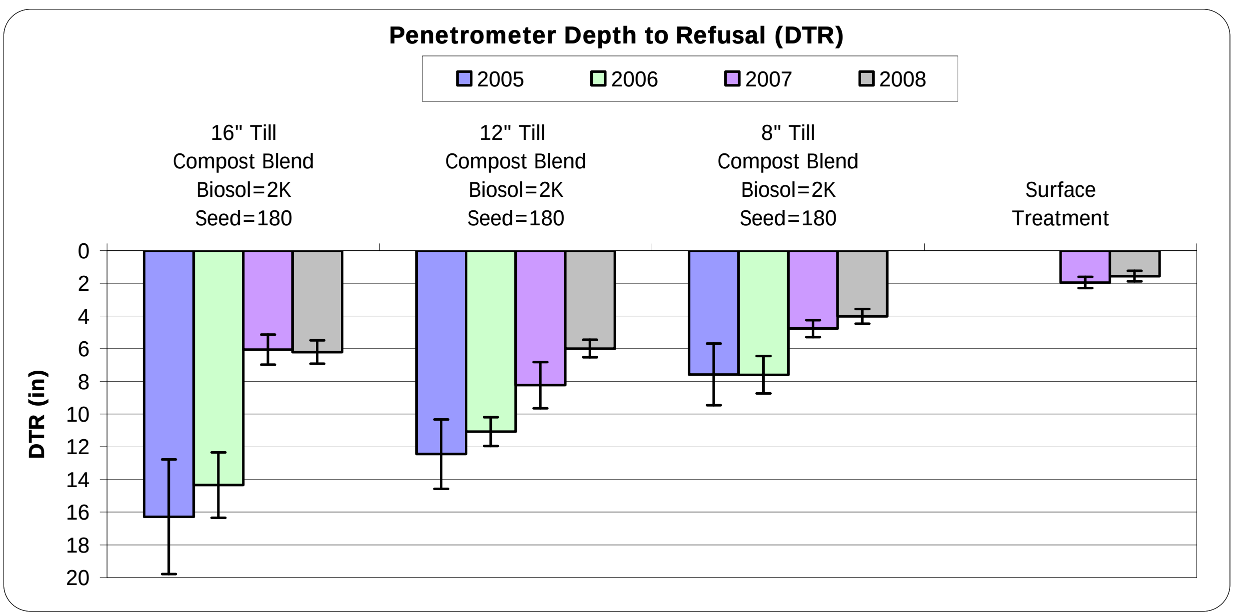

Figure 22. Penetrometer Depth to Refusal (DTR). From 2007 to 2008, penetrometer DTR readings were from 2.5 to 4.1 times deeper at the plots with soil loosening (two-year average range of 4.4 to 7.1 inches or 11 to 18 cm) compared to the surface treatment without soil loosening (two-year average of 1.8 inches or 4.6 cm). The 2005 DTR readings were taken directly after treatment and ranged from 8 to 16 inches (20-41 cm). In 2006, DTR ranged from 8 to 14 inches (19-36 cm). DTR was sampled in 2007 and 2008 only at the surface treatment plot. The error bars represent one standard deviation above and below the mean. Data is sorted by decreasing penetrometer DTR for 2008.

Cover

Ground Cover by Mulch and Bare Soil

Trends by Treatment Level

The mulch cover at the full treatment plots (two-year average of 89%) was similar to the mulch cover at the surface treatment plots (two-year average of 82%; Figure 23). The cover by bare soil ranged from 1 to 6% at all plots in 2007 and 2008 (Figure 24).

Trends by Year

Mulch cover between all plots decreased slightly (1.1 to 1.2 times) from 2007 to 2008, except for the 8 inch (20 cm) tilling plots, where mulch cover remained the same. The 16 inch (41 cm) tilling plots had the largest change in mulch cover, decreasing 1.2 times from 94% in 2007 to 80% in 2008 (Figure 23). Although the mulch cover decreased, ground cover by plants increased (no graph). This also led to a decrease in the amount of bare soil over time (Figure 24).

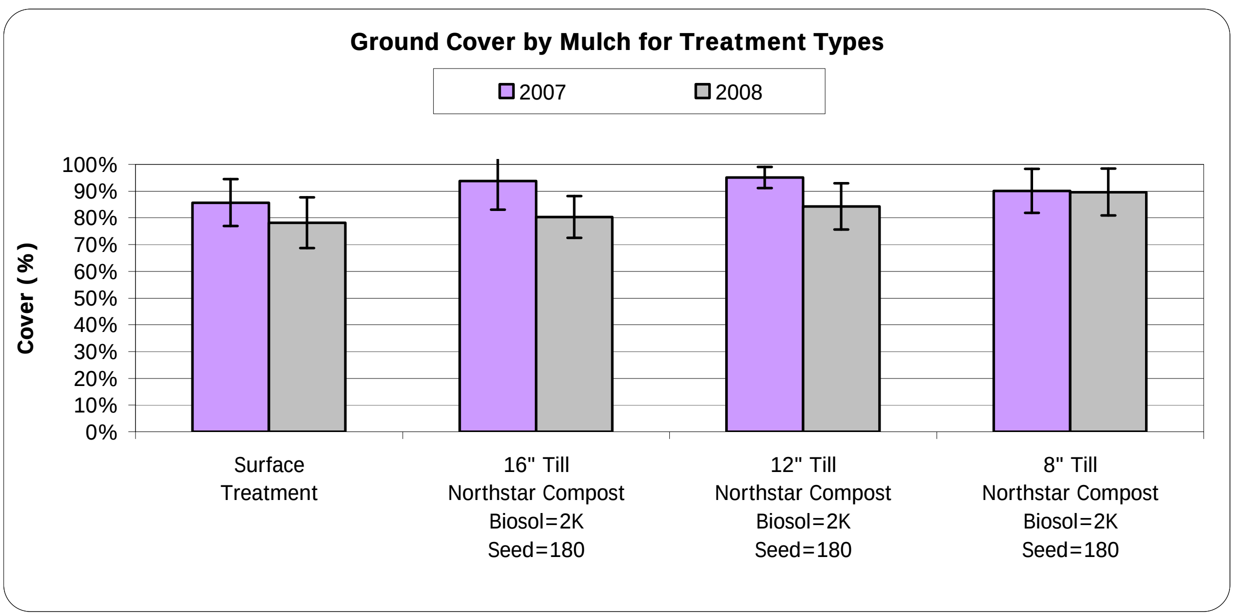

Figure 23. Ground Cover by Mulch for Treatment Types. The mulch cover at the full treatment plots (two-year average of 89%) was similar to the mulch cover at the surface treatment plots (two-year average of 82%). The error bars represent one standard deviation above and below the mean. Data is sorted by increasing 2008 mulch cover.

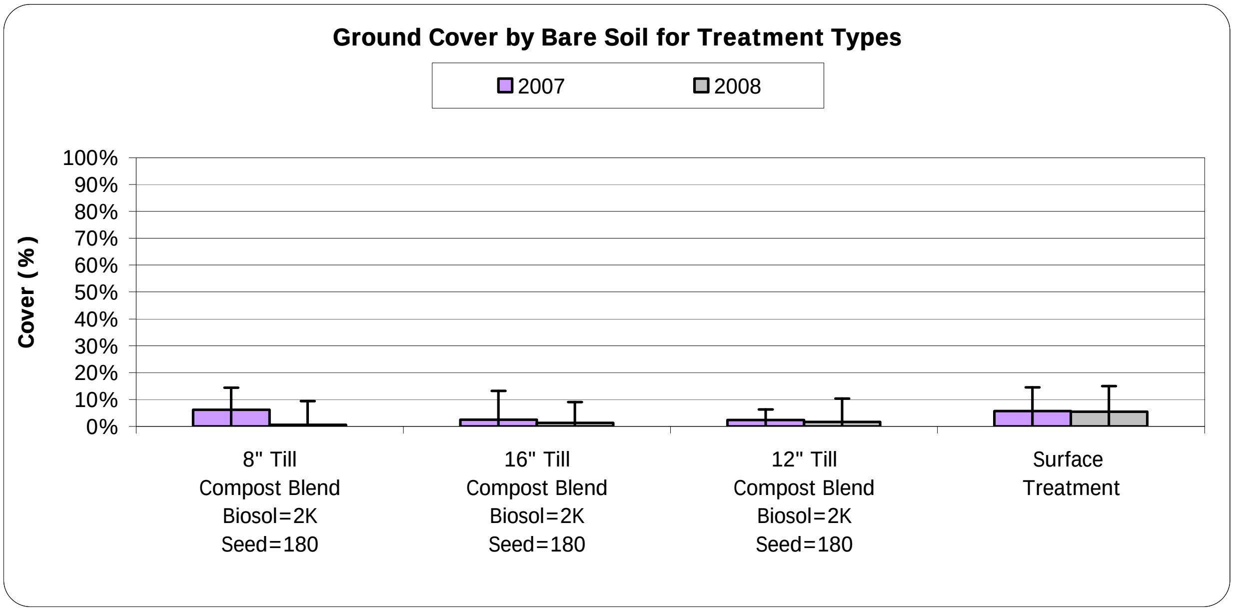

Figure 24. Ground Cover by Bare Soil for Treatment Types. The cover by bare soil ranging from 1 to 6% at all plots from 2007 to 2008. All plots exhibited a trend of decreasing cover by bare soil over the same time. The error bars represent one standard deviation above and below the mean. Data is sorted by increasing bare soil for 2008.

Plant Cover and Composition

Trends by Treatment Level

The three-year average foliar plant cover at the 8, 12, and 16 inch (20, 30, and 41 cm) till plots was similar and ranged from 30 to 32% (Figure 25). In 2007 and 2008, plant cover was 1.2 times higher at the surface treatment plot (two-year average of 35%) when compared to full treatment plots (two-year average of 29%; Figure 25). In 2007 and 2008, the perennial plant cover was 4.0 times higher at the surface treatment plots (two-year average of 25%) when compared to full treatment plots (three-year average of 6%; Figure 26, Figure 27 and Figure 28). Although perennial cover and total cover were higher at the surface treatment plot compared to the full treatment plots, the cover composition was less desirable at the surface treatment plots. In 2007 and 2008, cover by alien species was 2.2 higher at the surface treatment plots (ranging from 18 to 23%) compared to the full treatment plots (ranging from 4-12%; Figure 27 and Figure 28).

Cover by alien species was 1.3 to 2.6 times lower at the 8 inch (20 cm) till plot (three-year range 2-9%) compared to the 16 inch (41 cm) plot (4-12%; Figure 26, Figure 27 and Figure 28). It is unclear how the tilling depth or amendment concentration may have affected the plant composition.

Composition at test plots was dominated by native, annual plants that were not seeded. Seeded species composed less than 5% of cover at each plot from 2006-2008 (Figure 29). The lack of seeded cover may have been a result of the compost amendment, which was not tested for purity. Alien species can often out-compete native species; therefore, it is important to use organic material and seeds that are weed-free. This information demonstrates the importance of knowing the quality of the materials used in construction.

Trends by Year

Foliar cover at the full treatment plots were variable over time and ranged from 21 to 39% across all plots (Figure 25). Alien species increased 5 times at the full treatment plots from an average of 2% in 2006 to 10% in 2008 (Figure 26, Figure 27 and Figure 28). At the surface treatment plot, foliar cover increased 1.8 times from 25% in 2007 to 44% in 2008 (Figure 25) Alien species increased 1.3 times over the same time from 18% in 2007 to 23% in 2008 (Figure 27 and Figure 28).

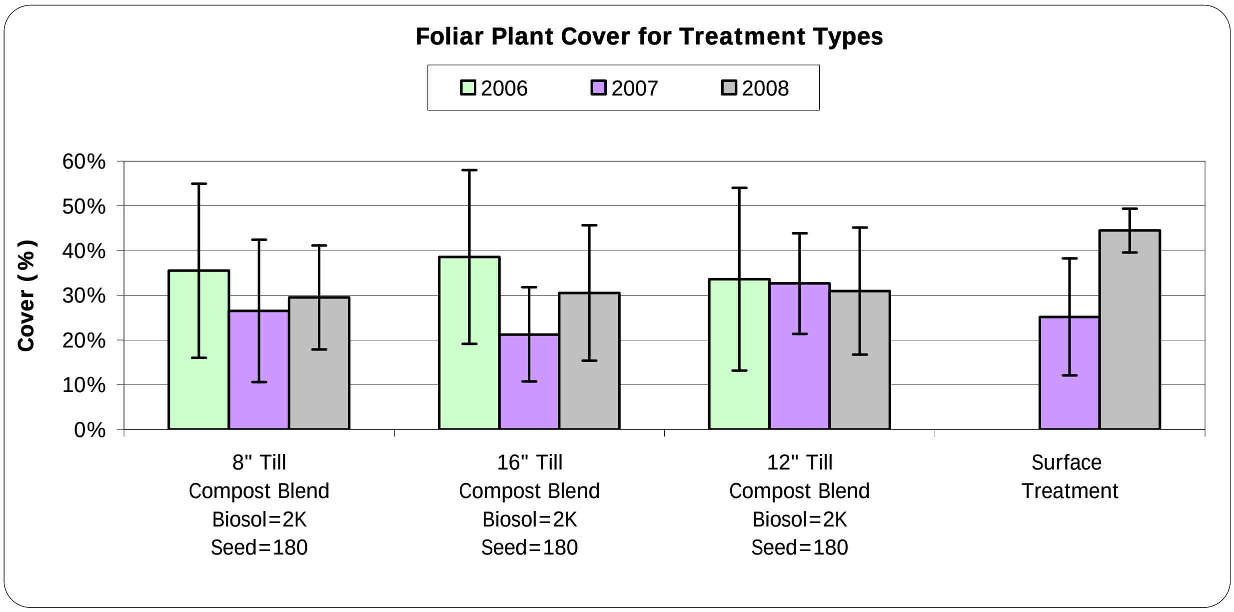

Figure 25. Foliar Plant Cover for Treatment Types. Plant cover was 1.2 times higher at the surface treatment plots compared to the full treatment plots from 2007 to 2008. Foliar cover was not measured at the surface treatment plot in 2006. The error bars represent one standard deviation above and below the mean. Data is sorted by increasing foliar plant cover for 2008.

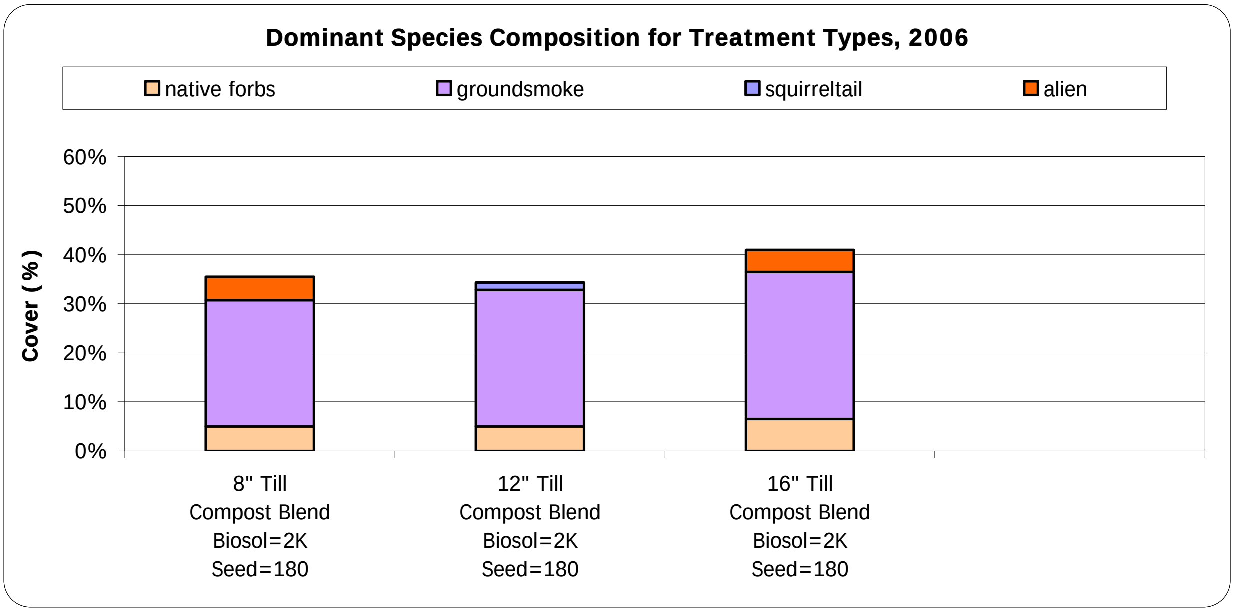

Figure 26. Dominant Species Composition for Treatment Types, 2006. The native annual groundsmoke was the dominant species at all plots.

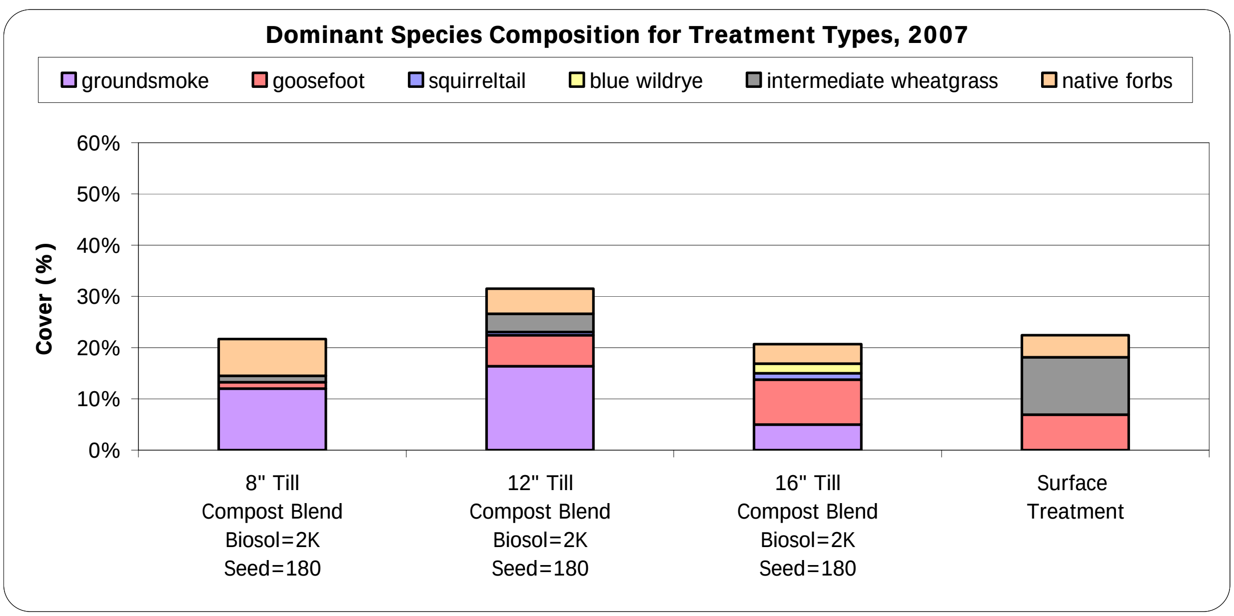

Figure 27. Dominant Species Composition for Treatment Types, 2007. The native annual groundsmoke dominated at the 8 and 12 inch (20 and 30 cm) till full treatment plots, but decreased from 2006. Alien species, including goosefoot, dominated the 16 inch (41 cm) till full treatment plot. Wheatgrass dominated at the surface treatment plot.

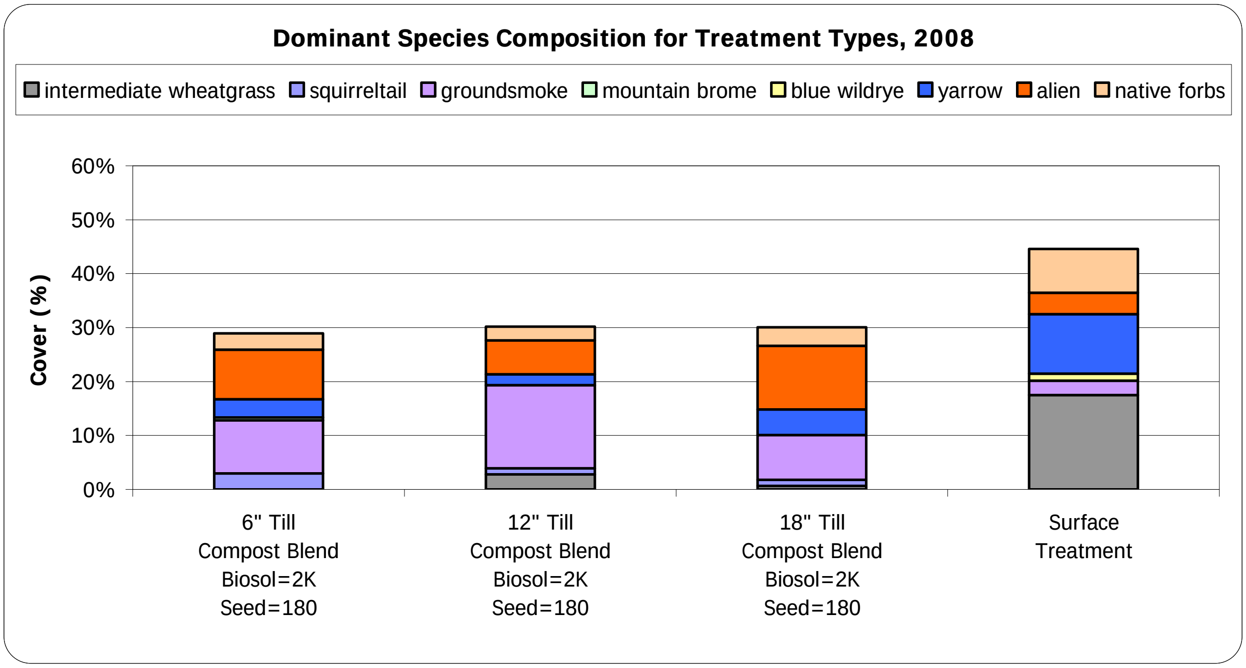

Figure 28. Dominant Species Composition for Treatment Types, 2008. The native annual groundsmoke continued to dominate the 8 and 12 inch (20 and 30 cm) till full treatment plots. Alien species, including goosefoot dominated the 16 inch (41 cm) till full treatment plot. Intermediate wheatgrass increased in cover at the surface treatment plot.

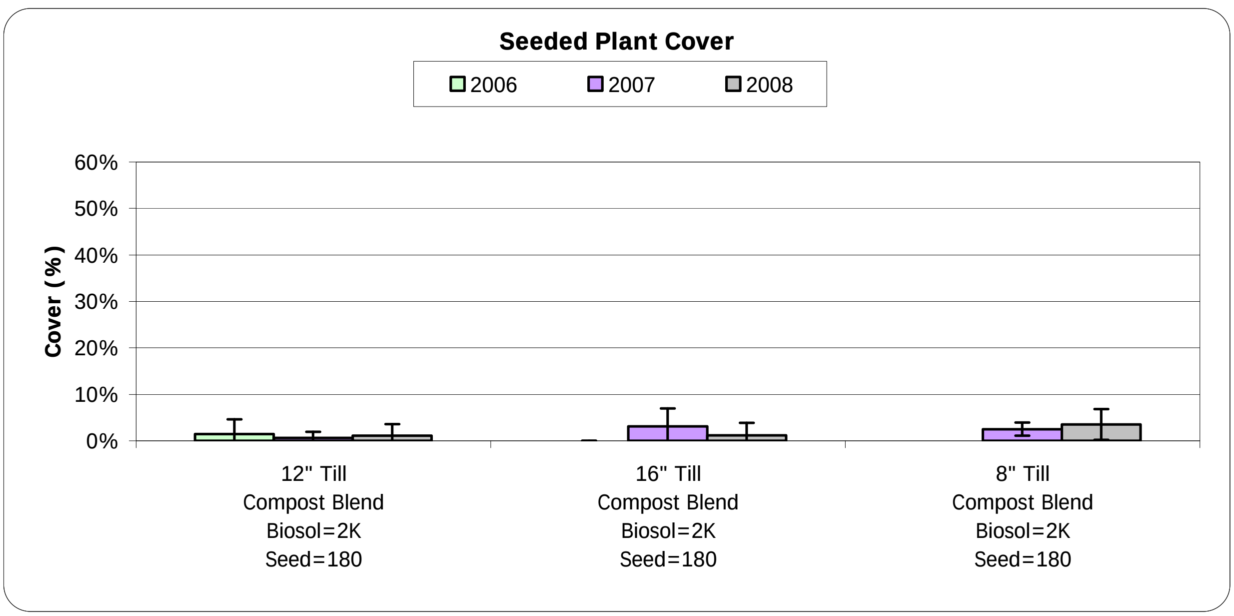

Figure 29. Seeded Plant Cover. Seeded cover was less than 5% at all plots from 2006 to 2008. Seeded cover was zero at the 8 and 16 inch (20 and 41 cm) till full treatment plots in 2006. The error bars represent one standard deviation above and below the mean. Data is sorted by 2008 seeded cover.

Soil Nutrients

Trends by Treatment Level

In 2008, the total Kjeldahl nitrogen (TKN) for full treatment plots and the surface treatment plot ranged from 2,343 to 3,240 ppm and was higher than the TKN at the native site (1,944 ppm; Figure 30). From 2006 to 2008, the TKN at the surface treatment plot (two-year average of 1,902 ppm) was 1.3 times lower than the TKN at the full treatment plots (three-year average of 2,502 ppm; Figure 30). The lower TKN at the surface treatment plots is most likely a result of the lack of organic amendments at the surface treatment.

In 2008, surface treatment and full treatment plots had similar organic matter content, which ranged from 8.1 to 8.7%. Both full and surface treatment plot had an organic matter content that was lower than that at the native site (14.4%; Figure 31). From 2006 to 2008, organic matter levels at the full treatment plots (three-year average of 10.5%) were 1.5 times higher than at the surface treatment plot (two-year average 7.2%; Figure 31).

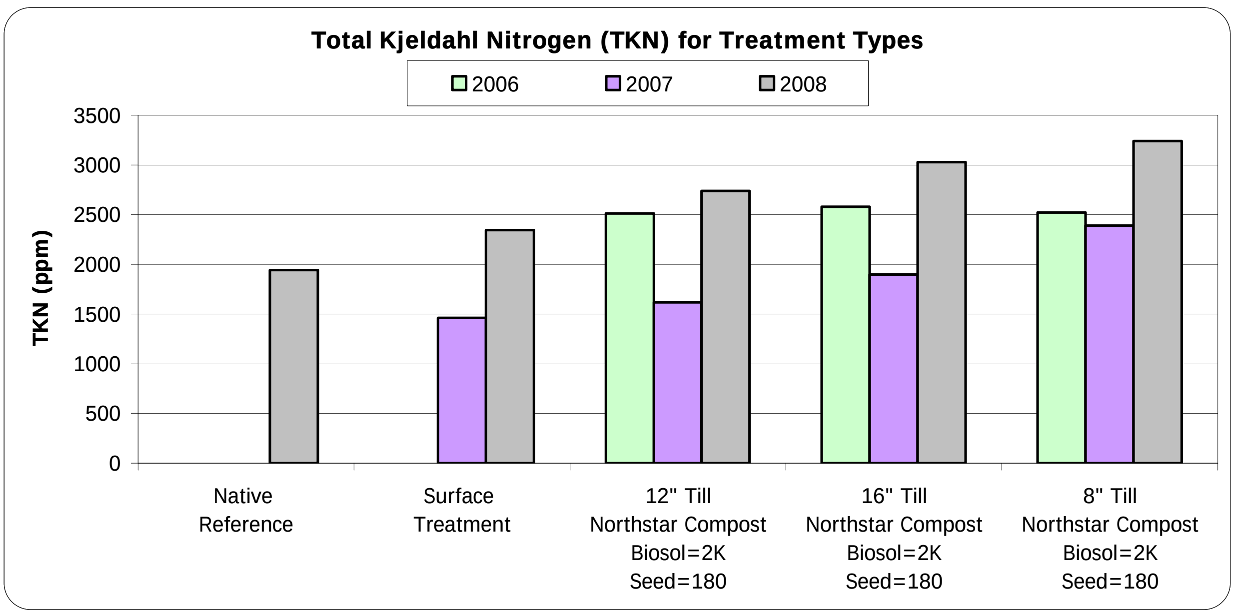

Figure 30. Total Kjeldahl Nitrogen (TKN) for Treatment Types. In 2008, the TKN at full treatment plots ranged from 2,740 to 3,240 ppm while TKN at the surface treatment plot was 2,343 ppm. Both full and surface treatment plots had higher TKN levels to the native site (1,944 ppm). Data is sorted by increasing TKN for 2008.

Trends by Year

The TKN decreased between 2006 and 2007 at all of the full treatment plots and increased between 2007 and 2008. The increase in TKN levels at the full treatment plots may be a result of the decomposition of the woody material in the compost. The decomposition would provide more nutrients in the soil. It is unclear why the TKN increased between 2007 and 2008 at the surface treatment plot.

The full treatment plots exhibited a trend of decreasing organic matter levels over time. The organic matter decreased an average of 1.6 times in 2008 (range of 8.1 to 8.7%) compared to

2006 (range of 12.8 to 13.6%). A higher amendment concentration is recommended in future treatments to ensure that organic matter content of treated areas reaches levels equivalent to native areas.

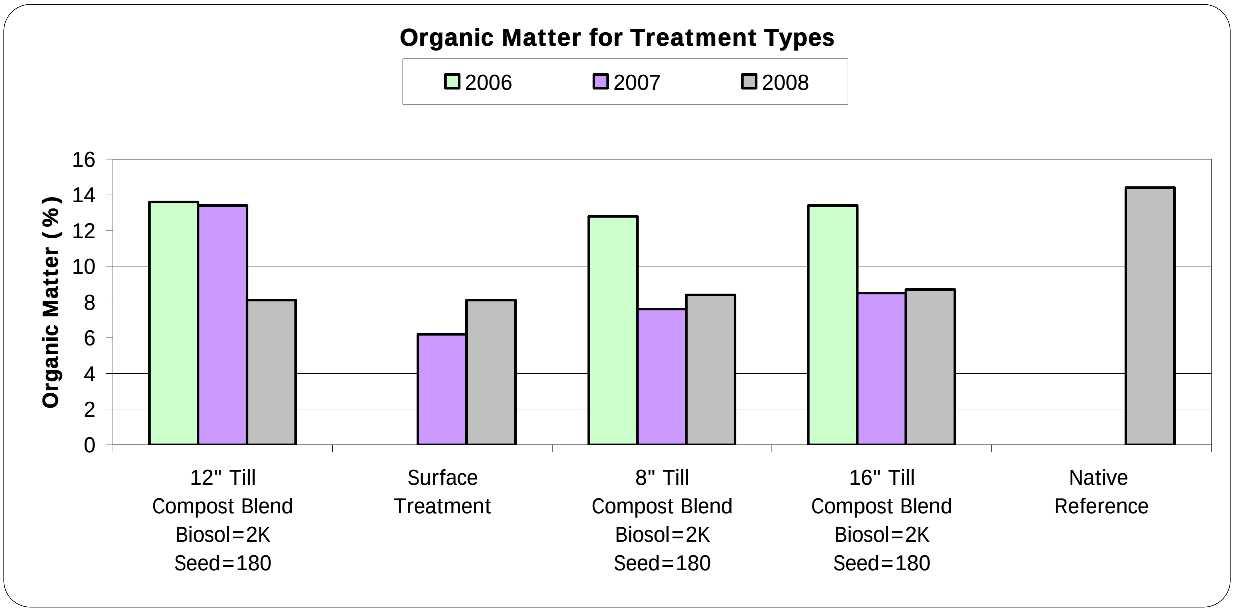

Figure 31. Organic Matter for Treatment Types. The full treatment plots had similar organic matter levels (average range of 9.6-11.7%) that were higher than at the surface treatment plot (range of 6.2-8.1%). Both treatment types had lower organic matter levels than the native site (14.4%). Data is sorted by increasing organic matter for 2008.

Recommendations

These recommendations are for moderately sloped sites with rocky soils on volcanic parent material, with solar exposures of 95-100% during the summer months, at approximately 6,907 feet (2,105 m) AMSL.

Tilling: 12 inches (30 cm)

Amendment: 5 inches (13 cm) weed free compost with 25% fines and 75% coarse overs at a nitrogen equivalent of approximately 1,908 lbs/acre (2,139 kg/ha)

Biosol: Biosol rate cannot be recommended

Seed: Rate and composition cannot be recommended

Mulch: pine needles, 2 inches (5 cm) and 99% cover

Full treatment versus Surface Treatment

Full treatment is recommended over surface treatment because full treatment plots exhibited:

- sediment yield (two-year average of 8.0 lbs/acre/in or 3.5 kg/ha/cm) that was an average of 3.2 to 3.9 times lower than the surface treatment plot, which produced sediment ranging from 26 to 31 lbs/acre/in (12-14 kg/ha/cm)

- infiltration rates that ranged from 4.5 to 4.7 in/hr (114-120 mm/hr), which was on average 1.2 times higher than the infiltration rates exhibited by the surface treatment plots, which ranged from 4.0 to 4.1 in/hr (102-104 mm/hr)
- consistently higher infiltration rates and lower sediment yield than the surface treatment plot
- penetrometer DTRs that were 4.1 times deeper at the 12 inch (30 cm) till plots than the surface treatment plot (two year average of 1.8 inches or 4.6 cm compared to 7.1 inches or 18 cm)
- TKN that was 1.3 times higher (three-year average of 2,502 ppm) than at the surface treatment plot (two-year average of 1,902 ppm)

Soil Loosening versus No Soil Loosening

Soil loosening by tilling is recommended to a depth of 12 inches (30 cm) for the following reasons. Plots with soil loosening exhibited:

- sediment yield (two-year average of 8.0 lbs/acre/in or 3.5 kg/ha/cm) that was an average of 3.2 to 3.9 times lower than at the surface treatment plot, which produced sediment ranging from 26.1 to 31.2 lbs/acre/in (11.5-13.8 kg/ha/cm)
- infiltration rates that ranged from 4.5 to 4.7 in/hr (114-120 mm/hr), which was on average 1.2 times higher than the infiltration rates exhibited by the surface treatment plots, which ranged from 4.0 to 4.1 in/hr (102-104 mm/hr)
- penetrometer DTRs that were 4.1 times deeper at the 12 inch (30 cm) till plots than the surface treatment plot (two year average of 1.8 inches or 4.6 cm compared to 7.1inches or 18 cm)

Amendment Type and Depth

Organic and weed free compost with woody debris is recommend. A 25% screened compost (1.25 inches or 3.2 cm) and 75% coarse overs (3.75 inches or 9.5 cm) blend is recommended at a total depth of 5 inches (13 cm). Coarse overs are the woody material remaining after the composting process. It is assumed that this composition is similar to the applied compost blend composition. However, the recommended concentration was increased to 5 inches (13 cm) for 12 inches (30 cm) of tilling compared to the tested 3 inches (8 cm) for 12 inches (30 cm) of tilling in an effort to reduce re-compaction.

Biosol Rate

Biosol rate cannot be recommended from the monitoring results of these plots. Seeded plants were unable to establish and therefore it is not known how effective the Biosol rate was for native grass establishment.

Seed Rate and Mix

Seed rate and composition cannot be recommended from the results of these plots.

Mulch Cover and Depth

Mulch composed of native pine needles should be applied at a depth of 2 inches (5 cm) and a ground cover of at least 99% for the following reasons. Plots with this application exhibited:

- reduced sediment yield (two-year average of 8.0 lbs/acre/in or 3.5 kg/ha/cm)

Appendix A

Species list for Bearpaw test plots, 2007. "X" indicates a species is present. A species list for the surface treatment plot was not recorded.

Lifeform	Family	Scientific name	Common name	Annual/ Perennial	Native/ Alien	Noxious	% in seed mix	16" till (1A)	8" till (1B)	12" till (2A)	16" till (2B)	8" till (3A)	12" till (3B)
Forb	Asteraceae	*Achillea millefolium*	yarrow	Perennial	Native			x	x	x	x	x	
Forb	Boraginaceae	*Amsinckia tessellata*	fiddleneck	Annual	Native			x		x	x	x	x
Forb	Asteraceae	*Antennaria rosea*	pussy toes	Perennial	Native								
Forb	Asteraceae	*Aster occidentalis*	western mountain aster	Perennial	Native								
Forb	Asteraceae	*Aster sp*	long-leaved aster	Perennial	Native								
Forb	Asteraceae	*Balsamorhiza sagittata*	arrow-leaved balsam-root	Perennial	Native					x		x	
Forb	Chenopodiaceae	*Chenopodium albens*	Goosefoot	Annual	Alien			x		x	x	x	x
Forb	Scrophulariaceae	*Collinsia parviflora*	blue-eyed mary	Annual	Native					x		x	x
Forb	Polemoniacea	*Collomia linearis*	narrow leaved collomia	Annual	Native			x		x		x	
Forb	Boraginaceae	*Cryptantha ambigua*	Wilke's cryptantha	Annual	Native			x		x		x	x
Forb	Onagraceae	*Epilobium ciliatum*	willow-herb	Perennial	Native					x		x	
Forb	Polygonaceae	*Eriogonum nudum*	nude buckwheat	Perennial	Native								
Forb	Polygonaceae	*Eriogonum spergulinum*	spurrey buckwheat	Annual	Native					x			
Forb	Onagraceae	*Gayophytum sp*	groundsmoke	Annual	Native			x	x	x	x	x	x
Forb	Polemoniaceae	*Gilia leptalea*	Bridge's Gilia	Annual	Native					x	x	x	x
Forb	Asteraceae	*Gnaphalium palustre*	cudweed	Annual	Native								
Forb	Asteraceae	*Lactuca serriola*	devil's lettuce	Annual	Alien	Invasive		x				x	x
Forb	Brassicaceae	*Lepidium campestre*	English pepperweed	Annual	Alien			x	x		x	x	x
Forb	Asteraceae	*Leucanthemum vulgare*	ox-eyed daisy	Perennial	Alien	Invasive				x		x	x
Forb	Fabaceae	*Lotus purshianus*	spanish lotus	Annual	Native					x		x	x
Forb	Asteraceae	*Madia glomerata*	mountain tarweed	Annual	Native							x	
Forb	Fabaceae	*Medicago lupulina*	black medick	Annual or Perennial	Alien							x	
Forb	Fabaceae	*Melilotus*	white sweet clover	Annual	Alien					x	x	x	x
Forb	Scrophulariaceae	*Mimulus guttatus*	monkey flower	Annual or Perennial	Native								
Forb	Polemoniaceae	*Navarretia intertexta*	needle-leaved navarretia	Annual	Native								
Forb	Onagraceae	*Oenethera sp.*	evening primrose	Perennial	Native								
Forb	Hydrophyllaceae	*Phacelia hastata*	silverleaf phacelia	Perennial	Native					x	x	x	x
Forb	Polemoniaceae	*Plox gracilis*	slender phlox	Annual	Native			x		x		x	x
Forb	Polygonaceae	*Polygonum arenastrum*	common knotweed	Annual	Native							x	
Forb	Polygonaceae	*Polygonum douglasii*	douglas knotweed	Annual	Native			x	x	x	x		
Forb	Polygonaceae	*Polygonum polygaloides ssp. kelloggii*	Kellog's knotweed	Annual	Native							x	
Forb	Rosaceae	*Potentilla glandulosa*	cinquefoil	Perennial	Perennial	Native							
Forb	Malvaceae	*Sidalcea oregana*	Oregon checker mallow	Perennial	Native								
Forb	Brassicaceae	*Sisymbrium altissimum*	tumble mustard	Annual	Alien								
Forb	Asteraceae	*Tanacetum parthenium*	feverfew	Perennial	Alien								

Lifeform	Family	Scientific name	Common name	Annual/ Perennial	Native/ Alien	Noxious	% in seed mix	16" till (1A)	8" till (1B)	12" till (2A)	16" till (2B)	8" till (3A)	12" till (3B)
Forb	Asteraceae	*Taraxacum officinale*	dandelion	Annual	Alien	Invasive		x					
Forb	Asteraceae	*Tragapogon dubius*	false salsify	Annual	Alien					x		x	x
Forb	Asteraceae	*Wyethia mollis*	mule ears	Perennial	Native			x	x				
Graminoid	Poaceae	*Elytrigia intermedia*	pubescent wheatgrass	Perennial	Alien	Invasive		x		x	x	x	x
Graminoid	Poaceae	*Bromus carinatus*	mountain brome	Perennial	Native		43.0%	x		x		x	
Graminoid	Poaceae	*Bromus secalinus*	rye brome	Annual	Alien								
Graminoid	Poaceae	*Bromus tectorum*	cheatgrass	Annual	Alien			x					
Graminoid	Poaceae	*Dactyls glomerata*	orchard grass	Perennial	Alien	Invasive				x		x	x
Graminoid	Poaceae	*Deschampsia cespitosa*	California Hairgrass	Perennial	Native								
Graminoid	Poaceae	*Elymus elymoides*	squirreltail	Perennial	Native		21.7%	x	x	x	x	x	x
Graminoid	Poaceae	*Elymus glaucus*	blue wildrye	Perennial	Native		32.4%					x	
Shrub	Brassicaceae	*Arabis holboellii*	Holboel's rockcress	Perennial	Native			x	x	x		x	
Shrub	Asteraceae	*Heliomeris multiflora var multiflora*	showy goldeneye	Perennial	Alien								
Shrub	Grossulariaceae	*Ribes cereum*	wax currant	Perennial	Native			x			x	x	x
Tree	Pinaceae	*Abies concolor*	white fir	Perennial	Native								

Species list and ocular estimates for Bearpaw test plots and the surface treatment plot, 2008. Ocular estimates are presented below the plot numbers/letters. “T” indicates a species present in trace amounts. The seed mix for the surface treatment plot is not known.

Lifeform	Family	Scientific name	Common name	Annual/ Perennial	Native/ Alien	Noxious	% in seed mix	16” till (1A)	8” till (1B)	12” till (2A)	16” till (2B)	8” till (3A)	12” till (3B)	Surface Treatment
Forb	Asteraceae	*Achillea millefolium*	yarrow	Perennial	Native			2	1	4	1	3	T	7
Forb	Brassicaceae	*Arabis holboellii*	Holboel's rockcress	Perennial	Native					T				
Forb	Asteraceae	*Aster occidentalis*	western mountain aster	Perennial	Native						T			
Forb	Asteraceae	*Aster sp*	long-leaved aster	Perennial	Native						T			
Forb	Fabaceae	*Astragalus*	locoweed											T
Forb	Chenopodiaceae	*Chenopodium album*	goosefoot	Annual	Alien			1	T	7	3	1	2	
Forb	Polemoniaceae	*Collomia linearis*	narrow-leaved collomia	Annual	Native				T	T		T		
Forb	Boraginaceae	*Cryptantha ambigua*	Wilke's cryptantha	Annual	Native				T	T			T	
Forb	Asteraceae	*Erigeron breweri*	brewer's fleabane	Perennial	Native						T			
Forb	Polygonaceae	*Eriogonum nudum*	nude buckwheat	Perennial	Native								T	
Forb	Onagraceae	*Gayophytum sp*	groundsmoke	Annual	Native			T	6	12	12	12	17	1
Forb	Brassicaceae	*Hesperis matronalis*	dame's rocket	Perennial	Alien									T
Forb	Asteraceae	*Lactuca serriola*	devil's lettuce	Annual	Alien	Of concern		17	11	1	T	2	T	
Forb	Brassicaceae	*Lepidium campestre*	English pepperweed	Annual	Alien			T	T			T	T	T
Forb	Asteraceae	*Leucanthemum vulgare*	ox-eye daisy	Perennial	Alien	Invasive		T						T
Forb	Asteraceae	*Madia glomerata*	mountain tarweed	Annual	Native			T				T	T	
Forb	Malvaceae	*Malva neglecta*	dwarf mallow	Annual	Alien					T				
Forb	Lamiaceae	*Monardella odoratissima*	mountain monardella	Perennial	Native					T				
Forb	Scrophulariaceae	*Penstemon laetus*	gay penstemon	Perennial	Native									T
Forb	Hydrophyllaceae	*Phacelia hastata*	silverleaf phacelia	Perennial	Native				T			T		
Forb	Polemoniaceae	*Phlox gracilis*	slender phlox	Annual	Native			T	T	T		T		1
Forb	Plantaginaceae	*Plantago lanceolata*	English plantain	Perennial	Alien	Invasive		T						
Forb	Polygonaceae	*Polygonum arenastrum*	common knotweed	Annual	Alien			T		T	T	T	T	
Forb	Rosaceae	*Potentilla glandulosa*	sticky cinqufoil	Perennial	Native			T	T		T			T
Forb	Malvaceae	*Sidalcea oregana*	Oregon checker mallow	Perennial	Native									
Forb	Brassicaceae	*Sisymbrium altissimum*	tumble mustard	Annual	Alien				T	T			T	
Forb	Asteraceae	*Taraxacum officinale*	dandelion	Annual	Alien	Of concern								T
Forb	Asteraceae	*Tragopogon dubius*	false salsify	Annual	Alien			T		T	T		T	T
Forb	Asteraceae	*Wyethia mollis*	Mule ears	Perennial	Native			T						T
Graminoid	Poaceae	*Bromus carinatus*	mountain brome	Perennial	Native		43.0%						T	
Graminoid	Poaceae	*Bromus secalinus*	rye brome	Annual	Alien			1		T				1
Graminoid	Poaceae	*Bromus tectorum*	cheatgrass	Annual	Alien	Invasive							T	
Graminoid	Poaceae	*Dactylis glomerata*	orchard grass	Perennial	Alien	Invasive						T		1
Graminoid	Poaceae	*Elymus elymoides*	squirreltail	Perennial	Native		21.7%	T	3	T	2	T	1	
Graminoid	Poaceae	*Elymus glaucus*	blue wildrye	Perennial	Native		32.4%		T	T	2	T	1	

Lifeform	Family	Scientific name	Common name	Annual/ Perennial	Native/ Alien	Noxious	% in seed mix	16” till (1A)	8” till (1B)	12” till (2A)	16” till (2B)	8” till (3A)	12” till (3B)	Surface Treatment
Graminoid	Poaceae	*Elytrigia intermedia ssp. intermedia*	intermediate wheatgrass	Perennial	Alien	Invasive		2	T	5		1	1	25
Graminoid	Poaceae	*Triticum aestivum*	wheat	Annual	Alien			T	T		T		T	
Shrub	Grossulariaceae	*Ribes cereum*	wax currant	Perennial	Native							T		
Tree	Pinaceae	*Abies concolor*	white fir	Perennial	Native					T			T	
TOTAL COVER (transects)								29	29	30	45	21	23	39
TOTAL COVER (ocular estimate)								25	21	23	34	22	23	32

Northstar Highlands View Road Test Plots Site Report

May 2009

Introduction

Monitoring results and treatment recommendations for a series of 12 test plots in the Northstar-at-Tahoe ski resort (Northstar) area will be presented in this report (Figure 1). Data was collected in two locations: the Highlands View Road test plots (test plots) and a nearby native reference plot. The test plots were constructed in the summer of 2007 and monitoring was conducted in the summer of 2008. The Highlands View Road test plots are located above the banks of West Martis Creek, upstream of the Highlands View Road bridge crossing. These plots are representative of road fill conditions in the Lake Tahoe area; therefore, the monitoring results from these plots are applicable to Caltrans roadside projects in the Lake Tahoe Basin and throughout the Sierra Nevada.

Figure 1. Satellite Map of the Northstar Highlands View Road project area location. The project area is just north of Lake Tahoe, in California.

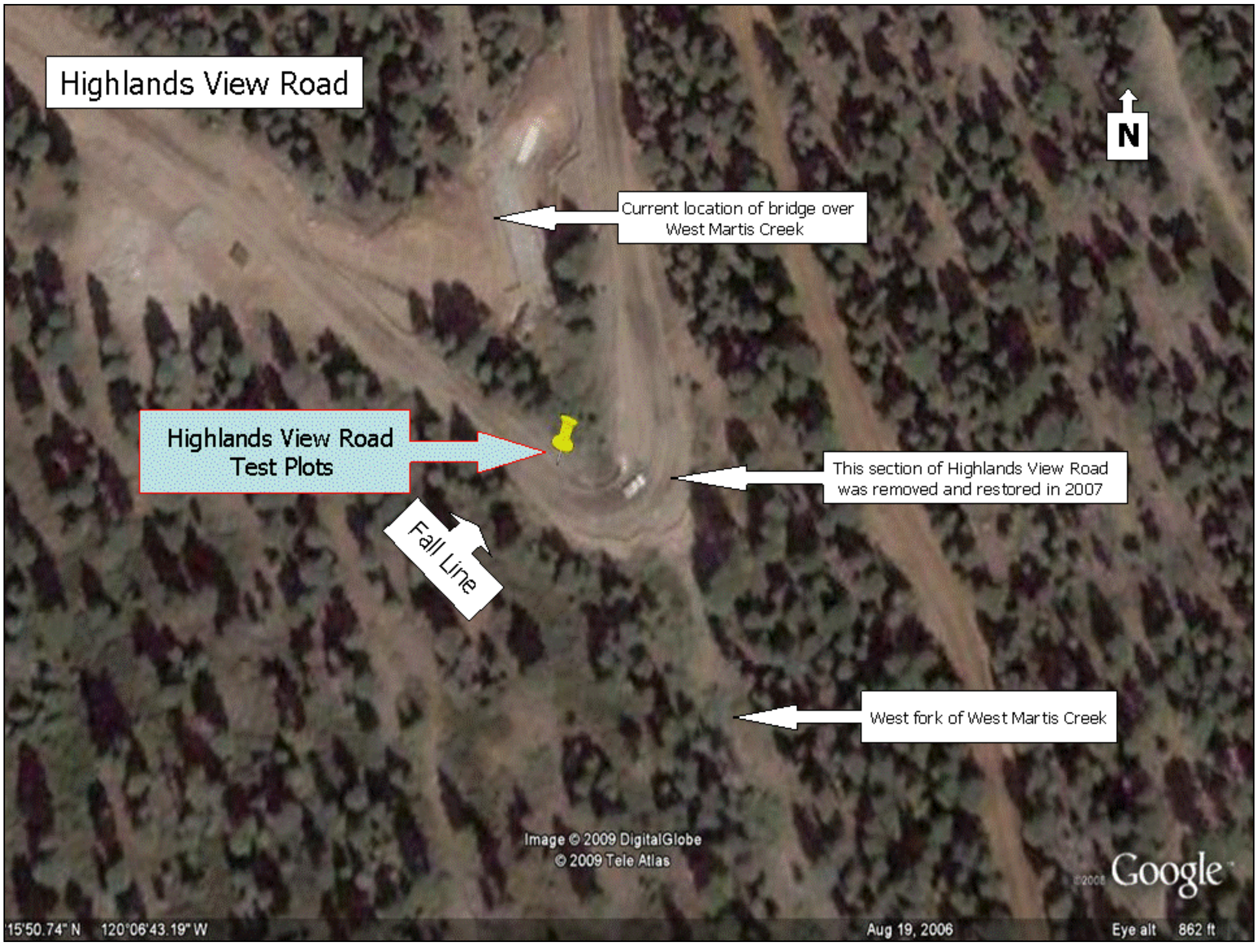

Figure 2. Satellite map of the Northstar Highlands View Road area, including the test plots. This image is from August 2006. In 2007, Highlands View Road was rerouted, paved, and sections that were no longer in use were ecologically restored.

Purpose

The project's monitoring objectives are outlined below. The following treatment definitions are included to aid understanding of these objectives.

Full Treatment: includes soil loosening by tilling, incorporation of an amendment such as fill soil, addition of fertilizer and native seed, and application of native mulch.

Partial Treatment: includes soil loosening by tilling, incorporation of an amendment such as fill soil, addition of native seed, and application of native mulch.

The monitoring data was studied and analyzed to investigate:

1. the effects of different seed rates on plant cover and composition
2. the effects of different Biosol rates on plant cover and composition

Site Description

Highland View Road Test Plots

The test plots are located on a northeast slope of the West Martis Creek drainage, upstream of the Highlands View Road bridge in Truckee, California (Figure 3). The site elevation is approximately 6,759 ft (2,060 m) above mean sea level (AMSL). The slope angle ranges between 25 and 30 degrees.

The date of first human disturbance in this area is not known. Logging has occurred in this area since the late 1800's. At some point, a logging road for steam tractors was built that ran parallel to the creek from the current lower portion of the modern Highlands View Road upstream through the test plot area. There are no written records available of the road building history. During summer of 2007, the logging road was removed and the surrounding slopes were restored. Fill soil was brought in from a local construction site to fill in and re-contour the slope to a more natural configuration. The soil parent material is volcanic in origin with up to 50% coarse fragments greater than 0.5 inches (1.3 cm) in diameter in some areas. The site is surrounded by local native vegetation consisting of an open Jeffrey pine (*Pinus jeffreyi*) and white fir (*Abies concolor*) canopy. The solar exposure is approximately 85-90% and there is less than 5% canopy cover over the test plots.

Native Reference Plot

The native reference plot is located near the Unit 7 test plots on the corner of Big Springs Drive and Overlook Place. The soil parent material is volcanic in origin with up to 65% coarse fragments. This plot was used for a native reference soil sample only.

Treatment Overview

All 12 plots received different variations of full treatment or partial treatment in 2007 (Figure 3). These treatments are explained in detail below. The plots were irrigated following construction in 2007 and again in 2008.

The native reference plot is undisturbed and was used as a baseline reference for soil nutrients for all other treatments.

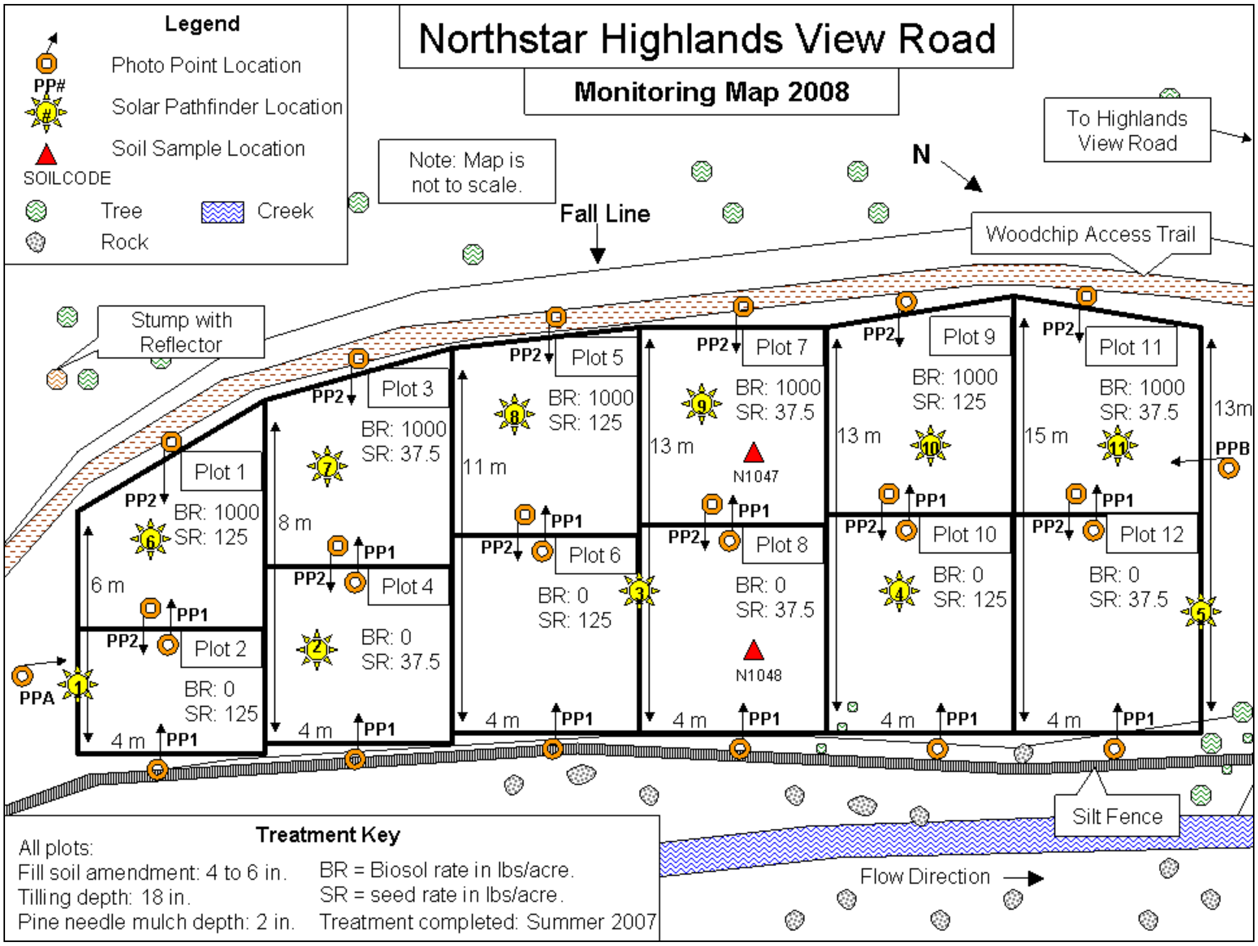

Figure 3. Map of the Northstar Highlands View Road test plots with treatment key. Photo points, soil samples, and Solar Pathfinder locations are marked. Irrigation was set up running horizontally between the top and bottom row of plots.

Test Plot Treatments

Test plot treatments are presented in Table 1. Descriptions of these treatments can be found following the table. Photos of the test plots before treatment are shown in Figure 4 and Figure 6. After-treatment photos are shown in Figure 5 and Figure 7.

Table 1. Northstar Highlands View Road Treatments.

Plot	Amendment	Soil Loosening	Biosol Rate (lbs/acre)	Seed Type	Seed Rate	Mulch
1	4” Fill soil	18” Tilled	1,000	IERS Upland seed mix	125 lbs/acre	2” Pine needles
2	4” Fill soil	18” Tilled	0	IERS Upland seed mix	125 lbs/acre	2” Pine needles
3	4” Fill soil	18” Tilled	1,000	IERS Upland seed mix	37.5 lbs/acre	2” Pine needles
4	4” Fill soil	18” Tilled	0	IERS Upland seed mix	37.5 lbs/acre	2” Pine needles
5	4” Fill soil	18” Tilled	1,000	IERS Upland seed mix	125 lbs/acre	2” Pine needles
6	4” Fill soil	18” Tilled	0	IERS Upland seed mix	125 lbs/acre	2” Pine needles
7	4” Fill soil	18” Tilled	1,000	IERS Upland seed mix	37.5 lbs/acre	2” Pine needles
8	4” Fill soil	18” Tilled	0	IERS Upland seed mix	37.5 lbs/acre	2” Pine needles
9	4” Fill soil	18” Tilled	1,000	IERS Upland seed mix	125 lbs/acre	2” Pine needles
10	4” Fill soil	18” Tilled	0	IERS Upland seed mix	125 lbs/acre	2” Pine needles
11	4” Fill soil	18” Tilled	1,000	IERS Upland seed mix	37.5 lbs/acre	2” Pine needles
12	4” Fill soil	18” Tilled	0	IERS Upland seed mix	37.5 lbs/acre	2” Pine needles

Figure 4. Highlands View Road test plots, pre-construction, 2007. Photo point A (Figure 3).

Figure 5. Highlands View Road test plots, 1 year following treatment, September 2008. Photo point A (Figure 3).

Figure 6. Highlands View Road test plots, pre-construction, 2007. Photo point B (Figure 3).

Figure 7. Highlands View Road test plots, 1 year following treatment, September 2008. Photo point B (Figure 3).

Soil Loosening

All test plots were tilled to a depth of approximately 18 inches (46 cm) by a rubber-tracked excavator following amendment application (Figure 3).

Amendment

Four inches (10 cm) of fill soil were used as an amendment at each of the test plots. The foreman from the construction of the test plots observed the soil had similar characteristics of topsoil, such as being darker in color than the soil used to fill the slope. However, the fill soil amendment was sourced from an unknown construction project at Northstar, and the nutrient condition of the soil was unknown. Therefore, it will be referred to as fill soil. The fill soil was spread evenly by excavator bucket prior to fertilizer and seed application.

Fertilizer

Following incorporation of fill soil at the full treatment plots, Biosol, a slow release fertilizer, was applied and raked approximately 1 inch (2.5 cm) into the soil at a rate of 1,000 lbs/acre (1,121 kg/ha). Plots 1, 3, 5, 7, 9, and 11 received Biosol and plots 2, 4, 6, 8, 10, and 12 did not receive Biosol.

Seeding

At the test plots, suitable native perennial grasses, forbs, and shrubs were seeded at a rate of either 37.5 lbs/acre (42 kg/ha) or 125 lbs/acre (140 kg/ha; Figure 3 and Table 2). Plots 1, 2, 5, 6, 9, and 10 received 125 lbs/acre (140 kg/ha) and plots 3, 4, 7, 8, 11, and 12 received 37.5 lbs/acre (42 kg/ha).

Table 2. IERS Upland Seed mix and approximate mix composition.

Common Name	*Scientific Name*	% Pure Live Seed
Mountain brome (Bromar)	*Bromus carinatus*	34%
Squirreltail	*Elymus elymoides*	26%
Blue wildrye	*Elymus glaucus*	26%
Antelope bitterbrush	*Purshia tridentata*	8%
Sulphur flower buckwheat	*Eriogonum umbellatum*	4%

Planting

All plots received native shrub and tree plantings. A specific list of what species were planted and where is not available. All plots received about the same number of plantings.

Mulch

Mulch was spread evenly by hand to achieve 99% cover at a depth of 2 inches (5 cm) on all test plots.

Irrigation

Irrigation was employed in 2007 and 2008 and was applied when soil moisture levels indicated it was necessary. MP rotator heads were used at rate of 4 gal/min (15 L/min) to irrigate the slopes. This style of irrigation head delivers water at a low flow and conserves water compared to high flow irrigation. A soil moisture probe was used to measure and maintain adequate moisture levels. A deep watering cycle was used initially to soak the soil; then two to three hour cycles were used to keep moisture levels high to encourage seed germination. During the summer this may have been done daily, depending on soil moisture readings.

After seed germination, the irrigation schedule was changed to three times a week for two weeks to encourage plant roots to penetrate deeper into the soil, where moisture levels were high. After the vegetation was established and approximately 2 to 3 inches (5-8 cm) in height, the schedule was reduced to once a week to maintain moisture at depth of 8 inches (20 cm). Irrigation continued as necessary to maintain moisture at the 8 inch (20 cm) depth.

In the fall, the moisture levels were reduced so that the vegetation would slowly become dormant in preparation for winter.

Monitoring Methods

The test plots and were monitored in 2008. In the text, both English and metric units will be given; however, tables will contain one or the other.

Cover

Cover point monitoring was conducted at the test plots in August of 2008.

Cover is measured using the statistically defensible cover point method along randomly located transects.[1] The cover pointer consists of a metal rod with a laser pointer mounted 3.3 ft (1 m) high. After the rod is leveled in all directions, the button on the laser pointer is depressed and two cover measurements are recorded (Figure 8 and Figure 9):

- the first hit cover, which is the first object intercepted starting from a height of 3.3 ft (1 m) above the ground
- the ground cover hit, which is the low-lying vegetation or soil below the first hit cover, at the ground level

The first hit cover measures the foliar cover by plants (leaves and stems). It does not measure the part of the plant rooted in the ground. The first hit vegetation is then moved aside and a ground cover hit measures the presence of litter/mulch, basal (or rooted) plant cover, rock and woody debris, and/or bare ground. Total ground cover represents any cover other than bare ground.

Figure 8. Cover pointer in use along transects.

Figure 9. Cover pointer rod with first hit and ground cover hit by the laser pointer. The laser pointer hits are circled in red. The first cover hit is a native grass and the ground cover hit is pine needle mulch.

Foliar and ground level plant cover is recorded by species and then organized into cover groups based on four categories: life form (herbaceous/woody), perennial/annual, native/alien (2007 and 2008), and seeded/volunteer (2007 and 2008). Perennial herbaceous species includes seeded grasses, native grasses and forbs, and any non-native perennial species. Annual herbaceous species include native annuals such as knotweed (*Polygonum sp.*)

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[1]Hogan, M. 2003. Luther Pass Monitoring Report: Plant and Soil Cover Monitoring for Evaluating Sediment Source Control Success in the Lake Tahoe Basin. Lahontan Regional Water Quality Control Board, South Lake Tahoe, CA.

and invasive species such as cheatgrass (*Bromus tectorum*). Woody species includes any tree or shrub species, either native or introduced. Each species is then classified based on whether it is native to the Tahoe area, and whether it was seeded during treatment. Data is presented on the amount of cover by species. An ocular estimate of cover at each plot is also recorded and includes many species not hit using cover point sampling. The species lists, as well as the ocular estimates of cover by species, are presented in Appendix A.

In most instances, the *Elymus* species had not produced seed at the time of sampling. Therefore, it was difficult to determine whether squirreltail (*Elymus elymoides*) or blue wildrye (*Elymus glaucus*) was present. Since identification was difficult, the two grass species were categorized as called *Elymus sp.*

Soil and Site Physical Conditions

Penetrometer Depth to Refusal and Soil Moisture

In 2008, soil density and soil moisture were randomly measured 10 times per plot (not on transects). A cone penetrometer with a ½ inch diameter tip is pushed straight down into the soil until a maximum pressure of 350 pounds per square inch (2,413 kPa) is reached (Figure 10 and Figure 11). The depth at which that pressure is reached is recorded as the depth to refusal (DTR).

Cone penetrometer DTR measurements are used as an index for soil density. A denser soil is less likely to allow infiltration. Rainfall simulations conducted on roadcuts in Oregon found increased infiltration rates in soils with penetrometer depths to refusal (DTRs) greater than 4 inches (10 cm).[2]

It is most informative to compare penetrometer DTR measurements collected in soils that have similar moisture levels. When soil moisture content increases, the resistance of the soil to the penetrometer decreases and DTR readings are deeper. Therefore, only penetrometer readings at the same soil moisture can be compared. A hydrometer was used to measure volumetric soil moisture content adjacent to the penetrometer readings at a depth of 4.7 inches (12 cm; Figure 12).

[2] Grismer, M.E. 2006. Simulated Rainfall Evaluation at Sunriver and Mt Bachelor Highways, Oregon. Unpublished.

Figure 10. Photo of a cone penetrometer dial, showing pressure applied in pounds per square inch.

Figure 11. Photo of conducting cone penetrometer readings along transects.

Solar Exposure

In 2008, solar exposure measurements were taken in each test plot. These measurements are taken using a Solar Pathfinder (Figure 13). Solar input affects evaporation rates and soil temperature, which may affect time of seed germination, germination rate, rate of plant growth, and soil microbial activity. Therefore, this is an important variable to consider when monitoring plant growth and soil development.

Figure 12. Conducting soil moisture readings along transects.

Figure 13. Solar pathfinder in use.

Soil Nutrient Analysis

Successful re-vegetation requires that nutrient capital be stored in the soil for release over time. Sufficient organic matter and a functioning microbial community are necessary to provide a long-term source of nitrogen for plants. Previous studies of soil nutrient levels at revegetation sites throughout the Tahoe area found that sites with high plant cover had significantly higher soil nutrients over the long-term than soils with lower plant cover levels.[3] Total Kjeldahl nitrogen and organic matter were used as indicators of soil health in this study. Total Kjeldahl nitrogen (TKN) is a measure of readily available nitrogen. Only three soil sub-samples were taken from each plot; therefore, differences in TKN and organic matter values may be a result of the variability within a plot.

In 2008, soil samples were collected from test plots 7, 8, and the native reference plot (Table 1 and Figure 3). Three soil sub-samples at each plot were collected from the mineral soil beneath any mulch layer to a depth of 12 inches (30 cm; Figure 14). These sub-samples were combined and sieved to remove any material larger than 0.08 inches (2 mm) in diameter, and sent to A&L Laboratories in Modesto, California for the S3C nutrient suite (macro and micronutrients), total Kjeldahl nitrogen (TKN), and organic matter analysis.

Figure 14. Soil sub-sample collection.

Statistical Analysis

The Mann-Whitney statistical test was used to determine significant differences between treatments. The Mann-Whitney is a non-parametric test that can be applied to data sets with non-normal distributions. Non-normal distributions are common within small data sets. Some of the sample sizes at the Highland View Road test plots were small (n=3), making it necessary to use a non-parametric test.

[3]Claassen, V.P., and M.P. Hogan. 2002. Soil Nutrients Associated with Revegetation of Disturbed Sites in the Lake Tahoe Basin. Restoration Ecology 10:195-203.

Results and Discussion

Soil Moisture

Soil moisture ranged from 14.9 to 16.6% between plots (Figure 15). This narrow difference between the soil moisture levels at the plots allows for comparison of penetrometer DTRs.

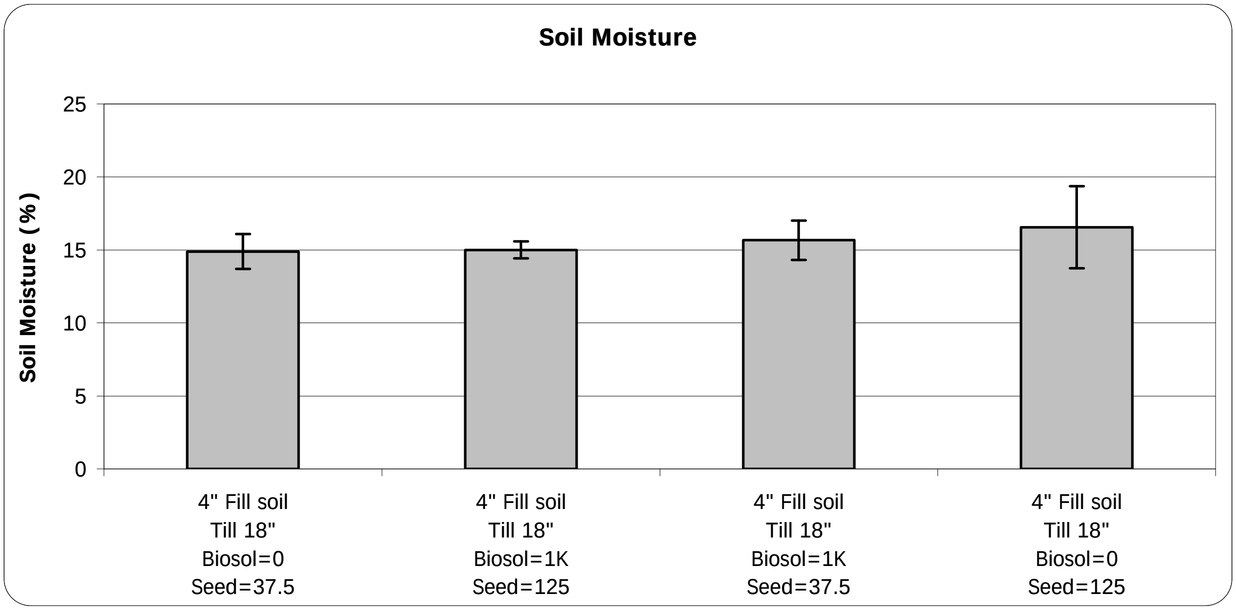

Figure 15. Soil Moisture. Soil moisture levels were similar across all plots. The error bars represent one standard deviation above and below the mean. Data is sorted by increasing 2008 soil moisture.

Penetrometer Depth to Refusal

Penetrometer DTRs measured at the test plots indicated un-compacted conditions and ranged from 10.9 to 11.4 inches (28 to 29 cm; Figure 16). Biosol and seed rates did not affect DTR in 2008.

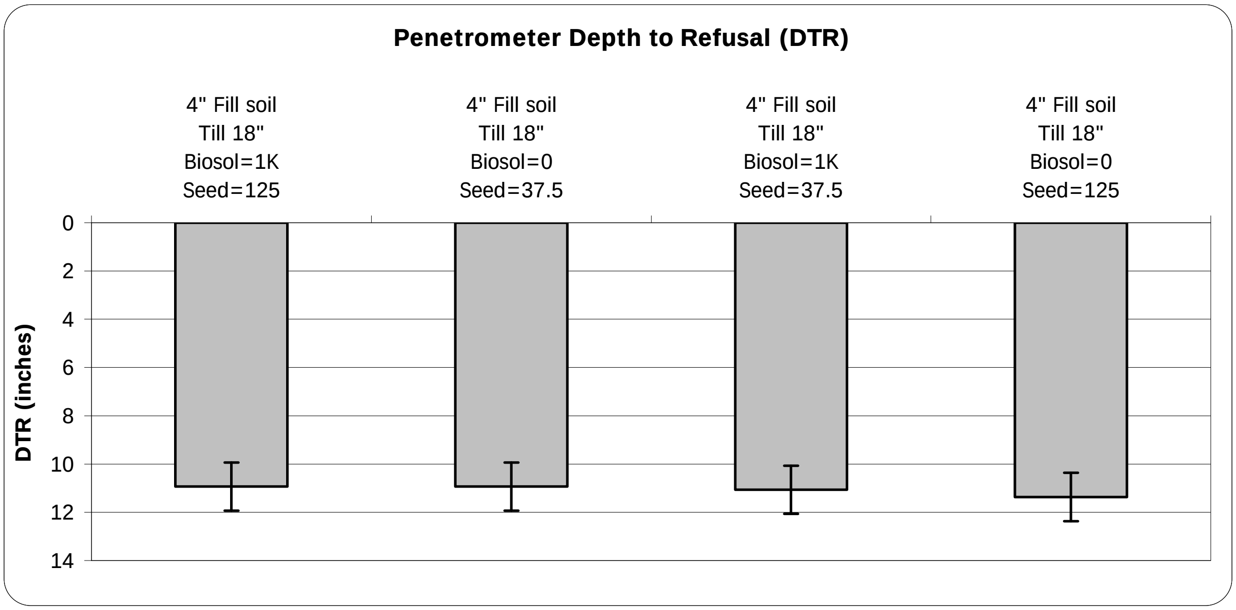

Figure 16. Penetrometer DTR. The penetrometer DTRs were similar across all plots. The error bars represent one standard deviation above and below the mean. Data is sorted by decreasing penetrometer DTR for 2008.

Cover

Ground Cover by Mulch and Bare Soil

Mulch cover ranged from 83 to 91% across the plots (Figure 17). Mulch cover is an important variable in erosion reduction through sediment source control because treatments with cover by pine needle mulch have been shown to reduce sediment yields substantially.[4] There were no visible signs of water erosion or pine needle movement at any of the plots. Bare ground ranged from 3 to 4% across the plots (Figure 18).

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[4]Grismer, M.E., and M.P. Hogan. 2004. Simulated rainfall evaluation of revegetation/mulch erosion control in the Lake Tahoe Basin: 1. Method assessment. Land Degradation & Development 15:573-588.

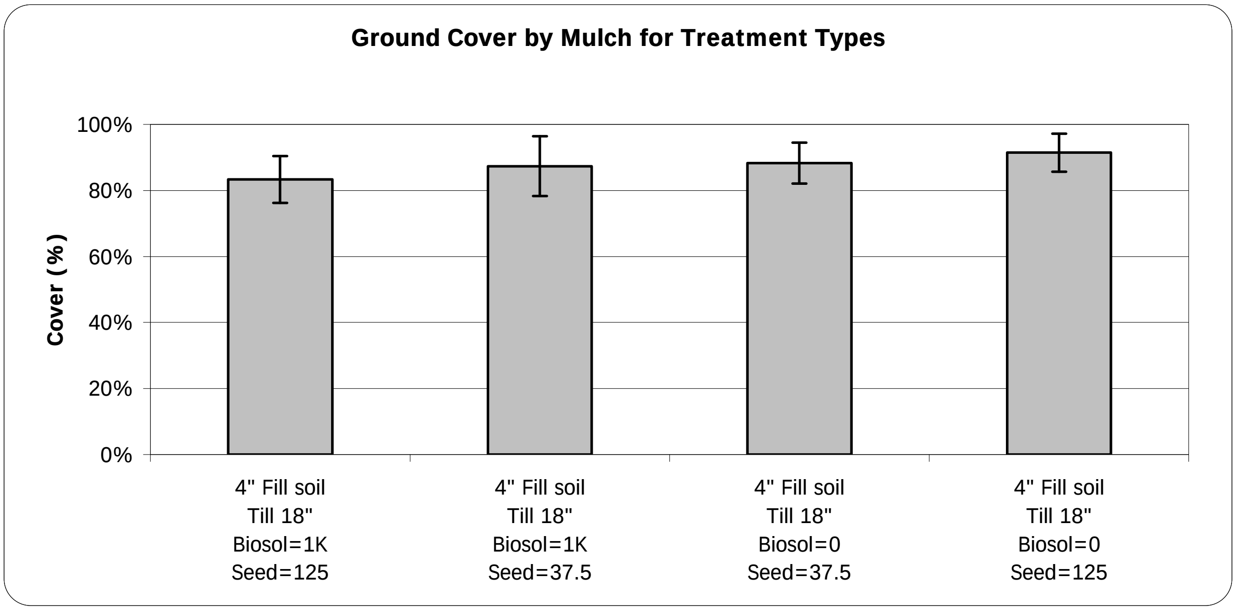


Figure 17. Ground Cover by Mulch for Treatment Types. The mulch cover was similar across all plots. The error bars represent one standard deviation above and below the mean. Data is sorted by increasing 2008 mulch cover.

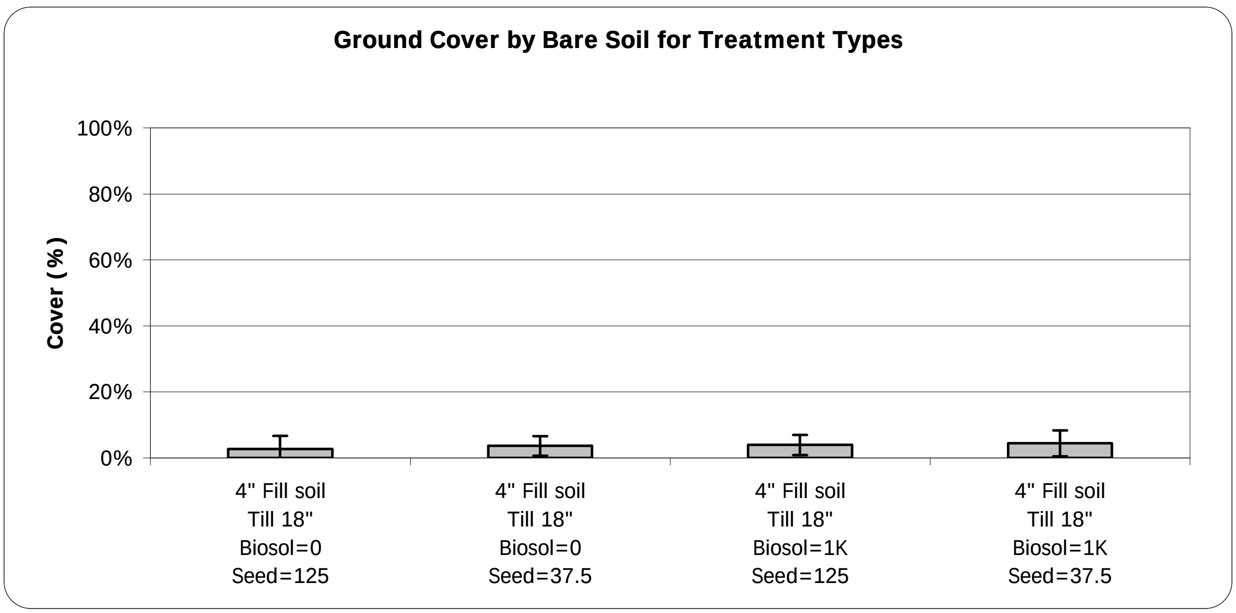


Figure 18. Ground Cover by Bare Soil for Treatment Types. The cover by bare soil was similar across all plots. The error bars represent one standard deviation above and below the mean. Data is sorted by increasing bare soil for 2008.

Plant Cover and Composition

Effects of Biosol Rate on Plant Cover

At plots that were seeded at 125 lbs/acre (140 kg/ha), plant cover was not significantly different between plots with varying Biosol rates (Table 3). However, plots that were seeded at a rate of 125 lbs/acre (140 kg/ha) exhibited foliar plant cover 3.3 times higher with 1,000 lbs/acre (1,121 kg/ha) Biosol (18%) compared to plots with no Biosol (5%; Figure 19).

At plots that were seeded at a rate of 37.5 lbs/acre (42 kg/ha), foliar plant cover was not significantly different for different Biosol rates (Table 3). Foliar plant cover was similar in the plots with 1,000 lbs/acre (1,121 kg/ha) Biosol (9%) compared to those with no Biosol (8%; Figure 19). This suggests that the presence of Biosol does not necessarily increase plant cover when low seed rates are used.

Effect of Biosol Rate on Plant Composition

The 1,000 lbs/acre (1,121 kg/ha) Biosol plots exhibited a trend toward higher cover by mountain brome (*Bromus carinatus*), compared to plots without Biosol, for both seed rates. The plot with 1,000 lbs/acre (1,121 kg/ha) Biosol and 125 lbs/acre (140 kg/ha) seed had 8% mountain brome cover, while the plot with 1,000 lbs/acre (1,121 kg/ha) Biosol and 37.5 lbs/acre (42 kg/ha) seed had 4% cover by mountain brome. The two plots with no Biosol had 1-2% mountain brome cover (Figure 20). Mountain brome may thrive in the higher nutrient conditions created by the Biosol use. The combination of Biosol with a high seed rate resulted in higher cover by this species.

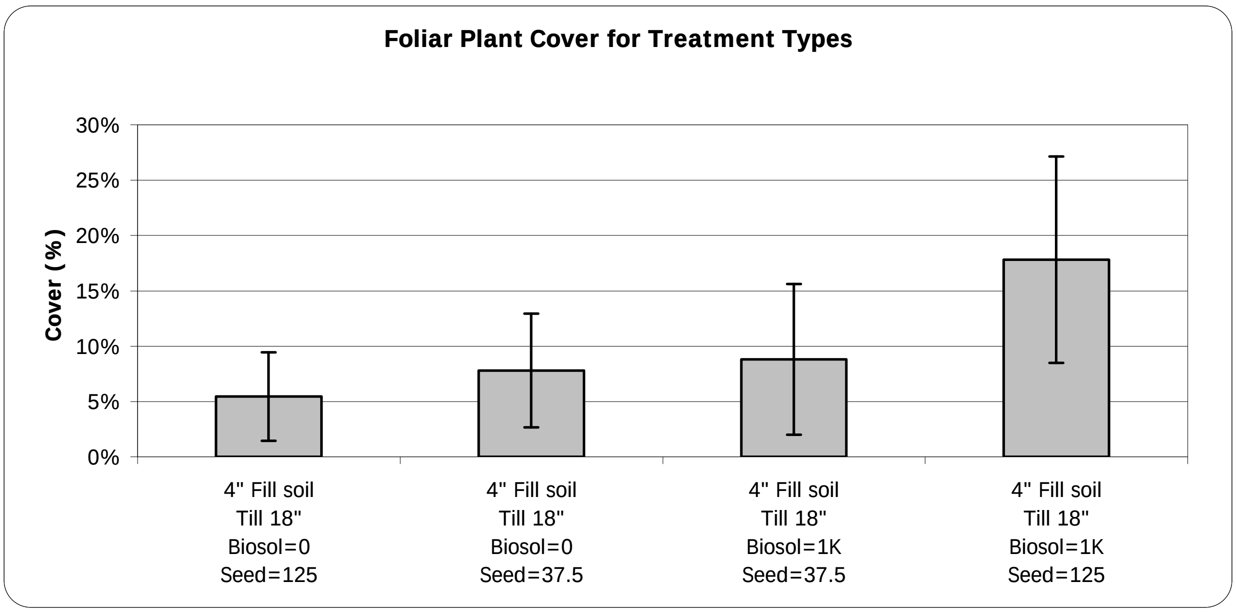


Figure 19. Foliar Cover for Treatment Types. Plant cover was highest at the full treatment plots with 1,000 lbs/acre (1,121 kg/ha) Biosol (1,121 kg/ha) and 125 lbs/acre (140 kg/ha) seed (18%) compared to all other treatments (ranged from 5 to 9%). The error bars represent one standard deviation above and below the mean. Data is sorted by increasing foliar plant cover for 2008.

Effect of Seed Rate on Plant Cover

There was no significant difference in foliar cover among plots with differing seed rates and 1,000 lbs/acre of Biosol (1,121 kg/ha; Table 3). However, foliar cover was 2 times higher at plots that received 1,000 lbs/acre (1,121 kg/ha) Biosol and was seeded at 125 lbs/acre (140 kg/ha; 18%), compared to the plots with the same Biosol rate and seed rate of 37.5 lbs/acre

(42 kg/ha; 9%; Figure 19). This suggests that it is beneficial to combine high seed and Biosol rates in treatments.

There was no significant difference in foliar cover among plots with differing seed rates and no Biosol (Table 3). Foliar plant cover was 8% at the plots seeded at a rate of 37.5 lbs/acre (42 kg/ha), compared to 5% at the plots seeded with 125 lbs/acre (140 kg/ha; Figure 19). Foliar cover may not be related to the rate of seeding when lower nutrient conditions are created as a result of the lack of Biosol.

Effect of Seed Rate on Plant Composition

Foliar plant cover of seeded perennial grasses (mountain brome, squirreltail and blue wildrye) were similar when comparing seed mix rates of 37.5 and 125 lbs/acre (42 kg/ha and 140 kg/ha) in plots that received 1,000 lbs/acre (1,121 kg/ha) Biosol. Plots with 125 lbs/acre (140 kg/ha) seed had 10% cover by the three seeded grass species, compared to plots with the 37.5 lbs/acre (42 kg/ha) seed rate which had 7% cover by the three seeded grass species (Figure 20).

At plots that were seeded at a rate of 125 lbs/acre (140 kg/ha), foliar plant cover of seeded perennial grasses (mountain brome, squirreltail, and blue wildrye) was 4.5 times higher at the plots with 1,000 lbs/acre (1,121 kg/ha) Biosol (10%) than those with no Biosol (2%; Figure 20). The highest tested Biosol and seed rates produced the highest cover by seeded species, suggesting that native species may thrive under higher nutrient and seed rates conditions.

Combined Effect of Seed and Biosol Rates on Seeded Plant Cover

There was no significant difference in seeded cover for plots regardless of seed or Biosol rate (Table 3). However, seeded plant cover was highest at the plots with Biosol rate of 1,000 lbs/acre (1,121 kg/ha) and seed rate of 125 lbs/acre (140 kg/ha) (12%), compared to all other plots, which had cover that ranged from 4 to 7% (Figure 21). This indicates that the combination of the higher seed and Biosol rate may produce higher cover than either used alone or at lower rates.

Although squirreltail and blue wildrye species combined composed over 50% of the seed mix, cover by these species was between 1-3% at all the plots, regardless of seed or Biosol rate (Figure 20 and Table 2).

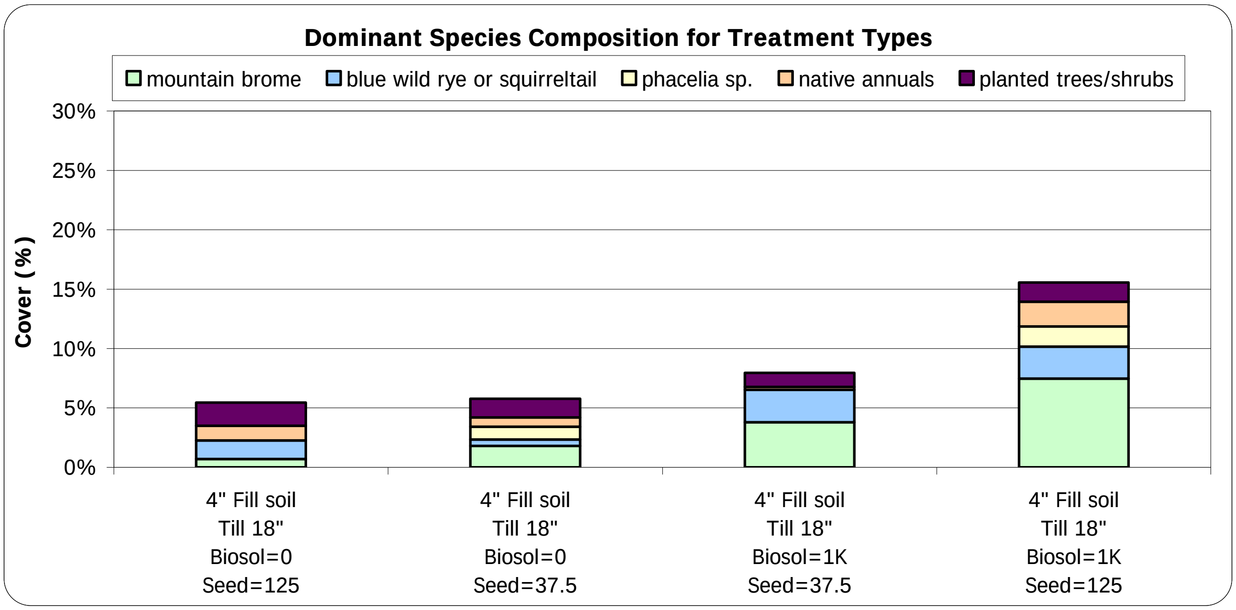


Figure 20. Dominant Species Composition for Treatment Types. Mountain brome was the dominant species at all the plots except at the partial treatment plots with no Biosol and 125 lbs/acre (140 kg/ha) seed. Data is sorted by increasing cover by mountain brome in 2008.

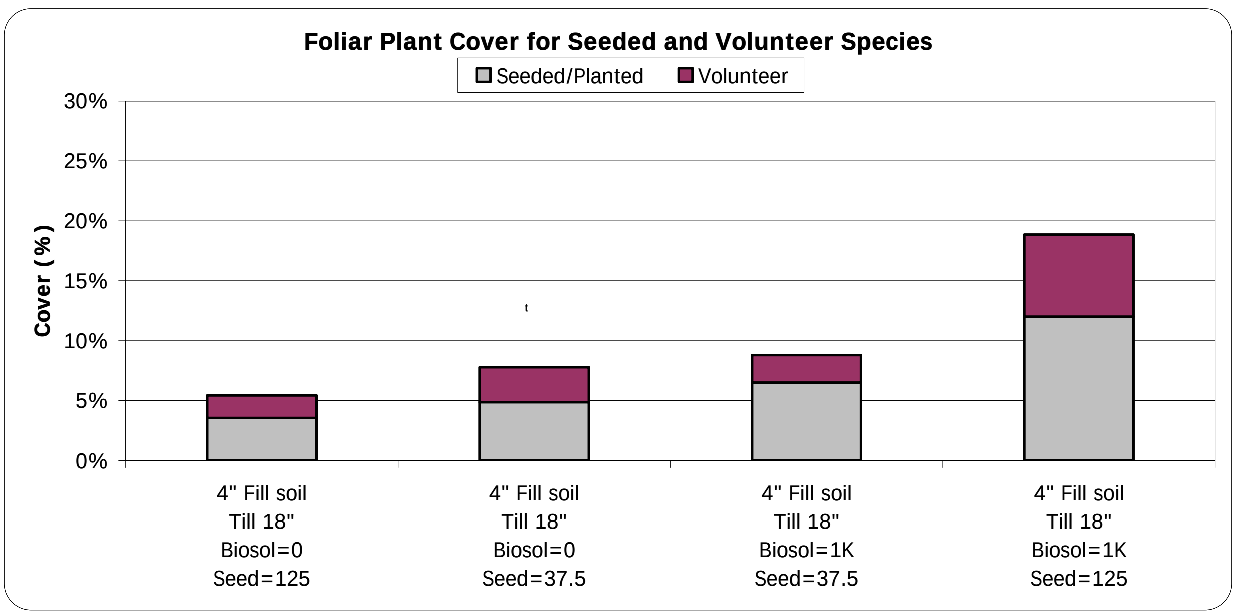


Figure 21. Foliar Plant Cover for Seeded and Volunteer Species. Seeded plant cover was highest at the full treatment plots with 1,000 lbs/acre (1,121 kg/ha) Biosol and 125 lbs/acre (140 kg/ha) seed (12%), compared to all other plots, which had seeded cover that ranged from 4 to 7%. Data is sorted by increasing seeded cover for 2008.

Soil Nutrients

Total Kjeldahl Nitrogen (TKN)

TKN was 1.3 times higher in plots with 1,000 lbs/acre (1,121 kg/ha) Biosol (1,066 ppm) compared to the plots with no Biosol (839 ppm; Figure 22). TKN was 1.8 times higher at the native site (1,944 ppm) compared to the 1,000 lbs/acre (1,121 kg/ha) Biosol plots (1,066 ppm). TKN was 2.3 times higher at the native site (1,944 ppm) compared to the no Biosol plots (839 ppm; Figure 22). Incorporation of organic amendments, such as a compost mix, coarse overs, or tub grindings would be necessary to increase TKN to native reference levels. The nutrients in the fill soil were not sufficient to re-capitalize the soil to native reference levels.

Organic Matter

Organic matter was 1.3 times higher in plots with 1,000 lbs/acre (1,121 kg/ha) Biosol (4.2%) compared to the plots with no Biosol (3.3%; Figure 22). Organic matter was 3.4 times higher at the native site (14.4%) compared to the 1,000 lbs/acre (1,121 kg/ha) Biosol plots (4.2%). Organic matter was 4.4 times higher at the native site (14.4%) compared to the no Biosol plots (3.3%; Figure 22). Incorporation of organic amendments, such as a compost mix, coarse overs, or tub grindings would be necessary to increase organic matter to native levels. The nutrients in the fill soil were not sufficient to re-capitalize the soil to native reference levels.

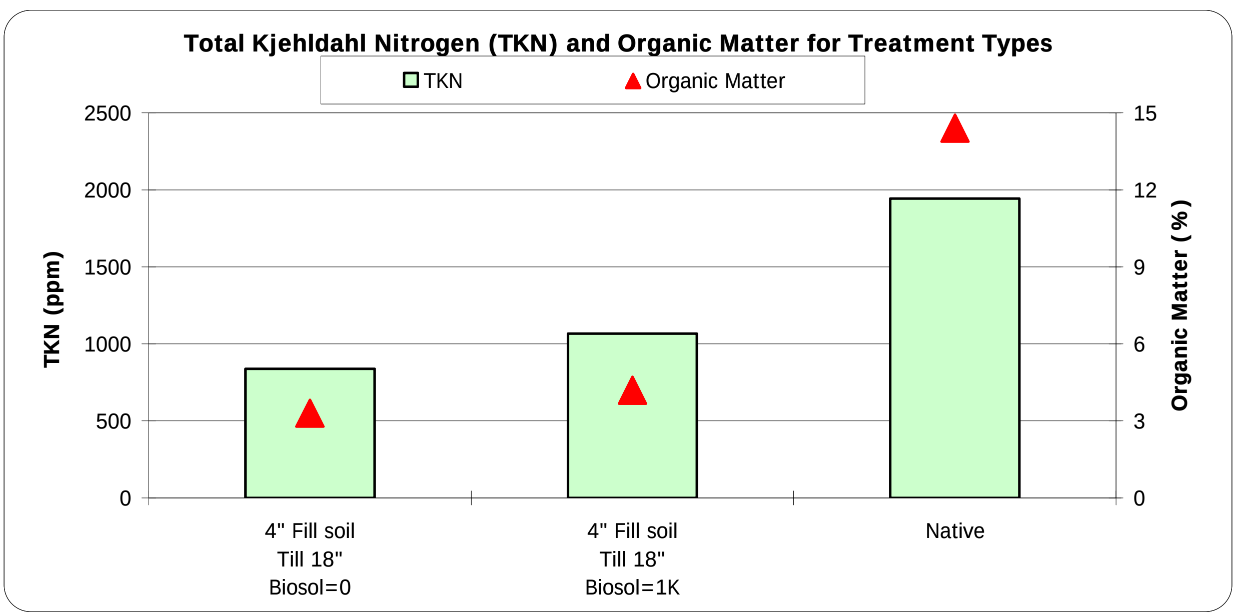


Figure 22. Total Kjehldahl Nitrogen and Organic Matter for Treatment Types. The test plots had lower TKN (range from 839 to 1,066 ppm) and organic matter levels (3.3 to 4.2%) than the native site (1,944 ppm TKN and 14.4% organic matter). Data is sorted by increasing TKN for 2008.

Statistical Results

Statistical results are presented in the order in which they appear in the Results and Discussion section.

Table 3. Statistical Results. A probability of less than 0.1 is considered significant.

Statistical Test	Factors	Variable	Year	Result	Test Statistics	Probability
Mann-Whitney	Biosol Rate: 0 and 1,000 lbs/acre	Plant Cover for plots with 125 seed rate	2008	No difference in plant cover	U(3.3)=8.00	0.200
Mann-Whitney	Biosol Rate: 0 and 1,000 lbs/acre	Plant Cover for plots with 37.5 seed rate	2008	No difference in plant cover	U(3.3)=6.00	0.700
Mann-Whitney	Seed Rate: 37.5 lbs/acre and 125 lbs/acre	Plant Cover for plots with 1,000 Biosol	2008	No difference in plant cover	U(3.3)=7.00	0.400
Mann-Whitney	Seed Rate: 37.5 lbs/acre and 125 lbs/acre	Plant Cover for plots with no Biosol	2008	No difference in plant cover	U(3.3)=6.00	0.700
Mann-Whitney	Seed Rate: 37.5 lbs/acre and 125 lbs/acre	Seeded Plant Cover for plots with 1,000 Biosol	2008	No difference in seeded plant cover	U(3.3)=6.00	0.700
Mann-Whitney	Seed Rate: 37.5 lbs/acre and 125 lbs/acre	Seeded Plant Cover for plots with no Biosol	2008	No difference in seeded plant cover	U(3.3)=5.00	1.000
Mann-Whitney	Biosol Rate: 0 and 1,000 lbs/acre	Seeded Plant Cover for plots with 37.5 seed rate	2008	No difference in seeded plant cover	U(3.3)=6.00	0.700
Mann-Whitney	Biosol Rate: 0 and 1,000 lbs/acre	Seeded Plant Cover for plots with 125 seed rate	2008	No difference in seeded plant cover	U(3.3)=6.00	0.700

Recommendations

These recommendations are for sites with rocky soils on volcanic parent material, with slope angles between 20 and 25 degrees, solar exposures of 78 to 92% during the summer months, at 6,759 feet (2,060 m) AMSL.

Tilling: 18 inches (46 cm)

Amendment: 4 inches (10 cm) topsoil

Biosol: 1,000 lbs/acre (1,121 kg/ha)

Seed: 125 lbs/acre (140 kg/ha) seed with the following composition:

squirreltail and/or blue wildrye: 50%
mountain brome: 40%
native forbs and shrubs: 10%

Mulch: 2 inches (5 cm) of pine needles with 99% cover

Soil Loosening

Soil loosening is recommended to a depth of 18 inches (46) in conjunction with 4 inches (10 cm) of topsoil for the following reason:

- The soil remained loose and penetrometer DTRs ranged from 10.9 to 11.4 inches (28 to 29 cm) one year following treatment

Amendment Type and Rate

Four inches (10 cm) of topsoil, sourced from Northstar, are recommended, with a tilling depth of 18 inches (46 cm). The nutrient composition of the amendment is unknown, so it is difficult to recommend topsoil from a different source. Amendments should always be tested before application to determine whether the nutrient content is sufficient to re-capitalize the soil.

Biosol Rate

Biosol is recommended at 1,000 lbs/acre (1,121 kg/ha) rather than no Biosol. Plots with Biosol exhibited:

- a trend of higher foliar and seeded cover than plots without (Figure 19)
- plant cover that was on average 2.0 to 3.3 times higher at the plots with Biosol rate of 1,000 lbs/acre (1,121 kg/ha) and seed rate of 125 lbs/acre (140 kg/ha; 18%), compared to all other plots, which had cover that ranged from 5 to 9% (Figure 19)
- seeded plant cover was from 1.7 to 3.0 times higher at the plots with the Biosol rate of 1,000 lbs/acre (1,121 kg/ha) and seed rate of 125 lbs/acre (140 kg/ha; 12%), compared to all other plots, which had cover that ranged from 4 to 7% (Figure 21)
- 8% mountain brome cover at the plot with 1,000 lbs/acre (1,121 kg/ha) Biosol and 125 lbs/acre (140 kg/ha) seed and 4% mountain brome cover at the plot with 1,000 lbs/acre (1,121 kg/ha) Biosol and 37.5 lbs/acre (42 kg/ha) compared to 1-2% mountain brome cover at the plots without Biosol (Figure 20)

Seed Mix and Rate

A native grass, forb, and shrub seed mix is recommended at a rate 125 lbs/acre (140 kg/ha), rather than at 37.5 lbs/acre (42 kg/ha). Suggested species composition is:

squirreltail: 50%
mountain brome: 40%
native forbs and shrubs: 10%

For the following reasons:

- foliar cover was 2 times higher at plots that received 1,000 lbs/acre (1,121 kg/ha) Biosol and was seeded at 125 lbs/acre (140 kg/ha) (18%), compared to the plots with the same Biosol rate and seed rate of 37.5 lbs/acre (42 kg/ha; 9%)

Mulch Type and Depth

Mulch composed of native pine needles should be applied at a depth of 2 inches (5 cm) and a ground cover of at least 99% for the following reasons. Plots with this application exhibited:

- mulch cover ranged from 83 to 91% one year following treatment
- cover by bare soil ranged from 3 to 4% one year following treatment

Irrigation

Use of low flow irrigation with water conserving heads (for example: MP rotator heads) at 4 gal/min (15 L/min), is recommended with the following schedule:

Initial: A deep watering cycle, then two to three hour cycles to keep moisture levels high to encourage seed germination.

After germination: three times a week for two weeks to encourage plant roots to penetrate deeper into the soil, where moisture levels are high.

After vegetation reaches 2-3 inches (5-8 cm) in height: once a week or as needed to maintain moisture at depth of 8 inches (20 cm).

Late fall: schedule reduced to less than once a week to encourage dormancy in preparation for winter.

This irrigation equipment and schedule is recommended for the following reasons:

- Increased plant growth was visually observed after irrigation was employed in 2008
- First-year plant growth ranged from 5 to 18%
- Visual signs of erosion were not present that are commonly observed after irrigation with higher flow systems (rills)

Appendix A

Species list and ocular estimates (in percent) for Northstar Highlands View Road test plots, 2008.

Lifeform	Family	Scientific name	Common name	Annual/ Perennial	Native/ Alien	Noxious	Planted	% In seed mix?	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10	Plot 11	Plot 12
Forb	Asteraceae	*Achillea millefolium*	yarrow	Perennial	Native											T				
Forb	Brassicaceae	*Arabis sp.*	rockcress	Perennial	Native						T		T		T	T		T		
Forb	Chenopodiaceae	*Chenopodium album*	goosefoot	Annual	Alien								T		T	T			T	
Forb	Asteraceae	*Cirsium vulgare*	bull thistle	Annual	Alien	Invasive										T		T		T
Forb	Scrophulariaceae	*Collinsia parviflora*	blue-eyed mary	Annual	Native															T
Forb	Polemoniaceae	*Collomia linearis*	narrow-leaved collomia	Annual	Native								T				T		T	T
Forb	Boraginaceae	*Cryptantha ambigua*	Wilke's cryptantha	Annual	Native				T		T	T	1	T	T	T	T	1-2	T	T
Forb	Polygonaceae	*Eriogonum nudum*	nude buckwheat	Perennial	Native						T		T			T		T		T
Forb	Polygonaceae	*Eriogonum umbellatum*	sulphur flower buckwheat	Perennial	Native			4%	T	T	T	T	T	T	T		T	T	T	T
Forb	Rubiaceae	*Galium aparine*	bedstraw	Annual	Native						T				T		T			
Forb	Onagraceae	*Gayophytum sp*	groundsmoke	Annual	Native				T		T		T	T	T	T	T	T	T	T
Forb	Brassicaceae	*Lepidium campestre*	English pepperweed	Annual	Alien						T				T		T			T
Forb	Polemoniaceae	*Leptosiphon ciliatus*	whiskerbrush	Annual	Native							T			T					
Forb	Asteraceae	*Leucanthemum vulgare*	ox-eye daisy	Perennial	Alien	Invasive			T		T		T		T	T				
Forb	Fabaceae	*Lotus purshianus var. purshianus*	Spanish lotus	Perennial	Native				T					T				T		
Forb	Asteraceae	*Madia glomerata*	mountain tarweed	Annual	Native										T			T		
Forb	Fabaceae	*Medicago lupulina*	black medick	Annual	Alien													T		
Forb	Fabaceae	*Melilotus sp.*	sweet clover	Annual	Alien								T			T		T		
Forb	Hydrophyllaceae	*Nemophila sp*	nemophila	Annual	Native												T		T	
Forb	Hydrophyllaceae	*Phacelia ramosissima*	branching phacelia	Perennial	Native						T									
Forb	Hydrophyllaceae	*Phacelia sp.*	phacelia	Perennial	Native				1		T		2	T	3	T	T	T	T	2
Forb	Polemoniaceae	*Phlox gracilis*	slender phlox	Annual	Native				T											
Forb	Polygonaceae	*Polygonum sp.*	knotweed	Annual	Native				T		T	T			T		T	T		T
Forb	Asteraceae	*Tragopogon dubius*	false salsify	Annual	Alien															T
Forb	Fabaceae	*Trifolium repens*	white clover	Perennial	Alien					T										
Graminoid	Poaceae	*Bromus carinatus*	mountain brome	Perennial	Native			34%	17	T	8	T	15	1-2	5	2	3	5	2	3
Graminoid	Poaceae	*Bromus tectorum*	cheatgrass	Annual	Alien				T		T		T				T			T
Graminoid	Poaceae	*Elymus elymoides*	squirreltail	Perennial	Native			26%												
Graminoid	Poaceae	*Elymus glaucus*	blue wildrye	Perennial	Native			26%							T					
Graminoid	Poaceae	*Elymus sp*	squirreltail or blue wildrye	Perennial	Native				T		2	T	T	T		1	2	2		T
Shrub	Rosaceae	*Amelanchier alnifolia*	service berry	Perennial	Native		X										T	T	T	T
Shrub	Rhamnaceae	*Ceanothus velutinus*	tobacco brush or snow brush	Perennial	Native		X												T	T
Shrub	Caprifoliaceae	*Lonicera conjugialis*	double honeysuckle or twin berry	Perennial	Native		X				T	T		2						
Shrub	Rosaceae	*Purshia tridentata*	antelope bitterbrush	Perennial	Native			8%	T	T	T	T	T	T	T	T	T	T	T	T

Lifeform	Family	Scientific name	Common name	Annual/ Perennial	Native/ Alien	Noxious	Planted	% In seed mix?	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10	Plot 11	Plot 12
Shrub	Grossulariaceae	*Ribes cereum*	wax currant	Perennial	Native		X				T		T				T	T	T	T
Shrub	Rosaceae	*Rosa woodsii*	Woods' rose	Perennial	Native		X		1	1	1	1	T		1	1	T	2	1-2	
Shrub	Salicaceae	*Salix sp*	willow	Perennial	Native		X				T						T			
Shrub	Rosaceae	*Spiraea densiflora*	mountain spiraea	Perennial	Native		X			T			T		1	1				
Shrub	Caprifoliaceae	*Symphoricarpos albus*	common snowberry	Perennial	Native		X						T	1					1	1
Shrub	Caprifoliaceae	*Symphoricarpos mollis*	trailing snowberry	Perennial	Native														T	
Shrub	Caprifoliaceae	*Symphoricarpos rotundifolius*	roundleaf snowberry	Perennial	Native		X										1			
Shrub/Tree	Betulaceae	*Alnus incana ssp. tenuifolia*	creek alder	Perennial	Native		X			T			T		T			T		
TOTAL PERCENT COVER (transects)									21	1	10	2	23	3	11	5	9	12	5	15
TOTAL PERCENT COVER (ocular estimate)									21	2	14	3	21	6	13	8	9	14	7	9

Northstar Unit 7 Site Report

May 2009

Introduction

Monitoring results and erosion control treatment recommendations for three tests areas at the Northstar-at-Tahoe Resort (Northstar) will be presented in this report. Northstar is located in Placer County, California, on State Route (SR) 267 between Truckee and King's Beach (Figure 1). Data for three different treatments was collected in three locations: the Overlook East and hydroseed plots at the Unit 7 area, and the SR 267 cut slope near the entrance to Northstar (Figure 2). Monitoring was conducted over a six-year period from 2002 to 2008 at these areas. One additional area at Unit 7, with the same treatment as Overlook East, Overlook West, was not monitored in 2008, but historical data will be presented with the 2008 data. The Unit 7 area is located northwest of the Village at Northstar in the Big Springs residential area, on the southwest corner of the intersection of Big Springs Drive and Overlook Place. These plots are representative of Caltrans roadside conditions in the Lake Tahoe area; therefore, the monitoring results from these plots will be applicable Basin and Sierra-wide.

Figure 1. Satellite Map of the Northstar Unit 7 project area location. The project area is just north of Lake Tahoe, in California.

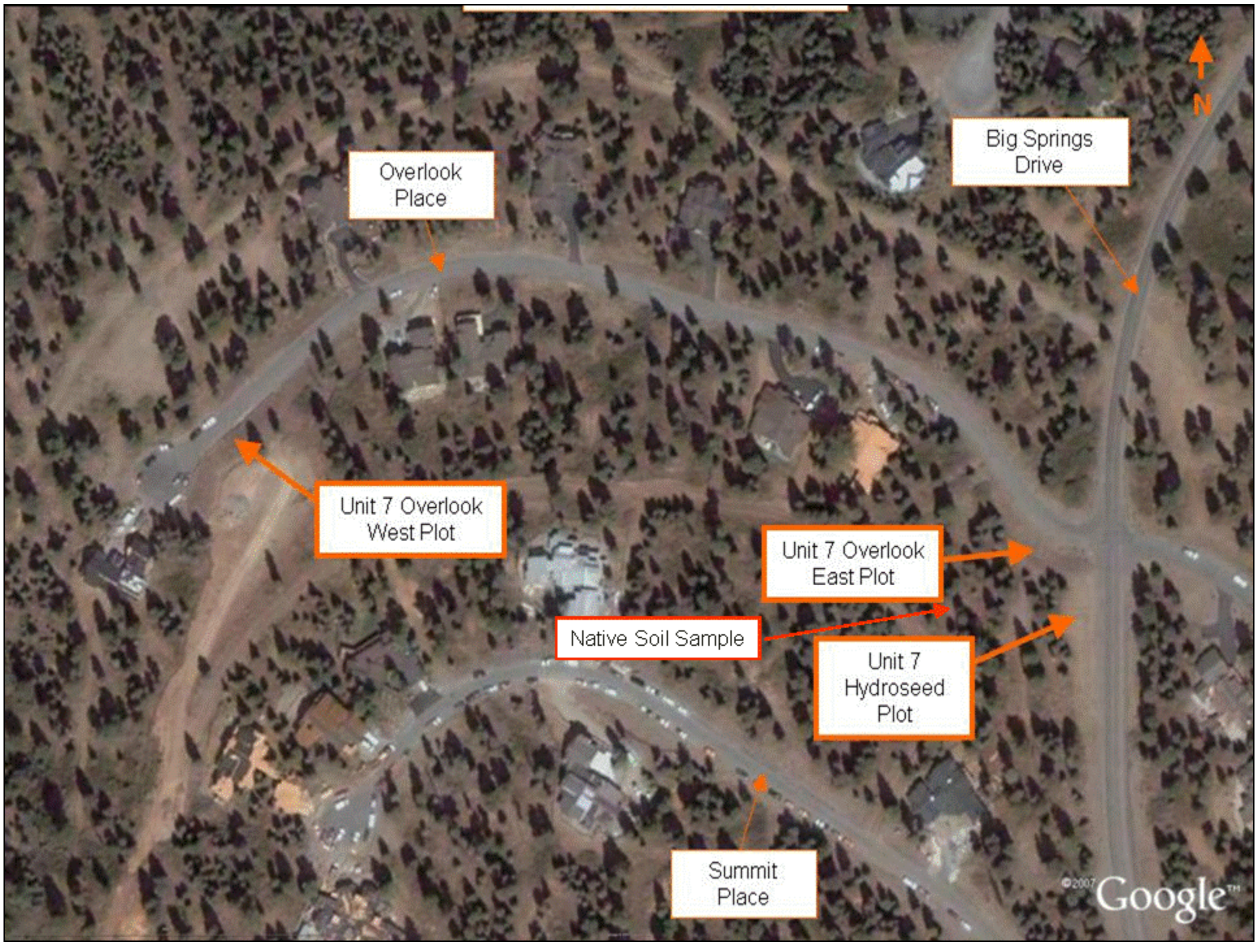


Figure 2. Satellite showing the location of the Overlook East, Overlook West, and hydroseed plots at Northstar Unit 7. The reference soil sample was collected in the forested area above the Overlook East and hydroseed plots. The SR 267 cut slope plot is not located on this map.

Purpose

The project's monitoring objectives are outlined below. The following treatment definitions are included to aid understanding of these objectives.

Full Treatment: includes soil loosening by tilling, incorporation of an organic amendment such as topsoil or woodchips, addition of fertilizer and native seed, and application of native mulch.

Surface Treatment: does not include the incorporation of organic matter into the soil. This treatment may include surface fertilizing, seeding, or hydromulching and is similar to Caltrans Erosion Control Type D (EC Type D).

The monitoring data was studied and analyzed to investigate:

1. the erosion control differences between full treatment and surface treatment plots
2. the erosion control difference between plots with different amendment types

Site Description

Overlook East and West Plots

The Overlook East and Overlook West plots are positioned on a north-facing cut slope in a residential neighborhood in Truckee, California. The site elevation is approximately 6,599 ft (2,011 m) above mean sea level (AMSL). The slope ranges from 25 to 30 degrees. The soil originated from volcanic parent material and is classified as a sandy loam with approximately 60% sand, 20% silt, and 20% clay. The soil at both plots is rocky and contains up to 45% coarse fragments at Overlook East and 25% course fragments at Overlook West. There is very little canopy cover and the solar exposure averages between 73-78% during the summer. Surrounding vegetation consists of an overstory of white fir (*Abies concolor*) and Jeffrey pine (*Pinus jeffreyi*) with an understory of greenleaf manzanita (*Arctostaphylos patula*), antelope bitterbrush (*Purshia tridentata*), tobacco brush (*Ceanothus velutinus*), and bitter cherry (*Prunus emarginata*). This area was initially disturbed in 2001 during construction of the Overlook Place road. Subsequent restoration of the disturbed area occurred later in 2001 and the monitoring plots were established in 2002. In 2007 a stairway was built in the middle of the Overlook West plot. Construction of the stairway disturbed the plot significantly, rendering it unsuitable for monitoring.

Hydroseed Plot

The hydroseed plot is located on a northeast facing slope, at the same elevation as the Overlook plots, with slope angle of 24 degrees. The soil originated from volcanic parent material and is classified as a sandy loam with approximately 68% sand, 22% silt, and 19% clay. The soil is rocky and contains up to 30% coarse fragments. The solar exposure averages between 73-78% during the summer and there is very little canopy cover. Surrounding vegetation is the same as at the Overlook plots and consists of an overstory of white fir (*Abies concolor*) and Jeffrey pine (*Pinus jeffreyi*) with an understory of greenleaf manzanita (*Arctostaphylos patula*), antelope bitterbrush (*Purshia tridentata*), tobacco brush (*Ceanothus velutinus*), and bitter cherry (*Prunus emarginata*). The hydroseed treatment was applied in 1999 after disturbance during road construction. The monitoring plot was established in 2002.

SR 267 Cut Slope

The SR 267 cut slope plot was added in 2008 to replace the Overlook West plot. The treatment is similar and will be used to compare full treatment to surface treatment. The monitoring plot at the SR 267 cut slope is positioned on a southeast-facing, 26 degree cut slope. The soil originated from volcanic parent material and contains about 50% coarse fragments. There is no canopy cover and is at an elevation of 6,225 feet (1,897 m) AMSL. The solar exposure at the cut slope is similar to the other plots, averaging between 73 to 78%. Surrounding vegetation consists of an overstory of Jeffrey pine (*Pinus jeffreyi*) and an understory of antelope bitterbrush (*Purshia tridentata*). The SR 267 cut slope was restored in 2005 after disturbance resulting from the widening of the road for the installation of the traffic light at the corner of SR 267 and Northstar Drive. Slope failures occurred during the winter of 2005-6 and were repaired during the following construction season. The monitoring plot was established in 2008.

Native Reference Plot

The native reference plot is located in a flat, undisturbed area above the Overlook East and hydroseed test plots on the corner of Big Springs Drive and Overlook Place. The soil parent material is volcanic in origin with up to 65% coarse fragments. This plot was used for a native reference soil sample only.

Treatment Overview

Of the 4 plots, there are 3 plots (Overlook East, Overlook West, and the SR 267 cut slope) that received different variations of full treatment (Figure 3 and Figure 4), while one plot received a surface treatment. These treatments are presented in Table 1 and explained in detail below. Photos of the Overlook, SR 267 cut slope, and hydroseed plots before and after treatment are shown in Figure 5, Figure 6, Figure 7, Figure 8, Figure 9, Figure 10, Figure 11 and Figure 12.

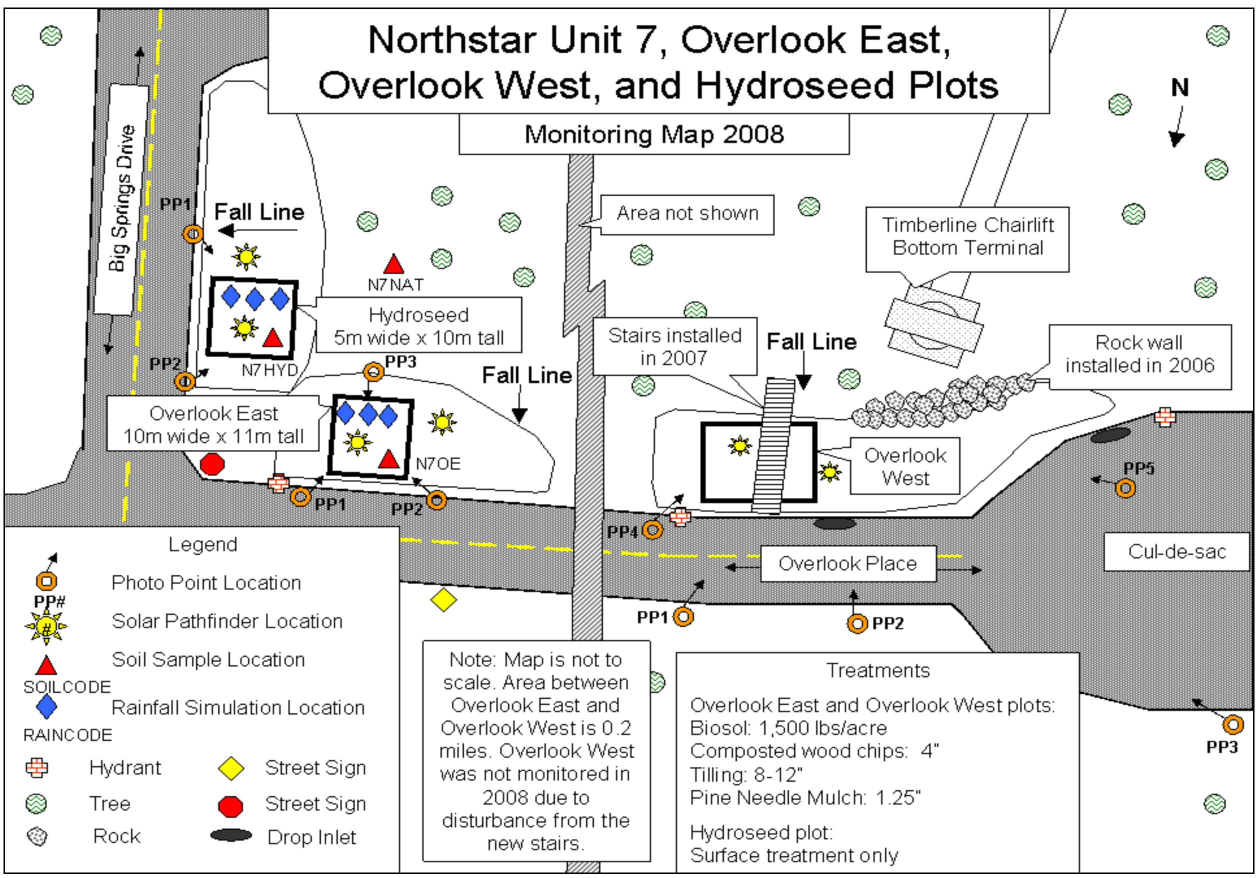


Figure 3. Monitoring and treatment map of Northstar Unit 7 plots with treatment key. Rainfall simulation, photo points, soil sample, and Solar Pathfinder locations are marked. Some of the treatment abbreviations used on this map will be used throughout the report. The native reference plot is located between the hydroseed and Overlook East plots. The SR 267 cut slope plot is not included on this map.

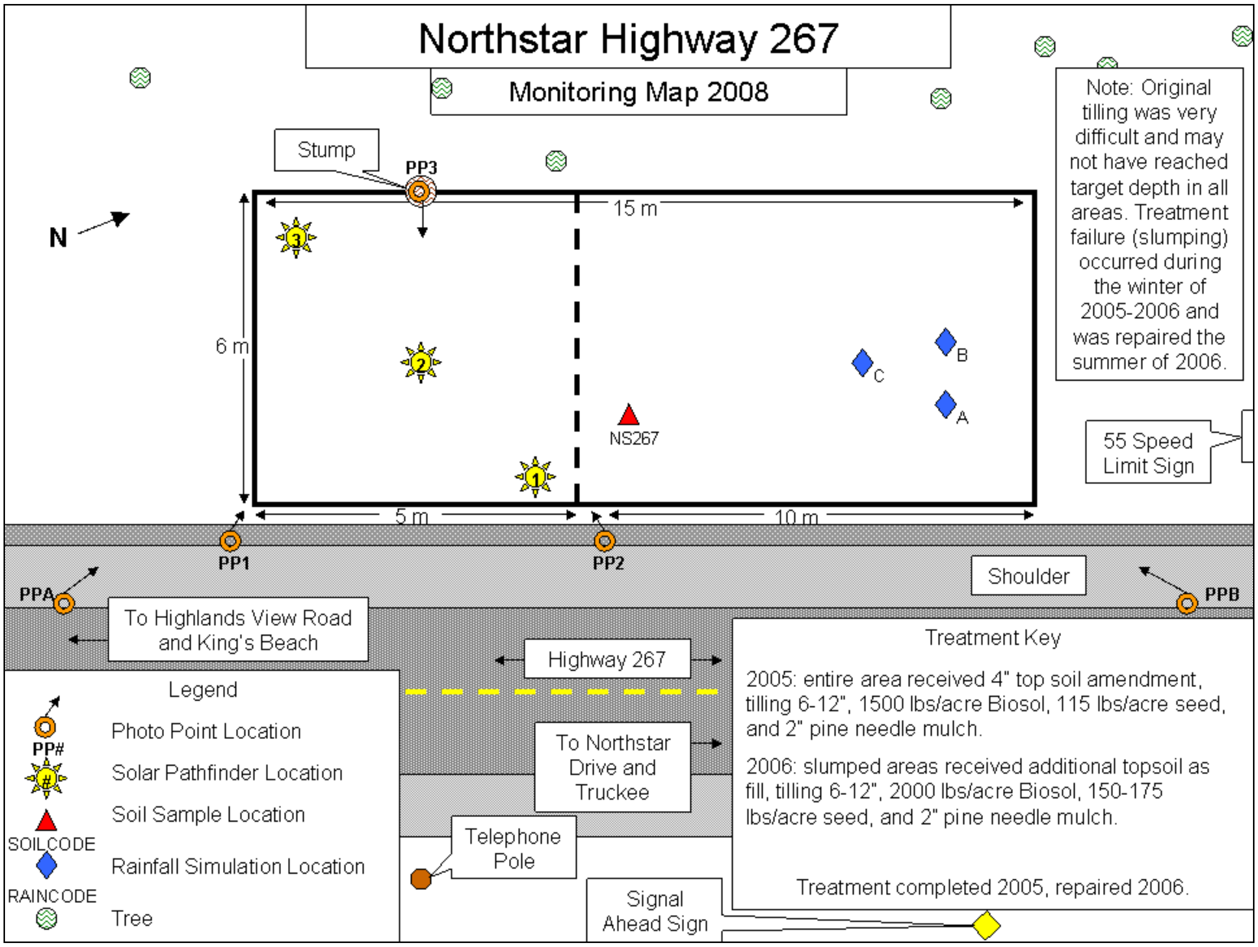


Figure 4. Monitoring and treatment map of SR 267 cut slope plot. Rainfall simulation, photo points, soil sample, and Solar Pathfinder locations are marked. Some of the treatment abbreviations used on this map will be used throughout the report.

Table 1. Unit 7 and SR 267 cut slope treatments.

Plot Name	Amendment	Soil Loosening	Biosol Rate (lbs/acre)	Seed Type	Seed Rate	Mulch
Overlook West	4” Aged wood waste (woodchips)	8-12” Tilled	1,500	Native seed mix	110.5 lbs/acre	Pine needle mulch 1.25” applied with Shred Vac
Overlook East	4” Aged wood waste (woodchips)	8-12” Tilled	1,500	Native seed mix	110.5 lbs/acre	Pine needle mulch 1.25” applied with Shred Vac
SR 267 cut slope (original application)	4” Topsoil	6-12” Tilled	2,000	IERS Upland seed mix	115 lbs/acre	Pine needle mulch 2” applied by hand

Plot Name	Amendment	Soil Loosening	Biosol Rate (lbs/acre)	Seed Type	Seed Rate	Mulch
SR 267 cut slope (repair)	4” Topsoil	6-12” Tilled	2,000	Upland seed mix	150 lbs/acre	Pine needle mulch 2” applied by hand
Hydroseed	Unknown	None	Unknown	Unknown	Unknown	Unknown

Figure 5. Unit 7, Overlook East and West, pre-treatment, 2001.

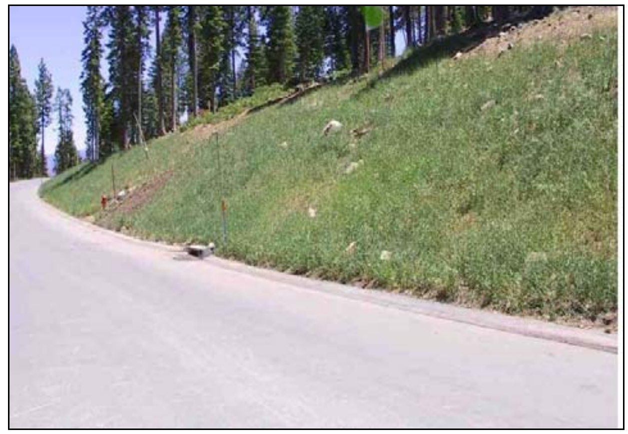


Figure 6. Unit 7 Overlook West, post-treatment.

Figure 7. Overlook West plot, 6 years following treatment, July 2007.

Figure 8. Overlook East plot, 7 years following treatment, August 2008.

Figure 9. SR 267 cut slope, slope failure, December 2005.

Figure 10. SR 267 cut slope, 3 years following treatment, 2 years following repairs, June 2008.

Figure 11. Hydroseed plot, July 2007.

Figure 12. Hydroseed plot, August 2008.

Soil Loosening

Overlook West and East plots were tilled to a depth of approximately 8 to 12 inches (20-30 cm) first using a backhoe with teeth extensions then with a reach forklift. The SR 267 cut slope was tilled in 2005 to 6 to 12 inches (15-30 cm) using an excavator bucket. It was re-tilled in 2006 to the same depth. The hydroseed plot did not receive a soil loosening treatment.

Amendments

Two types of amendments were incorporated at the full treatment test plots (Overlook plots and the SR 267 cut slope): aged woodchips and topsoil. Each is described in detail below.

Aged Woodchips

Aged woodchips were applied at the Overlook plots, although it is unknown for how long they were aged. Further information on the source is unknown as well. The aged woodchips were spread to depth of 4 inches (10 cm) before tilling.

Topsoil

Topsoil was used as an amendment at the SR 267 cut slope in 2005 and again for repairs in 2006. Topsoil was spread to a depth of 4 inches (10 cm) before tilling. The topsoil source and nutrient content is not known.

Fertilizer

Following incorporation of amendments at the full treatment plots (Overlook East, West, and the SR 267 cut slope), Biosol, a slow release fertilizer, was applied and raked approximately 1 inch (2.5 cm) into the soil at a rate of either 1,500 lbs/acre (1,684 kg/ha) or 2,000 lbs/acre (2,241 kg/ha). The Overlook plots received 1,500 lbs/acre (1,684 kg/ha). The SR 267 cut slope plot received 2,000 lbs/acre (2,241 kg/ha) Biosol during the original treatment as well as when it was re-treated in 2006.

Seeding

At the Overlook plots and the SR 267 cut slope plot were seeded with a seed mix of suitable native perennial grasses, forbs, and shrubs. The Overlook plots were seeded at a rate of 110.5 lbs/acre (124 kg/ha). The SR 267 cut slope plot was first seeded at 115 lbs/acre (129 kg/ha)in 2005, then seeded at 150 lbs/acre (168 kg/ha) when it was repaired in 2006 (Figure 3, Figure 4, Table 2, and Table 3). The hydroseed plot was hydroseeded with an unknown seed mix at an unknown rate.

Table 2. Overlook plots seed mix composition for a seed rate of 110.5 lbs/acre.

Common Name	Scientific Name	% Pure Live Seed
Mountain brome (Bromar)	*Bromus carinatus*	31.7%
Blue wildrye	*Elymus glaucus*	31.7%
Squirreltail	*Elymus elymoides*	31.7%
Shrub/forb mix		5.0%
Yarrow	*Achillea millefolium*	0.5%

Table 3. The SR 267 cut slope seed mix composition for a seed rate of 115 lbs/acre.

Common Name	Scientific Name	% Pure Live Seed
Squirreltail	*Elymus elymoides*	34.0%
Blue wildrye	*Elymus glaucus*	25.6%
Mountain brome (Bromar)	*Bromus carinatus*	23.9%
Antelope bitterbrush	*Purshia tridentate*	15.0%
Sulphur flower buckwheat	*Eriogonum umbellatum*	1.8%
Greenleaf manzanita	*Arctostaphylos patula*	1.4%

Common Name	Scientific Name	% Pure Live Seed
Wax currant	*Ribes cereum*	1.1%
Sagebrush, big mountain	*Artemisia tridentata ssp.vasseyana*	0.23%

Mulch

Mulch was spread evenly using a Shred Vac mulch blower to achieve 99% cover at a depth of 1.25 inches (3.2 cm) at the Overlook plots. Tackifier was then applied.

Mulch was spread evenly by hand to achieve 99% cover at a depth of 2 inches (5 cm) at the SR 267 cut slope plot during each treatment. No tackifier was applied at the SR 267 cut slope.

It is unclear whether mulch was applied at the hydroseed plot.

Monitoring Methods

The Overlook East plot was monitored in 2002, 2003, and 2005-8. The Overlook West plot was monitored in 2002, 2003, 2005-7; however, cover point monitoring was not conducted in 2006. The hydroseed plot was monitored in 2003 and 2006-8. The SR 267 cut slope and the native reference plot were monitored in 2008 only. In the text, both English and metric units will be given, however, tables will contain one or the other.

Rainfall Simulation

In 2006 and 2007, rainfall simulation was conducted at the Overlook East, West and the hydroseed plot. In 2008, rainfall simulation was conducted at the Overlook East, hydroseed, and SR 267 cut slope plots (Figure 3).

The rainfall simulator "rains" on a square plot from a height of 3.3 ft (1 m; Figure 13 and Figure 14). The rate of rainfall is controlled, and runoff is collected from a trough at the bottom of a 6.5 ft^2 (0.6 m$^{2)}$ frame that has been pounded into the ground. The volume of water collected is measured and the volume of infiltration is calculated by subtracting the volume of runoff from the total volume of water applied to the plot. If runoff is not observed during the first 30 minutes (in 2006 and 2007) or the first 45 minutes (in 2008), the simulation is halted. The collected runoff samples are then analyzed for the amount of sediment they contain. This measurement is presented as the average steady state sediment yield and is hereafter referred to as "sediment yield". The steady state infiltration rate is calculated and will hereafter be referred to as "infiltration rate".

Before rainfall simulations, in the area of the frames, a cone penetrometer is used to record the depth to refusal (DTR), which is an index for soil density. The 2006 DTR pre-rainfall values were recorded at a maximum pressure of 250 psi (1,724 kPa), while the 2007 and 2008 DTR values were recorded at 350 psi (2,413 kPa). Soil moisture is measured in each frame prior to and following (2008 only) rainfall simulations. After rainfall simulation, at least three holes are dug with a trowel to determine the depth to wetting front, which shows how deeply water infiltrated into the soil. In 2007 and 2008, at least nine holes were dug to measure the depth to wetting front.

Simulation rates were variable over the three sampling years for which rainfall simulation was conducted. At the hydroseed plot, in 2006 and 2007, one rainfall simulation per year was conducted at the rate of 2.8 in/hr (72 mm/hr), and two simulations were conducted at 4.7 in/hr (120 mm/hr). During both years, when runoff was not observed at the lower rate, the higher rate was used to produce runoff and therefore collect sediment data for analysis (Figure 22 and Figure 23).

From 2006 to 2008 rainfall rates of 4.7 in/hr (120 mm/hr) were applied to all plots, so that data could be more easily compared. This rate is in excess of the 20-year, one hour 'design storm' rate of 0.7 to 1.0 in/hr (18-25 mm/hr) for the Truckee-Tahoe area. The design storm rate is used to design most storm water routing plans.

Figure 13. Photo of the rainfall simulator and frame.

Figure 14. Photo of rainfall simulation at Truckee Bypass test plots, June 2006.

Cover

Cover was measured at both Overlook East and West plots in 2002, 2003, 2005, and 2007, and at the hydroseed plot in 2003, 2006, 2007, and 2008. Cover was also measured at Overlook East in 2006 and 2008, but not at Overlook West. Cover was measured in 2008 at the SR 267 cut slope plot.

Cover is measured using the statistically defensible cover point method along randomly located transects.[1] The cover pointer consists of a metal rod with a laser pointer mounted 3.3

[1] Hogan, M. 2003. Luther Pass Monitoring Report: Plant and Soil Cover Monitoring for Evaluating Sediment Source Control Success in the Lake Tahoe Basin. Lahontan Regional Water Quality Control Board, South Lake Tahoe, CA.

feet (1 m) high. After the rod is leveled in all directions, the button on the laser pointer is depressed and two cover measurements are recorded (Figure 15 and Figure 16):

- the first hit cover, which is the first object intercepted starting from a height of 3.3 ft (1 m) above the ground
- the ground cover hit, which is the low-lying vegetation or soil below the first hit cover, at the ground level

The first hit cover measures the foliar cover by plants (leaves and stems). It does not measure the part of the plant rooted in the ground. The first hit vegetation is then moved aside and a ground cover hit measures the presence of litter/mulch, basal (or rooted) plant cover, rock and woody debris, and/or bare ground. Total ground cover represents any cover other than bare ground. Mulch cover is an important variable in erosion reduction through sediment source control because treatments with cover by pine needle mulch have been shown to reduce sediment yields substantially.[2]

Figure 15. Cover pointer in use along transects.

Figure 16. Cover pointer rod with first hit and ground cover hit by the laser pointer. The laser pointer hits are circled in red. The first cover hit is a native grass and the ground cover hit is pine needle mulch.

Foliar and ground level plant cover is recorded by species and then organized into cover groups based on four categories: life form (herbaceous/woody), perennial/annual, native/alien (2007 and 2008), and seeded/volunteer (2007 and 2008). Perennial herbaceous species includes seeded grasses, native grasses and forbs, and any non-native perennial species. Annual herbaceous species include native annuals such as groundsmoke (*Gayophytum* sp.) and invasive species such as cheatgrass (*Bromus tectorum*). Woody species includes any tree or shrub species, either native or introduced. Each species is then classified based on

[2] Grismer, M.E., and M.P. Hogan. 2004. Simulated rainfall evaluation of revegetation/mulch erosion control in the Lake Tahoe Basin: 1. Method assessment. Land Degradation & Development 15:573-588.

whether it is native to the Tahoe area, and whether it was seeded during treatment. Data is presented on the amount of cover by species. An ocular estimate of cover at each plot is also recorded and includes many species not hit using cover point sampling. The species lists, as well as the ocular estimates of cover by species, are presented in Appendix A.

Soil and Site Physical Conditions

Penetrometer Depth to Refusal and Soil Moisture

In 2006, 2007, and 2008, penetrometer depth to refusal (DTR) and soil moisture were measured along the same transects as the cover point data. Penetrometer data was collected at Overlook West in 2005-7, Overlook East in 2005-8, the hydroseed plot in 2003, 2006-8, and at the SR 267 cut slope in 2008.

A cone penetrometer with a ½ inch diameter tip is pushed straight down into the soil until a maximum pressure of 350 pounds per square inch (2,413 kPa) is reached (Figure 17 and Figure 18). Although the rainfall frame maximum pressure was 250 psi in 2006, the maximum pressure for DTRs measured on transects was 350 psi for all years, including 2006. The depth at which that pressure is reached is recorded as the depth to refusal (DTR).

Cone penetrometer DTR measurements are used as an index for soil density. Soils with higher DTRs are generally less dense than those with lower DTRs. A denser soil is less likely to allow infiltration. Rainfall simulations conducted on roadcuts in Oregon found increased infiltration rates in soils with penetrometer depths to refusal (DTRs) greater than 4 inches (10 cm).[3]

It is most informative to compare penetrometer DTR measurements collected in soils that have similar moisture levels. When soil moisture content increases, the resistance of the soil to the penetrometer decreases and DTR readings are deeper. Therefore, only penetrometer readings at the same soil moisture can be compared. A hydrometer was used to measure volumetric soil moisture content adjacent to the penetrometer readings at a depth of 4.7 inches (12 cm; Figure 19). Soil moisture readings were not collected before 2006 in conjunction with penetrometer DTR. Comparisons are made in the results sections; however, is it important to understand that soil moisture values for those time periods are unknown.

[3] Grismer, M.E. 2006. Simulated Rainfall Evaluation at Sunriver and Mt. Bachelor Highways, Oregon. Unpublished.

Figure 17. Photo of a cone penetrometer dial, showing pressure applied in pounds per square inch.

Figure 18. Photo of conducting cone penetrometer readings along transects.

Solar Exposure

In 2006, solar exposure measurements were taken throughout the Overlook plots, as well as at the hydroseed plot. These measurements are taken using a Solar Pathfinder (Figure 20). Since there was no change in solar obstructions at the test plots, the solar pathfinder data was not collected more than one at each plot. In 2008, solar radiation was recorded at the SR 267 cut slope plot. Solar input affects evaporation rates and soil temperature, which may affect time of seed germination, germination rate, rate of plant growth, and soil microbial activity. Therefore, this is an important variable to consider when monitoring plant growth and soil development.

Figure 19. Conducting soil moisture readings along transects.

Figure 20. Solar pathfinder in use.

Soil Nutrient Analysis

Successful re-vegetation requires that nutrient capital be stored in the soil for release over time. Sufficient organic matter and a functioning microbial community are necessary to provide a long-term source of nitrogen for plants. Previous studies of soil nutrient levels at revegetation sites throughout the Tahoe area found that sites with high plant cover had significantly higher soil nutrients over the long term than soils with lower plant cover levels.[4] Total Kjeldahl nitrogen and organic matter were used as indicators of soil health in this study. Total Kjeldahl nitrogen (TKN) is a measure of readily available nitrogen. Only three soil sub-samples were taken from each plot; therefore, differences in TKN and organic matter values may be a result of the variability within a plot.

In 2003, a soil sample was taken from the hydroseed plot. In 2006 and 2007, soil samples were collected the Overlook and hydroseed plots. In 2008, soil samples were taken from the Overlook East, hydroseed, SR 267 cut slope, and the native reference plots. Three soil sub-samples at each plot were collected from the mineral soil beneath any mulch layer to a depth of 12 inches (30 cm; Figure 21). These sub-samples were combined and sieved to remove any material larger than 0.08 inches (2 mm) in diameter, and sent to A&L Laboratories in Modesto, California for the S3C nutrient suite (macro and micronutrients), total Kjeldahl nitrogen (TKN), and organic matter analysis.

Figure 21. Soil sample collection.

Results and Discussion

Rainfall Simulation

Trends by Treatment Level

Rainfall simulation application rates were not consistent among plots and across years. Infiltration rates and sediment yield will only be compared between plots from simulations

[4]Claassen, V.P., and M.P. Hogan. 2002. Soil Nutrients Associated with Revegetation of Disturbed Sites in the Lake Tahoe Basin. Restoration Ecology 10:195-203.

that were conducted at the same rate (4.7 in/hr or 120 mm/hr). In 2006 and 2007, the rainfall simulation at the hydroseed plot was conducted at two different rates: 2.8 and 4.7 in/hr (72 and 120 mm/hr). In 2006, sediment was produced during each simulation (Figure 22), indicating that the runoff threshold was below 2.8 in/hr (72 mm/hr). In 2007, sediment was not produced at the lower rate, but was produced the higher rate (Figure 23). This indicates that the threshold for runoff is variable over time as the threshold was between 2.8 and 4.7 in/hr (72-120 mm/hr) in 2007. Further simulations at various rates would need to be conducted to establish the actual infiltration threshold.

Full treatment plots demonstrated superior rainfall infiltration capacity compared to the surface treatment plot. From 2006 to 2008, percent infiltration at the full treatment plots ranged from 94 to 100%. At the hydroseed surface treatment plot, infiltration ranged from 79 to 91% and was consistently lower than the full treatment plots over the same time (Figure 24). From 2006 to 2008, the average percent infiltration at the Overlook treatment plots was more than 99%, which was 1.2 times higher than the percent infiltration at the hydroseed plot at 85% (Figure 24). The percent infiltration at the SR 267 cut slope was 94%, which was 1.2 times higher than the hydroseed plot in 2008 (79%; Figure 24).

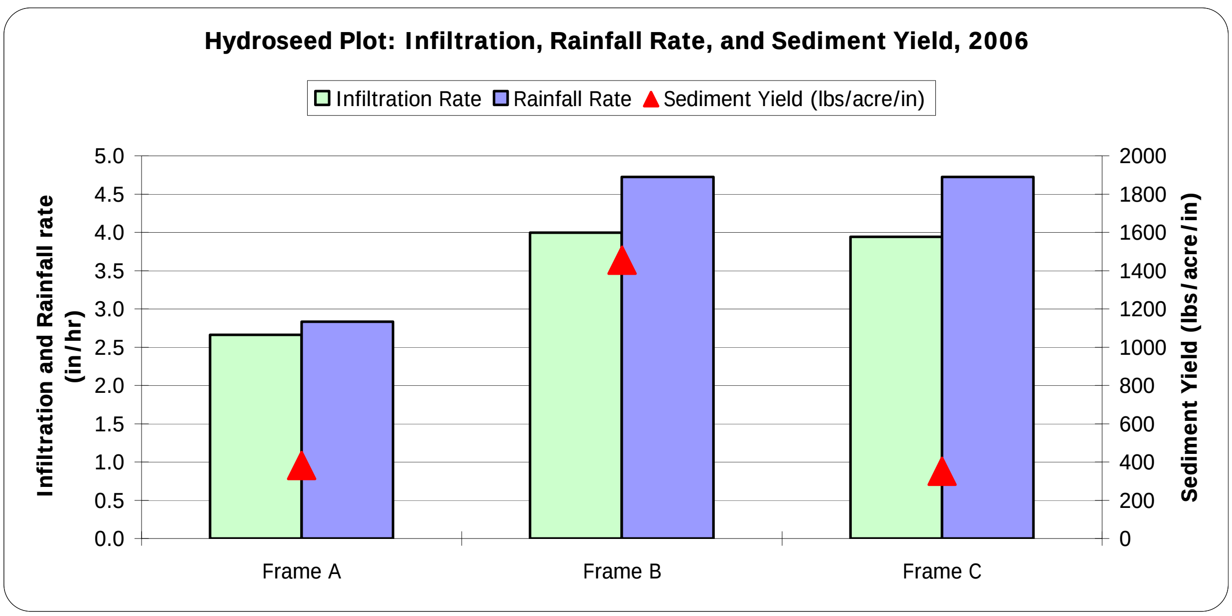


Figure 22. Hydroseed Plot: Infiltration, Rainfall Rate, and Sediment Yield, 2006. Sediment yield was highest at frame B that had a rainfall rate of 4.7 in/hr (120 mm/hr) and produced 1,454 lbs/acre/in (642 kg/ha/cm) of sediment.

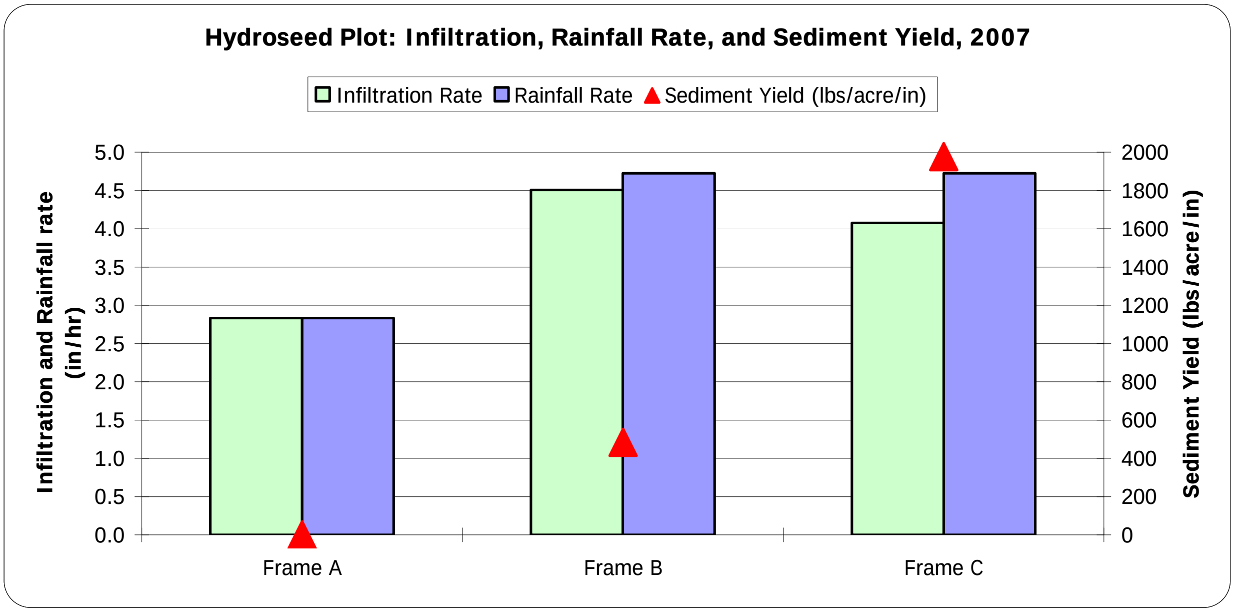


Figure 23. Hydroseed Plot: Infiltration, Rainfall Rate, and Sediment Yield, 2007. The runoff threshold is between 2.8 and 4.7 in/hr (72-120 mm/hr). Sediment yields were highly variable at the hydroseed plot in 2007 (range from 0 to 1,977 lbs/acre/in or 0-872 kg/ha/cm).

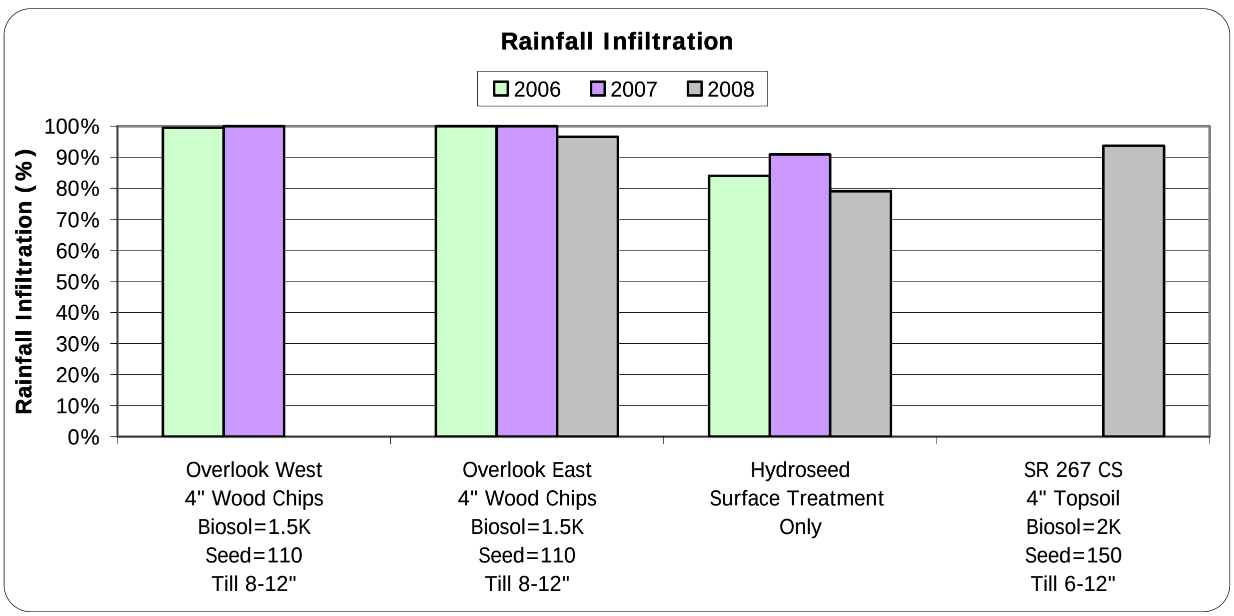


Figure 24. Rainfall Infiltration. From 2006 to 2008, the average percent infiltration at the Overlook treatment plots was greater than 99%, which was 1.2 times higher than the percent infiltration at the hydroseed plot (86%). Rainfall was simulated at the SR 267 cut slope plot in 2008 only. The percent infiltration was 94%, 1.2 times higher than the hydroseed plot in 2008, 79%. Rainfall was not simulated at the Overlook West plot in 2008. All simulations compared in this graph were conducted at the same rainfall rate, 4.7 in/hr (120 mm/hr).

Over three years, the average sediment yield at the hydroseed plot ranged from 903 to 1,866 lbs/acre/in (398-823 kg/ha/cm) when rainfall was simulated at 4.7 in/hr (120 mm/hr). Over the same time, the sediment yield at the full treatment for Overlook East and West plots combined was zero to 11 lbs/acre/in (0-5 kg/ha/cm; Figure 25).

The three-year average sediment yield (1,333 lbs/acre/in or 588 kg/ha/cm) at the hydroseed plot was 609 times higher than the three-year average at the full treatment Overlook plots (4 lbs/acre/in or 2 kg/ha/cm; Figure 25).

The SR 267 cut slope plot exhibited sediment yields that were more similar to those of the Overlook plots than the hydroseed plot. The 2008 sediment yield at the cut slope plot (134 lbs/acre/in or 59 kg/ha/cm) was 14 times higher than the sediment yield at the hydroseed plot (1,866 lbs/acre/in or 823 kg/ha/cm). The cut slope sediment yield was 12 times higher than the highest sediment yield at the Overlook East plot which was 11 lbs/acre/in (5 kg/ha/cm) in 2008 (Figure 25).

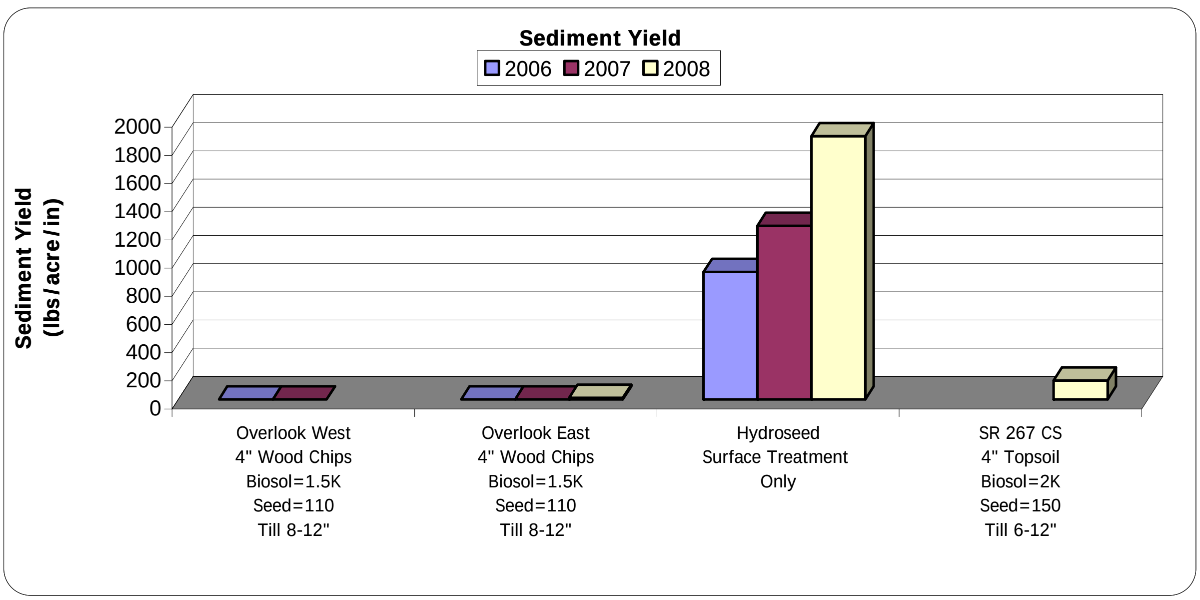


Figure 25. Sediment Yield. From 2006 to 2008, the sediment yield at the Overlook plots was an average of 2.2 lbs/acre/in (1.0 kg/ha/cm). Over the same three years, the sediment yield at the hydroseed plot was 1,333 lbs/acre/in (588 kg/ha/cm), which was 609 times higher than the sediment yield at Overlook plots, and 9.9 times higher than the SR 267 cut slope (134 lbs/acre/in or 59 kg/ha/cm). Rainfall was not simulated at the Overlook West plot in 2008 or the SR 267 cut slope plot in 2006 and 2007. All simulations compared in this graph were conducted at the same rate, 4.7 in/hr (120 mm/hr).

Trends by Year

In 2008, the steady state sediment yield for the hydroseed plot was 1,866 lbs/acre/in (823 kg/ha/cm), which was an increase of 1.8 times from the previous years (two-year average of 1,066 lbs/acre/in or 470 kg/ha/cm). The infiltration rate was variable ranging from 84 to 91% from 2006 to 2008. The hydroseed plot exhibited a trend of increasing sediment yield and inconsistent infiltration.

The three-year average steady state sediment yield for the Overlook plots was 2.2 lbs/acre/in (1.0 kg/ha/cm). This was nearly the same as in previous years, during which no sediment was produced. Although there was a small amount of sediment produced at the Overlook East plot in 2008, the overall trend exhibited at these two plots is low to no sediment yield (Figure 25). Over the same time period, infiltration remained fairly steady, varying between 97 and 100% (Figure 24).

Soil Moisture

From 2006 to 2008, the hydroseed plot exhibited soil moisture that was 2.7 times higher than at the Overlook plots (Figure 26). The average soil moisture at the hydroseed plot was 19%, compared to an average of 7% at the Overlook plots. The difference in soil moisture can be explained by the different soil treatments. The untilled soil at the hydroseed plot consisted of C horizon soil with a very high soil density (Figure 27). High density volcanic soils are able to hold water better than soils with lower densities, but only in the top few inches of the soil. High density soils prevent water from effectively moving down through the soil column, as seen by the low infiltration and high sediment yields observed at the hydroseed plot (Figure 24 and Figure 25). The tilling and organic matter addition at Overlook East and Overlook West positively changed the water-holding capacity and moisture distribution in the soil column. Although there was variation in soil moisture levels among the Overlook and hydroseed plots, penetrometer depths will be compared with the understanding that the DTRs at the hydroseed plot may be deeper at 19% soil moisture than if measured at 7% moisture. The current comparison will give conservative estimates of differences in DTR between the two treatments.

Soil moisture at the SR 267 cut slope was 10%, which was similar to the soil moistures at the Overlook plots. These similar moisture levels allow for comparison of penetrometer depth to refusal (DTR) across all years and treatments among these three plots (Figure 26).

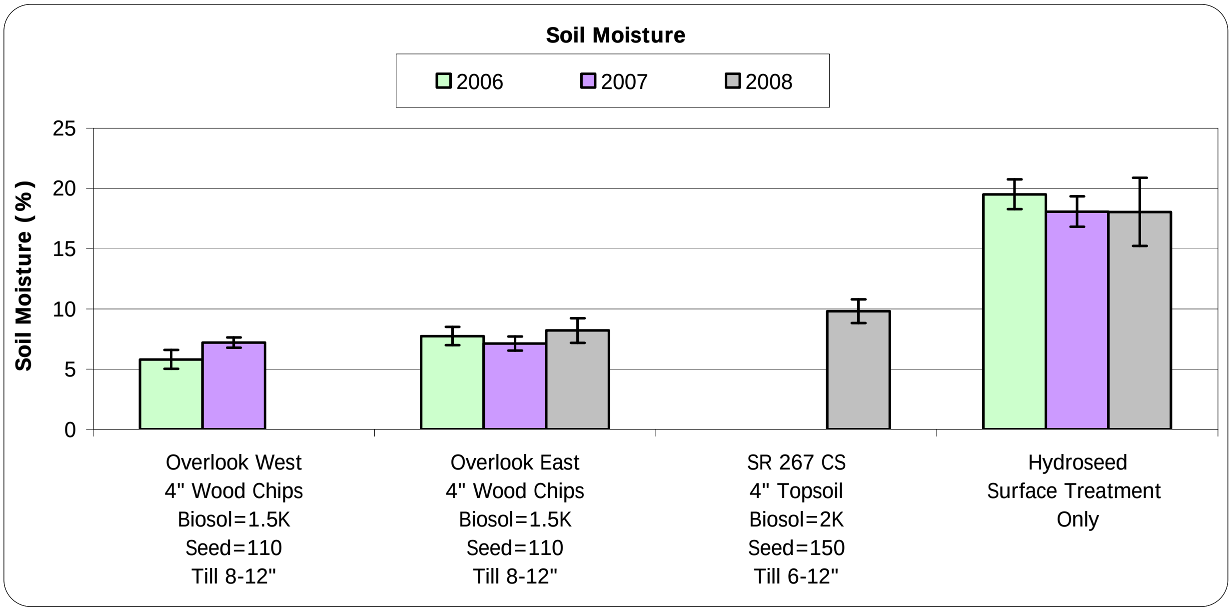


Figure 26. Soil Moisture. The hydroseed plot had the highest soil moisture, as measured in the top 4.7 inches (12 cm) of the soil. The error bars represent one standard deviation above and below the mean. Data is sorted by increasing 2008 soil moisture.

Penetrometer Depth to Refusal

Trends by Treatment Level

The four-year average (2005-2008) DTR for the full treatment Overlook plots (7.3 inches or 19 cm) was deeper by an average of 2.4 times when compared to the hydroseed plot without soil loosening (four-year average of 3.1 inches or 8 cm; Figure 27). In 2008, the DTR at the SR 267 cut slope was 10.8 inches (27 cm). The plots with soil loosening had penetrometer depths that ranged from 6.2 to 10.8 inches (16-27 cm), while the hydroseed plot without soil loosening had depths that ranged from 2.6 to 3.5 inches (7-9 cm; Figure 27). The average DTR varied slightly between Overlook East (7 inches or 18 cm) and for Overlook West (9 inches or 23 cm), which is most likely a result of variability in tilling during installation.

Trends by Year

The average penetrometer depth to refusal for all plots, regardless of whether soil loosening was employed, did not change more than 1 inch (2.5 cm) per plot from 2005 to 2008 (Figure 27). Over the four-year period, the DTRs at the full treatment plots were consistently deeper than at the surface treatment plot, demonstrating that full treatment applications are more successful at maintaining less dense soils. Shallow penetrometer DTRs, as exhibited at the hydroseed plot, have been associated with high sediment yields in previous research. Rainfall simulation results in similar soils showed a reduction in sediment yield in soils when penetrometer DTRs were greater than 4 inches (10 cm).[5]

[5] Grismer, M.E. 2006. Simulated Rainfall Evaluation at Sunriver and Mt. Bachelor Highways, Oregon. Unpublished.

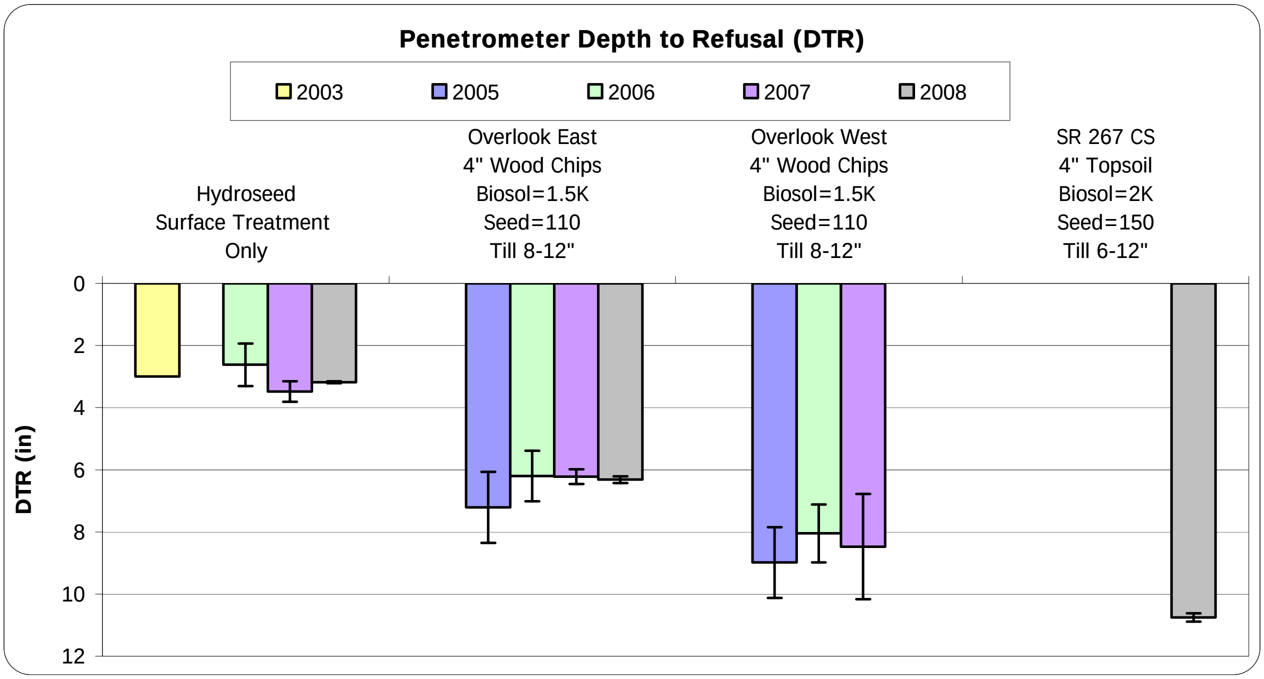


Figure 27. Penetrometer DTR. The penetrometer DTR was 2.4 times deeper for the Overlook plots with soil loosening (four-year average of 7.3 inches or 19 cm) compared to the hydroseed plot without soil loosening (four-year average of 3.1 inches or 8 cm). The SR 267 cut slope plot was tilled in 2006 and was only monitored in 2008. It has the deepest DTR at 10.8 inches or 27 cm. No penetrometer readings were taken at the Overlook West plot in 2008. The error bars represent one standard deviation above and below the mean. Data is sorted by decreasing penetrometer DTR for 2008.

Cover

Ground Cover by Mulch and Bare Soil

Trends by Treatment Level

Ground cover by mulch at the hydroseed plot (three-year average of 20%) was 4.2 times less than ground cover by mulch at the Overlook plots (three-year average of 83%; Figure 28). In addition to the lowest mulch cover, the hydroseed plot also produced the highest sediment yield. High mulch cover is often associated with sediment reduction.[6] Mulch cover at the SR 267 cut slope plot was 94%, which was slightly higher than mulch Overlook plots (83%; Figure 28).

Trends by Year

Ground cover by mulch was consistent over time at the Overlook East full treatment plot. However, the hydroseed surface treatment plot cover by mulch increased over the past 3 years, from 11% in 2006 to 26% in 2008. This increase may be a result of pine needle cast from trees in the surrounding area.

[6] Grismer, M.E., and M.P. Hogan. 2004. Simulated rainfall evaluation of revegetation/mulch erosion control in the Lake Tahoe Basin: 1. Method assessment. Land Degradation & Development 15:573-588.

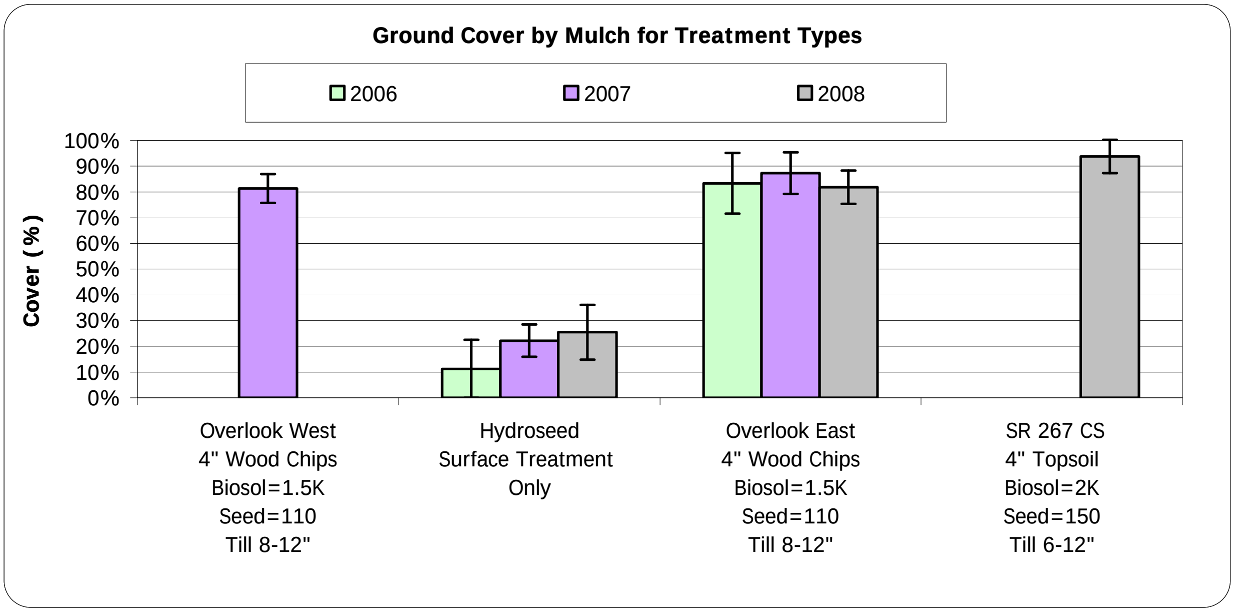


Figure 28. Ground Cover by Mulch for Treatment Types. The mulch cover at the Overlook plots (three-year average of 83%) was on average 4.2 times higher than the mulch cover at the hydroseed plots (three year average of 20%) and similar to the mulch cover at the SR 267 cut slope plot (94%). Ground cover by mulch readings were not taken at the Overlook West plot in 2006 or 2008 and not at the SR 267 cut slope plot in 2006 or 2007. The error bars represent one standard deviation above and below the mean. Data is sorted by increasing 2008 mulch cover.

Trends by Treatment Level

The cover by bare soil was lower by an average 6.2 times at the Overlook plots (three-year average of 8%) when compared to the bare soil cover at the hydroseed surface treatment plot (three-year average of 47%; Figure 29). The SR 267 cut slope plot had less than 2% bare soil when sampled in 2008.

Trends by Year

Ground cover by bare soil increased over time at both the Overlook and hydroseed plots. However, bare soil cover increased at a faster rate at the hydroseed plot. Cover by bare soil increased 4% at the Overlook plots (from 6 to 10%) while bare soil increased 10% at the hydroseed plot (from 44 to 54%) from 2006 to 2008.

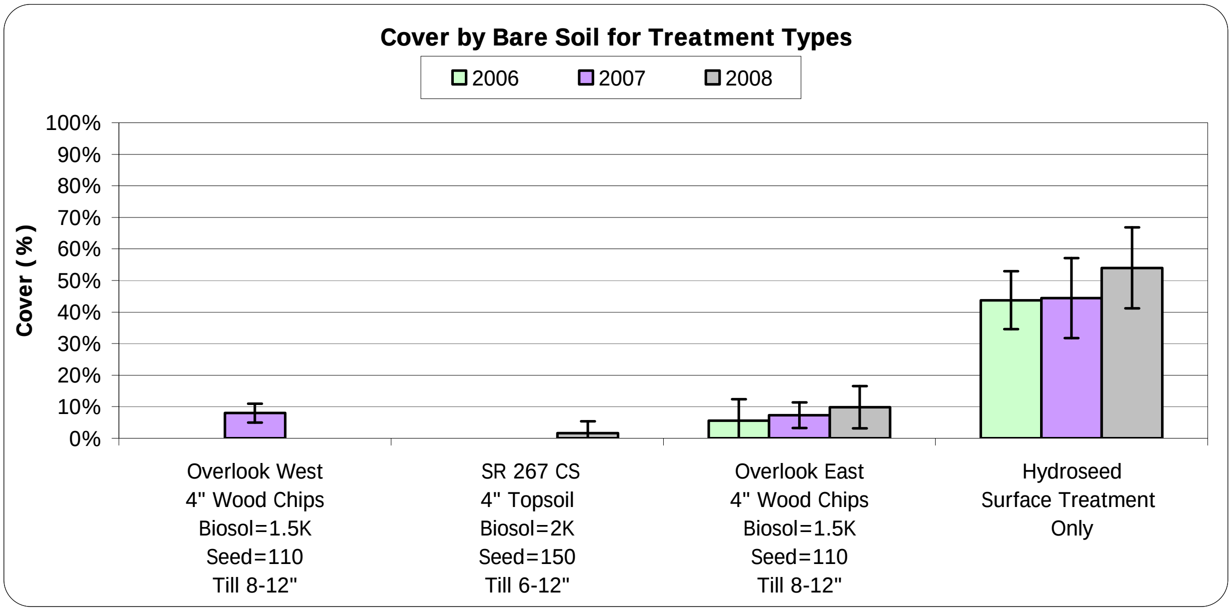


Figure 29. Ground Cover by Bare Soil for Treatment Types. The cover by bare soil was on average 7.2 times lower at the full treatment plots (three-year average of 7%) when compared to the bare soil cover at the surface treatment plots (three-year average of 47%). The SR 267 cut slope plot had less than 2% bare soil when sampled in 2008. The error bars represent one standard deviation above and below the mean. Data is sorted by increasing bare soil for 2008.

Plant Cover

Trends by Treatment Level

Foliar plant cover was variable within each plot between years. However, average foliar cover values are presented to assist in understanding general trends among treatment types. Overlook East and Overlook West plots exhibited foliar plant cover that was on average 2.1 times higher than the foliar cover at the hydroseed plot over the six-year monitoring period (Figure 30). The average foliar plant cover over six years of sampling was 33% at Overlook East. The four-year average at Overlook West was 38%. In comparison, the four-year average foliar plant cover at the hydroseed plot was 16%. The same trends can be observed visually in Figure 7, Figure 8, Figure 11, and Figure 12.

The SR 267 cut slope plot had the most cover in 2008 (56%), which was 3.4 times more than at the hydroseed plot. It is important to note that the SR 267 cut slope was treated two years prior, as opposed to nine years earlier at the hydroseed plot and seven years earlier at the Overlook plots.

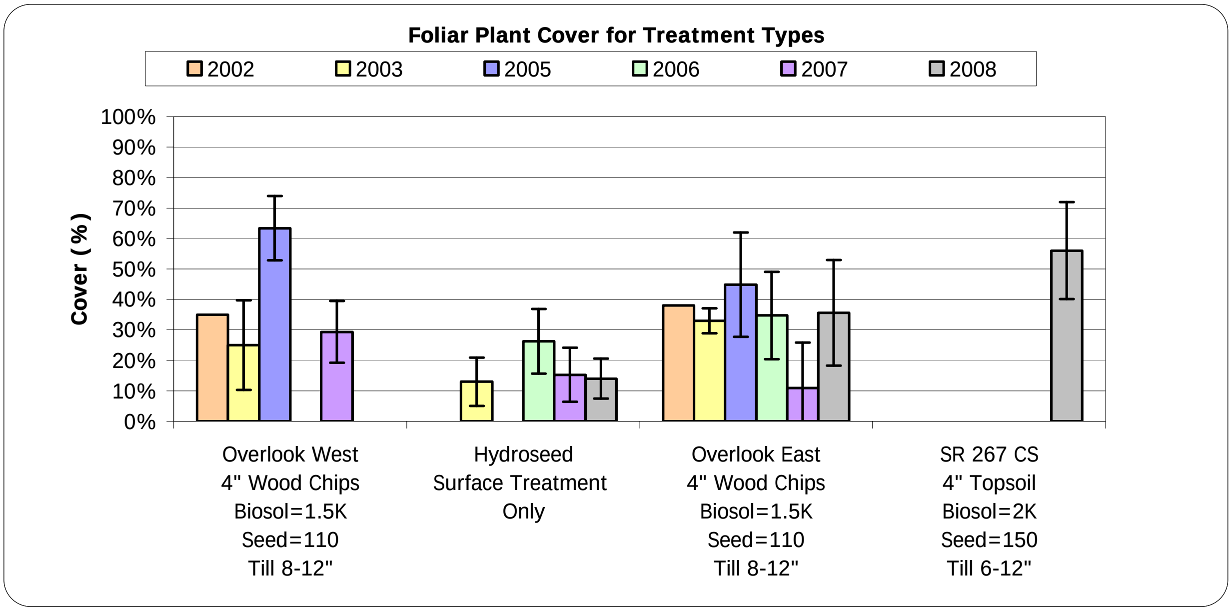


Figure 30. Foliar Cover for Treatment Type. Overlook East and Overlook West plots exhibited foliar plant cover that was on average 2.1 times higher than the foliar cover at the hydroseed plot over the six year monitoring period. The average foliar plant cover over six years of sampling was 33% at Overlook East. The four-year average at Overlook West was 38%. In comparison, the four-year average foliar plant cover at the hydroseed plot was 16%. The SR 267 cut slope plot had the most cover in 2008 (56%), which was 3.4 times more than at the hydroseed plot. The error bars represent one standard deviation above and below the mean. Data is sorted by increasing foliar plant cover for 2008.

Trends by Year

Plant cover and composition at each plot varied by year and was most likely dependent on a combination of precipitation during the previous year, the month during which the plots were sampled, and the prevalence of late-season snowpack (Figure 30). The plant cover is generally known to increase during years with higher than normal precipitation and decrease in years with lower than normal precipitation. The average annual precipitation for the Tahoe area is 30 inches (76 cm). Between 2002 and 2008, precipitation ranged from 22.5 to 51.1 inches (57-129 cm) during the water year (October 1 to September 30).[7] It is ideal to measure plant cover during the peak of the growing season; however, this is not always possible. Early in the season, many of the plants, especially perennial species, have not yet appeared, leading to lower cover readings. Late in the season, many of the plants have dried up and some begin to lie on the ground, also reducing the foliar cover. Late-season snowpack can also lead to lower plant cover early in the growing season.

Plant Composition

Trends by Treatment Level

Perennial and seeded plant cover was the highest in 2008 at the SR 267 cut slope plot (53%), and was dominated by mountain brome (51%, *Bromus carinatus*). The SR 267 cut slope plot

[7] Snotel data from: http://www.wcc.nrcs.usda.gov/snotel/snotel.pl?sitenum=834&state=ca

had 53% perennial cover and 3% annual cover in 2008 (Figure 36). This slope was not treated in the same timeframe as the full treatment plot, so a comparison is not possible (Figure 34 and Figure 36).

Cover at the Overlook East plot was 36% and consisted mainly of the seeded species, including blue wildrye (14%, *Elymus glaucus*) and squirreltail (5%, *Elymus elymoides*). Annual natives composed 11% of total annual cover, and annual aliens were less than 2% of the cover in 2008. Overlook East had the most annual cover of all the plots in 2008 (Figure 36). Eight years after establishment, the Overlook East plot had 19% cover by seeded species, indicating that it can sustain native, perennial growth over time.

Although cover at the hydroseed plot (14%) was lower in 2008 compared to the other treatments, it consisted of all perennial species. Red fescue (*Festuca rubra*) was the dominant species at 6%. Orchard grass (*Dactylis glomerata)* was the only alien species observed at 3% cover (Figure 36).

Although red fescue, mountain brome, squirreltail, and blue wildrye are all bunchgrass, red fescue can be undesirable in terms of erosion control on steep slopes. Compared to the other grasses, red fescue has a denser formation where the plant is rooted in the soil. Over time, a pedestal is created by the base of the plant (Figure 31). Water eroding down a hill side can travel around the base of the fescue plant, creating preferential flow paths. Mountain brome, squirreltail, and blue wildrye tend to spread, rather than become denser, which can provide more cover and encourage infiltration instead of erosion (Figure 32).

Figure 31. Red fescue (*Festuca rubra*) in rainfall frame at the hydroseed plot.

Figure 32. Mountain brome (*Bromus carinatus*) in rainfall frame at the SR 267 cut slope plot.

Trends by Year

Perennial plant cover at the hydroseed plot decreased from 2006 to 2008. In 2006, perennial plant cover was highest at 21%. It decreased slightly to 15% in 2007 and in 2008 it decreased slightly again to 13%. From 2006 to 2008, the cover decreased by 1.6 times. As the perennial plant cover decreased, the sediment yield increased, indicating a possible relationship between the two variables (Figure 25, Figure 34, Figure 35, Figure 36, and Figure 36).

From 2006 to 2008 perennial plant cover at the Overlook plots was inconsistent. The perennial plant cover in 2006 was 25%, which is similar to the perennial plant cover in 2008 (23%). In 2007, perennial plant cover was 6% (Figure 34, Figure 35, Figure 36, and Figure 36). The perennial and total plant cover reduction at the Overlook plot between 2006 and 2007 may be a function of a higher than average water year in 2005-6, followed by a lower than average water year in 2006-7. The average annual precipitation in the Truckee area is approximately 31 inches (79 cm); however, during the 2005-2006 water year (October 1, 2005 to September 30, 2006), the total precipitation was 51.1 inches (129 cm).[8] In the 2006-7 water year, the yearly precipitation was 23 inches (58 cm).The increase in plant cover, mostly from blue wildrye, from 2007 to 2008 at the Overlook plots is noteworthy because during the 2007-8 water year, the precipitation total was less than average (25 inches or 64 cm).

From 2006 to 2008, at the Overlook full treatment plots, the amount of the native grass, squirreltail, remained fairly consistent at 0-5%. Mountain brome was also fairly consistent and less than 2% cover at the Overlook plots over this same time. The most successful seeded plant at the Overlook East plot was blue wildrye. Cover of blue wildrye fluctuated from 19% in 2006 to 2% in 2007 and 14% in 2008 (Figure 34, Figure 35 and Figure 36). Success of blue wildrye after the first low water at Overlook East suggests that blue wildrye is more adapted to consistent water availability and can take time to adjust to low water conditions.

Annual plant cover in the Overlook East plot remained fairly consistent from 2006 to 2008, ranging from 6 to 13%. Annual plant cover decreased at the hydroseed plot from 4% in 2006 to none in 2007 and 2008. This follows the trend of decreasing foliar plant cover at this plot over the same time period (Figure 34, Figure 35 and Figure 36).

[8] Snotel data from: http://www.wcc.nrcs.usda.gov/snotel/snotel.pl?sitenum=834&state=ca

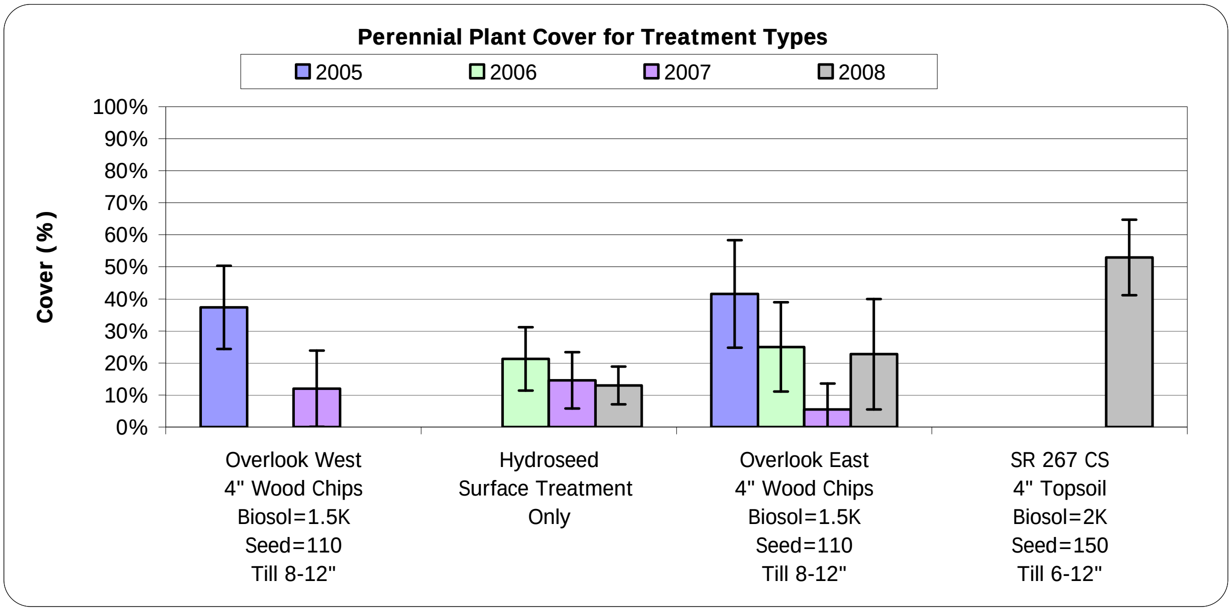


Figure 33. Perennial Plant Cover for Treatment Types. Perennial plant cover was the highest in 2008 at the SR 267 cut slope plot at 53%. This slope was not treated in the same timeframe as the Overlook full treatment plots, so a comparison is not possible.

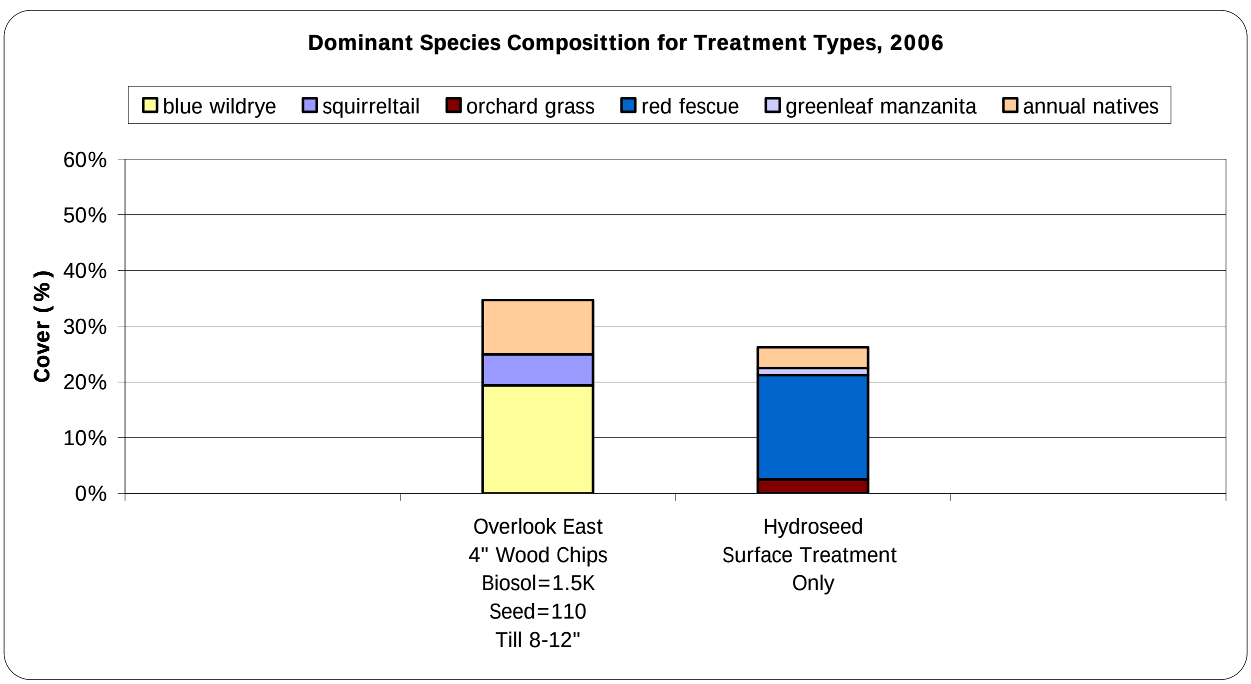


Figure 34. Plant Cover Composition, 2006. Annual plants are shaded in tan; all other plants are perennial. Both plots are dominated by perennial plants. Plant cover was measured at the foliar (first hit cover) level. Overlook West and the SR 267 cut slope were not sampled in 2006.

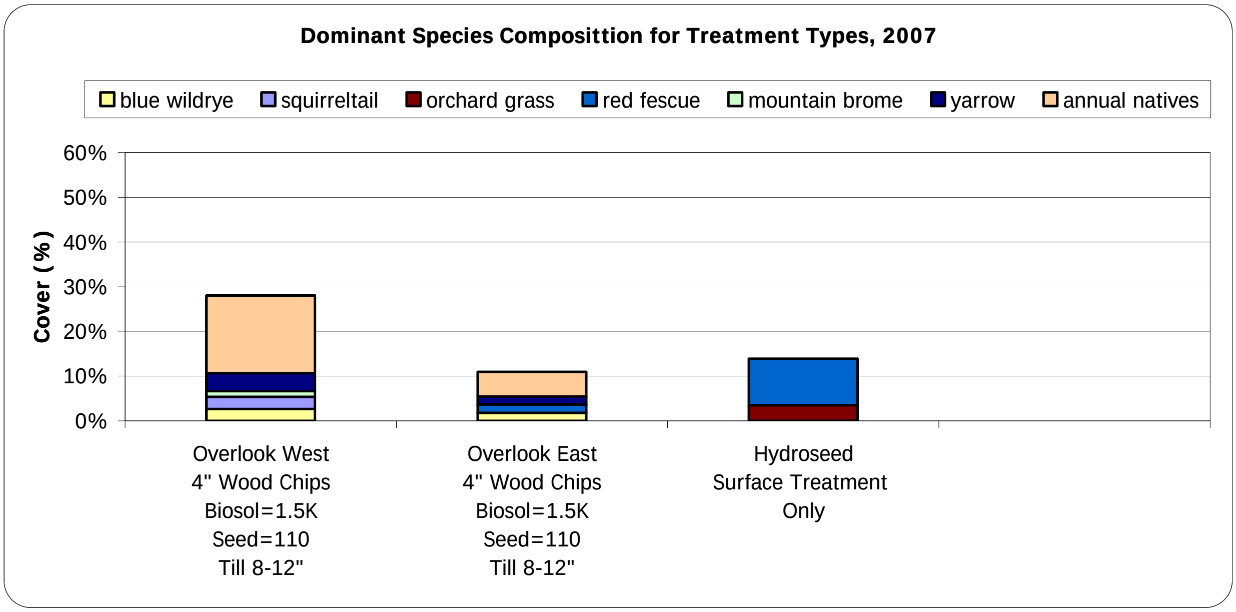


Figure 35. Plant Cover Composition, 2007. Annual plants are shaded in tan; all other plants are perennial. The hydroseed plot has the highest perennial plant cover. The perennial cover at the Overlook plots decreased from 2006. Plant cover was measured at the foliar (first hit cover) level. The SR 267 cut slope plot was not sampled in 2007.

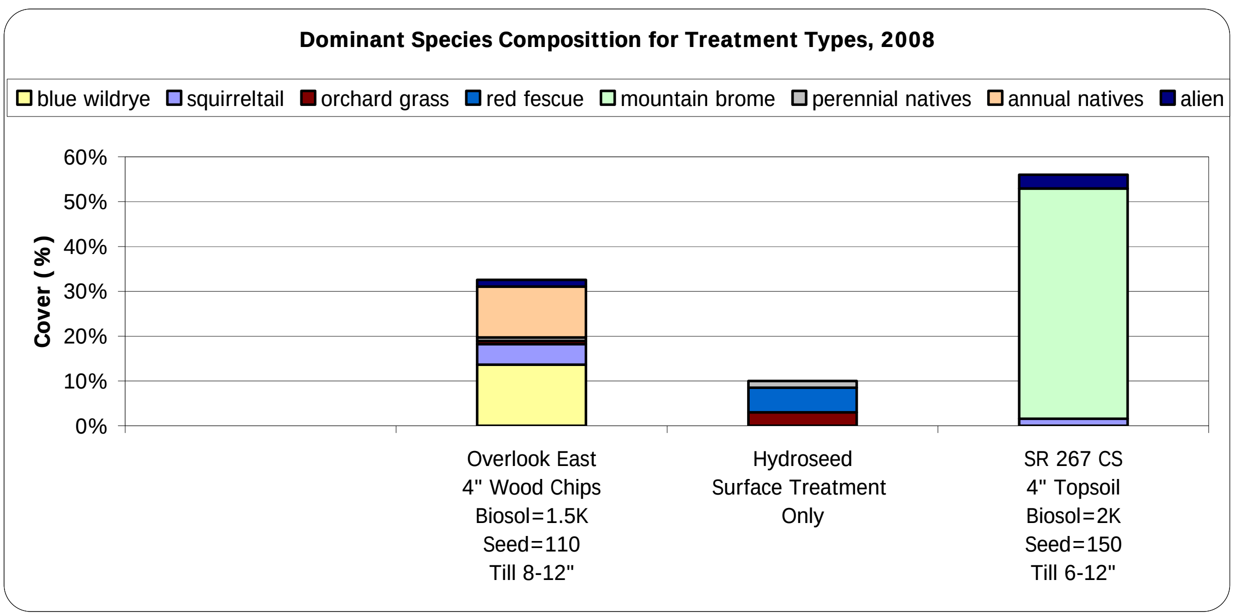


Figure 36. Plant Cover Composition, 2008. Annual native plants are shaded in tan, annual alien plants are shaded navy blue; all other plants are perennial. The SR 267 cut slope plot has the highest perennial plant cover. The perennial cover at the Overlook East plot increased from 2007, while the hydroseed plot decreased. Plant cover was measured at the foliar (first hit cover) level. The Overlook West plot was not sampled in 2007.

Soil Nutrients

Total Kjeldahl Nitrogen (TKN)

Trends by Treatment Level

The TKN at the Overlook East plot was variable over the three sampling years, and ranged from 1,953 ppm in 2006 to 5,240 ppm in 2008. This wide range of values may be a result of local variation, and will be averaged to compare with other treatments. From 2006 to 2008, the average TKN at the Overlook East plot (3,138 ppm) was 4.3 times higher than the three-year average TKN at the hydroseed plot (738 ppm) and 1.8 times higher than at the SR 267 cut slope plot (1,174 ppm; Figure 37). The TKN was highest at the Overlook West plots (average of 4,844 ppm). Although there was variation among nutrient levels at the full treatment plots (Overlook and SR 267 cut slope plots) the TKN at all of the full treatment plots was similar or higher than at the native reference plot (1,944 ppm).

The Overlook plots were amended with aged wood chips, which provide a slow release of nutrients over time as the wood breaks down. It is likely that the addition of aged woodchips contributed to nutrients levels that were similar to or higher than native reference levels. The SR 267 cut slope was amended with topsoil that contained an unknown amount of TKN, which was sufficient to re-capitalize the soil to near native reference levels. The hydroseed plot did not receive an organic amendment, which is most likely why the TKN was below native reference levels. In rainfall simulations, Overlook East and Overlook West generated little to no runoff, suggesting that healthy soil nutrient levels and therefore healthy plant and root systems may be related to higher infiltration rates and lower sediment yields. The hydroseed site produced high sediment yields and had low infiltration rates, suggesting that the nutrient status of soil affects both plant production and the hydrologic function of the soil and plant community (Figure 24, Figure 25, and Figure 37).

Trends by Year

From 2006 to 2008, the TKN at the Overlook East plot increased from 1,953 to 5,240 ppm, which was most likely a result of local variation in the soil. From 2006 to 2008 TKN levels at the hydroseed plots ranged from 623 to 967 ppm (Figure 37). Although TKN levels at the hydroseed plot were lower than all other treated and native reference sites sampled, TKN increased over time for unknown reasons (Figure 37). The soil TKN remained stable at the Overlook West plots and ranged from 4,656 to 5,031 ppm.

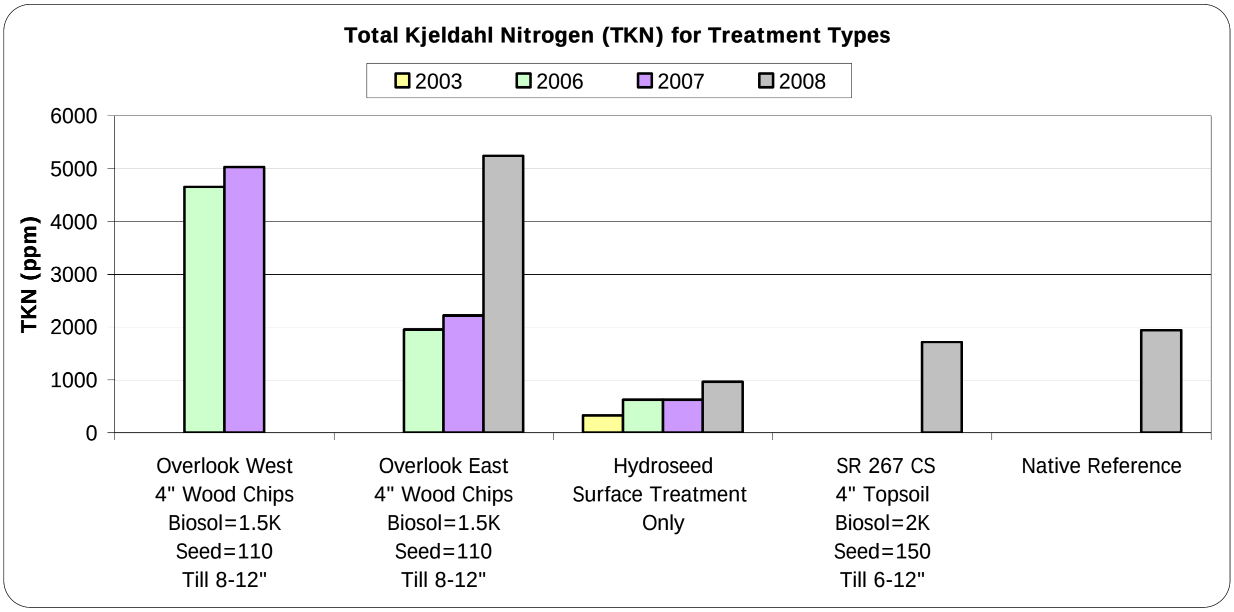


Figure 37. Total Kjeldahl Nitrogen for Treatment Types. Overlook full treatment plots amended aged wood chips (TKN range of 1,953-5,240 ppm) had TKN levels higher than the native reference plot (TKN of 1,944 ppm) in 2008. The hydroseed surface treatment plots (TKN range of 327-967 ppm) had lower TKN levels to the native reference plot.

Organic Matter

Trends by Treatment Level

From 2006-8, the Overlook plots had an average organic matter level of 10.7%, 1.4 times lower than the native reference plot at 14.4%. The Overlook plots had the highest organic matter out of all the treatment plots, 3.1 times higher than the hydroseed plot (three-year average 3.5%) and 1.8 times higher than the SR 267 cut slope plot (5.9%; Figure 38).

The low organic matter level (compared to the native reference plot) at the hydroseed plot and the SR 267 cut slope plots may be a result of the lack of amendments or amendment type. The topsoil amendment incorporated at the SR 267 cut slope was not sufficient to re-capitalize TKN or organic matter levels. In 2008, the SR 267 cut slope (5.9%) and surface treatment plot (4.6%) had similar organic matter levels (Figure 38).

Although the organic matter level at the Overlook plots was slightly lower than native reference levels, it is apparent that the aged woodchip amendment was more effective than topsoil for re-capitalizing the soil.

Trends by Year

From 2006 to 2008 organic matter levels have fluctuated between 6.2 and 14% at the Overlook East plot, with no clear trend. The varying organic matter levels may be due to variations in the treatment, such as pockets of organic matter that were not fully integrated into the soil.

Organic matter levels at the hydroseed plot have remained steady from 2003 to 2008 (sampling did not occur in 2004 or 2005). Organic matter levels ranged from 2.5 to 4.6% over this time.

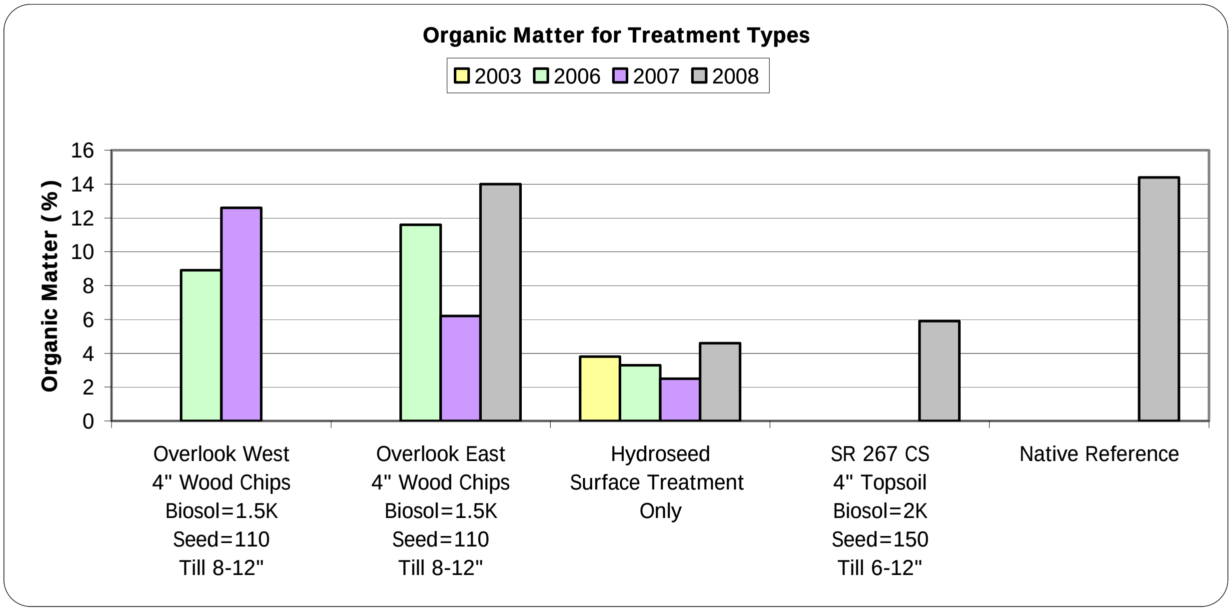


Figure 38. Organic Matter for Treatment Types. The Overlook plots had the highest average organic matter level compared to all other treated plots (average range of 10.6-10.8%). The SR 267 cut slope plot and surface treatment plot had similar organic matter levels (average range of 3.5-5.9%), but all treatment types had lower organic matter levels than the native reference plot (14.4%).

Recommendations

These recommendations are for sites with rocky soils on volcanic parent material, with slope angles between 25 and 30 degrees, solar exposures of 73-78% during the summer months, at 6,599 feet (2,011 m) AMSL:

Tilling: 12 inches (30 cm)

Amendment: 4 inches (10 cm) aged woodchips

Biosol: 2,000 lbs/acre (2,241 kg/ha)

Seed: 115 lbs/acre (129 kg/ha) seed with the following composition:

squirreltail: 34%
blue wildrye 28%
mountain brome: 28%
native forbs and shrubs: 10%

Mulch: pine needles, 2 inches (5 cm) and 99% cover

Full treatment versus Surface Treatment

Full treatment is recommended over surface treatment because full treatment plots exhibited:

- sediment yield from 2006 to 2008 at the Overlook full treatments plots that was zero to 11 lbs/acre/in (0 to 5 kg/ha/cm), which was on average 609 times higher than the sediment yield at the surface treatment plot (903 to 1,866 lbs/acre/in or 398 to 823 kg/ha/cm)
- percent infiltration from 2006 to 2008 that ranged from 94 to 100%, compared to percent infiltration that ranged from 79 to 91% at the surface treatment plot
- sediment production that was steady over the three-year sampling period, compared to the surface treatment plot at which sediment yield increased from 903 lbs/acre/in or 399 kg/ha/cm in 2006 to 1,866 lbs/acre/in or 823 kg/ha/cm in 2008
- an average penetrometer DTRs over four years (2005-2008) of 7.3 inches (18.5 cm) that was deeper by an average of 2.4 times compared to the surface treatment plot DTR (3.1 inches or 7.9 cm)
- penetrometer DTRs that remained consistently deep over time, compared to the consistently shallow DTRs at the surface treatment plot
- ground cover by mulch (three-year average of 83%) that was consistent over time and 4.2 times higher than the mulch cover at the surface treatment plot (three-year average of 20%)
- cover by bare soil that ranged from 2 to 10% and was 4.7 to 24 times higher than the cover by bare soil at the surface treatment plot (three-year average of 47%)
- foliar plant cover that was on average 2.1 times higher at the Overlook full treatment plots (33-38%) compared to the surface treatment plot (16%)
- foliar plant cover that was on average 3.4 times higher at the SR 267 cut slope full treatment plot (56%) compared to the surface treatment plot (16%)
- foliar plant composition that was dominated by the more desirable steep slope erosion control species (mountain brome, blue wildrye, and squirreltail), compared to red fescue at the surface treatment plot
- seeded, perennial plant cover that increased from 2% in 2007 to 19% at Overlook East in 2008 during a less-than-average water year
- TKN that was 4.3 times higher at the full treatment Overlook East plot (3,138 ppm) compared to the three-year average TKN at the hydroseed plot (738 ppm)
- TKN that was 6.6 times higher at the full treatment Overlook West plot (4,844 ppm) compared to the three-year average TKN at the hydroseed plot (738 ppm)
- TKN that was 1.8 times higher at the SR 267 cut slope full treatment plot (1,714 ppm) compared to the hydroseed plot (738 ppm)

- TKN that was similar to or higher than (range of 1,714-5,240 ppm) those measured at the native reference plot (1,944 ppm)
- organic matter content at the full treatment Overlook plots (10.7%) that was similar to the native reference plot (14.4%) and 3.1 times higher than the organic matter content at the surface treatment plot (three-year average of 3.5%)
- organic matter content at the full treatment SR 267 cut slope plots (5.9%) that was 3.1 times higher than the organic matter content at the surface treatment plot (three-year average of 3.5%)

Soil Loosening versus No Soil Loosening

Tilling is recommended to a depth of 12 inches (30 cm) for the following reasons. Plots with soil loosening exhibited:

- sediment yield from 2006 to 2008 at the plots with soil loosening was zero to 11 lbs/acre/in (0-5 kg/ha/cm), which was on average 609 times higher than the sediment yield at plots no soil loosening (903 to 1,866 lbs/acre/in or 398-823 kg/ha/cm)
- percent infiltration from 2006 to 2008 that ranged from 94 to 100%, compared to percent infiltration that ranged from 79 to 91% at the plots no soil loosening
- sediment production that was steady over the three-year sampling period, compared to the plots with no soil loosening at which sediment yield increased from 903 lbs/acre/in or 399 kg/ha/cm in 2006 to 1,866 lbs/acre/in or 823 kg/ha/cm in 2008
- an average penetrometer DTRs over four years (2005-2008) of 7.3 inches (18.5 cm) that was deeper by an average of 2.4 times compared to the plots with no soil loosening DTR (3.1 inches or 7.9 cm)
- penetrometer DTRs that remained consistently deep over time, compared to the consistently shallow DTRs at the plots with no soil loosening
- ground cover by mulch (three-year average of 83%) that was consistent over time and 4.2 times higher than the mulch cover at the plots with no soil loosening (three-year average of 20%)
- cover by bare soil that ranged from 2 to 10% and was 4.7 to 24 times higher than the cover by bare soil at the plots with no soil loosening (three-year average of 47%)
- foliar plant cover that was on average 2.1 times higher at the Overlook plots with soil loosening (33-38%) compared to the plots with no soil loosening (16%)
- foliar plant cover that was on average 3.4 times higher at the SR 267 cut slope plots with soil loosening (56%) compared to the plots with no soil loosening (16%)
- foliar plant composition that was dominated by the more desirable steep slope erosion control species (mountain brome, blue wildrye, and squirreltail), compared to red fescue at the plots with no soil loosening

- seeded, perennial plant cover that increased from 2% in 2007 to 19% at Overlook east in 2008 during a less-than-average water year
- TKN that was 4.3 times higher at the full treatment Overlook East plot with soil loosening (3,138 ppm) compared to the three-year average TKN at the hydroseed plot without soil loosening (738 ppm)
- TKN that was 6.6 times higher at the full treatment Overlook West plot with soil loosening (4,844 ppm) compared to the three-year average TKN at the hydroseed plot without soil loosening (738 ppm)
- TKN that was 1.8 times higher at the SR 267 cut slope full treatment plot with soil loosening (1,714 ppm) compared to the hydroseed plot without soil loosening (738 ppm)
- TKN that was similar to or higher than (range of 1,714-5,240 ppm) those measured at the native reference plot (1,944 ppm)
- organic matter content at the full treatment Overlook plots with soil loosening (10.7%) that was similar to the native reference plot (14.4%) and 3.1 times higher than the organic matter content at the plots with no soil loosening (three-year average 3.5%)
- organic matter content at the full treatment 267 cut slope plots with soil loosening (5.9%) that was 3.1 times higher than the organic matter content at the plots with no soil loosening (three-year average 3.5%)

Amendment Type (Aged Woodchips versus Topsoil)

Aged woodchips are recommended over topsoil for the following reasons. Plots amended with aged woodchips exhibited:

- a sediment yield that was zero to 11 lbs/acre/in (0-5 kg/ha/cm), compared to 134 lbs/acre/in (or 59 kg/ha/cm) at the plot amended with topsoil, a difference of up to 12 times
- average TKN that was 3,138 ppm and 4,844 at the plots amended with aged woodchips, which ranged from 1.8 to 2.8 times higher than at the SR 267 cut slope plot (1,174 ppm)
- average organic matter (three-year average 3.5%) that was 1.8 times higher than the organic matter at the SR 267 cut slope plot (5.9%; Figure 38)

The addition of aged woodchips may also contribute to lower soil density over time. The SR 267 cut slope requires study over time to determine whether the lack of a coarse amendment negatively affects the penetrometer DTR and consequently infiltration and sediment yield.

Amendment Rate

It is essential to consider amendment rate in conjunction with soil loosening depth, as the concentration of the amendment is more important than the depth alone. The tested depth of aged woodchips, 4 inches (10 cm), is recommended with the tested tilling depth of 12 inches (30 cm) for the following reasons. The plots amended with 4 inches of woodchips exhibited:

- no sediment yield or sediment yield that was less than 11 lbs/acre/in (5 kg/ha/cm)
- percent infiltration that was 97% or higher
- penetrometer depths that ranged from 6 to 9 inches (15-23 cm)
- TKN that was similar to native reference levels and ranged from 1,953 ppm to 5,240 ppm
- organic matter that was on average near native reference levels and that ranged from 6.2 to 14.0%

Biosol Rate

Biosol is recommended at 2,000 lbs/acre (2,241 kg/ha) rather than 1,500 lbs/acre (1,681 kg/ha) for the following reasons:

- This study was unable to capture the effects of Biosol at the Overlook plots (1,500 lbs/acre or 1,681 kg/ha application) because Biosol is usually effective for the first few years following treatment. The first year of in-depth study at the Overlook plots was in 2006, five years following treatment.
- The plant cover at the SR 267 cut slope plot, at which 2,000 lbs/acre (2,241 kg/ha) of Biosol was applied, was 56% two years following treatment. A lower Biosol rate may have resulted in lower plant cover.

Seed Rate and Mix

A mix of native, perennial grasses, forbs, and shrubs is recommended at 115 lbs/acre (129 kg/ha) with the following composition:

squirreltail: 34%
blue wildrye 28%
mountain brome: 28%
native forbs and shrubs: 10%

This composition is similar to the mixes used at the Overlook and SR 267 cut slope full treatment plots. Native forbs and shrubs were present in the SR 267 cut slope mix, but were not present in the Overlook mix; however, they are recommended here. A few native shrubs were present during sampling at the Overlook plots, indicating conditions are favorable for shrub growth. Seeding these shrubs may increase native shrub cover. Native forbs provide diversity to the grass-dominated mix.

Red fescue, which was most likely seeded at the hydroseed surface treatment plot, is not recommended here, as it can cause formation of preferential flow paths on steep slopes that may lead to increased erosion potential.

Mulch Cover and Depth

Mulch composed of native pine needles should be applied at a depth of 2 inches (5 cm) and a ground cover of at least 99% for the following reasons. Plots with this application exhibited:

- greater than 94% mulch cover after two years at the SR 267 cut slope plot

Appendix A

Species list and ocular estimates for Northstar Unit 7 Plots 2006. "X" indicates a species present. Hydroseed seed mix is unknown.

Lifeform	Family	Scientific name	Common name	Annual / Perennial	Native / Alien	Noxious	% in Overlook seed mix	Overlook East	Overlook West	Hydroseed Plot
Forb	Chenopodiaceae	*Chenopodium album*	goosefoot	Annual	Alien				x	
Forb	Polemoniaceae	*Collomia linearis*	narrow-leaved collomia	Annual	Native			x	x	
Forb	Boraginaceae	*Cryptantha ambigua*	Wilke's cryptantha	Annual	Native			x	x	
Forb	Brassicaceae	*Descurainia sophia*	herb Sophia	Annual	Alien	Invasive			x	
Forb	Asteraceae	*Lactuca serriola*	devil's lettuce	Annual	Alien	Invasive			x	
Forb	Fabaceae	*Melilotus sp.*	sweet clover	Annual	Alien			x	x	x
Forb	Brassicaceae	*Sisymbrium altissimum*	tumble mustard	Annual	Alien			x		
Forb	Asteraceae	*Tragapogon dubius*	false salsify	Annual	Alien			x	x	
Forb	Brassicaceae	*Lepidium campestre*	English pepperweed	Annual	Alien			x	x	x
Forb	Asteraceae	*Achillea millefolium*	yarrow	Perennial	Native		.5	x		x
Forb	Papaveraceae	*Eschscholzia californica*	California poppy	Perennial	Native					
Forb	Onagraceae	*Gayophytum diffusum*	groundsmoke	Perennial	Native			x	x	x
Forb	Fabaceae	*Lotus purshianus*	Spanish clover	Perennial	Native					x
Forb	Scrophulariaceae	*Penstemon sp.*	penstemon	Perennial	Native					x
Forb	Hydrophyllaceae	*Phacelia hastata*	silverleaf phacelia	Perennial	Native			x	x	
Forb	Poaceae	*Poa bulbosa*	bulbous bluegrass	Perennial	Alien			x		x
Graminoid	Poaceae	*Bromus carinatus*	mountain brome	Perennial	Native		31.7	x	x	x
Graminoid	Poaceae	*Dactylis glomerata*	orchard grass	Perennial	Alien	Invasive				x
Graminoid	Poaceae	*Elymus elymoides*	squirreltail	Perennial	Native		31.7	x	x	
Graminoid	Poaceae	*Elymus glaucus*	blue wildrye	Perennial	Native		31.7	x	x	x
Graminoid	Poaceae	*Festuca rubra*	red fescue	Perennial	Native			x	x	x
Shrub	Ericaceae	*Arctostaphylos nevadensis*	pinemat manzanita	Perennial	Native					x
Shrub	Rosaceae	*Purshia tridentata*	antelope bitterbrush	Perennial	Native					x
Shrub	Grossulariaceae	*Ribes cereum*	wax currant	Perennial	Native				x	
Tree	Pinaceae	*Abies concolor*	white fir	Perennial	Native				x	
Tree	Pinaceae	*Pinus jefferyi*	Jeffrey pine	Perennial	Native			x		

Species list and ocular estimates for Northstar Unit 7 Plots 2007. "T" indicates a species present in trace amounts. Hydroseed seed mix is unknown.

Lifeform	Family	Scientific name	Common name	Annual / Perennial	Native / Alien	Noxious	% in Overlook seed mix	Overlook East	Overlook West	Hydroseed Plot
Forb	Asteraceae	*Achillea millefolium*	yarrow	Perennial	Native		0.5	< 5	<5	
Forb	Brassicaceae	*Arabis holboelii*	Holboel's rockcress	Perennial	Native			T		
Forb	Chenopodaceae	*Chenopodium album*	goosefoot	Annual	Alien			T		
Forb	Polemoniaceae	*Collomia linearis*	narrow-leaved collomia	Annual	Native			T	5	
Forb	Boraginaceae	*Cryptantha ambigua*	Wilke's cryptantha	Annual	Native			T	<5	
Forb	Brassicaceae	*Descurainia sophia*	herb sophia	Annual	Alien			T		
Forb	Papaveraceae	*Eschscholzia californica*	California poppy	Perennial	Native					
Forb	Onagraceae	*Gayophytum diffusum*	groundsmoke	Perennial	Native			< 5	<5	
Forb	Fabaceae	*Lupinus lepidus*	lupine	Perennial	Native				T	
Forb	Fabaceae	*Medicago lupulina*	black medic	Annual	Alien				T	
Forb	Fabaceae	*Melilotus sp*	sweet clover	Annual	Alien					T
Forb	Onagraceae	*Oenothera elata*	evening primrose	Perennial	Native			T		
Forb	Hydrophyllaceae	*Phacelia hastata*	silverleaf phacelia	Perennial	Native			5		
Forb	Polygonaceae	*Polygonum douglasii*	Douglas knotweed	Perennial	Native			T		
Forb	Brassicaceae	*Sisymbrium altissimum*	tansy mustard	Annual	Alien			T		
Forb	Asteraceae	*Wyethia mollis*	mule ears	Perennial	Native			T		
Graminoid	Poaceae	*Bromus carinatus*	mountain brome	Perennial	Native		31.7	5		
Graminoid	Poaceae	*Dactylis glomerata*	orchard grass	Perennial	Alien	Invasive				<5
Graminoid	Poaceae	*Elymus elymoides*	squirreltail	Perennial	Native		31.7	5	7	
Graminoid	Poaceae	*Elymus glaucus*	blue wildrye	Perennial	Native		31.7	35	22	
Graminoid	Poaceae	*Festuca rubra*	red fescue	Perennial	Native			T	7	15
Graminoid	Poaceae	*Poa secunda*	pine bluegrass	Perennial	Native			5	5	
Shrub	Ericaceae	*Arctostaphylos patula*	greenleaf manzanita	Perennial	Native					T
Shrub	Rhamnaceae	*Ceanothus velutinus*	tobacco brush	Perennial	Native			T		
Shrub	Rosaceae	*Purshia tridentata*	antelope bitterbrush	Perennial	Native			<5		
Shrub	Grossulariaceae	*Ribes cereum*	wax currant	Perennial	Native			T		
Tree	Pinaceae	*Abies concolor*	white fir	Perennial	Native					T
Tree	Pinaceae	*Pinus jeffreyi*	Jeffrey pine	Perennial	Native			T	T	

Species list and ocular estimate for Northstar Unit 7 and SR 267 cut slope plots, 2008. Ocular estimates are presented below the plot numbers/letters. "T" indicates a species present in trace amounts. Seed mix is not known for the Hydroseed plot. Overlook West plot was not observed in 2008.

Lifeform	Family	Scientific name	Common name	Annual/ Perennial	Native / Alien	Noxious	% in Overlook seed mix	Overlook East	Overlook West	Hydroseed Plot	% In 267 CS Seed Mix	267 cut slope
Forb	Asteraceae	*Achillea millefolium*	yarrow	Perennial	Native		0.5	2		T		
Forb	Brassicaceae	*Arabis holboellii*	Holboel's rockcress	Perennial	Native			T				
Forb	Chenopodiaceae	*Chenopodium album*	goosefoot	Annual	Alien			T				
Forb	Scrophulariaceae	*Collinsia parviflora*	blue-eyed mary	Annual	Native			T				
Forb	Polemoniaceae	*Collomia linearis*	narrow-leaved collomia	Annual	Native			1				
Forb	Boraginaceae	*Cryptantha ambigua*	Wilke's cryptantha	Annual	Native			5				
Forb	Brassicaceae	*Descurainia sophia*	herb Sophia	Annual	Alien	Invasive						
Forb	Papaveraceae	*Eschscholzia californica*	California poppy	both	Native							
Forb	Onagraceae	*Gayophytum sp*	groundsmoke	Annual	Native			1				
Forb	Brassicaceae	*Hesperis matronalis*	dame's rocket	Perennial	Alien			T				
Forb	Fabaceae	*Lupinus lepidus*	Culberton's lupine	Perennial	Native			T				
Forb	Fabaceae	*Medicago lupulina*	black medick	Annual or Perennial	Alien							
Forb	Fabaceae	*Melilotus sp*	sweet clover	Annual	Alien							
Forb	Onagraceae	*Oenothera elata*	evening primrose	Perennial	Native							
Forb	Scrophulariaceae	*Penstemon azureus*	blue penstemon	Perennial	Native					T		
Forb	Hydrophyllaceae	*Phacelia hastata*	silverleaf phacelia	Perennial	Native			T				
Forb	Polygonaceae	*Polygonum douglasii*	Douglas knotweed	Annual	Native			T				
Forb	Polemoniaceae	*Phlox gracilis*	slender phlox	Annual	Native							
Forb	Asteraceae	*Wyethia mollis*	mule ears	Perennial	Native							
Graminoid	Poaceae	*Bromus carinatus*	mountain brome	Perennial	Native		31.7	T			23.9	43
Graminoid	Poaceae	*Bromus tectorum*	cheatgrass	Annual	Alien	Invasive						T
Graminoid	Poaceae	*Dactylis glomerata*	orchard grass	Perennial	Alien	Invasive		T		3		
Graminoid	Poaceae	*Elymus elymoides*	squirreltail	Perennial	Native		31.7	2			34.0	4
Graminoid	Poaceae	*Elymus glaucus*	blue wildrye	Perennial	Native		31.7	24			25.6	
Graminoid	Poaceae	*Festuca rubra*	red fescue	Perennial	Native			1		5		
Graminoid	Poaceae	*Poa secunda*	pine bluegrass	Perennial	Native			T		3		
Shrub	Ericaceae	*Arctostaphylos patula*	greenleaf manzanita	Perennial	Native					2	1.4	
Shrub	Rhamnaceae	*Ceanothus velutinus*	tobacco brush or snow brush	Perennial	Native							
Shrub	Rosaceae	*Purshia tridentata*	antelope bitterbrush	Perennial	Native						15.0	
Shrub	Grossulariaceae	*Ribes cereum*	wax currant	Perennial	Native						1.1	
Tree	Pinaceae	*Abies concolor*	white fir	Perennial	Native					T		
Tree	Pinaceae	*Pinus jeffreyi*	Jeffrey pine	Perennial	Native					T		
TOTAL PERCENT COVER (by cover point)								36		14		56
TOTAL PERCENT COVER (by ocular estimate)								38		14		47

Northstar Woods Run Bridge Test Plots Site Report

May 2009

Introduction

Monitoring results and treatment recommendations for a series of 10 test plots in the Truckee area will be presented in this report (Figure 1). Data was collected in two locations: the Northstar Woods Run Bridge test plots and the native reference plot. The Woods Run Bridge test plots are located where Highlands View Road crosses underneath the Woods Run ski bridge at the Northstar-at-Tahoe ski resort in Truckee, California. Construction of the test plots was completed in 2007 and monitoring was conducted in 2008 (Figure 2). The native reference plot is located on the corner of Big Springs Drive and Overlook Place in a Northstar residential area. This area was both established and monitored in 2008. These plots are representative of Caltrans roadside conditions in the Lake Tahoe area, therefore the monitoring results from these plots will be applicable Basin-wide and throughout the Sierra Nevada.

Figure 1. Satellite Map of the Northstar Woods Run Bridge project area location. The project area is just north of Lake Tahoe, in California.

Figure 2. Satellite map of the plot locations in the Woods Run Bridge area, including the test plots. This image is from August 2006. In 2007, Highlands View Road was paved and rerouted to go underneath the bridge. The bridge is now complete and functions as a ski run in the winter and a mountain bike trail in the summer. Test plots were constructed on the corners of land between the bridge and Highlands View Road.

Purpose

The project's monitoring objective is outlined below. The following treatment definition is included to aid understanding of these objectives.

Full Treatment: includes soil loosening by tilling, incorporation of an organic amendment such as fill soil or tub grindings, addition of fertilizer and native seed, and application of native mulch.

The monitoring data was studied and analyzed to investigate:

- the effects of different seed rates and seed mixes on plant cover and composition when full treatment is employed

Site Description

Woods Run Bridge Test Plots

The test plots are located on the four fill slopes adjacent to the supports of the Woods Run Bridge on Highlands View Road in Truckee, California (Figure 2). Test plots 1-7 are north to northeast facing and test plots 8-10 are south facing. The site elevation is approximately 6,762 ft (2,061 m) above mean sea level (AMSL). The slopes range from 11 to 18 degrees at the wildflower mix A plots, 28 to 29 degrees at wildflower mix B plots, and 15 to 27 degrees at the wildflower mix C plots (Figure 3).

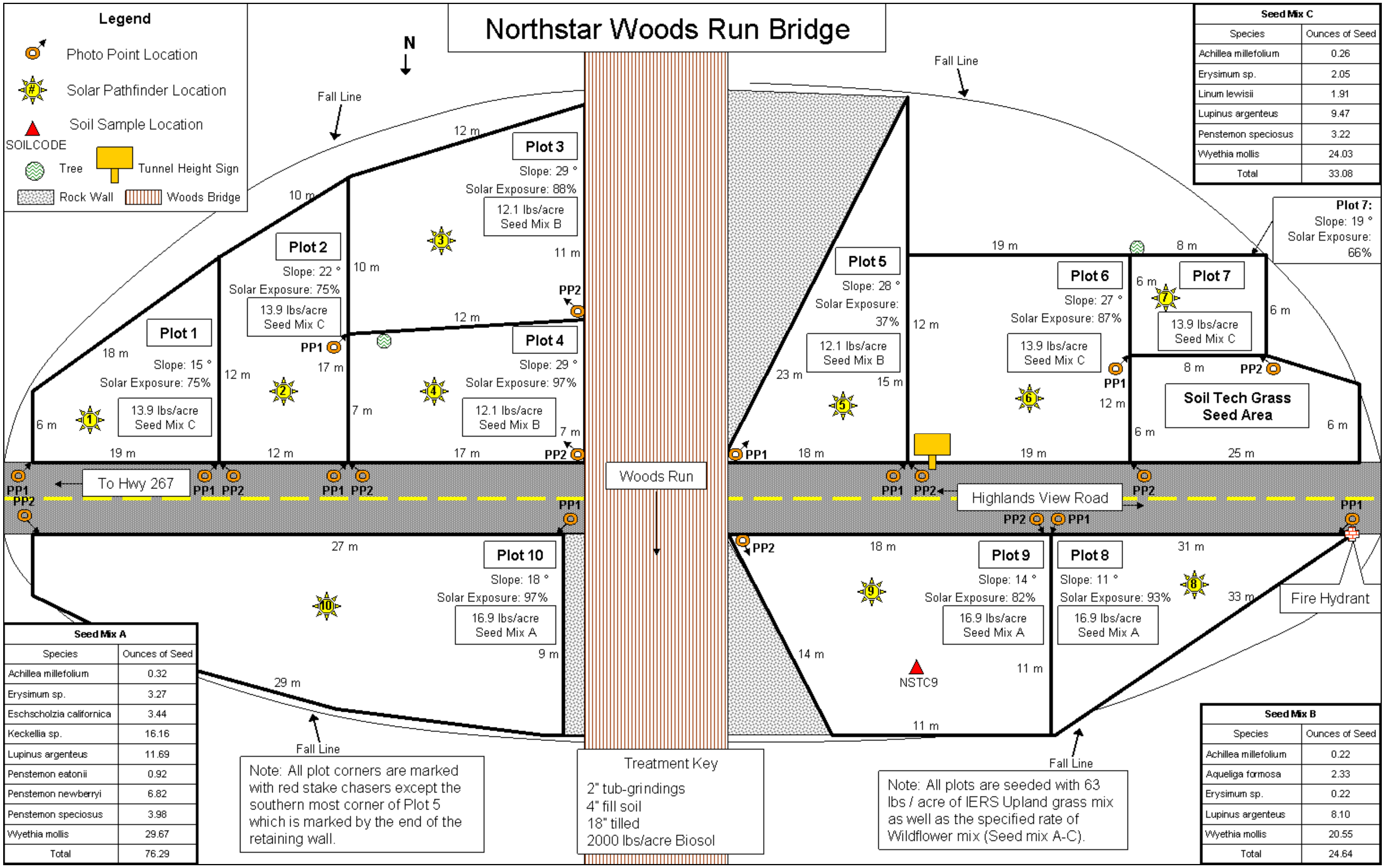
The test plots were initially disturbed during the construction of the Woods Run Bridge in 2006. Much of the native topsoil was disturbed during this construction. The slopes were formed from the remaining sub-soil and were mechanically compacted by heavy machinery. The soil parent material is volcanic in origin and has up to 15% coarse fragments greater than 0.5 inches (1.3 cm) in diameter in some areas. The site is surrounded by local native vegetation consisting of an open white and red fir (*Abies concolor* and *Abies magnifica*) canopy, with an understory of greenleaf manzanita (*Arctostaphylos patula*) and tobacco brush (*Ceanothus velutinus*). A few native bunchgrasses and forbs are also present. The solar exposure in the summer is an average of 91% at the wildflower mix A plots, 76% at the wildflower mix C plots, and 74% in the wildflower mix B plots. There is 15-20% canopy cover (Figure 3).

Native Reference Plot

The native reference plot is located near the Unit 7 test plots on the corner of Big Springs Drive and Overlook Place. The soil parent material is volcanic in origin with up to 65% coarse fragments. This plot was used for a native reference soil sample only.

Treatment Overview

In 2007, all 10 plots received full treatment with different variations of the wildflower seed mix (Figure 3). The treatments are explained in detail below and in Table 1. Some of the treatment abbreviations in Figure 3 will be used throughout the report. All plots were irrigated in 2007. The native reference plot was undisturbed and used as a soil nutrient reference for the full treatment plots.



Seed Mix A

Species	Ounces of Seed
Achillea millefolium	0.32
Erysimum sp.	3.27
Eschscholzia californica	3.44
Keckellia sp.	16.16
Lupinus argenteus	11.69
Penstemon eatonii	0.92
Penstemon newberryi	6.82
Penstemon speciosus	3.98
Wyethia mollis	29.67
Total	76.29

Seed Mix B

Species	Ounces of Seed
Achillea millefolium	0.22
Aqueliga formosa	2.33
Erysimum sp.	0.22
Lupinus argenteus	8.10
Wyethia mollis	20.55
Total	24.64

Seed Mix C

Species	Ounces of Seed
Achillea millefolium	0.26
Erysimum sp.	2.05
Linum lewisii	1.91
Lupinus argenteus	9.47
Penstemon speciosus	3.22
Wyethia mollis	24.03
Total	33.08

Figure 3. Map of the Northstar Woods Run Bridge test plots with treatment key. Photo points, soil sample, and Solar Pathfinder locations are marked. Seed mix A is called wildflower mix A throughout the report, similarly seed mix B and C are called wildflower mix B and wildflower mix C.

Test Plot Treatments

Test plot treatments are presented in Table 1. Descriptions of these treatments can be found following the table. Photos of the test plots before and after treatment are shown in Figure 4, Figure 5, Figure 6, Figure 7, Figure 8, Figure 9, Figure 10 and Figure 11.

Plot names are based on the supplemental seed mix (seed mix A-C) added to each plot. Seed mixes A through C are wild flower mixes designed to perform in various sun and shade conditions. Seed mix species are listed in Table 2, Table 3, Table 4, and Table 5.

Table 1. Woods Run Bridge Test Plots Treatments.

Plot	Plot Name	Amendment	Soil Loosening	Biosol Rate	Seed Type	Seed Rate	Mulch
1	Wildflower Mix C	2” tub grindings + 4” of fill soil	Tilled to 18”	2,000 (lbs/acre)	IERS Upland Mix + seed mix C	63 lbs/acre + 13.9 lbs/acre	Pine needle mulch 2”
2	Wildflower Mix C	2” tub grindings + 4” of fill soil	Tilled to 18”	2,000 (lbs/acre)	IERS Upland Mix + seed mix C	63 lbs/acre + 13.9 lbs/acre	Pine needle mulch 2”
3	Wildflower Mix B	2” tub grindings + 4” of fill soil	Tilled to 18”	2,000 (lbs/acre)	IERS Upland Mix + seed mix B	63 lbs/acre + 12.1 lbs/acre	Pine needle mulch 2”
4	Wildflower Mix B	2” tub grindings + 4” of fill soil	Tilled to 18”	2,000 (lbs/acre)	IERS Upland Mix + seed mix B	63 lbs/acre + 12.1 lbs/acre	Pine needle mulch 2”
5	Wildflower Mix B	2” tub grindings + 4” of fill soil	Tilled to 18”	2,000 (lbs/acre)	IERS Upland Mix + seed mix B	63 lbs/acre + 12.1 lbs/acre	Pine needle mulch 2”
6	Wildflower Mix C	2” tub grindings + 4” of fill soil	Tilled to 18”	2,000 (lbs/acre)	IERS Upland Mix + seed mix C	63 lbs/acre + 13.9 lbs/acre	Pine needle mulch 2”
7	Wildflower Mix C	2” tub grindings + 4” of fill soil	Tilled to 18”	2,000 (lbs/acre)	IERS Upland Mix + seed mix C	63 lbs/acre + 13.9 lbs/acre	Pine needle mulch 2”
8	Wildflower Mix A	2” tub grindings + 4” of fill soil	Tilled to 18”	2,000 (lbs/acre)	IERS Upland Mix + seed mix A	63 lbs/acre + 16.9 lbs/acre	Pine needle mulch 2”
9	Wildflower Mix A	2” tub grindings + 4” of fill soil	Tilled to 18”	2,000 (lbs/acre)	IERS Upland Mix + seed mix A	63 lbs/acre + 16.9 lbs/acre	Pine needle mulch 2”
10	Wildflower Mix A	2” tub grindings + 4” of fill soil	Tilled to 18”	2,000 (lbs/acre)	IERS Upland Mix + seed mix A	63 lbs/acre + 16.9 lbs/acre	Pine needle mulch 2”

Figure 4. Woods Run Bridge test plots, plots 1-4, post treatment, September 2007.

Figure 5. Woods Run Bridge test plots, plots 1-4, 1 year following treatment, September 2008.

Figure 6. Woods Run Bridge test plots, plots 5-7, post treatment, September 2007.

Figure 7. Woods Run Bridge test plots, plots 5-7, 1 year following treatment, September 2008.

Figure 8. Woods Run Bridge test plots, plots 8 and 9, post treatment, September 2007.

Figure 9. Woods Run Bridge test plots, plots 8 and 9, 1 year following treatment, September 2008.

Figure 10. Woods Run Bridge test plots, plot 10, post treatment, September 2007.

Figure 11. Woods Run Bridge test plots, plot 10, 1 year following treatment, September 2008.

Soil Loosening

All test plots were tilled to a depth of approximately 18 inches (46 cm) by a rubber-tracked excavator (Cat 322) using a 48-inch (122 cm) bucket.

Amendments

Two types of amendments were incorporated at the full treatment test plots during tilling: tub grindings and fill soil. Each is described in detail below.

Tub Grindings

The Type 1 tub grindings were obtained at Northstar and are composed of only raw trees, not the processed construction wood that comprises some tub grindings. Type 1 tub grindings often include root material with attached soil and often possess more nutrients than woodchips. Tub grindings have a high surface area and are longer, narrower, and coarser than woodchips. The tub grindings were spread to a depth of 2 inches (5 cm) and tilled to a depth of 18 inches (46 cm) at all plots.

Fill Soil

Fill soil was obtained from Northstar, though it is not known from which 2006 construction location it originated. Fill soil was spread to a depth of 4 inches (10 cm) tilled in with the tub grindings to a depth of 18 inches (46 cm). The nutrient condition of the fill soil is also unknown.

Fertilizer

Following incorporation of amendments, Biosol, a slow release fertilizer, was applied and raked approximately 1 inch (2.5 cm) into the soil at a rate of 2,000 lbs/acre (2,241 kg/ha).

Seeding

After fertilizer application, suitable native perennial grasses, forbs, and shrubs were seeded at a rate of 63 lbs/acre (71 kg/ha; Figure 3 and Table 2). In addition, plots received an additional wild flower mix based. All seed was lightly raked into the soil to ensure contact.

Table 2. IERS Upland mix (all plots)

Common Name	*Scientific Name*	% Pure Live Seed
Mountain brome	*Bromus carinatus*	34.0%
Blue wildrye	*Elymus glaucus*	26.0%
Squirreltail	*Elymus elymoides*	26.0%
Antelope bitterbrush	*Purshia tridentata*	8.2%
Sulphur flower buckwheat	*Eriogonum umbellatum*	3.5%

% Pure live seed is approximate

Table 3. Wildflower mix A (plots 8-10)

Common Name	*Scientific Name*	% Pure Live Seed
Mule ears	*Wyethia mollis*	38.90%
Bush penstemon	*Keckellia sp.*	21.20%
Silver lupine	*Lupinus argenteus*	15.30%
Mountain pride	*Penstemon newberryi*	8.90%
Royal beardtongue	*Penstemon speciosus*	5.20%
California poppy	*Eschscholzia californica*	4.50%
Wall flower	*Erysimum sp.*	4.30%
Eaton firecracker	*Penstemon eatonii*	1.20%
Yarrow	*Achillea millefolium*	0.42%

Table 4. Wildflower Mix B (plots 3-5)

Common Name	*Scientific Name*	% Pure Live Seed
Mule ears	*Wyethia mollis*	65.40%
Silver lupine	*Lupinus argenteus*	25.80%
Western columbine	*Aguilegia formosa*	7.40%
Yarrow	*Achillea millefolium*	0.70%
Wall flower	*Erysimum sp.*	0.70%

Table 5. Wildflower Mix C (plots 1-2 and 6-7)

Common Name	*Scientific Name*	% Pure Live Seed
Mule ears	*Wyethia mollis*	59.70%
Silver lupine	*Lupinus argenteus*	23.10%
Royal beardtongue	*Penstemon speciosus*	7.90%
Wall flower	*Erysimum sp.*	5.00%
Blue flax, Lewis flax	*Linum lewisii*	4.70%
Yarrow	*Achillea millefolium*	0.64%

Planting

All plots received native shrub and tree plantings. A detailed list of planted species and locations is not available. All plots received about the same number of plantings.

Irrigation

Irrigation was employed in 2007 and was applied when soil moisture levels indicated it was necessary. MP rotator heads were used at a rate of 4 gal/min (15 L/min) to irrigate the slopes. This style of irrigation head delivers water at a low flow and conserves water relative to high flow irrigation. A soil moisture probe was used to measure and maintain adequate moisture levels. A deep watering cycle was used initially to soak the soil; then two to three hour cycles were used to keep moisture levels high to encourage seed germination. During the summer irrigation may have occurred daily, depending on soil moisture readings.

After seed germination, the irrigation schedule was changed to three times a week for two weeks to encourage plant roots to penetrate deeper into the soil, where moisture levels were high. Once the vegetation was established and approximately 2 to 3 inches (5.1-7.6 cm) in height, the schedule was reduced to once a week to maintain moisture at depth of 8 inches (20 cm). Irrigation continued as necessary to maintain moisture at the 8 inch (20 cm) depth.

In the fall, the moisture levels were reduced so that the vegetation would slowly become dormant in preparation for winter.

Mulch

Mulch was spread evenly by hand to achieve 99% cover at a depth of 2 inches (5 cm) on all full treatment test plots.

Monitoring Methods

The test plots were monitored in 2008. Additionally, in 2008, monitoring was conducted at a native reference plot for soil nutrients. In the text, both English and metric units will be given, however, tables will contain one or the other.

Cover

Cover point monitoring was conducted at the test plots in September of 2008.

Cover is measured using the statistically defensible cover point method along randomly located transects.[1] The cover pointer consists of a metal rod with a laser pointer mounted 3.3 ft (1 m) high. After the rod is leveled in all directions, the button on the laser pointer is depressed and two cover measurements are recorded (Figure 12 and Figure 13):

- the first hit cover, which is the first object intercepted starting from a height of 3.3 ft (1 m) above the ground
- the ground cover hit, which is the low-lying vegetation or soil below the first hit cover, at the ground level

The first hit cover measures the foliar cover by plants (leaves and stems). It does not measure the part of the plant rooted in the ground. The first hit vegetation is then moved aside and a ground cover hit measures the presence of litter/mulch, basal (or rooted) plant cover, rock and woody debris, and/or bare ground. Total ground cover represents any cover other than bare ground.

Figure 12. Cover pointer in use along transects.

Figure 13. Cover pointer rod with first hit and ground cover hit by the laser pointer. The laser pointer hits are circled in red. The first cover hit is a native grass and the ground cover hit is pine needle mulch.

Foliar and ground level plant cover is recorded by species and then organized into cover groups based on four categories: life form (herbaceous/woody), perennial/annual, native/alien, and seeded/volunteer. Perennial herbaceous species includes seeded grasses, native grasses and forbs, and any non-native perennial species. Annual herbaceous species include native annuals such as knotweed (*Polygonum sp.*) and invasive species such as

[1] Hogan, M. 2003. Luther Pass Monitoring Report: Plant and Soil Cover Monitoring for Evaluating Sediment Source Control Success in the Lake Tahoe Basin. Lahontan Regional Water Quality Control Board, South Lake Tahoe, CA.

cheatgrass (*Bromus tectorum*). Woody species includes any tree or shrub species, either native or introduced. Each species is then classified based on whether it is native to the Tahoe area, and whether it was seeded during treatment. Data is presented on the amount of cover by species. An ocular estimate of cover at each plot is also recorded and includes many species not hit using cover point sampling. The species lists, as well as the ocular estimates of cover by species, are presented in Appendix A.

Soil and Site Physical Conditions

Penetrometer Depth to Refusal and Soil Moisture

Penetrometer depth to refusal (DTR) and soil moisture were measured 10 times at random for each plot. A cone penetrometer with a ½ inch diameter tip is pushed straight down into the soil until a maximum pressure of 350 pounds per square inch (2,413 kPa) is reached (Figure 14 and Figure 15). The depth at which that pressure is reached is recorded as the DTR.

Cone penetrometer DTR measurements are used as an index for soil density. Soils with higher DTRs are generally less dense than those with lower DTRs. A denser soil is less likely to allow infiltration. Rainfall simulations conducted on roadcuts in Oregon found increased infiltration rates in soils with DTRs greater than 4 inches (10 cm).[2]

It is most informative to compare penetrometer DTR measurements collected in soils that have similar moisture levels. When soil moisture content increases, the resistance of the soil to the penetrometer decreases and DTR readings are deeper. Therefore, only penetrometer readings at the same soil moisture can be compared. A hydrometer was used to measure volumetric soil moisture content adjacent to the penetrometer readings at a depth of 4.7 inches (12 cm; Figure 16).

[2] Grismer, M.E. 2006. Simulated Rainfall Evaluation at Sunriver and Mt. Bachelor Highways, Oregon. Unpublished.

Figure 14. Photo of a cone penetrometer dial, showing pressure applied in pounds per square inch.

Figure 15. Photo of conducting cone penetrometer readings along transects.

Solar Exposure

In 2007, solar exposure measurements were taken at each test plot. These measurements are taken using a Solar Pathfinder (Figure 17). Since there was no change in solar obstructions at the test plots, the solar pathfinder data was not collected again in 2008. Solar input affects evaporation rates and soil temperature, which may affect time of seed germination, germination rate, rate of plant growth, and soil microbial activity. Therefore, this is an important variable to consider when monitoring plant growth and soil development.

Figure 16. Conducting soil moisture readings along transects.

Figure 17. Solar pathfinder in use.

Soil Nutrient Analysis

Successful re-vegetation requires that nutrient capital be stored in the soil for release over time. Sufficient organic matter and a functioning microbial community are necessary to provide a long-term source of nitrogen for plants. Previous studies of soil nutrient levels at revegetation sites throughout the Tahoe area found that sites with high plant cover had significantly higher soil nutrients over the long-term than soils with lower plant cover levels.[3] Total Kjeldahl nitrogen and organic matter were used as indicators of soil health in this study. Total Kjeldahl nitrogen (TKN) is a measure of readily available nitrogen. Only three soil sub-samples were taken from each plot; therefore, differences in TKN and organic matter values may be a result of the variability within a plot.

In 2008, soil samples were taken from test plot 9 and the native reference plot (Figure 3). Three soil sub-samples at each plot were collected from the mineral soil beneath any mulch layer to a depth of 12 inches (30 cm; Figure 18). These sub-samples were combined and sieved to remove any material larger than 0.08 inches (2 mm) in diameter, and sent to A&L Laboratories in Modesto, California for the S3C nutrient suite (macro and micronutrients), total Kjeldahl nitrogen (TKN), and organic matter analysis.

Figure 18. Soil sub-sample collection.

Results and Discussion

Soil Moisture

Soil moisture ranged from 6.2 to 9.2% among plots (Figure 19). The slightly lower soil moisture at the wildflower mix A plots was most likely is due to the higher solar exposure at these plots.

[3]Claassen, V.P., and M.P. Hogan. 2002. Soil Nutrients Associated with Revegetation of Disturbed Sites in the Lake Tahoe Basin. Restoration Ecology 10:195-203.

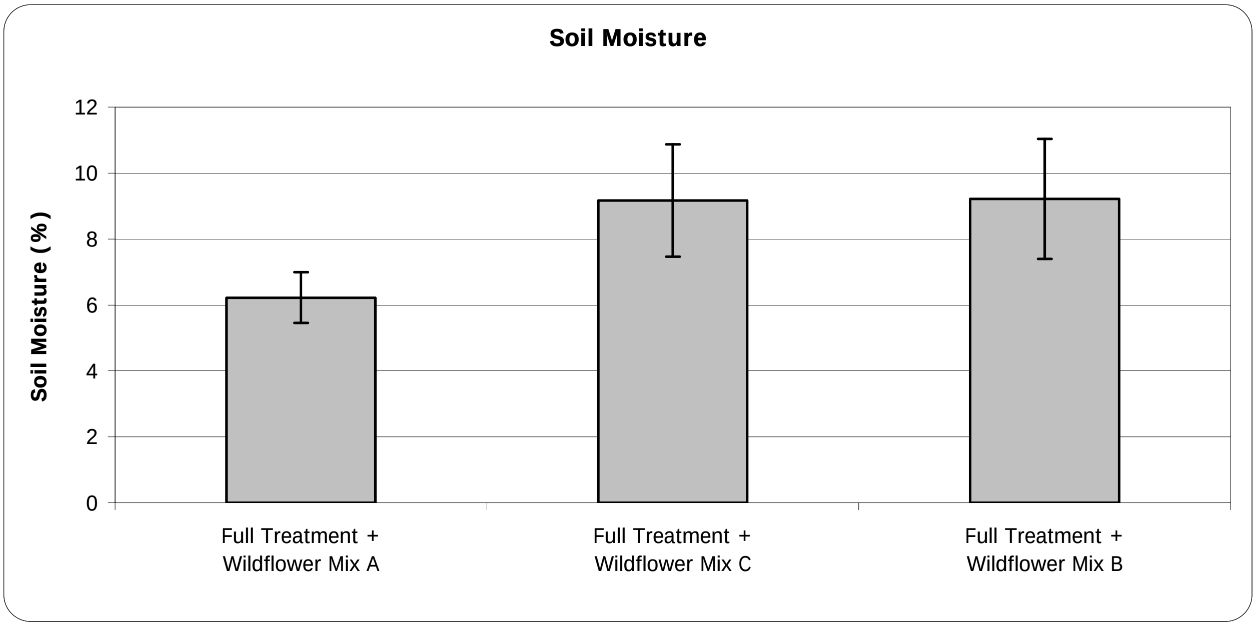


Figure 19. Soil Moisture. Soil moisture levels were similar across all plots. The wildflower mix A plots had slightly lower soil moisture, most likely due to the higher solar exposure. The error bars represent one standard deviation above and below the mean. Data is sorted by increasing soil moisture.

Penetrometer Depth to Refusal

Penetrometer DTRs measured in the full treatment plots ranged from 2.4 to 3.3 inches (6.1-8.4 cm; Figure 19). The penetrometer DTRs were 5.5 to 8.2 times shallower than the tilling depth of 18 inches (46 cm) and were unusually shallow for an area that had been tilled one year previously. One possible explanation is that the slopes were re-compacted after tilling during the landscaping process. Crew members frequently walked up and down the slopes, carrying plants and tools.It may also be possible that the tilling depth did not reach the 18 inches (46 cm), as in the specification. Tilling depths were not verified following the restoration. It is also possible that the nature of the volcanic soil at this site allowed for re-compaction and that a higher proportion of woody material, which can help reduce soil re-compaction, should be considered for future projects.

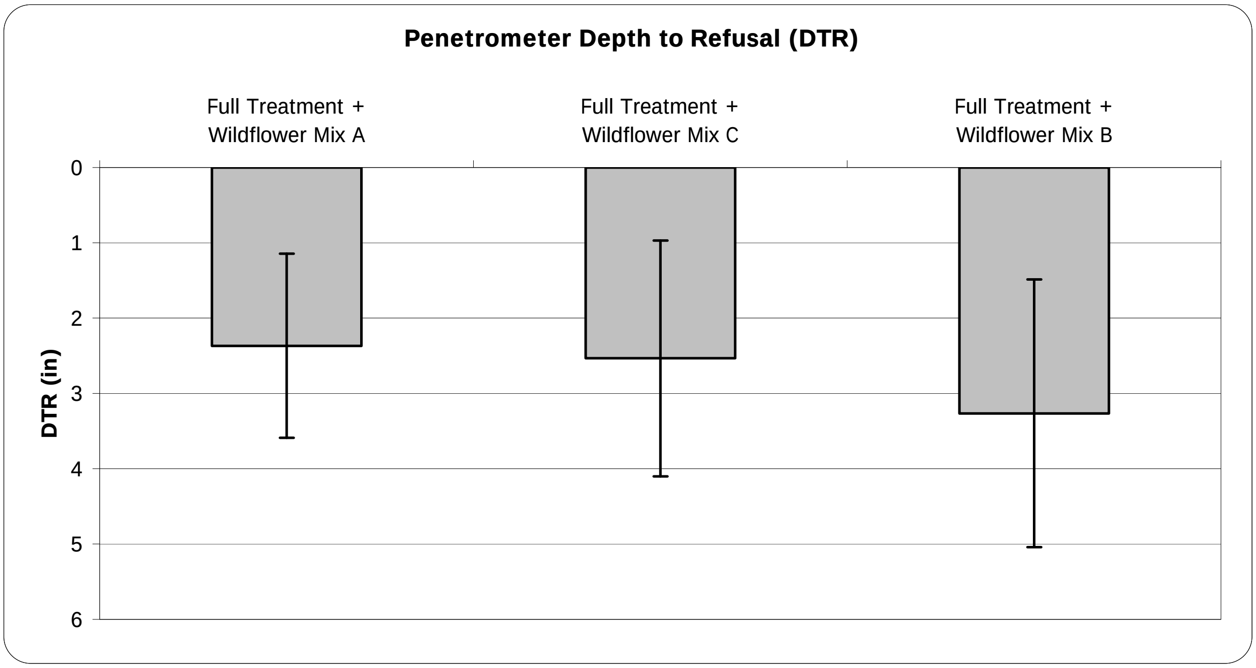


Figure 20. Penetrometer DTR. The penetrometer DTR ranged between 2.4 to 3.3 inches (6.1-8.4 cm) for all the plots. The error bars represent one standard deviation above and below the mean. Data is sorted by decreasing penetrometer DTR.

Cover

Ground Cover by Mulch and Bare Soil

Mulch cover ranged from 83 to 88% across the plots (Figure 21). Mulch cover is an important variable in erosion reduction through sediment source control because treatments with cover by pine needle mulch have been shown to reduce sediment yields substantially.[4]

Pine needle movement was observed in plots 2, 3, and 4. These plots should be re-evaluated in 2009, as pine needle movement is often an indicator of water erosion. However, in this case it may be a result of the excessive foot traffic during planting.

Ground cover by bare soil ranged from 2 to 4% across the plots (Figure 22).

[4] Grismer, M.E., and M.P. Hogan. 2004. Simulated rainfall evaluation of revegetation/mulch erosion control in the Lake Tahoe Basin: 1. Method assessment. Land Degradation & Development 15:573-588

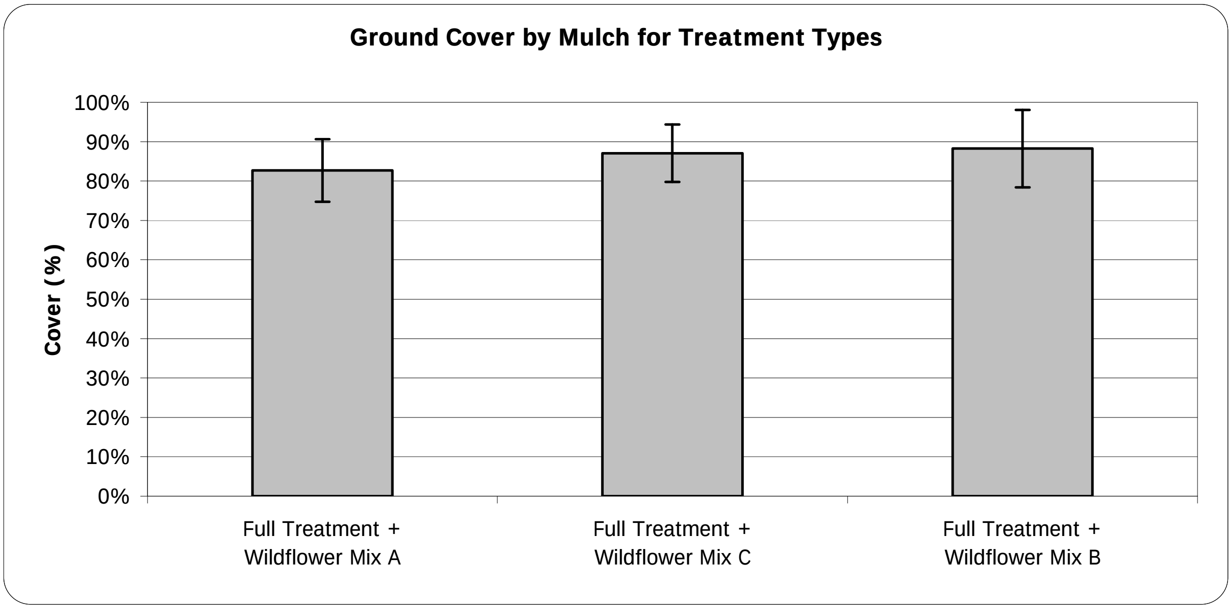


Figure 21. Ground Cover by Mulch for Treatment Types. The mulch cover ranged from 83 to 88% across the plots. The error bars represent one standard deviation above and below the mean. Data is sorted by increasing mulch cover.

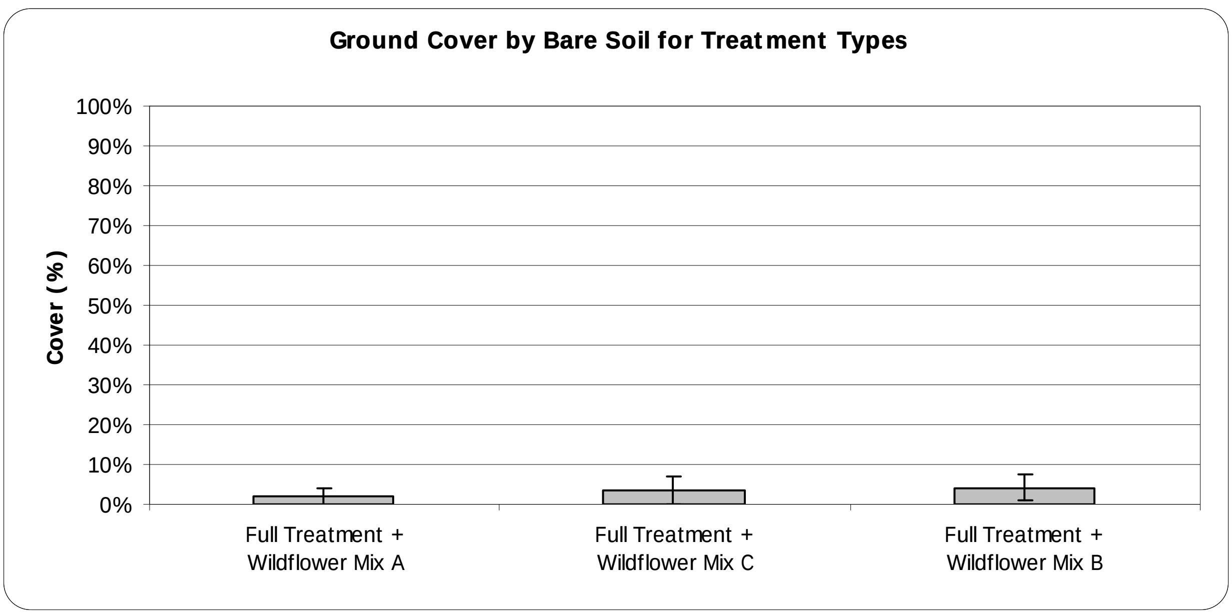


Figure 22. Ground Cover by Bare Soil for Treatment Types. The cover by bare soil ranged from 2 to 4% across the plots. The error bars represent one standard deviation above and below the mean. Data is sorted by increasing bare soil.

Plant Cover and Composition

Trends by Wildflower Mix

Foliar plant cover was the highest in the wildflower mix A plots at an average of 23%. Foliar cover was 2.3 times higher compared to the wildflower mix B plots (average of 10%) and 2.1

times higher compared to the wildflower mix C plots (average of 11%; Figure 23). Seeded and planted cover composed of 92 to 100% percent of total cover at all plots. The wildflower mix B plot had 100% cover by seeded or planted plants. Average foliar cover by seeded grasses was 3.3 times higher at the wildflower mix A plots (17%) compared to the wildflower mix C and wildflower mix B plots, which both had 5% cover by seeded grasses (Figure 24). Average cover by mountain brome was 3.6 times higher at the wildflower mix A plots (16%) compared to the wildflower mix B plots (4%) and 3.1 times higher compared to the wildflower mix C plots (5%; Figure 24). All plots were seeded with the same amount of mountain brome.

It is unclear why foliar, seed, and mountain brome cover was highest at the wildflower mix A plots. It is possible that these plots were less disturbed by foot traffic from plant than the others because the slope angles were gentler. Slope angles were 11 to 18 degrees at plots with wildflower mix A compared to 15 to 29 degrees at the wildflower B and C plots (Figure 3). In addition, the wildflower mix A plots were south facing, while the other plots were north to northeast-facing. The difference aspect may be related to the plant cover.

Cover by the wildflower mixes ranged from 0% at the wildflower mix A plots, to 0.4% at the wildflower mix B plots, to 1.5% at the wildflower mix C plots. Cover by the wildflower mix was low overall in the first season after treatment; therefore, further study is necessary to determine which seed mix will produce the most cover.

Planted trees and shrubs composed approximately 3 to 5% of the foliar cover (Figure 24). Success of planted trees and shrubs cannot be compared between plots because accurate records of plantings were not kept during the restoration process.

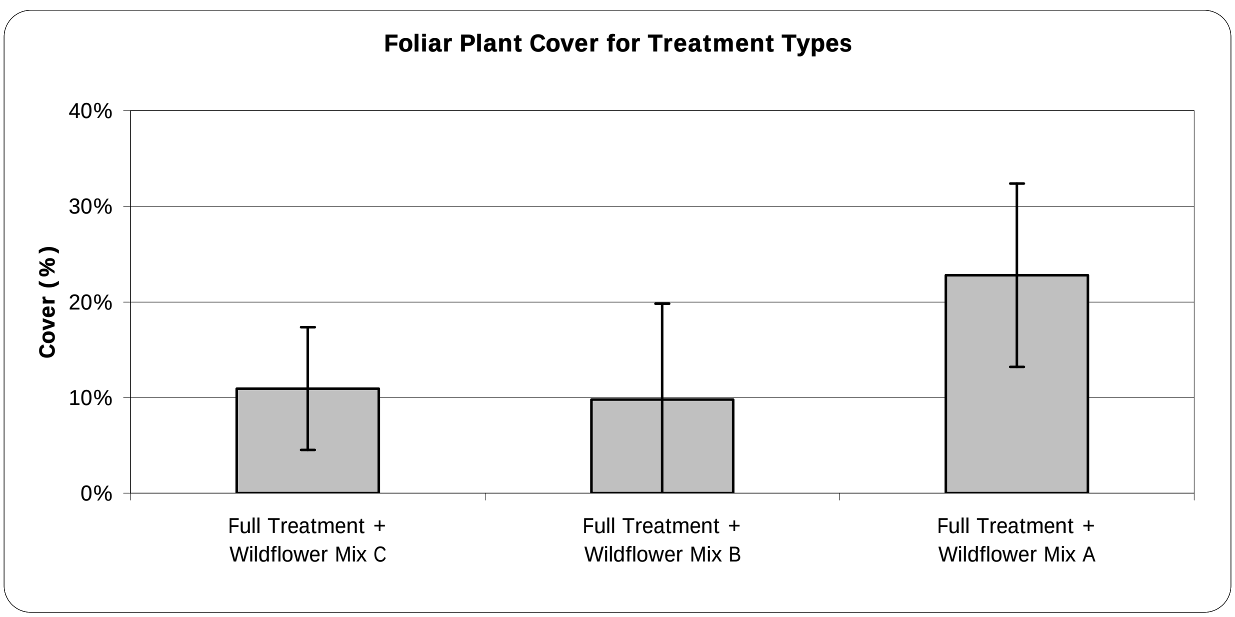


Figure 23. Foliar Cover for Treatment Type. Plant cover was 2.1 to 2.3 times higher at the wildflower mix A plots (23%) when compared to the wildflower mix C plots (11%) and the plots (10%). The error bars represent one standard deviation above and below the mean. Data is sorted by increasing foliar plant cover.

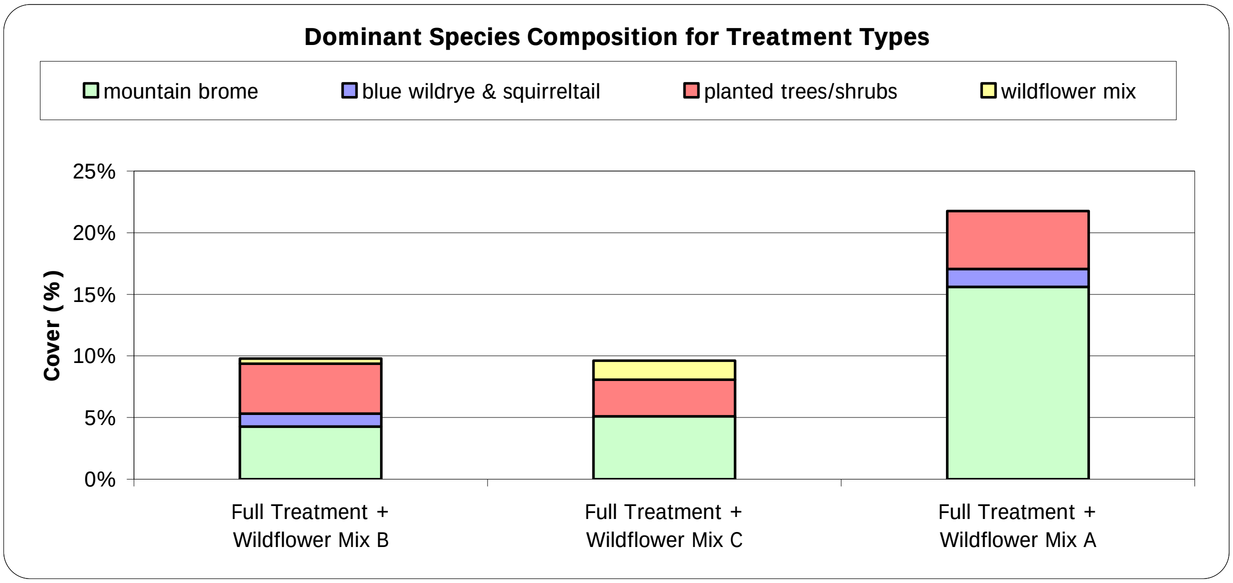


Figure 24. Dominant Species Composition for Treatment Type. Mountain brome was the dominant species at the full treatment plots. Data is sorted the same way as the previous graph for easy comparison.

Soil Nutrients

TKN was 1.2 times higher at the native reference plot (1,944 ppm) than at the Woods Run Bridge (1,681 ppm), which received full treatment (Figure 25). Organic matter was 2.3 times higher at the native reference plot (14.4%) than at the Woods Run Bridge (6.2%), which received full treatment (Figure 25). The low organic matter level suggests that a higher proportion of soil amendments or a different composition of amendments is necessary to re-capitalize the soil.

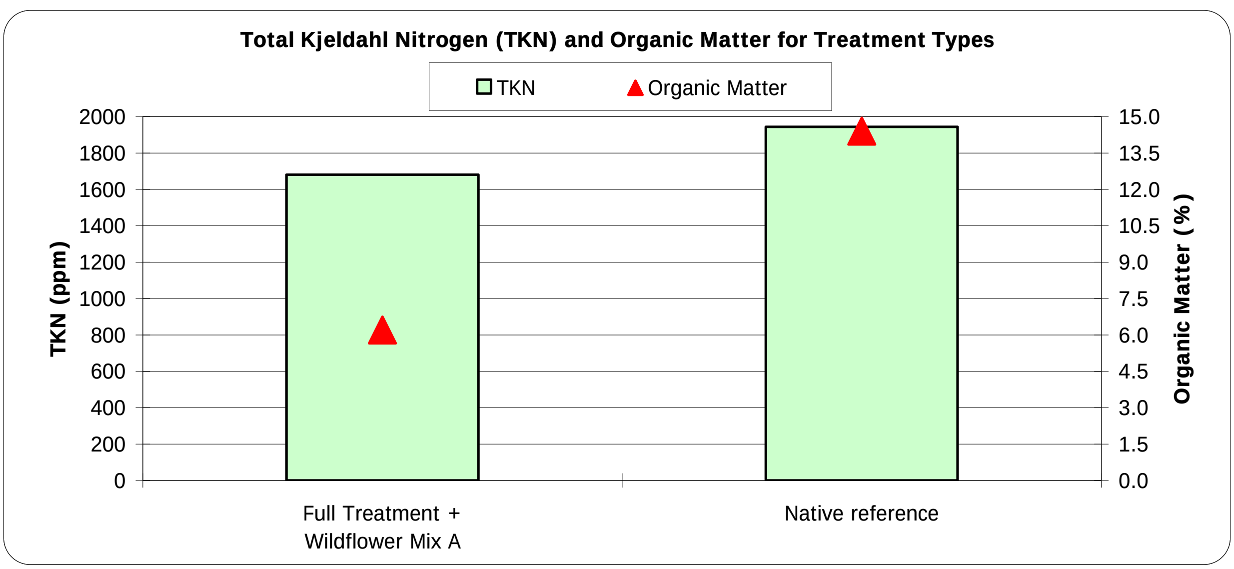


Figure 25. Total Kjeldahl Nitrogen and Organic Matter for Treatment Types. TKN was 1.2 times higher at the native reference plot (1,944 ppm) compared to the full treatment plots (1,681 ppm). Organic Matter was 2.3 times higher at the native reference plot (14.4% compared to the full treatment plots (6.2%). Data is sorted by increasing TKN for 2008.

Recommendations

These recommendations are for sites with rocky soils on volcanic parent material, with slope angles between 10 and 30 degrees, solar exposures of 37-97% during the summer months, at 6,762 feet (2,061 meters) AMSL:

Tilling: 18 inches (46 cm)

Amendment: 7 inches (18 cm) tub grindings

Biosol: 2,000 lbs/acre (2,241 kg/ha)

Grass/Shrub/Forb Seed: 63 lbs/acre (71 kg/ha) seed with the following composition:

squirreltail: 26%
mountain brome: 34%
blue wildrye: 26%
antelope bitterbrush: 8.2%
eriogonum umbellatum: 3.5%

Wildflower Seed: 12 to 17 lbs/acre (13.5 -19 kg/ha)

royal beardtongue
wall flower
Western columbine
blue flax (Lewis flax)

Mulch: pine needles, 2 inches (5 cm) and 99% cover

Soil Loosening

Soil loosening is recommended at the tested depth, 18 inches (46 cm), in conjunction with an increased amendment depth to reduce the occurrence of soil re-compaction.

Amendment Type and Rate

Tub grindings are recommended at a depth of 7 inches (18 cm) instead of the applied 2 inches (5 cm) because penetrometer DTRs were 5.5 to 8.2 time shallower than the tilling depth of 18 inches (46 cm). Additional application of a coarse amendment, such as tub grindings, may reduce the occurrence of soil re-compaction.

Biosol Rate

Biosol is recommended at the applied rate of 2,000 lbs/acre (2,241 kg/ha) because first year plant growth was between 10 and 23%.

Seed Mix and Rate

Grass/shrub/forb seed is recommended at 50 lbs/acre (56 kg/ha) seed with the composition below because this mix produced 4 to 16%, with all seeded species present in the first year after treatment (Appendix A).

squirreltail: 26%
mountain brome: 34%
blue wildrye: 26%
antelope bitterbrush: 8.2%
eriogonum umbellatum: 3.5%

Wildflower mix is recommended at 12 to 17 lbs/acre (13.5-19 kg/ha), composed of some or all of the following species:

royal beardtongue
wall flower
western columbine
blue flax (Lewis flax)

Although first year cover by wildflowers was less than 5%, the intended effect was achieved – a more visually aesthetic landscape.

Mulch Type and Depth

Native pine needle mulch is recommended to a depth of 2 inches (5 cm) and 99% cover. This application depth was effective, as average mulch cover was greater than 80% at the plots.

Irrigation

Use of low flow irrigation with water-conserving heads (for example: MP rotator heads) at 4 gal/min (15 L/min), is recommended with the following schedule:

Initial: A deep watering cycle, then two to three hour cycles to keep moisture levels high to encourage seed germination.

After germination: three times a week for two weeks to encourage plant roots to penetrate deeper into the soil, where moisture levels are high.

After vegetation reaches 2-3 inches (5.1-7.6 cm) in height: once a week or as needed to maintain moisture at depth of 8 inches (20 cm).

Late fall: schedule reduced to less than once a week to encourage dormancy in preparation for winter.

For the following reasons:

- First-year plant growth ranged from 10 to 23%. It has been observed in some areas amended with tub grindings without irrigation that first year plant cover is less than 5%

- Visual signs of erosion were not present that are commonly observed after irrigation with higher flow systems (rills)

Appendix A

Species list and ocular estimates for Northstar Woods Run Bridge Test Plots, 2008.

Lifeform	Family	Scientific name	Common name	Annual/ Perennial	Native/ Alien	Noxious	Planted	% IERS seed mix	% in seed mix C	Plot 1	Plot 2	% in Seed mix B	Plot 3	Plot 4	Plot 5	% in seed mix C	Plot 6	Plot 7	% in seed mix A	Plot 8	Plot 9	Plot 10
Forb	Asteraceae	*Achillea millefolium*	yarrow	Perennial	Native				0.64%	T		0.7%				0.64%			0.42%			1
Forb	Ranunculaceae	*Aguilegia formosa*	columbine, crimson columbine	Perennial	Native						T	7.4%		T	T						T	T
Forb	Asteraceae	*Anthemis tinctoria*	golden marguerite	Perennial	Alien										T		T	T				
Forb	Chenopodiaceae	*Chenopodium album*	goosefoot	Annual	Alien					T				T	T		T					T
Forb	Onagraceae	*Clarkia sp.*	clarkia	Annual	Native						T											
Forb	Scrophulariaceae	*Collinsia parviflora*	blue-eyed mary	Annual	Native												T					
Forb	Boraginaceae	*Cryptantha ambigua*	Wilke's cryptantha	Annual	Native																	T
Forb	Boraginaceae	*Cryptantha watsonii*	Watson's cryptantha	Annual	Native												T					
Forb	Brassicaceae	*Descurainia sophia*	herb Sophia	Annual	Alien	Invasive																
Forb	Polygonaceae	*Eriogonum umbellatum*	sulphur flower buckwheat	Perennial	Native			3.51%		T			T		T		T	T			T	
Forb	Brassicaceae	*Erysimum sp*	wall flower	Perennial	Native				5.0%	T	T	0.7%	T	T	2	5.0%	T	5	4.3%	T	T	T
Forb	Papaveraceae	*Eschscholzia californica*	California poppy	both	Native														4.5%			
Forb	Onagraceae	*Gayophytum sp*	groundsmoke	Annual	Native					T					T		T	T				
Forb	Polemoniaceae	*Gilia sp.*	gilia	Annual	Native										T		T					
Forb	Asteraceae	*Lactuca serriola*	devil's lettuce	Annual	Alien	Of concern											T					
Forb	Brassicaceae	*Lepidium campestre*	English pepperweed	Annual	Alien					T	T						T			1	T	T
Forb	Linaceae	*Linum lewisii*	blue flax, Lewis flax	Perennial	Native				4.7%		T					4.7%						
Forb	Fabaceae	*Lupinus argenteus*	silver lupine	Perennial	Native				23.1%		1	25.8%				23.1%			15.3%			
Forb	Fabaceae	*Lupinus sp*	lupine	Perennial	Native		Yes						T		T		T				T	2P
Forb	Fabaceae	*Melilotus sp*	sweet clover	Annual	Alien												T					
Forb	Lamiaceae	*Monardella odoratissima*	mountain monardella	Perennial	Native																	
Forb	Scrophulariaceae	*Penstemon eatonii*	Eaton firecracker	Perennial	Native														1.2%			
Forb	Scrophulariaceae	*Penstemon newberryi*	mountain pride	Perennial	Native														8.9%			
Forb	Scrophulariaceae	*Penstemon sp.*	penstomen	Perennial	Native					T	T											T
Forb	Scrophulariaceae	*Penstemon speciosus*	royal beardtongue	Perennial	Native				7.9%							7.9%	T	T	5.2%			
Forb	Hydrophyllaceae	*Phacelia hastata*	silverleaf phacelia	Perennial	Native										T			T				
Forb	Polemoniaceae	*Phlox gracilis*	slender phlox	Annual	Native																	
Forb	Plantaginaceae	*Plantago lanceolata*	English plantain	Perennial	Alien	Invasive																
Forb	Polygonaceae	*Polygonum douglasii*	Douglas knotweed	Annual	Native						T									T		
Forb	Brassicaceae	*Sisymbrium altissimum*	tumble mustard	Annual	Alien					T												
Forb	Scrophulariaceae	*Verbascum thapsus*	mullen	Annual	Native	Invasive									T			T				
Forb	Asteraceae	*Wyethia mollis*	mule ears	Perennial	Native				59.7%			65.4%				59.7%			38.9%			
Graminoid	Poaceae	*Bromus carinatus*	mountain brome	Perennial	Native			26.0%		11	12		6	15	T		T	T		25	6	20

Lifeform	Family	Scientific name	Common name	Annual / Perennial	Native / Alien	Noxious	Planted	% IERS seed mix	% in seed mix C	Plot 1	Plot 2	% in Seed mix B	Plot 3	Plot 4	Plot 5	% in seed mix C	Plot 6	Plot 7	% in seed mix A	Plot 8	Plot 9	Plot 10
Graminoid	Poaceae	*Bromus tectorum*	cheatgrass	Annual	Alien	Invasive				T										T		
Graminoid	Poaceae	*Elymus elymoides*	Squirreltail	Perennial	Native			26.0%			T		T	T			T	T		T	T	2
Graminoid	Poaceae	*Elymus glaucus*	blue wildrye	Perennial	Native			34.0%					T		T		T	T		T		T
Graminoid	Poaceae	*Lolium multiflorum*	Italian rye grass	Annual Biennial	Alien																	
Graminoid	Poaceae	*Elytrigia intermedia*	intermediate wheatgrass	Perennial	Alien																	T
Shrub	Rosaceae	*Amelanchier alnifolia*	service berry	Perennial	Native		Yes							T			T	T				
Shrub	Rhamnaceae	*Ceanothus prostratus*	Squaw carpet	Perennial	Native												T					
Shrub	Rhamnaceae	*Ceanothus velutinus*	tobacco brush or snow brush	Perennial	Native												T					
Shrub	Scrophulariaceae	*Keckiella sp.*	keckiella	Perennial	Native														21.2%			
Shrub	Rosaceae	*Prunus emarginata*	bitter cherry	Perennial	Native		Yes						T									
Shrub	Rosaceae	*Purshia tridentata*	antelope bitterbrush	Perennial	Native			8.2%		T	T		T		T		T	T		T	1	T
Shrub	Grossulariaceae	*Ribes cereum*	Wax currant	Perennial	Native												T/T					
Shrub	Grossulariaceae	*Ribes nevadense*	sierra currant,	Perennial	Native		Yes															
Shrub	Grossulariaceae	*Ribes sp*	currant	Perennial	Native					T	T		T	1P	T					T	T	T
Shrub	Grossulariaceae	*Ribes viscosissimum*	sticky currant	Perennial	Native		Yes											T				
Shrub	Rosaceae	*Rosa woodsii*	Woods' rose	Perennial	Native		Yes				T		T	T	1P			2		T	T	T
Shrub	Rosaceae	*Rubus parviflorus*	thimbleberry	Perennial	Native										T							
Shrub	Rosaceae	*Rubus spectabilis*	salmon berry	Perennial	Native															T		
Shrub	Caprifoliaceae	*Sambucus sp.*	red elderberry	Perennial	Native		Yes															
Shrub	Rosaceae	*Sorbus californica*	California mountain ash	Perennial	Native																	T
Shrub	Rosaceae	*Spiraea densiflora*	mountain spiraea	Perennial	Native									T			T					
Tree	Pinaceae	*Abies concolor*	white fir	Perennial	Native												T					
Tree	Pinaceae	*Abies magnifica*	red fir	Perennial	Native								1									
Tree	Rosaceae	*Cercocarpus ledifolius*	curl leaf mountain mahogany	Perennial	Native		Yes															
Tree	Pinaceae	*Pinus jeffreyi*	Jeffrey pine	Perennial	Native		Yes			1	2		1	2	1		T				T	2
TOTAL PERCENT COVER (transects)										11	16		4	18	7		4	12.5		25	18	25
TOTAL PERCENT COVER (ocular estimate)										14	15		9	18	7		5	6		27	8	24

Resort at Squaw Creek Site Report

May 2009

Introduction

Monitoring results and erosion control treatment recommendations for six plots at the Resort at Squaw Creek in Placer County, California, will be presented in this report (Figure 1). Monitoring was conducted from 2003 to 2008 at the plots, which are located in three areas on a ski slope uphill from the resort facilities. The first two areas, Old Reveg and Snow King, are located below the Juniper Mountain saddle (Figure 2). Old Reveg has two plots, which were hydroseeded in 1991. One was modified in 2003 and both were designated for testing in 2003. Snow King has three plots that were constructed in 2002. The third area contains the native reference plot and is located downhill of the first two areas, beside a groomed ski run in an undisturbed area. Although these plots are located at a ski area rather than on a roadside, the monitoring results from the tests at these areas will be applicable to Caltrans roadside projects Basin-wide and throughout the Sierra Nevada.

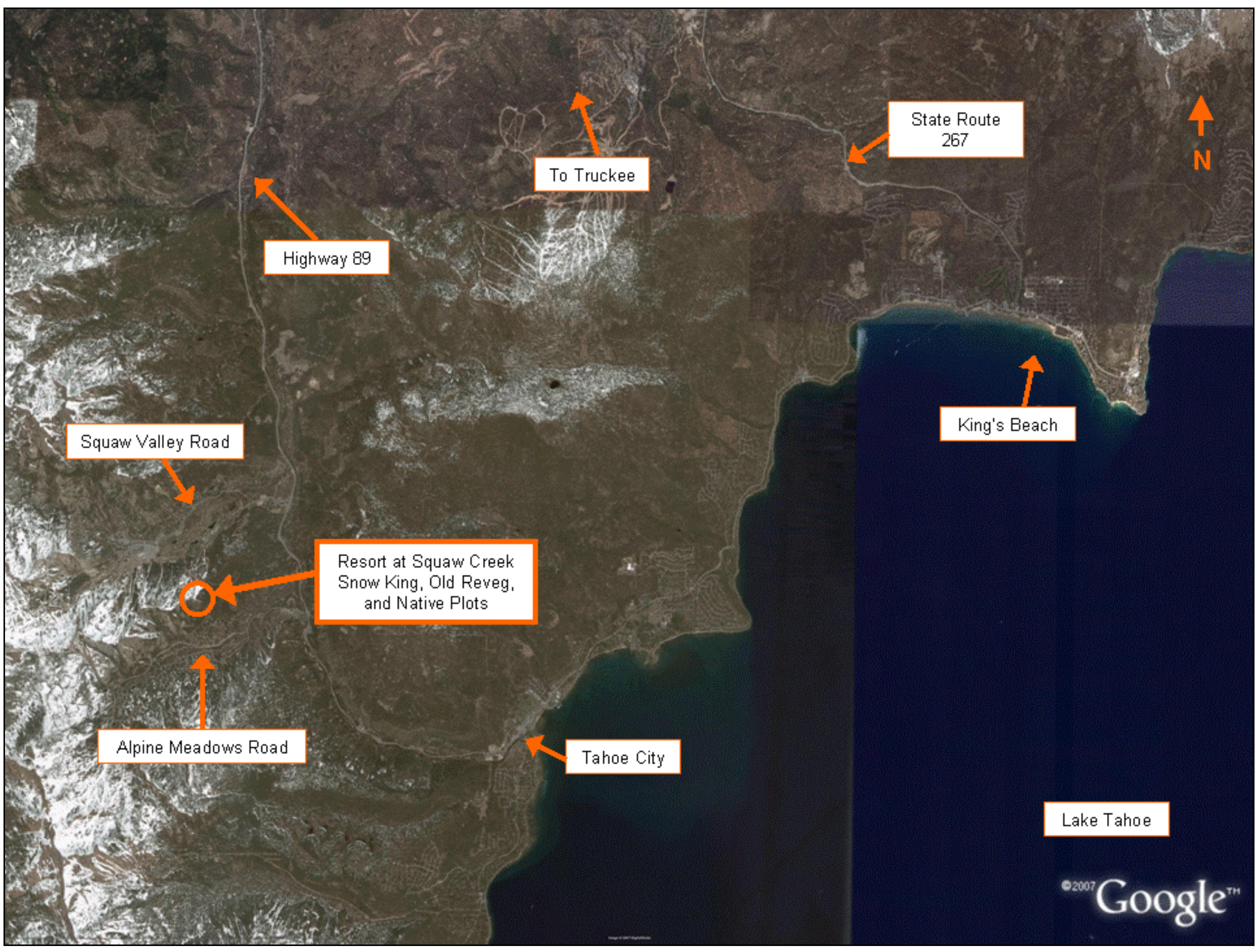


Figure 1. Satellite image of the Resort at Squaw Creek location in relation to Lake Tahoe.

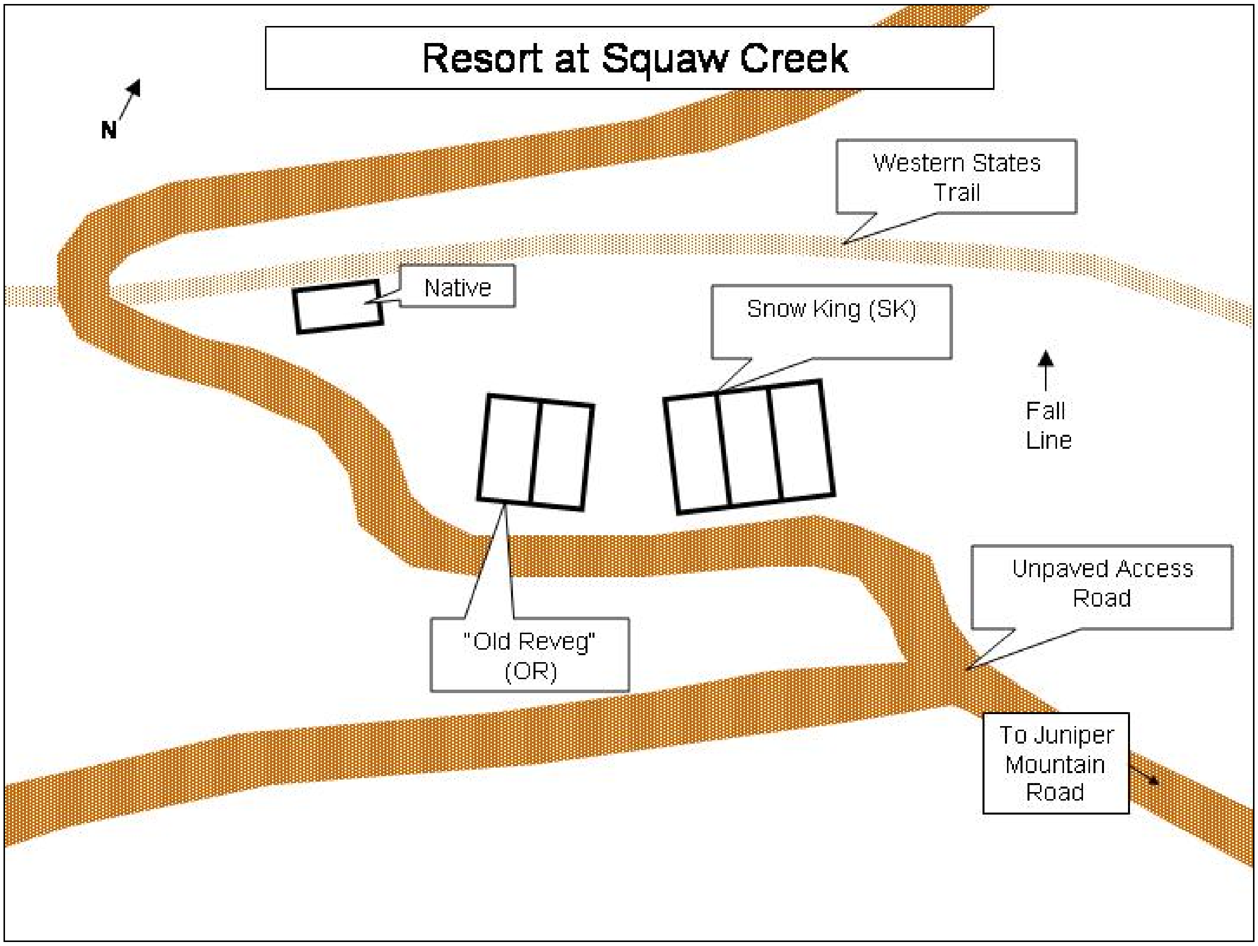


Figure 2. Overview of Juniper Mountain treatment and native reference monitoring areas. This map is not to scale.

Purpose

The project's monitoring objectives are outlined below. The following treatment definitions are included to aid understanding of the objectives.

Full Treatment: includes soil loosening by ripping, incorporation of an organic amendment such as compost or woodchips, addition of fertilizer and native seed, and application of native mulch.

Surface Treatment: does not include the incorporation of organic matter into the soil. This treatment may include surface fertilizing, seeding, or hydromulching and is similar to Caltrans Erosion Control Type D (EC Type D).

Partial Treatment: includes surface treatment with subsequent soil loosening by ripping.

The monitoring data was studied and analyzed to investigate:

1. the erosion control differences between full treatment, surface treatment, and partial treatment plots
2. the effects of different amendment types on penetrometer depth to refusal (DTR), soil nutrient levels and availability, and plant growth

Site Description

The Resort at Squaw Creek is a year-round resort complex located in Olympic Valley, California, in eastern Placer County. It is within the South Fork Squaw Creek watershed. Part of the resort consists of a ski complex know as Snow King, which is interconnected with the Squaw Valley ski resort.

Old Reveg and Snow King Plots

The Old Reveg and Snow King plots are located on a northwest facing ski slope just below the Juniper Mountain saddle with slope angles ranging from 19-25 degrees and a solar exposure of 91% during the summer (Figure 2). The site elevation is approximately 6,900 feet (2,103 m) above mean sea level (AMSL). The soil parent material is volcanic in origin and contains approximately 30% coarse material greater than 0.5 inches (1.3 cm) in diameter. The soil is classified as sandy loam and contains 19% clay, 22% silt, and 58% sand. During soil sampling, areas with higher clay content were encountered. In the surrounding area, the overstory consists of white fir (*Abies concolor*) and red fir (*Abies magnifica*), while the understory is dominated by greenleaf manzanita (*Arctostaphylos patula*) and native bunchgrasses and forbs. This ski slope, as with many in the surrounding area, is dominated by the non-native wheatgrass species (*Elytrigia intermedia*), which was part of the original hydroseed surface treatment. In December of 2005, a slump formed in the bottom half of the partial treatment plot (OR1).

Native Reference Plot

The native reference plot is located west and downhill of the Old Reveg and Snow King plots (Figure 2). The slope is approximately 20 degrees and the elevation is approximately 6,676 feet (2,034 m) AMSL. The aspect is northwest and the vegetation is typical of that found locally in undisturbed areas. The overstory consists of white fir (*Abies concolor*) and red fir (*Abies magnifica*), while the understory is dominated by greenleaf manzanita (*Arctostaphylos patula*) and native bunchgrasses and forbs.

Figure 3. Native reference plot with mature shrubs and trees.

Treatments

Old Reveg and Snow King treatments are presented in Table 1 and Figure 4 and explained in detail below.

Table 1. Treatment descriptions

Plot	Plot Name	Amendment Type	Soil Loosening Method	Seed Type	Seed Rate	Organic Fertilizer Rate	Mulch Type and Depth
OR1	Partial Treatment Woodchips	Woodchips (depth is unknown)	12" Ripping	non-native	Unknown	Unknown	Unknown
OR2	Surface Treatment	None	None	non-native	Unknown	Unknown	Unknown
SK1	Full Treatment Compost	3" Compost	12" Ripping	native	104 lbs/acre	Biosol 1,500 lbs/acre	Pine needles 1"
SK2	Full Treatment Compost and Woodchips	3" Compost and Woodchips	12" Ripping	native	104 lbs/acre	Biosol 1,500 lbs/acre	Pine needles 1"
SK3	Full Treatment Woodchips	3" Woodchips	12" Ripping	native	104 lbs/acre	Biosol 1,500 lbs/acre	Pine needles 1"

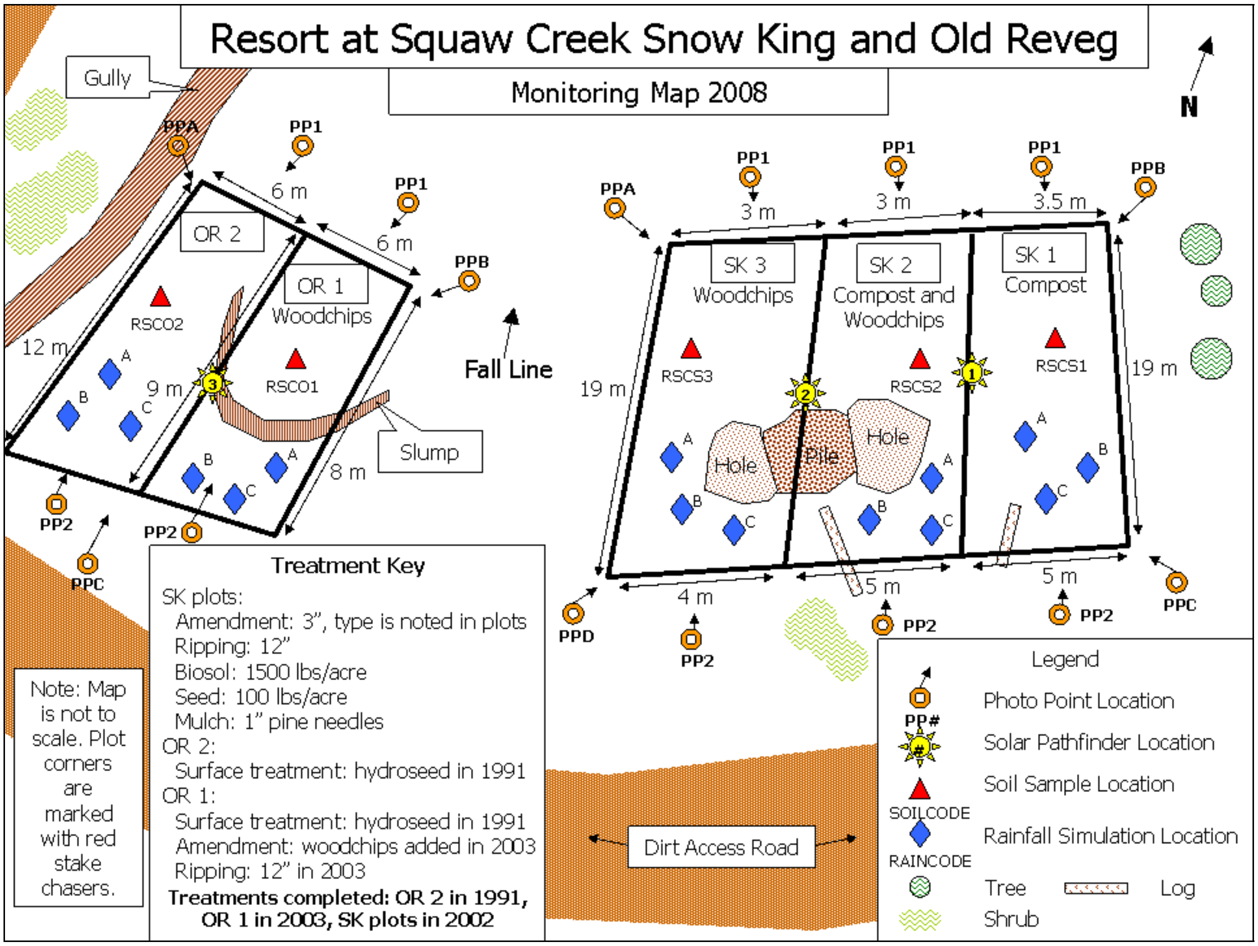


Figure 4. 2007 Monitoring and Treatment Map. Treatments, photo point locations, rainfall locations, and soil sample locations are shown.

Old Reveg

The Old Reveg plots, partial treatment (OR1) and surface treatment (OR2), were both treated in 1991 with a surface hydroseed treatment commonly applied on the Resort at Squaw Creek ski runs (Table 1). This surface treatment is similar to the Caltrans Erosion Control Type D treatment and is representative of traditional slope stabilization/erosion control treatments used locally on ski slopes and road cuts. Fertilizer and seed rates applications are unknown for this treatment; however, wheatgrass now dominates the ski run. In 2003, an area with this treatment was designated as the surface treatment plot OR2. Just east of the OR2 plot, woodchips were ripped 12 inches (30 cm) into the existing treatment and designated as the surface treatment plot OR1. Photos are shown in Figure 5, Figure 6, and Figure 7, where the monoculture of wheatgrass is apparent.

Figure 5. Old Reveg plots, 2006.

Figure 6 Old Reveg plots, 2007.

Figure 7 Old Reveg plots, 2008.

Snow King

The Snow King plots, full treatment with compost (SK1), full treatment with compost and woodchips (SK2), and full treatment with woodchips (SK3) were constructed in October 2002 (Table 1 and Figure 2). All plots received the same ripping treatment, Biosol rate, seed rate, and mulch type and depth; however, amendment type was varied between the plots. At the full treatment with compost plot, 3 inches (7.6 cm) of screened compost were spread on the soil. At the full treatment plot with compost and woodchips, a mixture of 50% screened compost and 50% woodchips, 3 inches (7.6 cm) deep, was spread on the soil. At the full treatment plot with woodchips (SK3), 3 inches (7.6 cm) of woodchips were spread on the soil. After amendment spreading, the plots were ripped to a depth of 12 inches (30 cm) using specially constructed ripper tines mounted on a Kubota 4WD tractor with a rear-mounted winch (Figure 8). The winch was used to stabilize the tractor while ripping the steep slope.

Figure 8. Winched Kubota tractor ripping the soil on the Snow King plots.

Following ripping and incorporation of the soil amendments, Biosol was applied evenly over the area at a rate of 1,500 lbs/acre (1,681 kg/ha) and lightly raked into the soil. A native grass seed mix was then applied at a rate of 100 lbs/acre (112 kg/ha). The mix consisted of equal amounts of squirreltail (*Elymus elymoides*), mountain brome (*Bromus carinatus*) and blue wildrye (*Elymus glaucus*). Approximately 5 lbs/acre (5.6 kg/ha) of antelope bitterbrush

(*Purshia tridentata*) was also included for a total seed rate of 104 lbs/acre (117 kg/ha; Table 2). All seed was lightly raked into the soil surface. Following seeding, the entire treatment area was mulched with pine needles to a depth of approximately 1 inch (3 cm) using a Shred-Vac mulch blower. All plots were then tackified. Photos are shown in Figure 9, Figure 10, and Figure 11, which contrast with the photos of the Old Reveg plots. The Snow King plots have a variety of grasses, trees, and shrubs compared to the monoculture of wheatgrass at the Old Reveg plots.

Table 2. Seed mix and composition for the Snow King full treatment plots, applied at 104 lbs/acre (117 kg/ha).

Common Name	Scientific Name	% of Mix
Squirreltail	*Elymus elymoides*	32
Blue wildrye	*Elymus glaucus*	32
Mountain brome	*Bromus carinatus*	32
Antelope bitterbrush	*Purshia tridentata*	5

Figure 9. Snow King plots, 2006.

Figure 10. Snow King plots, 2007.

Figure 11. Snow King plots, 2008.

Monitoring Methods

The Resort at Squaw Creek test plots have been monitored periodically since 2003. A consistent monitoring program that includes site assessment, plant cover, soil moisture, photo documentation, and rainfall simulation was implemented in 2006 and continued through 2008. In the text, both English and metric units will be given; however, tables will contain one or the other.

Rainfall Simulation

Rainfall simulation was conducted at various plots from 2003 to 2008 (Table 3). In 2007, standard frame installation protocols were not followed at all plots. Non-standard frame installation records are not available. Normally, the entire frame is hammered into the ground as one unit. During some installations, the frame was broken down into separate pieces and each piece was installed independently to form the original square configuration. This may have allowed some water to pass through the joining points of the frame pieces, which would decrease the amount of water captured in the trough.

Table 3. Rainfall simulation conducted during 2003-2008.

Year	Rainfall Simulation Plots
2003	OR1, OR2, Full treatment (plot # unknown)
2004	OR1, OR2, Full treatment (plot # unknown)
2005	OR1
2006	OR1, SK1, SK2, SK3, Native
2007	OR1, OR2, SK1, SK2, SK3
2008	OR1, OR2, SK1, SK2, SK3

The rainfall simulator "rains" on a square plot from a height of 3.3 feet (1 m; Figure 12 and Figure 13). The rate of rainfall is controlled, and runoff is collected from a trough at the bottom of a 6.5 ft^2 (0.6 m^2) frame that has been pounded into the ground. The volume of water collected is measured and the volume of infiltration is calculated by subtracting the volume of runoff from the total volume of water applied to the plot. If runoff is not observed during the first 30 minutes (in 2006 and 2007) or the first 45 minutes (in 2008), the simulation is halted. It is not known how long simulations ran before 2006. The collected runoff samples are then analyzed for the amount of sediment they contain. This measurement is presented as the average steady state sediment yield and is hereafter referred to as "sediment yield". The steady state infiltration rate is calculated and will hereafter be referred to as "infiltration rate".

The cone penetrometer is used to record the depth to refusal (DTR), which is an index for soil density, in the area of the frames before rainfall simulations. In 2004 and 2005, the DTR was recorded at 100 psi (689 kPa). The 2006 DTR pre-rainfall values were recorded at a maximum pressure of 250 psi (1,724 kPa), while the 2007 and 2008 DTR values were recorded at 350 psi (2,413 kPa). Soil moisture is measured in each frame prior to and following (2008 only) rainfall simulations. After rainfall simulation in 2006, at least three holes were dug with a trowel to determine the depth to wetting front, which shows how deeply water infiltrated into the soil. In 2007 and 2008, at least nine holes were dug to measure the depth to wetting front.

Different rainfall rates were applied to different plots depending on their propensity to runoff. For most plots, the initial rainfall rate applied was 2.8 in/hr (72 mm/hr). If runoff was not observed, the rainfall rate was increased to 4.7 in/hr (120 mm/hr) until runoff was observed or all the water was infiltrated. In 2008, 4.7 in/hr (120 mm/hr) was applied to all plots, so that data from the plots could be more easily compared. The lowest rainfall rate, 2.8 in/hr (72 mm/hr), is in excess of the 20-year, one hour 'design storm' rate of 0.7 to 1.0 in/hr (18 to 25 mm/hr) for the Truckee-Tahoe area. The design storm rate is used to design most storm water routing plans.

Figure 12. Rainfall simulator and frame.

Figure 13. Rainfall simulator set up at SK3.

Cover

Cover point monitoring was conducted in 2005, 2006, 2007, and 2008 at the Snow King and Old Reveg plots and in 2006 at the native reference plot. Detailed record of species type and composition were recorded starting in 2006.

Cover is measured using the statistically defensible cover point method along randomly located transects.[1] The cover pointer consists of a metal rod with a laser pointer mounted 3.3 feet (1 m) high. After the rod is leveled in all directions, the button on the laser pointer is depressed and two cover measurements are recorded (Figure 14 and Figure 15):

- the first hit cover, which is the first object intercepted starting from a height of 3.3 ft (1 m) above the ground
- the ground cover hit, which is the low-lying vegetation or soil below the first hit cover, at the ground level

The first hit cover measures the foliar cover by plants (leaves and stems). It does not measure the part of the plant rooted in the ground. The first hit vegetation is then moved aside and a ground cover hit measures the presence of litter/mulch, basal (or rooted) plant cover, rock and woody debris, and/or bare ground. Total ground cover represents any cover other than bare ground.

[1]Hogan, M. 2003. Luther Pass Monitoring Report: Plant and Soil Cover Monitoring for Evaluating Sediment Source Control Success in the Lake Tahoe Basin. Lahontan Regional Water Quality Control Board, South Lake Tahoe, CA.

Figure 14. Cover pointer in use along transects.

Figure 15. Cover pointer rod with first hit and ground cover hit by the laser pointer. The laser pointer hits are circled in red. The first cover hit is a native grass and the ground cover hit is pine needle mulch.

Foliar and ground level plant cover is recorded by species and then organized into cover groups based on four categories, starting in 2006: life form (herbaceous/woody), perennial/annual, native/alien (2007 and 2008 only), and seeded/volunteer (2007 and 2008 only). Perennial herbaceous species includes seeded grasses, native grasses and forbs, and any non-native perennial species. Annual herbaceous species include native annuals such as Douglas knotweed (*Polygonum douglasii*) and invasive species such as cheatgrass (*Bromus tectorum*). Woody species includes any tree or shrub species, either native or introduced. Each species is then classified based on whether it is native to the Tahoe area, and whether it was seeded during treatment. Data is presented on the amount of cover by species. An ocular estimate of cover at each plot is also recorded and includes many species not hit using cover point sampling. The species lists, as well as the ocular estimates of cover by species, are presented in Appendix A.

Soil and Site Physical Conditions

Penetrometer Depth to Refusal and Soil Moisture

In 2006, 2007, and 2008, penetrometer depth to refusal (an index for soil density) and soil moisture were measured along the same transects as the cover point data for all plots. Penetrometer data was collected in 2005; however, the collection method is unknown. A cone penetrometer with a ½ inch diameter tip is pushed straight down into the soil until a maximum pressure of 350 pounds per square inch (2,411 kPa) is reached (Figure 16 and Figure 17). The depth at which that pressure is reached is recorded as the depth to refusal (DTR).

Cone penetrometer DTR measurements are used as an index for soil density. Soils with higher DTRs are generally less dense than those with lower DTRs. A denser soil is less likely to allow infiltration. Rainfall simulations conducted on roadcuts in Oregon found increased infiltration rates in soils with penetrometer depths to refusal (DTRs) greater than 4 inches (10 cm).[2]

It is most informative to compare penetrometer DTR measurements collected in soils that have similar moisture levels. When soil moisture content increases, the resistance of the soil to the penetrometer decreases and DTR readings are deeper. Therefore, only penetrometer readings at the same soil moisture can be compared. A hydrometer was used to measure volumetric soil moisture content adjacent to the penetrometer readings at a depth of 4.7 inches (12 cm; Figure 18).

Figure 16. Photo of a cone penetrometer dial, showing pressure applied in pounds per square inch.

Figure 17. Photo of conducting cone penetrometer readings along transects.

Solar Exposure

In 2006, solar exposure measurements were taken at the native reference plot. In 2007, measurements were taken at the Old Reveg and Snow King plots. These measurements were taken using a Solar Pathfinder (Figure 19). Since there was no change in solar obstructions at any of the plots, the solar pathfinder data was not collected again in 2008. Solar input affects evaporation rates and soil temperature, which may affect time of seed germination, germination rate, rate of plant growth, and soil microbial activity. Therefore, this is an important variable to consider when monitoring plant growth and soil development.

[2] Grismer, M.E. 2006. Simulated Rainfall Evaluation at Sunriver and Mt. Bachelor Highways, Oregon. Unpublished.

Figure 18. Conducting soil moisture readings along transects.

Figure 19. Solar pathfinder in use.

Soil Nutrient Analysis

Successful re-vegetation requires that nutrient capital be stored in the soil for release over time. Sufficient organic matter and a functioning microbial community are necessary to provide a long-term source of nitrogen for plants. Previous studies of soil nutrient levels at revegetation sites throughout the Tahoe area found that sites with high plant cover had significantly higher soil nutrients over the long-term than soils with lower plant cover levels.[3] Total Kjeldahl nitrogen and organic matter were used as indicators of soil health in this study. Total Kjeldahl nitrogen (TKN) is a measure of readily available nitrogen. Only three soil sub samples were taken from each plot; therefore, differences in TKN and organic matter values may be a result of the variability within a plot.

Soil samples were collected at the Snow King plots in 2003, at the Snow King and Old Reveg plot in 2006, 2007, and 2008, and at the native reference plot in 2006. Three soil sub-samples at each plot were collected from the mineral soil beneath any mulch layer to a depth of 12 inches (30 cm; Figure 20). These sub-samples were combined and sieved to remove any material larger than 0.08 inches (2 mm) in diameter, and sent to A&L Laboratories in Modesto, California for the S3C nutrient suite (macro and micronutrients), total Kjeldahl nitrogen (TKN), and organic matter analysis.

[3]Claassen, V.P., and M.P. Hogan. 2002. Soil Nutrients Associated with Revegetation of Disturbed Sites in the Lake Tahoe Basin. Restoration Ecology 10:195-203.

Figure 20. Soil sample collection.

Results and Discussion

Rainfall Simulation

Sediment Yields

From 2003 to 2008, the full treatment plots (five-year average of 68 lbs/acre/in or 30 kg/ha/cm) produced on average 6 times less sediment than the surface treatment plot (four-year average of 407 lbs/acre/in or 180 kg/ha/cm; Figure 21). However, both the surface treatment and the full treatment plots produced variable sediment throughout all years sampled.

From 2003 to 2008, the sediment yield at the full treatment plots ranged from 0 to 429 lbs/acre/in (0 to 189 kg/ha/cm). The sediment yield at the surface treatment plot was more variable, and ranged from 0 to 1,493 lbs/acre/in (0 to 659 kg/ha/cm; Figure 21).

The sediment yield at the partially treated plot was more consistent, ranging from 0 to 132 lbs/acre/in (0 to 58 kg/ha/cm) over six years of sampling. The six-year average sediment yield was 34 lbs/acre/in (15 kg/ha/cm), which was 2 times lower than the five-year average at the full treatment plots (68 lbs/acre/in or 30 kg/ha/cm) and 12 times higher than the four-year average at the surface treatment plot (407 lbs/acre/in or 179 kg/ha/cm; Figure 21).

The large variation in sediment yields produced at both the surface treatment plot and the full treatment plots may be a result of several different variables. In 2007, the non-standard frame installations described in the methods section may have reduced sediment yields and increased infiltration rates at the surface treatment plot. In 2008, a hard clay layer was observed in one of the full treatment frames, which may have resisted infiltration. Simulation notes are not available for 2003 to 2006.

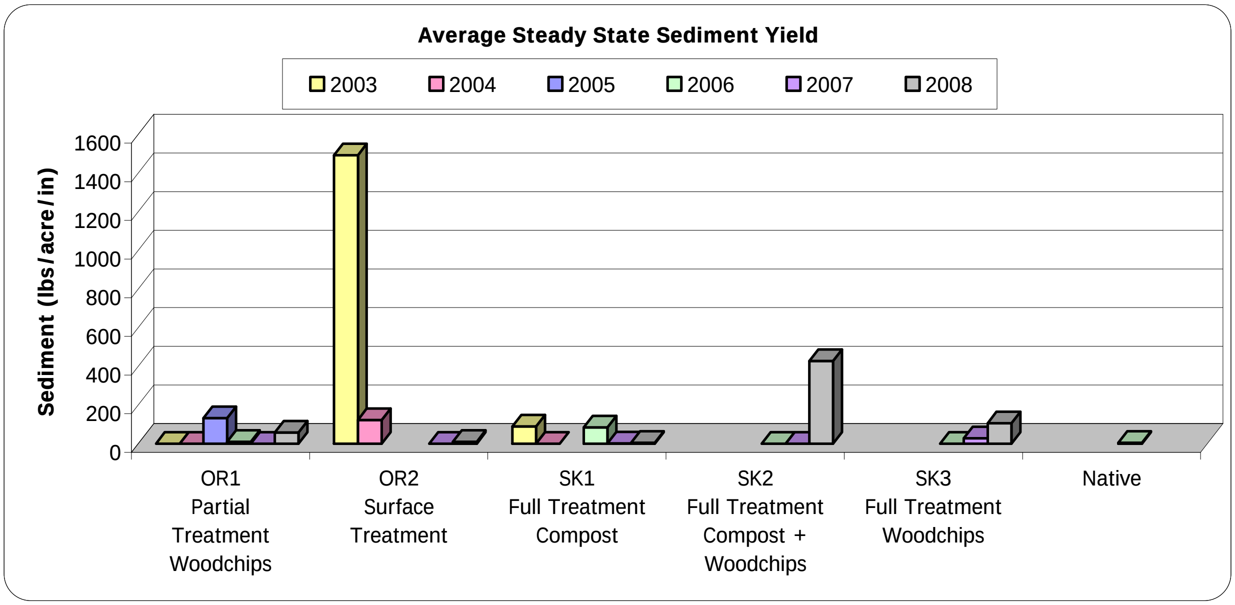


Figure 21. Sediment Yield. Sediment yields were highly variable over the six year sampling period and ranged from 0 to 429 lbs/acre/in (0-189 kg/ha/cm) at the full treatment plots, 0 to 132 lbs/acre/in (0-58 kg/ha/cm) at the partial treatment plot, and from 0 to 1,493 lbs/acre/in (0-659 kg/ha/cm) at the surface treatment plot.

Infiltration Rates

Infiltration rates were 1.3 times higher at the full treatment plots (four-year average of 4 in/hr or 102 mm/hr) compared to the surface treatment plot (four-year average of 3 in/hr or 76 mm/hr; Figure 22). However, the rainfall application rates at the full treatment plots were generally higher that those at the surface treatment plot. Therefore, it is more informative to consider percent infiltration values.

Percent infiltration was 1.1 times higher at the full treatment plots (four-year average of 94%) and partial treatment plot (four-year average of 95%) compared to the surface treatment plot (three-year average of 85%; Figure 22). Percent infiltration did not vary as widely as sediment yields at the full treatment plots (range of 80-100%); however, there was a large variation in percent infiltration at the surface treatment plot (61-100%; Figure 22). The percent infiltration at the partial treatment plots ranged from 86 to 100%.

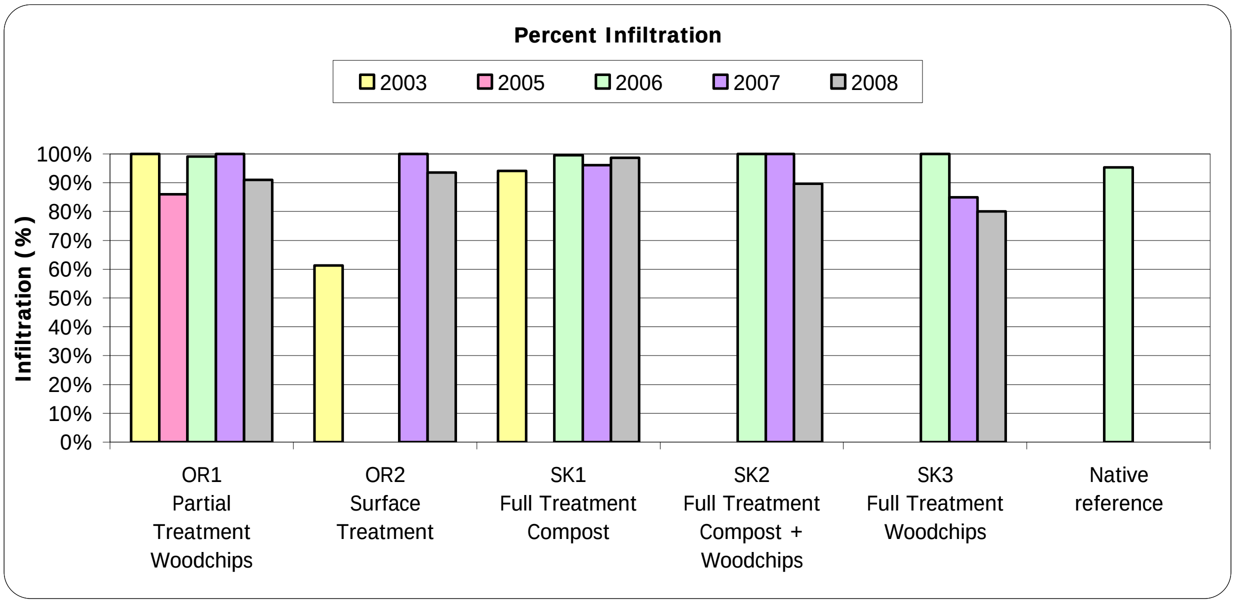


Figure 22. Percent Infiltration. Percent infiltration varied from 80 to 100% at the full treatment plot and from 61-100% at the surface treatment plot.

Soil Moisture

From 2006 to 2008, the soil moisture ranged between 4 and 11%, with most values falling between 4 and 8% (Figure 23). These similar values allow for comparison of penetrometer depths over time and among treatments.

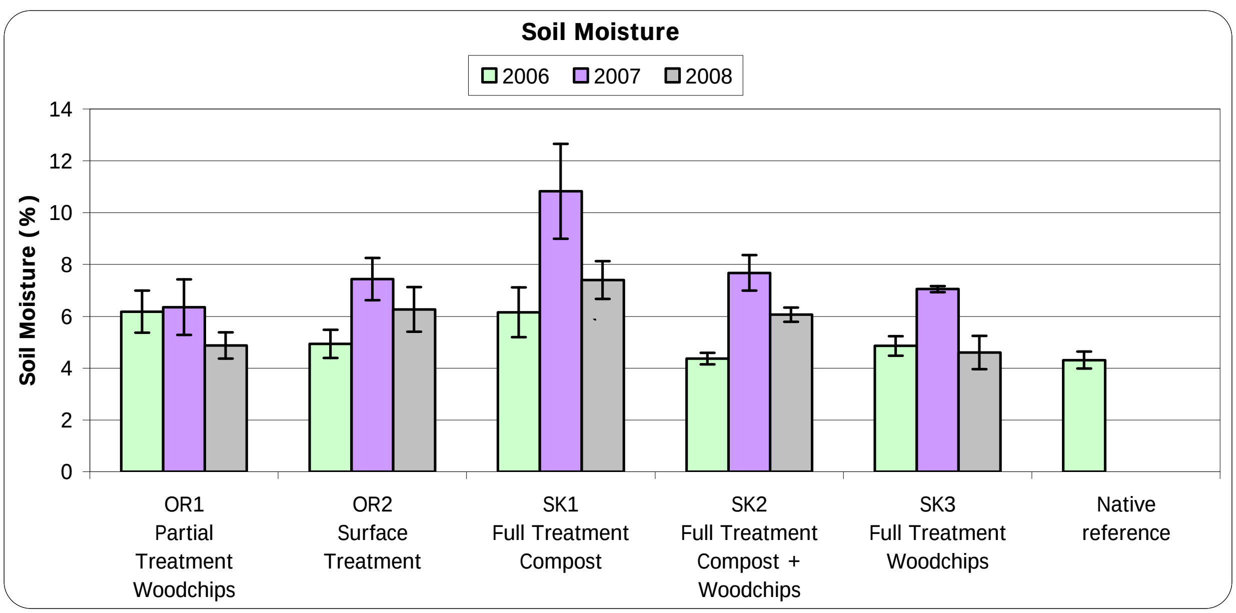


Figure 23. Soil Moisture. From 2006 to 2008, soil moisture values ranged from 4 to 11%, with most values falling within 4-8%.

Penetrometer Depth to Refusal (DTR)

Trends by Treatment Level

From 2006 to 2008, the full treatment and surface treatment plots had similar penetrometer DTR values. The three-year average for the full treatment plots was 3.6 inches (9 cm), compared to 4 inches (10 cm) at the surface treatment plots (Figure 24). The penetrometer DTR at the partial treatment plot (three-year average of 7.2 inches or 18 cm) was 1.7-1.9 times deeper than the DTR collected at the surface treatment plot (three-year average of 4 inches or 10 cm) or the full treatment plots (three-year average of 3.6 inches or 9 cm; Figure 24).

Trends by Year

In 2005, the penetrometer DTRs were deeper at all of the full treatment plots (range of 7.2-14 inches or 18-36 cm) compared to measurements taken from 2006 to 2008 (range of 3.3-5.0 inches or 8-13 cm; Figure 24). Those DTRs were not collected in conjunction with soil moisture, therefore it is unknown whether the soil re-compacted between 2005 and 2006 or whether penetrometer DTRs were measured at high soil moistures in 2005. From 2006 to 2008, the DTRs remained fairly consistent at the full treatment plots and at the surface treatment plots. DTRs ranged from 3.3 to 5.0 inches (8 to 13 cm) at the full treatment plots and from 3.3 to 4.1 inches (8 to10 cm) at the surface treatment plot.

The DTRs were somewhat inconsistent over time at the partial treatment plot; however, appreciable re-compaction over time is not likely. In 2005 the DTR was 8.5 inches (22 cm; unknown moisture level), in 2006 the DTR was 4.8 inches (12 cm), in 2007 the DTR was 8.5 inches (22 cm), while in 2008 the DTR was 7 inches (18 cm). Although the DTR was lower in 2006 than in other years, the standard deviation was higher than in other years.

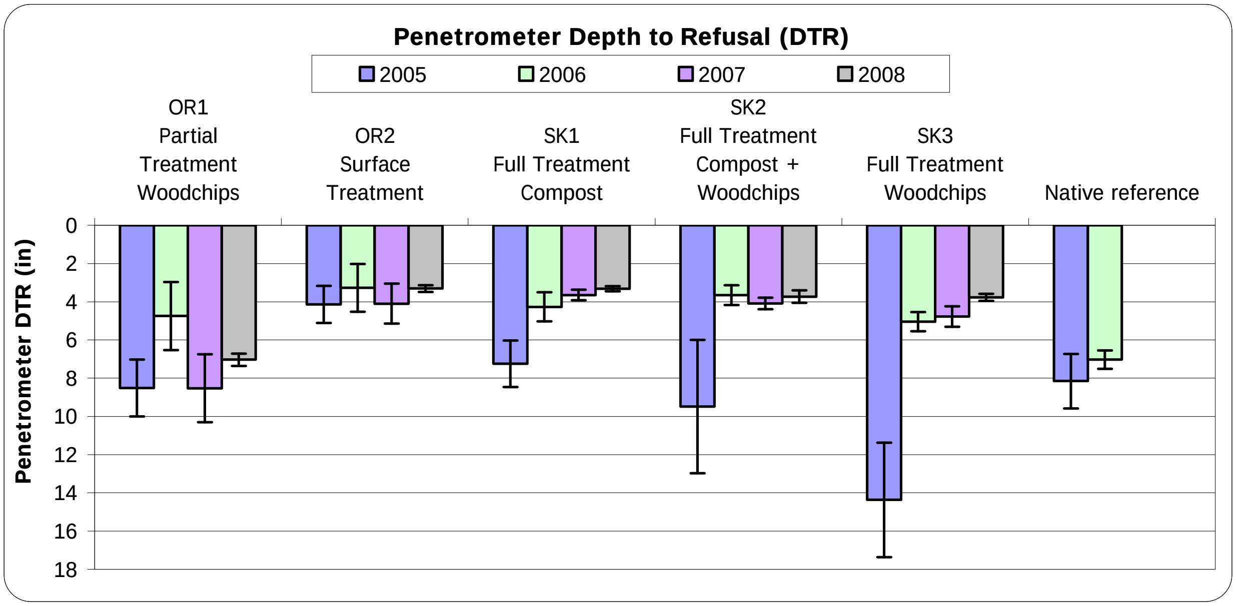


Figure 24. Penetrometer Depth to Refusal (DTR). In 2005, DTRs were collected at an unknown moisture level. From 2006 to 2008, DTRs remained fairly consistent at the full treatment and surface treatment plots, ranging from 3.3 to 5.0 inches. The DTR was variable at the partial treatment plot, but did not increase or decrease appreciable over time.

Cover

Ground Cover by Mulch

Trends by Treatment Level

From 2006 to 2008, the average three-year mulch cover was 1.1 times higher at the surface treatment plot (range of 78-100%) and the partial treatment plot (range of 75-100%) compared to the full treatment plots (range of 79-84%; Figure 25). Treatments with considerable mulch cover have been shown to reduce sediment yields substantially.[4] The increase in mulch cover at the surface treatment plot may be related to the decrease in sediment yield over time.

Trends by Year

The mulch cover at the surface treatment plot increased from 75% in 2006 to 100% in 2007 and 2008, while the full treatment plots had consistent mulch cover over the three-year period. The mulch cover at the partial treatment plot increased from 75% in 2006 to 98% in 2007 and 100% in 2008 (Figure 25).

[4] Grismer, M.E., and M.P. Hogan. 2004. Simulated rainfall evaluation of revegetation/mulch erosion control in the Lake Tahoe Basin: 1. Method assessment. Land Degradation & Development 15:573-588.

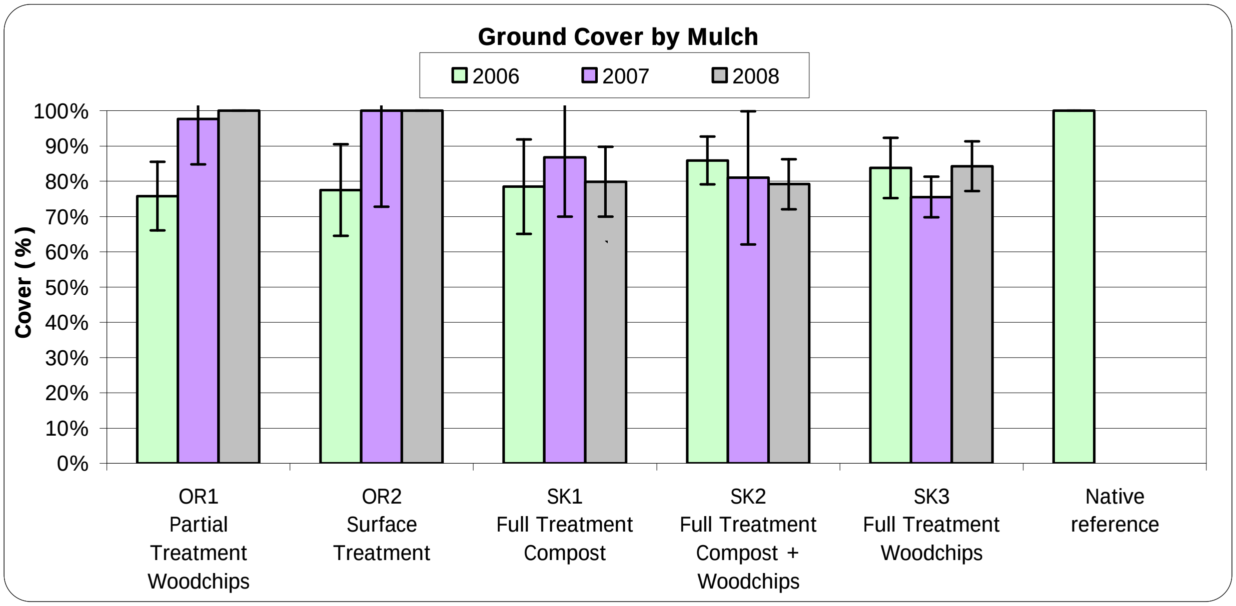


Figure 25. Ground Cover by Mulch. In 2008, mulch cover was highest at the partial and surface treatment plots, 100%, and ranged from 79 to 84% at the full treatment plots. Mulch cover was most consistent over time at the full treatment plots and increased over time at the partial and surface treatment plots.

Plant Cover and Composition

Foliar Plant Cover Trends by Treatment Level and Year

From 2005 to 2008, all treatment plots had foliar plant cover in excess of 20% and all but one measurement was above 30% (Figure 26). It is notable that plant cover exhibited an increasing trend at all plots from 2007 to 2008 (29 to 43%) because the 2006-7 and 2007-8 water years were below normal with the yearly precipitation totaling 23 and 25 inches (58 and 64 cm), respectively (compared to a 28-year average of 36 inches or 91 cm; Figure 26).[5]

Foliar plant cover was variable at the full treatment plots and will be discussed in more detail by amendment type in the next section. Foliar plant cover was also variable at the surface treatment plot and ranged from 43 to 89% (Figure 26). The plant cover was highest in 2005, and decreased by approximately one half in 2006. Slight increases followed in the subsequent years.

Plant cover varied widely within treatments between years; however, average values were calculated to better understand the difference between treatment types. From 2005 to 2008, foliar plant cover was approximately 2 times higher at the surface treatment plot (four-year average of 69%) compared to the full treatment plots (four-year average of 34%) and approximately 1.6 times higher compared to the partial treatment plot (four-year average of 56%; Figure 26). From 2005 to 2008, foliar plant cover was 1.6 times higher at the partial treatment plot (four-year average of 56%) compared to the full treatment plots (four-year average of 34%; Figure 26).

[5] Snotel data from: http://www.wcc.nrcs.usda.gov/snotel/snotel.pl?sitenum=834&state=ca

Foliar Plant Cover and Trends by Amendment and Year

Foliar plant cover decreased over time at the full treatment plots amended with compost and woodchips or compost. Plant cover was highest at these two plots in 2005 (63-64%), then decreased by approximately one half in 2006 (30-32%). Slight increases followed in 2007 and 2008, with cover in 2008 ranging from 38-45% (Figure 26). Foliar plant cover most likely decreased over time at the plots amended with compost because compost has a low carbon to nitrogen ratio, making nutrients more available to plants initially and less so over time as the nutrients are depleted. The opposite trend prevailed at the full treatment plot amended with woodchips. Foliar cover increased over time, from 20% in 2005 to 45% in 2008 (Figure 26). Woodchips have a high carbon to nitrogen ratio, which makes nutrients less available directly following treatment. Plant cover increased at the plot amended with woodchips as the nutrients became available over time. Foliar plant cover was similar among all full treatment plots in 2008, regardless of amendment (38 to 45%; Figure 26). Although plots amended with compost showed a decreasing trend in foliar cover over time and the plot amended with woodchips showed an increasing trend over time, the plots converged at similar cover values in 2008.

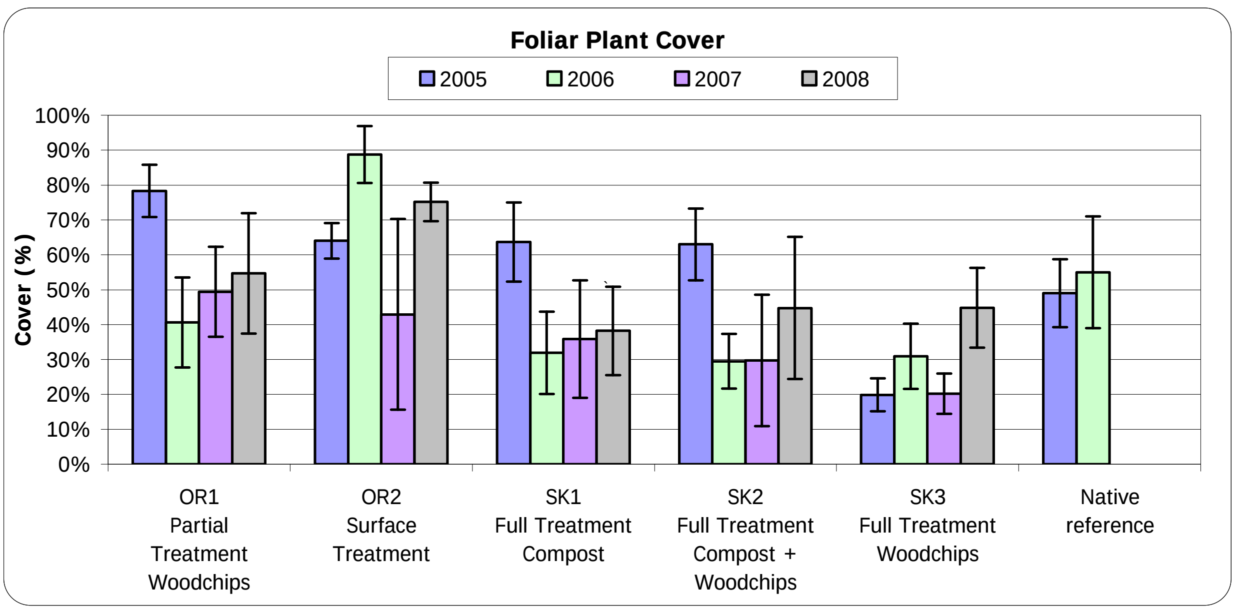


Figure 26. Foliar Plant Cover. Foliar cover was variable across all years and treatment types. Overall, plots with full treatment had the lowest foliar plant cover compared to the surface treatment and partial treatment plots. Plots amended with compost exhibited a decreasing plant cover trend over time, while plots amended with woodchips exhibited an increasing trend over time.

Plant Composition Trends by Year

The plant cover at the surface treatment and partial treatment plots was dominated by the non-native wheatgrass, (Figure 27, Figure 28, and Figure 29). Few other species exist in these plots because native plants have been outcompeted by fast-growing wheatgrass, which has formed a monoculture. The plant composition did not change appreciably over time at the partial treatment or surface treatment plots.

From 2006 to 2008, the full treatment plots were dominated by a mix of seeded and volunteer native species. Seeded species decreased slightly over time, while native volunteer species increased slightly over time. From 2006 to 2008, squirreltail and blue wildrye, two of the three seeded species, were present in small quantities at the full treatment plots, from 1 to 10% (Figure 27, Figure 28, and Figure 29). The composition by seeded species did not change considerably over time. Western needlegrass (*Achnatherum occidentale*), a native species that can thrive under low water and nutrient conditions, was not seeded, but its cover has increased slightly over time at the full treatment plots (Figure 27, Figure 28, and Figure 29). Groundsmoke (*Gayophytum sp.*), a native annual forb, was present in quantities ranging from 3-17% at the full treatment plots and decreased slightly between 2007 and 2008 (Figure 27, Figure 28, and Figure 29). This species is common in recently disturbed areas and often decreases as perennial, native plants establish.

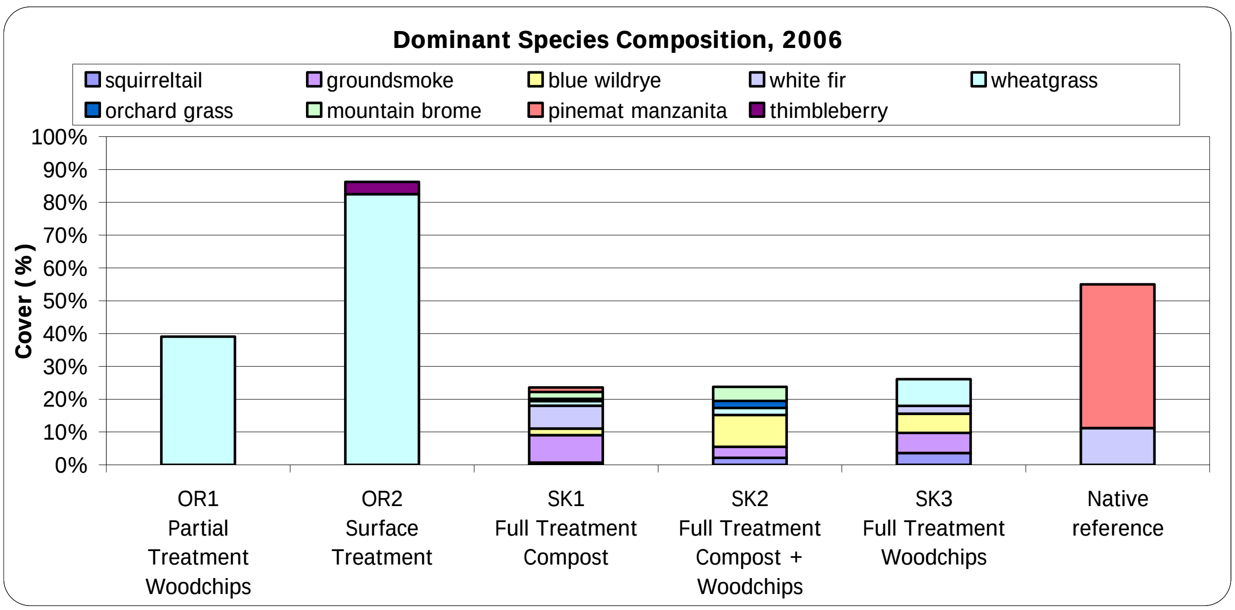


Figure 27. Dominant Species Composition, 2006. The partial and surface treatment plots exhibited a monoculture of wheatgrass, and the full treatment plots were composed predominantly of native volunteer or seeded species. Pinemat manzanita dominated at the native reference plot.

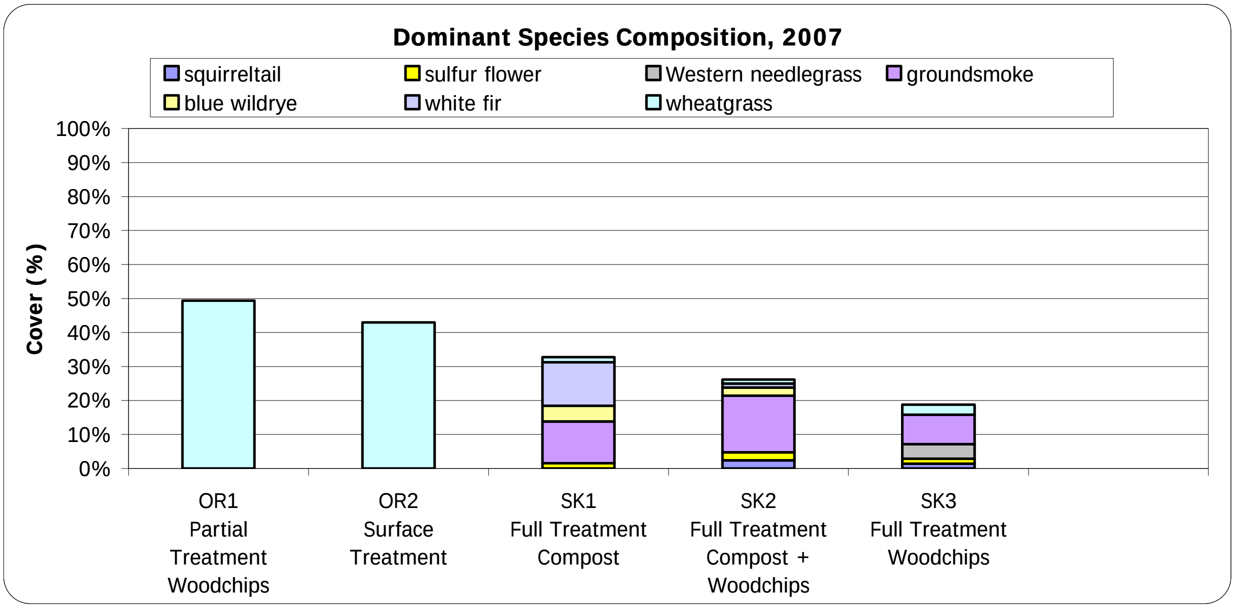


Figure 28. Dominant Species Composition, 2007. The partial and surface treatment plots maintained a monoculture of wheatgrass from 2006 to 2007, while the full treatment plots exhibited a slight decrease in seeded species and an increase in native volunteer species.

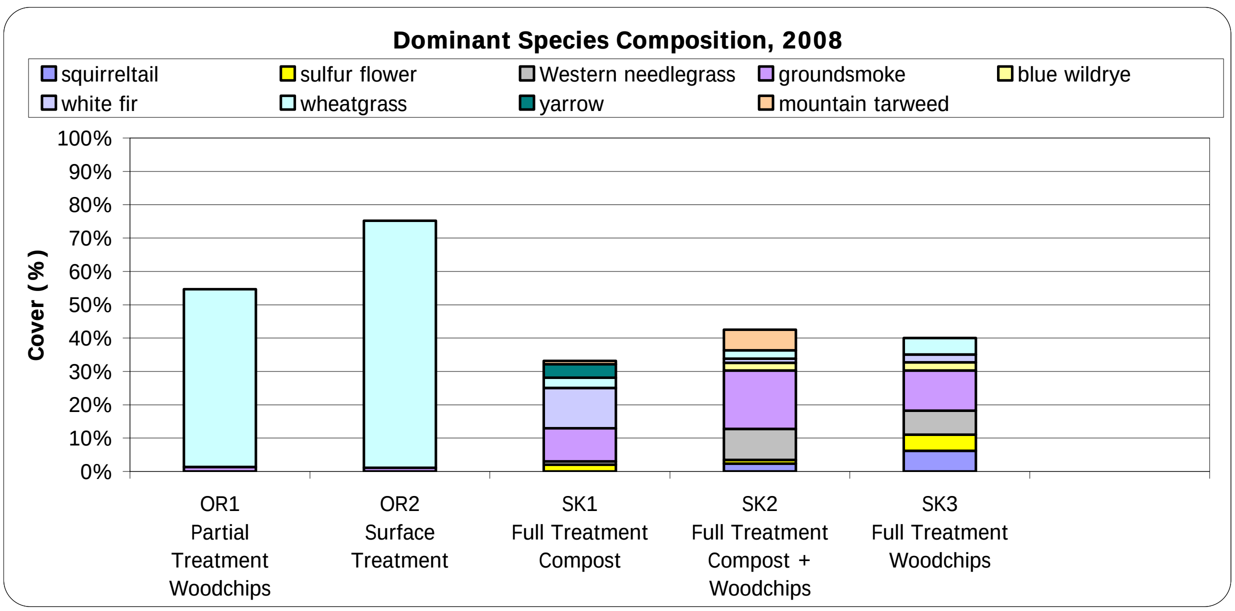


Figure 29. Dominant Species Composition, 2008. Wheatgrass continued to dominate at the partial and surface treatment plots. Volunteer native species continued to increase slightly at the full treatment plots.

Soil Nutrients

TKN Trends by Treatment Level

From 2003 to 2008, the TKN at the compost full treatment plot (SK1) was consistent (average of 1,037 ppm) and was 1.6 times lower than the TKN at the native reference plot (1,627 ppm; Figure 30). The low TKN levels relative to the native reference plot suggest that higher quantities of amendment are necessary to sufficiently re-capitalize the soil. From 2006 to 2008, the surface treatment plot had a TKN (range of 1,388-1,519 ppm) that was similar to that of the native reference plot (1,627 ppm; Figure 30). The TKN at the partial treatment plot increased from 2006 to 2008 from 946 to 1,620 ppm, which was similar to the TKN at the native reference plot (1,627 ppm; Figure 30).

TKN Trends by Year

The TKN values varied widely at the compost and woodchips (SK2) and the woodchips (SK3) full treatment plots (Figure 30). However, both plots exhibited the same trend over time: an increasing trend from 2003 to 2007 and a decreasing trend in 2008. The increase in TKN from 2003 to 2007 may be the result of the additional nutrients available as the woodchips decomposed. This increase led to a TKN level close to native reference levels at the plot amended with woodchips (1,506 ppm) and higher than native reference levels at the plot amended with compost and woodchips (2,143 ppm). The decrease in TKN in 2008 may be a result of the increased plant growth at these plots in 2008, which was possible because of the increase in available nutrients.

In 2008, the TKN was 1,250 ppm at the compost and woodchips plot and 768 ppm at the woodchips plot. These values ranged from 1.3 times lower at the woodchips plot to 2.1 times lower at the compost and woodchips plot than the TKN at the native reference plot (1,627 ppm; Figure 30).

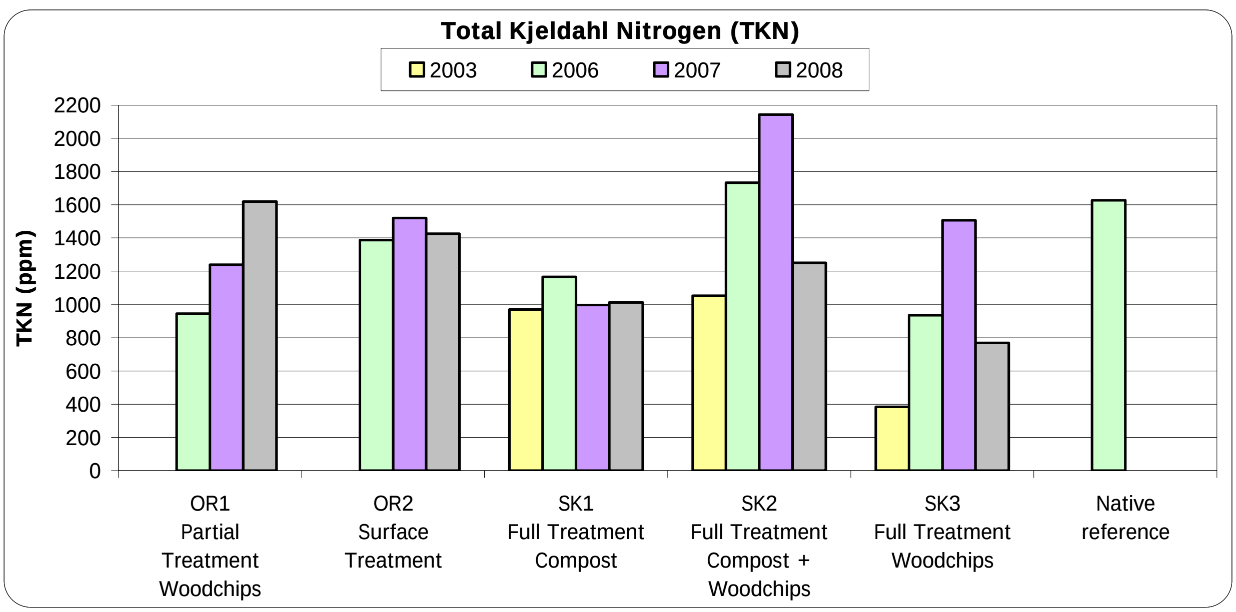


Figure 30. Total Kjeldahl Nitrogen (TKN). In 2008, the TKN at the surface treatment and partial treatment plots were similar to native reference levels (1,627 ppm). The TKN at the full treatment plots did not reach native reference levels in 2008, suggested that higher quantities of amendments are necessary to sufficiently re-capitalize the soil.

Organic Matter Trends by Treatment Level

The organic matter levels at the partial treatment plot ranged from 5.5 to 7.8% over time and were comparable to the organic matter level at the native reference plot, 7.7% (Figure 31). In

2008, the organic matter level at the surface treatment plot, 5.5%, was slightly higher than the organic matter level at the full treatment plots, which ranged from 3.2 to 4.6% (Figure 31). Neither the organic matter at the surface treatment plot, nor the organic matter at the full treatment plots reached native reference levels (7.7%) in any year (Figure 31). The low organic matter levels at the full treatment plots compared to the native reference plot suggest that the quantity of amended applied was not sufficient to sufficiently re-capitalize the soil.

Organic Matter Trends by Year

Organic matter content varied slightly over time at the full treatment plots and ranged from 3.3 to 5.0% from 2003 to 2008 (Figure 31). An increasing trend was observed from 2003 to 2008 at the full treatment plot amended with woodchips (SK3), which was most likely a result of the breakdown of woodchips over time (Figure 31). Organic matter was not consistent over time at the partial treatment plot and ranged from 7.8% in 2006 to 5.5% in 2007 to 6.6% in 2008 (Figure 31). Organic matter content was consistent over time at the surface treatment plot and ranged from 5.1 to 5.6% (Figure 31).

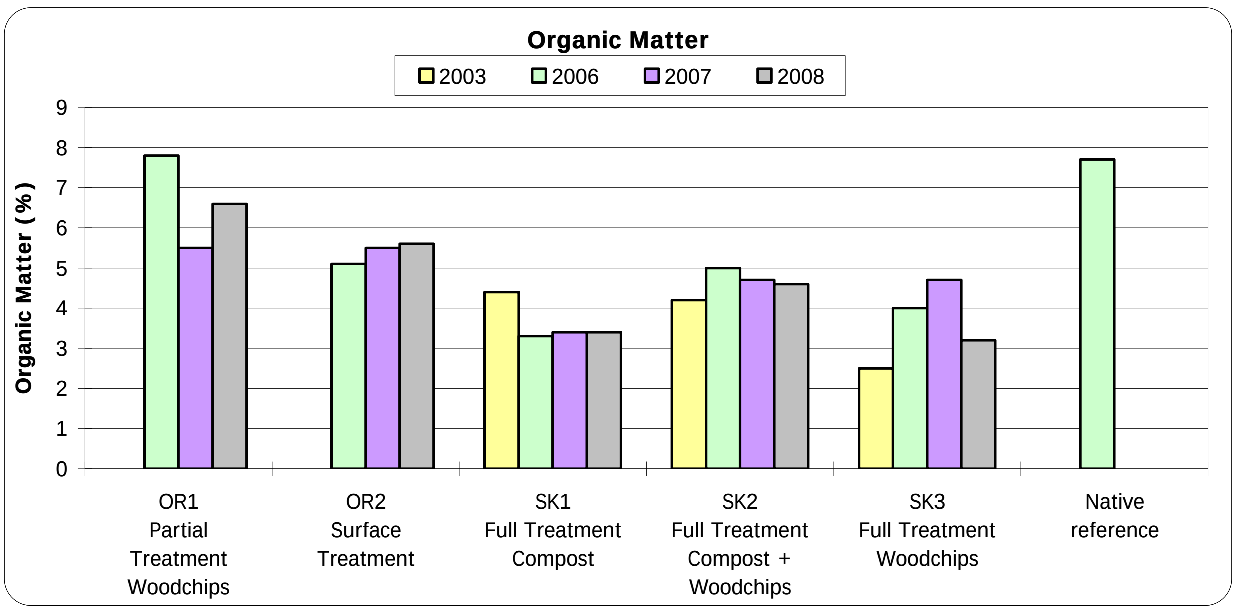


Figure 31. Organic Matter. Organic matter content at the full treatment and surface treatment plots did not reach native reference levels, suggesting that a higher quantity of amendment in the full treatment plots is necessary to re-capitalize the soil.

Recommendations

For sites with rocky soil, from volcanic parent material, with a slope of approximately 19 degrees, at an elevation of approximately 6,900 ft:

Ripping: 12 inches (30 cm)

Amendment: 5 inches (13 cm) of a 50/50 combination of screened compost and woodchips

Biosol: 2,000 lbs/acre (2,242 kg/ha)

Seed: 100 lbs/acre (112 kg/ha) seed with the following composition:

mountain brome: 22.5%
squirreltail: 22.5%
blue wildrye: 22.5%
Western needlegrass: 22.5%
native forbs and shrubs: 10%

Mulch: pine needles, 3 inches (8 cm) and 99% cover

Full Treatment versus Surface Treatment

Full treatment is recommended over surface treatment for the following reasons. Full treatment plots exhibited:

- sediment yields from 2003 to 2008 that were on average 6 times less (five-year average of 68 lbs/acre/in or 30 kg/ha/cm) than sediment yields at the surface treatment plot (four-year average of 407 lbs/acre/in or 180 kg/ha/cm)
- sediment yield that ranged from 0 to 429 lbs/acre/in (0 to 189 kg/ha/cm), compared to 0 to 1,493 lbs/acre/in (0 to 659 kg/ha/cm) at the surface treatment plot
- sediment yields that were less variable than the sediment yields at the surface treatment plot
- percent infiltration that was 1.1 times higher (four-year average of 94%) compared to percent infiltration at the surface treatment plot (three-year average of 85%)
- percent infiltration that ranged from 80 to 100% compared to a less predictable and wider range of 61 to 100% at the surface treatment plot
- similar penetrometer DTR values (3.6 inches or 9 cm), compared to 4 inches (10 cm) at the surface treatment plot
- diverse seeded and volunteer plant composition that ranged from 38 to 44% cover in 2008, compared to a monoculture of non-native wheatgrass at the surface treatment plots that had a higher cover (75%)
- an increase in native volunteer species over time, such as Western needlegrass, compared to few native species at the surface treatment plot

Surface Treatment versus Surface Treatment with Subsequent Ripping

Surface treatment with subsequent ripping (partial treatment) is recommended over no further action for existing surface treatment areas for the following reasons. Partially treated plots exhibited:

- sediment yields that were 12 times lower over six years of sampling and ranged from 0 to 132 lbs/acre/in (0 to 58 kg/ha/cm) compared to the sediment yield at the surface treatment plot (range of 0 to 1,493 lbs/acre/in (0 to 659 kg/ha/cm)
- percent infiltration that was 1.1 times higher (four-year average of 95%) compared to percent infiltration at the surface treatment plot (three-year average of 85%)
- percent infiltration that ranged from 86 to 100% compared to a less predictable and wider range of 61-100% at the surface treatment plot
- penetrometer DTRs that were 1.7-1.9 times deeper (four-year average of 7.2 inches or 18 cm) than the DTRs collected at the surface treatment plot (four-year average of 4 inches or 10 cm)
- similar plant composition to the surface treatment plot with adequate plant cover (55%)
- similar TKN values in 2008 compared to the surface treatment plot and the native reference plots (1,425 ppm at the partial treatment compared to 1,620 ppm at the surface treatment, and 1,627 ppm at the native reference plot)
- organic matter levels that were ranged from 5.5 to 7.8% over time and were comparable to the organic matter level at the native reference plot, 7.7% (Figure 31)
- organic matter levels that were slightly higher than at the surface treatment plot (range from 5.1 to 5.6% at the surface treatment plot)

Soil Loosening versus No Soil Loosening

Initial treatment with soil loosening versus no soil loosening is recommended for the following reasons. Plots with soil loosening exhibited:

- sediment yields from 2003 to 2008 that were on average 6 times less (five-year average of 68 lbs/acre/in or 30 kg/ha/cm) than sediment yields at the no soil loosening plot (four-year average of 407 lbs/acre/in or 180 kg/ha/cm)
- sediment yield that ranged from 0 to 429 lbs/acre/in (0 to 189 kg/ha/cm), compared to 0 to 1,493 lbs/acre/in (0 to 659 kg/ha/cm) at the no soil loosening plot
- sediment yields that were less variable than the sediment yields at the no soil loosening plot
- percent infiltration that was 1.1 times higher (four-year average of 94%) compared to percent infiltration at plot without soil loosening (three-year average of 85%)
- percent infiltration that ranged from 80 to 100% compared to a less predictable and wider range of 61-100% at plot without soil loosening

- similar penetrometer DTR values (3.6 inches or 9 cm), compared to 4 inches (10 cm) at the plot without loosening (a higher concentration of amendments are recommended to resolve this)

Amendment Type and Rate (Compost, Woodchips, or Compost and Woodchips)

The combination of compost and woodchips, applied to a depth of 5 inches (12.7 cm) versus the 3 inches (8 cm) of applied amendments, is recommended over either amendment alone for the following reasons:

Compost and woodchips were chosen in combination because the plot with compost and woodchips exhibited:

- similar penetrometer DTRs (3.7 inches or 9.4 cm) to the plot with compost only (3.3 inches or 8 cm) or woodchips only (3.8 inches or 9.7 cm)
- similar plant composition to the plot with compost only or woodchips only
- the highest TKN level in 2008 (1,250 ppm) compared to the plot with compost only (1,013 ppm) or woodchips only (768 ppm)
- the highest organic matter content in 2008 (4.6%) compared the plot with compost only (3.4%) or woodchips only (3.2%)
- similar plant cover (45%) to the plot with compost only (38%) or woodchips only (45%) in 2008

Five inches of compost and woodchips are recommended over 3 inches (8 cm) because:

- although nutrients were higher than at plots with compost only or woodchips only, native reference levels were not obtained (1,250 ppm TKN compared to 1,627 ppm at the native reference plot and 4.6% organic matter compared to 7.7% organic matter at the native reference plot)
- penetrometer DTRs did not remain sufficiently deep over time with a low concentration of amendments and were below native reference levels (3.7 inches or 9 cm compared to an average of 7.5 inches or 19 cm)

Biosol

Biosol is recommended at a rate of 2,000 lbs/acre (2,250 kg/ha) rather than the applied rate of 1,500 lbs/acre (1,681 kg/ha) because TKN levels one year following treatment were not comparable to native reference levels. One year following treatment, the TKN levels ranged from 384 to 1,053 ppm, compared to 1,627 ppm at the native reference plot. The levels one year after treatment were examined because Biosol usually releases nutrients for 2-3 years after application. Data for 2-3 years after application was not available.

Seed Mix and Rate

Seed, applied at 100 lbs/acre (112 kg/ha) with the following composition is recommended:

mountain brome: 22.5%
squirreltail: 22.5%
blue wildrye: 22.5%
Western needlegrass: 22.5%
native forbs and shrubs: 10%

This composition was modified from the applied composition for the following reasons:

- Western needlegrass was included in the mix because it was observed as a volunteer species in increasing quantities in 2007 and 2008
- the percent of native forbs and shrubs was increased to broaden the diversity of native seeds

Mulch Type and Depth

Native pine needle mulch is recommended to a depth of 2 inches (5 cm), over the 1 inch (3 cm) applied application for the following reasons:

- mulch cover was less than 85% after six years at the plots that received 1 inch (3 cm) of pine needle mulch
- it is important to maintain high levels of mulch cover because adequate mulch cover is linked to decreased sediment production

Appendix A

Species list and ocular estimates for Resort at Squaw Creek Snow King, Old Reveg, and native reference plots, 2006. Ocular estimates, in percent, are presented below the plot descriptions. "T" indicates trace amounts of cover.

Lifeform	Family	Scientific name	Common name	Annual / Perennial	Native / Alien	Noxious / Invasive	Full Treatment Compost SK1	Full Treatment Compost and Woodchips SK2	Full Treatment Woodchips SK 3	Partial Treatment Woodchips OR1	Surface Treatment OR2	Native Reference
Forb	Asteraceae	*Achillea millefolium*	yarrow	Perennial	Native		< 5	< 5	5	T		
Forb	Asteraceae	*Antennaria rosea*	pussy toes	Perennial	Native							
Forb	Brassicaceae	*Arabis holboellii*	Holboel's rockcress	Perennial	Native			T				
Forb	Asteraceae	*Aster ascendens*	long-leaved aster	Perennial	Native			T	T			
Forb	Brassicaceae	*Capsella bursa-pastoris*	shepherd's purse	Annual	Alien							
Forb	Asteraceae	*Chaenactis douglasii*	Douglas pincushion	Perennial	Native		T					
Forb	Asteraceae	*Cirsium andersonii*	Anderson's thistle	Perennial	Native		T	T		T	T	
Forb	Polemoniaceae	*Collomia tinctoria*	staining collomia	Annual	Native				T	T		
Forb	Boraginaceae	*Cryptantha ambigua*	Wilke's cryptantha	Annual	Native		T	T				
Forb	Brassicaceae	*Descurainia sophia*	herb Sophia	Annual	Alien	Invasive						
Forb	Polygonaceae	*Eriogonum nudum*	nude buckwheat	Perennial	Native				T	T		
Forb	Polygonaceae	*Eriogonum umbellatum*	sulphur flower buckwheat	Perennial	Native		T	5 - 10	5 - 10			
Forb	Geraniaceae	*Erodium cicutarium*	red stem storksbill	Annual	Alien	Invasive						
Forb	Onagraceae	*Gayophytum diffusum*	groundsmoke	Perennial	Native		5 - 10	15 - 20	5 - 10			
Forb	Asteraceae	*Hieracium albiflorum*	Hawkweed	Perennial	Native		T					
Forb	Asteraceae	*Lactuca serriola*	devil's lettuce	Annual	Alien	Invasive						
Forb	Fabaceae	*Lathyrus latifolius*	sweet pea	Perennial	Alien				T			
Forb	Brassicaceae	*Lepidium campestre*	English pepperweed	Annual	Alien							
Forb	Asteraceae	*Leucanthemum vulgare*	ox-eye daisy	Perennial	Alien	Invasive	< 5	< 5	< 5	T		
Forb	Polemoniaceae	*Linanthus harkenssii*	Harken's linanthus	Annual	Native		T					
Forb	Fabaceae	*Lotus purshianus*	Spanish lotus	Perennial	Native							
Forb	Fabaceae	*Lupinus argenteus*	silver lupine	Perennial	Native							
Forb	Fabaceae	*Lupinus lepidus (culbertsonii)*	Culberton's lupine	Perennial	Native		< 5	< 5				
Forb	Asteraceae	*Madia glomerata*	mountain tarweed	Annual	Native		< 5	< 5	5 - 10	T		
Forb	Lamiaceae	*Monardella odoratissima*	mountain monardella	Perennial	Native			T		T		
Forb	Onagraceae	*Oenethera sp.*	evening primrose	Perennial	Native							
Forb	Scrophulariaceae	*Pedicularis semibarbata*	lousewort	Perennial	Native							T
Forb	Scrophulariaceae	*Penstemon laetus*	gay penstemon	Perennial	Native			T				
Forb	Hydrophyllaceae	*Phacelia hastata*	silverleaf phacelia	Perennial	Native							
Forb	Polemoniaceae	*Phlox gracilis*	slender phlox	Annual	Native							
Forb	Polygonaceae	*Polygonum douglasii*	Douglas knotweed	Annual	Native			T	< 5			
Forb	Ericaceae	*Pyrola picta*	wintergreen	Perennial	Native							T

Lifeform	Family	Scientific name	Common name	Annual / Perennial	Native / Alien	Noxious / Invasive	Full Treatment Compost SK1	Full Treatment Compost and Woodchips SK2	Full Treatment Woodchips SK 3	Partial Treatment Woodchips OR1	Surface Treatment OR2	Native Reference
Forb	Brassicaceae	*Sisymbrium altissimum*	tumble mustard	Annual	Alien							
Forb	Apiaceae	*Sphenosciadium capitellatum*	ranger's buttons	Perennial	Native					T	T	
Forb	Asteraceae	*Taraxacum officinale*	dandelion	Annual	Alien	Invasive	T					
Forb	Asteraceae	*Tragapogon dubius*	false salsify	Annual	Alien			T				
Forb	Fabaceae	*Trifolium repens*	white clover	Perennial	Alien		T					
Forb	Scrophulariaceae	*Verbascum thapsus*	mullen	Annual	Native	Invasive						
Graminoid	Poaceae	*Achnatherum nelsonii*	Nelson's needlegrass	Perennial	Native				5			
Graminoid	Poaceae	*Achnatherum occidentalis*	Western needlegrass	Perennial	Native		< 5	10				
Graminoid	Poaceae	*Elytrigia intermedia*	pubescent wheatgrass	Perennial	Alien					20 - 30	75	
Graminoid	Poaceae	*Elytrigia intermedia*	intermediate wheatgrass	Perennial	Alien		30	40	30 - 40	50 - 60	30	
Graminoid	Poaceae	*Bromus carinatus*	mountain brome	Perennial	Native		10	15 - 20	10			
Graminoid	Poaceae	*Bromus tectorum*	cheatgrass	Annual	Alien	Invasive						
Graminoid	Poaceae	*Dactylis glomerata*	orchard grass	Perennial	Alien	Invasive	10	10				
Graminoid	Poaceae	*Deschampsia elongata*	elongated hairgrass	Perennial	Native							
Graminoid	Poaceae	*Elymus elymoides*	squirreltail	Perennial	Native		10	20	10 - 15			
Graminoid	Poaceae	*Elymus glaucus*	blue wildrye	Perennial	Native		5 - 10	20 - 25	25			
Graminoid	Poaceae	*Hordeum vulgare*	barley	Annual	Alien							
Graminoid	Poaceae	*Poa secunda*	pine bluegrass	Perennial	Native		< 5					
Shrub	Ericaceae	*Arctostaphylos nevadensis*	pinemat manzanita	Perennial	Native		< 5					70
Shrub	Ramnaceae	*Ceanothus cordulatus*	buckthorne	Perennial	Native		T					
Shrub	Rosaceae	*Rubus parviflorus*	thimbleberry	Perennial	Native						5 - 10	
Shrub	Caprifoliaceae	*Symphoricarpos mollis*	trailing snowberry	Perennial	Native						T	
Tree	Pinaceae	*Abies concolor*	white fir	Perennial	Native		20	T	T			10 -20
Tree	Pinaceae	*Pinus jefferyi*	Jeffrey pine	Perennial	Native		T					

Species list and ocular estimates for Snow King, Old Reveg, and native reference plots, 2007. Ocular estimates, in percent, are presented below the plot descriptions. "T" indicates trace amounts of cover.

Lifeform	Family	Scientific name	Common name	Annual / Perennial	Native / Alien	Noxious / Invasive	Full Treatment Compost SK1	Full Treatment Compost and Woodchips SK2	Full Treatment Woodchips SK 3	Partial Treatment Woodchips OR1	Surface Treatment OR2	Native
Forb	Asteraceae	*Achillea millefolium*	yarrow	Perennial	Native		T	<5	<5			
Forb	Asteraceae	*Chaenactis douglasii*	Douglas pincushion	Perennial	Native		T	T	T			
Forb	Asteraceae	*Cirsium andersonii*	Anderson's thistle	Perennial	Native		T	T		T	T	
Forb	Polemoniaceae	*Collomia tinctoria*	staining collomia	Annual	Native				T	T		
Forb	Boraginaceae	*Cryptantha ambigua*	Wilke's cryptantha	Annual	Native			T				
Forb	Polygonaceae	*Eriogonum nudum*	nude buckwheat	Perennial	Native		T	T		T		
Forb	Polygonaceae	*Eriogonum umbellatum*	sulphur flower buckwheat	Perennial	Native		<5	5-10	5-10			
Forb	Geraniaceae	*Erodium cicutarium*	red stem storksbill	Annual	Alien	Invasive						
Forb	Onagraceae	*Gayophytum diffusum*	groundsmoke	Perennial	Native		10	15-20	10-15			
Forb	Asteraceae	*Leucanthemum vulgare*	ox-eye daisy	Perennial	Alien	Invasive	5	<5	<5	T		
Forb	Fabaceae	*Lupinus lepidus (culbertsonii)*	Culberton's lupine	Perennial	Native		T	T	T			
Forb	Asteraceae	*Madia glomerata*	mountain tarweed	Annual	Native		T	5	5-10	T		
Forb	Lamiaceae	*Monardella odoratissima*	mountain monardella	Perennial	Native			T	T	T		
Forb	Scrophulariaceae	*Pedicularis semibarbata*	lousewort	Perennial	Native							T
Forb	Scrophulariaceae	*Penstemon laetus*	gay penstemon	Perennial	Native			T				
Forb	Hydrophyllaceae	*Phacelia hastata*	silverleaf phacelia	Perennial	Native		T					
Forb	Polygonaceae	*Polygonum douglasii*	Douglas knotweed	Annual	Native			T	<5			
Forb	Ericaceae	*Pyrola picta*	wintergreen	Perennial	Native							T
Forb	Apiaceae	*Sphenosciadium capitellatum*	ranger's buttons	Perennial	Native					T	T	
Graminoid	Poaceae	*Achnatherum occidentale*	Western needlegrass	Perennial	Native		T	<5	<5			
Graminoid	Poaceae	*Elytrigia intermedia*	pubescent wheatgrass	Perennial	Alien					20	20	
Graminoid	Poaceae	*Elytrigia intermedia*	intermediate wheatgrass	Perennial	Alien		15	25	20	50	50	
Graminoid	Poaceae	*Bromus carinatus*	mountain brome	Perennial	Native		T	T	T			
Graminoid	Poaceae	*Bromus inermis*	smooth brome	Perennial	Alien					T	T	
Graminoid	Poaceae	*Dactylis glomerata*	orchard grass	Perennial	Alien	Invasive	T	5				
Graminoid	Poaceae	*Elymus elymoides*	squirreltail	Perennial	Native		<5	5-10	10			
Graminoid	Poaceae	*Elymus glaucus*	blue wildrye	Perennial	Native		5-10	10	10			
Graminoid	Poaceae	*Poa secunda*	pine bluegrass	Perennial	Native		<5					
Shrub	Ericaceae	*Arctostaphylos nevadensis*	pinemat manzanita	Perennial	Native		5					70
Shrub	Ramnaceae	*Ceanothus cordulatus*	buckthorne	Perennial	Native		<5					
Shrub	Rosaceae	*Purshia tridentata*	antelope bitterbrush	Perennial	Native							
Shrub	Rosaceae	*Rubus parviflorus*	thimbleberry	Perennial	Native						5-10	
Shrub	Caprifoliaceae	*Symphoricarpos mollis*	trailing snowberry	Perennial	Native						T	
Tree	Pinaceae	*Abies concolor*	white fir	Perennial	Native		30	T	T			10-20

Species list and ocular estimates for Snow King, Old Reveg, and native reference plots, 2008. Ocular estimates, in percent, are presented below the plot descriptions. “T” indicates trace amounts of cover.

Lifeform	Family	Scientific name	Common name	Annual / Perennial	Native / Alien	Noxious	In IERS seed mix?	% in IERS seed mix	Full Treatment Compost SK1	Full Treatment Compost and Woodchips SK2	Full Treatment Woodchips SK 3	In RSC seed mix?	Partial Treatment Woodchips OR1	Surface Treatment OR2
Forb	Asteraceae	*Achillea millefolium*	yarrow	Perennial	Native				2	1	T			
Forb	Brassicaceae	*Arabis holboellii*	Holboel's rockcress	Perennial	Native				T					
Forb	Asteraceae	*Chaenactis douglasii*	Douglas' dustymaiden	Both	Native									
Forb	Asteraceae	*Cirsium andersonii*	Anderson's thistle	Perennial	Native				T	T				T
Forb	Polemoniaceae	*Collomia tinctoria*	staining collomia	Annual	Native									
Forb	Convolvulaceae	*Convolvulus arvensis*	orchard morningglory, bindweed	Perennial	Alien	Invasive				T				
Forb	Boraginaceae	*Cryptantha ambigua*	Wilke's cryptantha	Annual	Native									
Forb	Polygonaceae	*Eriogonum nudum*	nude buckwheat	Perennial	Native				T					
Forb	Polygonaceae	*Eriogonum umbellatum*	sulphur flower buckwheat	Perennial	Native				3	3	2			
Forb	Geraniaceae	*Erodium cicutarium*	red stem storksbill	Annual	Alien	Invasive								
Forb	Onagraceae	*Gayophytum sp*	groundsmoke	Annual	Native				10	12	15		2	2
Forb	Asteraceae	*Leucanthemum vulgare*	ox-eye daisy	Perennial	Alien	Invasive			T	T	T			
Forb	Fabaceae	*Lupinus lepidus*	Culberton's lupine	Perennial	Native				T	T	T			
Forb	Asteraceae	*Madia glomerata*	mountain tarweed	Annual	Native				T	2-3	2			
Forb	Lamiaceae	*Monardella odoratissima*	mountain monardella	Perennial	Native									
Forb	Scrophulariaceae	*Pedicularis semibarbata*	lousewort	Perennial	Native				T					
Forb	Scrophulariaceae	*Penstemon laetus*	gay penstemon	Perennial	Native									
Forb	Hydrophyllaceae	*Phacelia hastata*	silverleaf phacelia	Perennial	Native									
Forb	Polygonaceae	*Polygonum douglasii*	Douglas knotweed	Annual	Native						T			
Forb	Ericaceae	*Pyrola picta*	wintergreen	Perennial	Native									
Forb	Apiaceae	*Sphenosciadium capitellatum*	ranger's buttons	Perennial	Native									T
Forb	Asteraceae	*Tragopogon dubius*	false salsify	Annual	Alien					T	T			
Forb	Asteraceae	*Wyethia mollis*	mule ears	Perennial	Native						T			
Graminoid	Poaceae	*Achnatherum occidentale*	Western needlegrass	Perennial	Native				5	6	6			
Graminoid	Poaceae	*Bromus carinatus*	mountain brome	Perennial	Native		X	32%	T	T	T			
Graminoid	Poaceae	*Bromus inermis ssp. inermis*	smooth brome	Perennial	Alien								T	T
Graminoid	Poaceae	*Dactylis glomerata*	orchard grass	Perennial	Alien	Invasive			T					
Graminoid	Poaceae	*Elymus elymoides*	squirreltail	Perennial	Native		X	32%	1	T	4			
Graminoid	Poaceae	*Elymus glaucus*	blue wildrye	Perennial	Native		X	32%	5	4	3			
Graminoid	Poaceae	*Elytrigia intermedia*	pubescent wheatgrass	Perennial	Alien				T	T	T	X	20	35
Graminoid	Poaceae	*Elytrigia intermedia*	intermediate wheatgrass	Perennial	Alien				5	4	7	X	30	35
Graminoid	Poaceae	*Poa secunda*	pine bluegrass	Perennial	Native				T					
Shrub	Ericaceae	*Arctostaphylos nevadensis*	pinemat manzanita	Perennial	Native				T					
Shrub	Ramnaceae	*Ceanothus cordulatus*	buck brush, whitethorn	Perennial	Native				T					
Shrub	Rosaceae	*Prunus emarginata*	bitter cherry	Perennial	Native						T			

Lifeform	Family	Scientific name	Common name	Annual / Perennial	Native / Alien	Noxious	In IERS seed mix?	% in IERS seed mix	Full Treatment Compost SK1	Full Treatment Compost and Woodchips SK2	Full Treatment Woodchips SK 3	In RSC seed mix?	Partial Treatment Woodchips OR1	Surface Treatment OR2
Shrub	Rosaceae	*Purshia tridentata*	antelope bitterbrush	Perennial	Native		X	5%						
Shrub	Rosaceae	*Rubus parviflorus*	thimbleberry	Perennial	Native									T
Shrub	Caprifoliaceae	*Symphoricarpos mollis*	trailing snowberry	Perennial	Native									
Tree	Pinaceae	*Abies concolor*	white fir	Perennial	Native				12	1	T			
Tree	Pinaceae	*Pinus jeffreyi*	Jeffrey pine	Perennial	Native				T					
TOTAL COVER (transects)									38%	45%	45%		54%	75%
TOTAL COVER (ocular estimate)									45%	35%	40%		52%	73%

Truckee Bypass Test Plots Site Report

May 2009

Introduction

Monitoring results and erosion control treatment recommendations for a series of 15 test plots in the Truckee area will be presented in this report (Figure 1). Data was collected in three locations: the Truckee Bypass test plots, the Caltrans Erosion Control Type D (EC Type D) surface treatment plot (Caltrans surface treatment plot), and a native reference plot. Monitoring was conducted in 2006, 2007, and 2008. The Truckee Bypass test plots are located on the corner of Brockway Road and State Route (SR) 267 in Truckee, California, and were constructed in 2005 (Figure 2). Further north on SR 267 is the Caltrans EC Type D plot (Figure 2). The native reference sampling area is also located north of the test plots on Joerger Drive. This area was both established and monitored in 2007 (Figure 2). These plots are representative of Caltrans roadside conditions in the Lake Tahoe area, therefore the monitoring results from these plots will be applicable Basin-wide and throughout the Sierra Nevada.

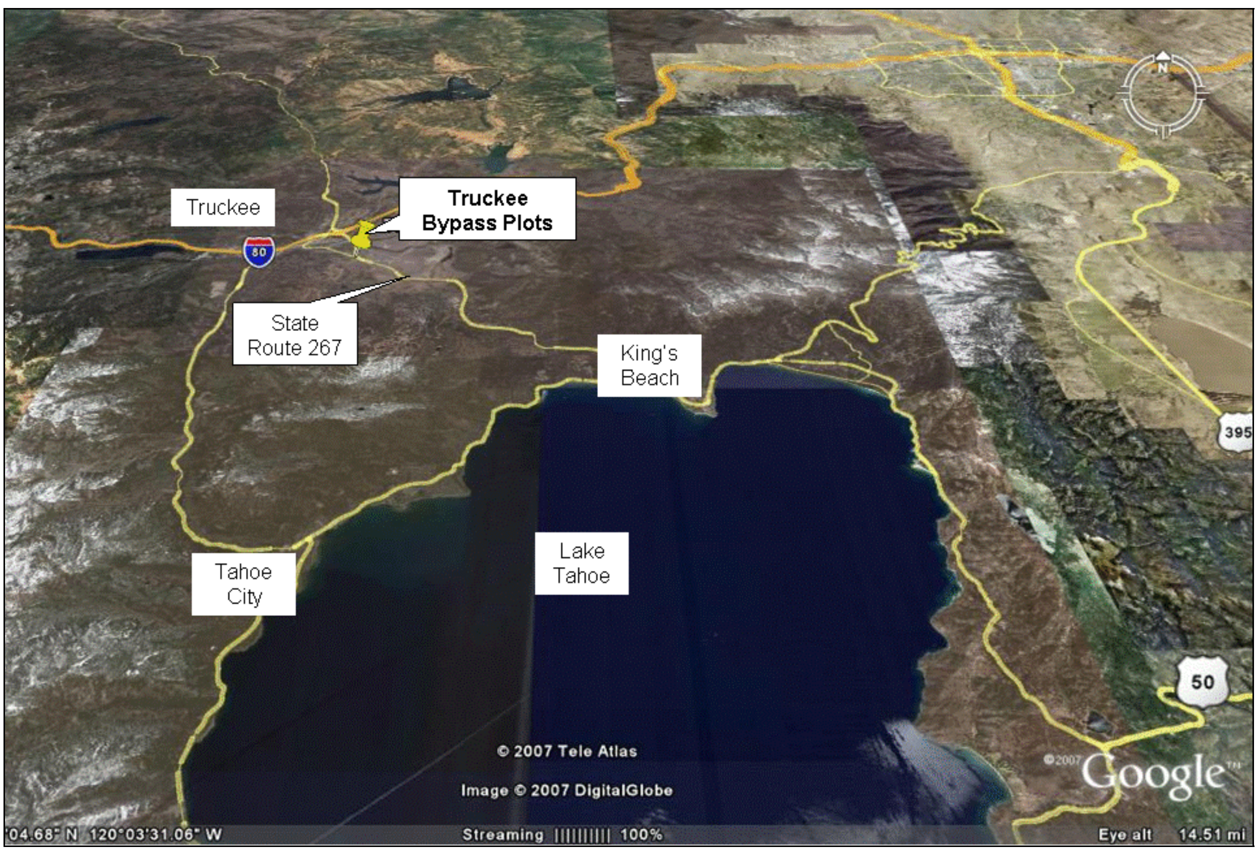


Figure 1. Satellite Map of the Truckee Bypass project area location. The three project areas, Truckee Bypass test plots, the Caltrans surface treatment plot, and a native reference plot are located at the "Truckee Bypass Plots" label. The project area is just north of Lake Tahoe, in California.

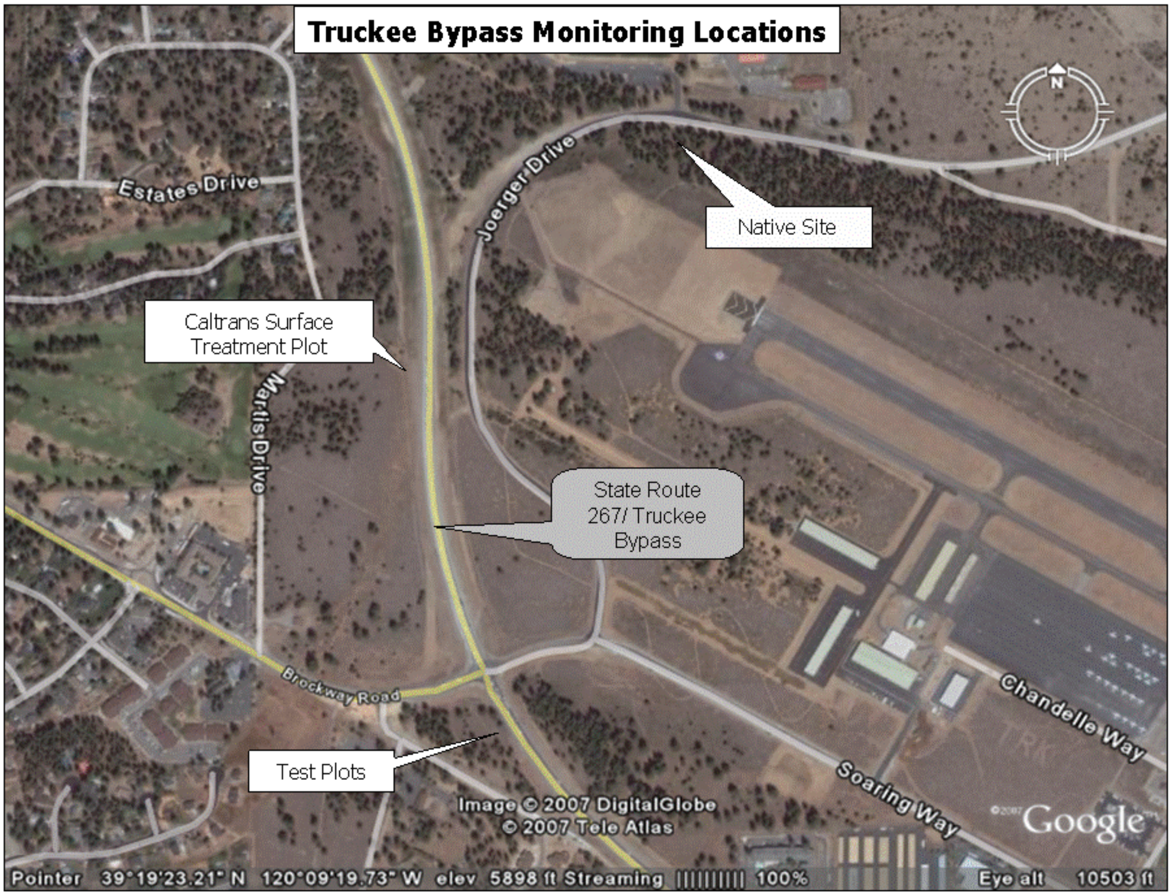


Figure 2. Satellite map of the plot locations in the Truckee Bypass area: the test plots, the Caltrans surface treatment plot, and the native reference plot.

Purpose

The project's monitoring objectives are outlined below. The following treatment definitions are included to aid understanding of these objectives.

Full Treatment: includes soil loosening by tilling or ripping, incorporation of an organic amendment such as compost or woodchips, addition of fertilizer, addition of native seed or plantings, and application of native mulch.

Surface Treatment: does not include the incorporation of organic matter into the soil. This treatment may include surface fertilizing, seeding, or hydroseeding and is similar to Caltrans Erosion Control Type D (EC Type D).

The monitoring data was studied and analyzed to investigate:

1. the erosion control differences between full treatment and surface treatment plots
2. the effects of different seed rates and seed mixes on plant cover and composition
3. the effects of tilling versus ripping on penetrometer depth to refusal (DTR) and infiltration

4. the effects of different types of organic matter (compost, tub grindings, and composted woodchips) on penetrometer DTR, soil nutrient levels and availability, and plant growth

Site Description

Test Plots and Caltrans Surface Treatment Plot

The test plots and the Caltrans surface treatment plot are located on a northeast facing cut slope beside SR 267 in Truckee, California. The site elevations are approximately 5,765 feet (1,758 m) above mean sea level (AMSL). The slope angle ranges between 20 and 25 degrees.

The test plots and the Caltrans surface treatment plot were initially disturbed during the construction of the Truckee Bypass (SR 267) that began in August of 1999 and was completed in October of 2002. Much of the native topsoil was removed during this construction. The slopes were formed from the remaining sub-soil and were mechanically compacted by heavy machinery. The soil parent material is volcanic in origin and is classified as a sandy loam with 66% sand, 18% silt, and 15% clay. The soil is very rocky, with up to 80% coarse fragments greater than 0.5 inches (1.3 cm) in diameter in some areas. The site is surrounded by local native vegetation consisting of an open Jeffrey pine (*Pinus jeffreyi*) canopy, with an understory of antelope bitterbrush (*Purshia tridentata*) and Wyoming sagebrush (*Artemisia tridentata ssp. wyomingensis*), and a few native bunchgrasses and forbs. The solar exposure is approximately 80% in the summer and there is no canopy cover.

Native Reference Plot

The native reference plot is located on a north-facing slope on Joerger Drive at an elevation of approximately 5,652 ft (1,723 m) AMSL. The slope angle is 16 degrees. The soil parent material is volcanic in origin and is classified as a sandy loam with 76% sand, 16% silt, and 7% clay. The soil is not very rocky, with approximately 15% coarse fragments greater than 0.5 inches (1.3 cm) in diameter. The vegetation consists of Jeffrey pine (*Pinus jeffreyi*) and white fir (*Abies concolor*) forest with an antelope bitterbrush (*Purshia tridentata*), Wyoming sagebrush (*Artemisia tridentata ssp. wyomingensis*), and native grass understory. The solar exposure is approximately 26% in the summer and the canopy cover is less than 5%.

Treatment Overview

Of the 15 plots, there are 10 test plots (2a-6b) that received different variations of full treatment in 2005 (Figure 3). Two of the test plots received partial treatments (1a and 1b) and three of the test plots (X, NT, and IRR) received a surface treatment. These treatments are explained in detail below. Some of the treatment abbreviations in Figure 3 will be used throughout the report.

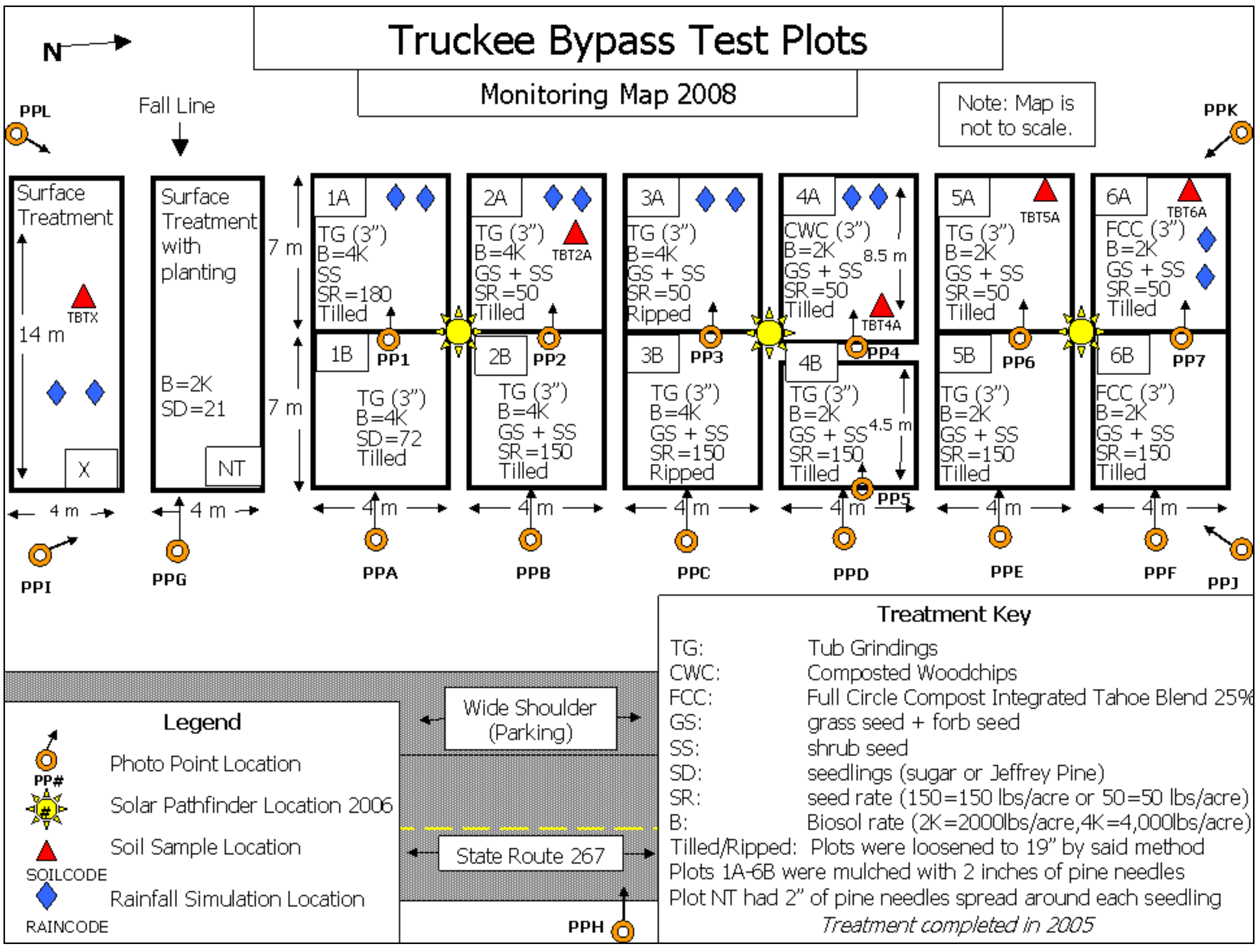


Figure 3. Map of the Truckee Bypass test plots with treatment key. Rainfall simulation, photo points, soil sample, and Solar Pathfinder locations are marked. Some of the treatment abbreviations used on this map will be used throughout the report. Plot IRR and the native plot are not shown on this map.

Full Treatment Test Plots (Plots 1a-6b)

Test plot treatments are presented in Table 1. Descriptions of these treatments can be found following the table. Photos of the test plots before and after treatment are shown in Figure 4, Figure 5, Figure 6, and Figure 7. A photo comparison of the surface treatment and full treatment, 3 years after treatment, are shown in Figure 8 and Figure 9.

Table 1. Truckee Bypass test plot treatments.

Plot	Plot Name	Amendment	Soil Loosening	Biosol Rate (lbs/acre)	Seed Type	Seed Rate	Mulch
X	Surface treatment	None	None	1,338	EC Type D	19.1 lbs/acre	Pine needle and wood-chip mulch 1 - 2"
NT	Surface treatment with planting	None	None	1,338, plus in planting holes	EC Type D, Seedlings	Seed rate 19.1 lbs/acre 21 seedlings	Pine needle and wood-chip mulch 1 - 2"
IRR	Caltrans surface treatment (irrigation in 2006 only)	None	None	1,338	EC Type D	19.1 lbs/acre	Pine needle and wood-chip mulch 1 – 6"
1a		3" Tub Grindings	19" Tilled	4,000	Shrub only	180 lbs/acre	Pine needles 2"
1b		3" Tub Grindings	19" Tilled	4,000, plus in planting holes	Seedlings	72 seedlings	Only surrounding seedlings
2a		3" Tub Grindings	19" Tilled	4,000	Grass and shrub seed	50 lbs/acre	Pine needles 2"
2b		3" Tub Grindings	19" Tilled	4,000	Grass and shrub seed	150 lbs/acre	Pine needles 2"
3a		3" Tub Grindings	19" Ripped	4,000	Grass and shrub seed	50 lbs/acre	Pine needles 2"
3b		3" Tub Grindings	19" Ripped	4,000	Grass and shrub seed	150 lbs/acre	Pine needles 2"
4a		3" Composted Woodchips	19" Tilled	2,000	Grass and shrub seed	50 lbs/acre	Pine needles 2"
4b		3" Tub Grindings	19" Tilled	2,000	Grass and shrub seed	150 lbs/acre	Pine needles 2"
5a		3" Tub Grindings	19" Tilled	2,000	Grass and shrub seed	50 lbs/acre	Pine needles 2"
5b		3" Tub Grindings	19" Tilled	2,000	Grass and shrub seed	150 lbs/acre	Pine needles 2"
6a		3" 25% Compost Blend	19" Tilled	2,000	Grass and shrub seed	50 lbs/acre	Pine needles 2"
6b		3" 25% Compost Blend	19" Tilled	2,000	Grass and shrub seed	150 lbs/acre	Pine needles 2"

Figure 4. Truckee Bypass test plots, pre-construction, 2005.

Figure 5. Truckee Bypass test plots, post-treatment, June, 2006.

Figure 6. Truckee Bypass test plots, 1 year following treatment, June 2007.

Figure 7. Truckee Bypass test plots, 2 years following treatment, June 2008.

Figure 8. Plot NT, surface treatment with planting, July 2008.

Figure 9. Plot 6a, full treatment with the 25% compost blend, July 2008.

Soil Loosening

Test plots 1a-6b were tilled or ripped to a depth of approximately 19 inches (48 cm) by a rubber-tracked excavator using a 24-inch (61 cm) bucket (tilling) or tines mounted on the bucket (ripping; Figure 3). The tilling and ripping depths were verified by penetrometer measurements directly after treatment.

Amendments

Three types of amendments were incorporated at the full treatment test plots (1a-6b): tub grindings, 25% compost blend, and composted woodchips. Each is described in detail below.

Tub Grindings

The Type 1 tub grindings were obtained from a local landfill and are composed of only raw trees, not processed construction wood that comprises some tub grindings. Type 1 tub grindings often include root material with attached soil and often possess more nutrients than woodchips. Tub grindings have a high surface area and are longer, narrower, and coarser than woodchips. The tub grindings were spread to a depth of 3 inches (7.6 cm) at plots 1a, 1b, 2a, 2b, 3a, 3b, 4b, 5a, and 5b, which provided a total nitrogen content of approximately 139 lbs/acre (156 kg/ha).

25% Compost Blend

Integrated Tahoe Blend 25% was obtained from Full Circle Compost in Minden, Nevada. It contains 25% humus fines of 3/8 inch (1 cm) or smaller and 75% compost wood overs. Wood overs (referred to in this report as coarse overs) are the woody material remaining after the composting process that do not pass through a 3/8 inch (1 cm) diameter screen, and range in size from 3/8 of an inch to 3 inches (1-7.6 cm). The Integrated Tahoe Blend 25% was spread to a depth of 3 inches (7.6 cm) at plots 6a and 6b, which provided a nitrogen equivalent of approximately 2,900 lbs/acre (3,250 kg/ha). This blend of 25% compost and 75% coarse overs will be referred to as the 25% compost blend throughout the report.

Composted Woodchips

The woodchips used at the Truckee Bypass site were composted for two years. Further information on the source is unknown. The composted woodchips were spread to depth of 3 inches (7.6 cm) at plot 4a, which provided a nitrogen equivalent of approximately 715 lbs/acre (802 kg/ha).

Fertilizer

Following incorporation of amendments at the full treatment plots, Biosol, a slow release fertilizer, was applied and raked approximately 1 inch (2.5 cm) into the soil at a rate of either 2,000 lbs/acre (2,241 kg/ha) or 4,000 lbs/acre (4,483 kg/ha). Plots 1a, 1b, 2a, 2b, 3a, and 3b received 4,000 lbs/acre (4,483 kg/ha) and plots 4a, 4b, 5a, 5b, 6a, and 6b received 2,000 lbs/acre (2,241 kg/ha). Biosol fertilizer was also placed in the bottom of the planting holes in plots 1b and NT.

Seeding

At the test plots 1a-6b, suitable native perennial grasses, forbs, and shrubs were seeded at a rate of either 50 lbs/acre (56 kg/ha) or 150 lbs/acre (168 kg/ha), and a shrub only seed mix was applied at a rate of 180 lbs/acre (209 kg/ha; Figure 3, Table 2, and Table 3). The seed was lightly raked into the soil to approximately 0.25 inches (0.6 cm) to ensure soil contact.

Table 2. Shrub seed mix (plot 1a), applied at 180 lbs/acre.

Common Name	*Scientific Name*	% Pure Live Seed
Sulphur flower buckwheat	*Eriogonum umbellatum*	17%
Snowbrush	*Ceanothus velutinus*	17%
Rydberg's penstemon	*Penstemon rydbergii*	17%
Common sagebrush	*Artemisia tridentata*	17%
Antelope bitterbrush	*Purshia tridentata*	17%
Wax currant	*Ribes cereum*	17%

Table 3. Grass and shrub seed mix (plots 2a-6b), applied at either 50 or 150 lbs/acre.

Common Name	*Scientific Name*	% Pure Live Seed
Mountain brome (Bromar)	*Bromus carinatus*	23%
Squirreltail	*Elymus elymoides*	21%
Snowbrush	*Ceanothus velutinus*	14%
Antelope bitterbrush	*Purshia tridentata*	14%
Sulphur flower buckwheat	*Eriogonum umbellatum*	7%
Common sagebrush	*Artemisia tridentata*	7%
Wax currant	*Ribes cereum*	7%
Western needlegrass	*Achnatherum occidentale*	7%
Rydberg's penstemon	*Penstemon rydbergii*	1%

Planting

Plot 1b received 72 shrub and tree seedlings, which were planted by hand (Table 4). Prior to planting, approximately 1 teaspoon of Biosol fertilizer was placed at the bottom of holes that were 8 inches (20 cm) deep and 10 inches (25 cm) in diameter. A thin layer of soil was then applied to cover the fertilizer and prevent direct root contact.

Table 4. Seedling list (plot 1b)

Common Name	*Scientific Name*	# of seedlings planted
Mountain pride	*Penstemon newberryi*	23
Sugar pine or Jeffrey pine	*Pinus sp.*	20
Huckleberry oak	*Quercus vaccinifolia*	10
Sulphur flower buckwheat	*Eriogonum umbellatum*	10
Mule ears	*Wyethia mollis*	9
Total		**72**

Mulch

Mulch was spread evenly by hand to achieve 99% cover at a depth of 2 inches (5 cm) on all full treatment test plots (1-6), except plot 1b. On plot 1b, mulch was only spread around each seedling.

Surface Treatment

The Caltrans Erosion Control Type D (EC Type D) treatment was applied to plot X, plot NT, and plot IRR. Plots X, NT, and IRR were treated in 2004; however, in 2005 plot NT was planted with 21 small native trees (sugar pine/*Pinus lambertiana*) or Jeffrey pine/*Pinus jeffreyi*). The same planting methods were used for plot NT as plot 1b. At the Caltrans surface treatment plot (IRR), planting also took place in 2005. This plot was irrigated in 2006 and will be referred to as the Caltrans surface treatment plot or the Caltrans surface treatment plot with irrigation in 2006, depending on the importance of the irrigation to the result.

The EC Type D specification was completed in four stages. First, seeds with the "dry" application type in Table 5 were applied at 4.7 lbs/acre (5.3 kg/ha). Second, hydroseeding equipment was used to apply the remainder of the seed, fertilizer, and compost. The hydroseeding mixture included 446 lbs/acre (500 kg/ha) of fiber, 15.5 lbs/acre (16.2 kg/ha) of the "hydroseed" application type, 1,338 lbs/acre (1,500 kg/ha) of fertilizer, and 1,784 lbs/acre (2,000 kg/ha) of screened compost. The slow-release fertilizer was between 6-7% nitrogen, 1-2% phosphoric acid, and 3-4% water soluble potash. It was 100% natural, at least 70% organic, and was sterilized and free of weeds. Third, 1-2 inches (2.5-5 cm) pine and woodchip mulch was applied. Fourth, hydroseeding equipment was used to apply 535 lbs/acre (500 kg/ha) of fiber, 1,606 lbs/acre (1,800 kg/ha) of compost, and 120 lbs/acre (135 kg/ha) of stabilizing emulsion. Subsequent pine needle and woodchip mulch applications occurred near or in the Caltrans surface treatment plot area (IRR) and varied from 1 to 6 (2.5-15 cm). A photo of the Caltrans surface treatment plot is included below (Figure 10).

Table 5. Erosion Control Type D (EC Type D) seed mix for the Caltrans surface treatment plot (IRR), applied at 19.1 lbs/acre

Common Name	*Scientific Name*	% Pure Live Seed	Application Type
Mountain brome	*Bromus carinatus*	23%	Hydroseed
Yarrow	*Achillea millefolium*	1%	Hydroseed
Idaho fescue	*Festuca idahoensis*	19%	Hydroseed
Blue wildrye	*Elymus glaucus*	19%	Hydroseed
Squirreltail	*Elymus elymoides*	14%	Hydroseed
Everlasting cudweed	*Pseudognaphalium canescens*	0.5%	Dry
Common sagebrush	*Artemisia tridentata*	0.5%	Dry
Rabbitbrush	*Chrysothamnus nauseosus*	0.5%	Dry
Stool lupine	*Lupinus lepidus var. sellulus*	14%	Dry
Spanish lotus	*Lotus purshianus*	9%	Dry

Native Reference Plot

The native reference plot, located just off SR 267, is undisturbed and was used as a baseline reference for all other treatments (Figure 11).

Figure 10. Caltrans surface treatment plot (irrigated in 2006), July 2008.

Figure 11. Truckee Bypass native reference plot, 2007.

Monitoring Methods

The test plots and the Caltrans surface treatment plot were both monitored in 2006, 2007, and 2008. Additionally, in 2007, monitoring was conducted at a native reference plot. In the text, both English and metric units will be given, however, tables will contain one or the other.

Rainfall Simulation

In 2006, rainfall simulation was conducted on test plots 1a, 2a, 3a, 4a, 6a, the surface treatment plot with planting (NT), the Caltrans surface treatment plot (IRR), and the surface treatment plot (X). In 2007, rainfall simulation was conducted on test plots 1a, 2a, 3a, 4a, 6a, IRR, X, and the newly established native reference plot. In 2008, rainfall simulation was conducted at plots 1a, 2a, 3a, 4a, 6a, IRR, and X.

The rainfall simulator "rains" on a square plot from a height of 3.3 feet (1 m; Figure 12 and Figure 13). The rate of rainfall is controlled, and runoff is collected from a trough at the bottom of a 6.5 ft^2 (0.6 m^2) frame that has been pounded into the ground. The volume of water collected is measured and the volume of infiltration is calculated by subtracting the volume of runoff from the total volume of water applied to the plot. If runoff is not observed during the first 30 minutes (in 2006 and 2007) or the first 45 minutes (in 2008), the simulation is halted. The collected runoff samples are then analyzed for the amount of sediment they contain. This measurement is presented as the average steady state sediment yield and is hereafter referred to as "sediment yield". The steady state infiltration rate is calculated and will hereafter be referred to as "infiltration rate".

The cone penetrometer is used to record the depth to refusal (DTR), which is an index for soil density, in the area of the frames before rainfall simulations. The 2006 DTR pre-rainfall values were recorded at a maximum pressure of 250 psi (1,724 kPa), while the 2007 and 2008 DTR values were recorded at 350 psi (2,413 kPa). Soil moisture is measured in each frame prior to and following rainfall simulations (2008 only). After rainfall simulation, at least three holes are dug with a trowel to determine the depth to wetting front, which shows how deeply water infiltrated into the soil. In 2007 and 2008, at least nine holes were dug to measure the depth to wetting front.

In 2006 and 2007, differing rainfall rates were applied to different plots depending on their propensity to runoff. In 2008, 4.7 in/hr (120 mm/hr) was applied to all plots, so that data from the plots could be more easily compared. In 2006, three rainfall rates were applied to the plots: 2.8 in/hr (72 mm/hr) at both the Caltrans surface treatment plot (IRR) and the surface treatment (X) plot, 3.3 in/hr (84 mm/hr) at the surface treatment plot with planting (NT), and 4.7 in/hr (120 mm/hr) at test plots. In 2007, the following rainfall rates were applied: 4.7 in/hr (120 mm/hr) at the test plots, 2.8 in/hr (72 mm/hr) at the surface treatment plot (X), and 4.1 in/hr (104 mm/hr) at the native reference and Caltrans surface treatment plot (IRR). The lowest rainfall rate, 2.8 in/hr, is in excess of the 20-year, one hour 'design storm' rate of 0.7 to 1.0 in/hr (18 to 25 mm/hr) for the Truckee-Tahoe area. The design storm rate is used to design most storm water routing plans.

Figure 12. Photo of the rainfall simulator and frame.

Figure 13. Photo of rainfall simulation at Truckee Bypass test plots, June 2006.

Cover

Cover point monitoring was conducted at the test plots and the Caltrans surface treatment plot (IRR) in August of 2006, June of 2007, and July of 2008. Cover was measured at the native reference plot in June of 2007.

Cover is measured using the statistically defensible cover point method along randomly located transects.[1] The cover pointer consists of a metal rod with a laser pointer mounted 3.3 feet (1 m) high. After the rod is leveled in all directions, the button on the laser pointer is depressed and two cover measurements are recorded (Figure 14 and Figure 15):

- the first hit cover, which is the first object intercepted starting from a height of 3.3 ft (1 m) above the ground
- the ground cover hit, which is the low-lying vegetation or soil below the first hit cover, at the ground level

The first hit cover measures the foliar cover by plants (leaves and stems). It does not measure the part of the plant rooted in the ground. The first hit vegetation is then moved aside and a ground cover hit measures the presence of litter/mulch, basal (or rooted) plant cover, rock and woody debris, and/or bare ground. Total ground cover represents any cover other than bare ground. Mulch cover is an important variable in erosion reduction through sediment source control because treatments with cover by pine needle mulch have been shown to reduce sediment yields substantially.[2]

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[1]Hogan, M. 2003. Luther Pass Monitoring Report: Plant and Soil Cover Monitoring for Evaluating Sediment Source Control Success in the Lake Tahoe Basin. Lahontan Regional Water Quality Control Board, South Lake Tahoe, CA.

[2] Grismer, M.E., and M.P. Hogan. 2004. Simulated rainfall evaluation of revegetation/mulch erosion control in the Lake Tahoe Basin: 1. Method assessment. Land Degradation & Development 15:573-588.

Figure 14. Cover pointer in use along transects.

Figure 15. Cover pointer rod with first hit and ground cover hit by the laser pointer. The laser pointer hits are circled in red. The first cover hit is a native grass and the ground cover hit is pine needle mulch.

Foliar and ground level plant cover is recorded by species and then organized into cover groups based on four categories: life form (herbaceous/woody), perennial/annual, native/alien (2007 and 2008), and seeded/volunteer (2007 and 2008). Perennial herbaceous species includes seeded grasses, native grasses and forbs, and any non-native perennial species. Annual herbaceous species include native annuals such as knotweed (*Polygonum sp.*) and invasive species such as cheatgrass (*Bromus tectorum*). Woody species includes any tree or shrub species, either native or introduced. Each species is then classified based on whether it is native to the Tahoe area, and whether it was seeded during treatment. Data is presented on the amount of cover by species. An ocular estimate of cover at each plot is also recorded and includes many species not hit using cover point sampling. The species lists, as well as the ocular estimates of cover by species, are presented in Appendix A.

Soil and Site Physical Conditions

Penetrometer Depth to Refusal and Soil Moisture

In 2006, 2007, and 2008, penetrometer depth to refusal (an index for soil density) and soil moisture were measured along the same transects as the cover point data for all plots. A cone penetrometer with a ½ inch diameter tip is pushed straight down into the soil until a maximum pressure of 350 pounds per square inch (2,413 kPa) is reached (Figure 16 and Figure 17). Although the rainfall frame maximum pressure was 250 psi in 2006, the maximum pressure for DTRs measured on transects was 350 psi for all years, including 2006. The depth at which that pressure is reached is recorded as the depth to refusal (DTR).

Cone penetrometer DTR measurements are used as an index for soil density. Soils with higher DTRs are generally less dense than those with lower DTRs. A denser soil is less likely to allow infiltration. Rainfall simulations conducted on roadcuts in Oregon found increased infiltration rates in soils with penetrometer depths to refusal (DTRs) greater than 4 inches (10 cm).[3]

It is most informative to compare penetrometer DTR measurements collected in soils that have similar moisture levels. When soil moisture content increases, the resistance of the soil to the penetrometer decreases and DTR readings are deeper. Therefore, only penetrometer readings at the same soil moisture can be compared. A hydrometer was used to measure volumetric soil moisture content adjacent to the penetrometer readings at a depth of 4.7 inches (12 cm; Figure 18).

Figure 16. Photo of a cone penetrometer dial, showing pressure applied in pounds per square inch.

Figure 17. Photo of conducting cone penetrometer readings along transects.

Solar Exposure

In 2006, solar exposure measurements were taken throughout the Truckee Bypass test plots, as well as at the Caltrans surface treatment plot (IRR). These measurements are taken using a Solar Pathfinder (Figure 19). Since there was no change in solar obstructions at the test plots, the solar pathfinder data was not collected again in 2007 or 2008. In 2007, solar radiation was recorded at the native reference plot. Solar input affects evaporation rates and soil temperature, which may affect time of seed germination, germination rate, rate of plant growth, and soil microbial activity. Therefore, this is an important variable to consider when monitoring plant growth and soil development.

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[3]Grismer, M.E. 2006. Simulated Rainfall Evaluation at Sunriver and Mt. Bachelor Highways, Oregon. Unpublished.

Figure 18. Conducting soil moisture readings along transects.

Figure 19. Solar pathfinder in use.

Soil Nutrient Analysis

Successful re-vegetation requires that nutrient capital be stored in the soil for release over time. Sufficient organic matter and a functioning microbial community are necessary to provide a long-term source of nitrogen for plants. Previous studies of soil nutrient levels at revegetation sites throughout the Tahoe area found that sites with high plant cover had significantly higher soil nutrients over the long term than soils with lower plant cover levels.[4] Total Kjeldahl nitrogen and organic matter were used as indicators of soil health in this study. Total Kjeldahl nitrogen (TKN) is a measure of readily available nitrogen. Only three soil sub samples were taken from each plot; therefore, differences in TKN and organic matter values may be a result of the variability within a plot.

In 2006, 2007, and 2008, soil samples were taken from test plots 2a, 4a, 5a, 6a, the Caltrans surface treatment plot (IRR/irrigated in 2006), and the surface treatment test plot X (Table 1and Figure 3). In 2007, a soil sample was also taken from the native reference plot. Three soil sub-samples at each plot were collected from the mineral soil beneath any mulch layer to a depth of 12 inches (30 cm; Figure 20). These sub-samples were combined and sieved to remove any material larger than 0.08 inches (2 mm) in diameter, and sent to A&L Laboratories in Modesto, California for the S3C nutrient suite (macro and micronutrients), total Kjeldahl nitrogen (TKN), and organic matter analysis.

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[4]Claassen, V.P., and M.P. Hogan. 2002. Soil Nutrients Associated with Revegetation of Disturbed Sites in the Lake Tahoe Basin. Restoration Ecology 10:195-203.

Figure 20. Soil sub-sample collection.

Statistical Analysis

Statistical tests were used to determine significant differences between treatments. The type of test employed depended on the number of variables tested and the normality of the sample. An Analysis of Variance (ANOVA) was used to investigate whether there were any significant differences in plant cover, soil moisture, or penetrometer DTR among plots with different treatments. An ANOVA sorts data by groups. In this case, data was sorted by amendment type (tub grindings, 25% compost blend, and composted woodchips). ANOVA is typically used with three or more groups.

If a difference was detected using the ANOVA test, the Mann-Whitney test was used to further investigate differences between two sub-groups or sample sets within the larger group. The Mann-Whitney is a non-parametric test that can be applied to data sets with non-normal distributions. Non-normal distributions are common within small data sets. Some of the sample sizes at the Truckee Bypass test plots were small (n=3), making it necessary to use a non-parametric test.

Results and Discussion

Rainfall Simulation

Trends by Treatment Level

From 2006 to 2008, surface treatment plots produced sediment yield ranging from 60 to 1,238 lbs/acre/in (26 to 546 kg/ha/cm), which is an average of 47 to 981 times higher than the three-year average sediment yield produced by the full treatment plots, 1.3 lbs/acre/in (0.6 kg/ha/cm; Figure 21, Figure 22, and Figure 23).

The three-year average sediment yield of 1.3 lbs/acre/in (0.6 kg/ha/cm) at the full treatment plots, was on average 4 times less than the average sediment yield at the native reference plot, 5.2 lbs/acre/in (2.3 kg/ha/cm; Figure 21, Figure 22, and Figure 23). The sediment yields at the full treatment and native plot were both low compared to the surface treatment plots.

The full treatment plots exhibited a three-year average infiltration rate of 4.7 in/hr (120 mm/hr), which was on average 1.3 to 1.6 times higher than the infiltration rates exhibited by the surface treatment plots, which ranged from 3.0 to 3.7 in/hr (75 to 94 mm/hr; Figure 21, Figure 22, and Figure 23). Slightly higher infiltration rates are expected when sediment yield is lower.

Trends by Year for Full Treatment Plots

From 2006 to 2008, 29 of 30 rainfall simulations conducted on full treatment plots did not produce any sediment. There was no increase in sediment yield over the three years (Figure 21, Figure 22, and Figure 23). It is unknown why one simulation out of the 30 produced sediment.

Trends by Year for Surface Treatment Plots

The sediment produced at the surface treatment plot (X) was fairly similar in 2006 and 2007 (86 and 161 lbs/acre/in or 26 and 71 kg/ha/cm), compared to the inconsistently high sediment production in 2008 (1,238 lbs/acre/in or 546 kg/ha/cm; Figure 21, Figure 22, and Figure 23). This is most likely a result of the higher rainfall rate that was applied in 2008 (4.7 in/hr or 120 mm/hr) compared to 2.8 in/hr (72 mm/hr) in 2006 and 2007.

The sediment yield at the Caltrans surface treatment plot (IRR) was also variable over time and decreased from 161 lbs/acre/in (71 kg/ha/cm) in 2006 to 59 lbs/acre/in (26 kg/ha/cm) in 2007, then increased to 311 lbs/acre/in (127 kg/ha/cm) in 2008 (Figure 21, Figure 22, and Figure 23). The general increase from 2006 and 2007 to 2008 may be a result of the higher rainfall rate applied in 2008 (4.7 in/hr or 120 mm/hr) compared to 2.8 in/hr (72 mm/hr) in 2006 and 4.1 in/hr (104 mm/hr) in 2007. It is unclear why the sediment yield decreased between 2006 and 2007 when the rainfall application rate increased. The sediment yield at the surface treatment plots was generally variable, indicating inconsistent erosion control performance over time.

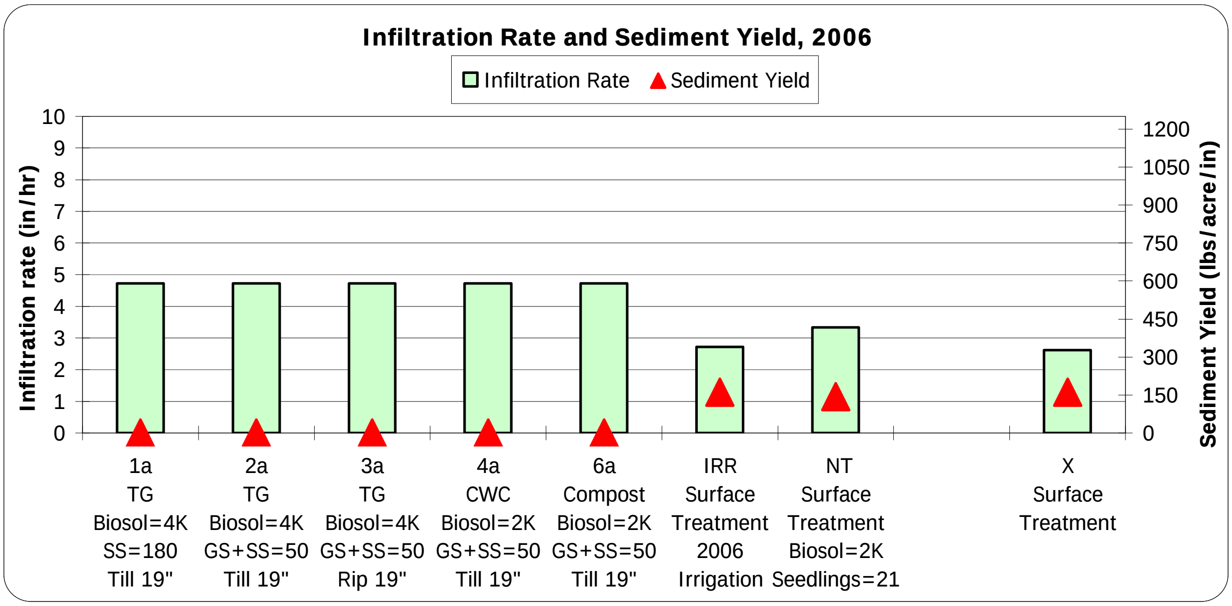

Figure 21. Infiltration Rate and Sediment Yield, 2006. The full treatment plots (1a, 2a, 3a, 4a, and 6a) did not produce any sediment and had high infiltration rates, 4.7 in/hr (120 mm/hr), while the sediment for the surface treatment plots (IRR, NT, and X) ranged from 143-161 lbs/acre/in (63.1-71.0 kg/ha/cm), and the infiltration rates ranged from 2.6-3.3 in/hr (66-84 mm/hr). Rainfall simulation was not conducted at the native reference plot in 2006. SS=shrub seed, GS=grass and forb seed, TG=tub grindings, CWC=composted woodchips, Compost= 25% compost blend.

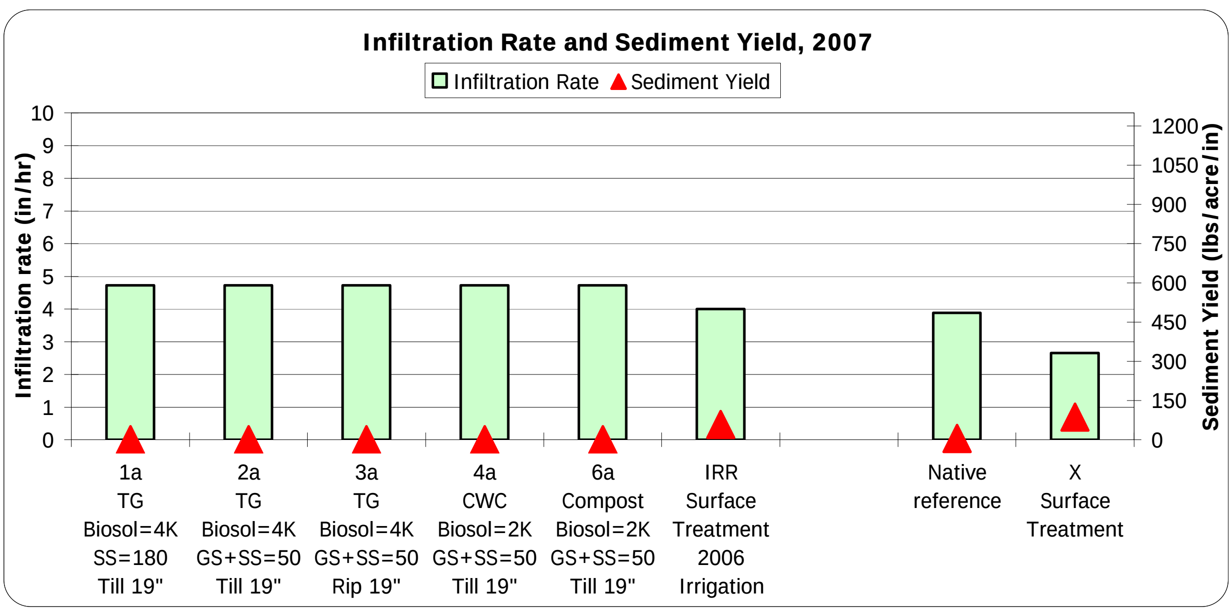

Figure 22. Infiltration Rate and Sediment Yield, 2007. The full treatment plots (1a, 2a, 3a, 4a, and 6a) did not produce any sediment and had high infiltration rates, 4.7 in/hr (120 mm/hr), while the sediment for the surface treatment plots (IRR, NT, and X) ranged from 59-86 lbs/acre/in (26-38 kg/ha/cm), and the infiltration rates ranged from 2.7-4.0 in/hr (69-102 mm/hr). SS=shrub seed, GS=grass and forb seed, TG=tub grindings, CWC=composted woodchips, Compost= 25% compost blend.

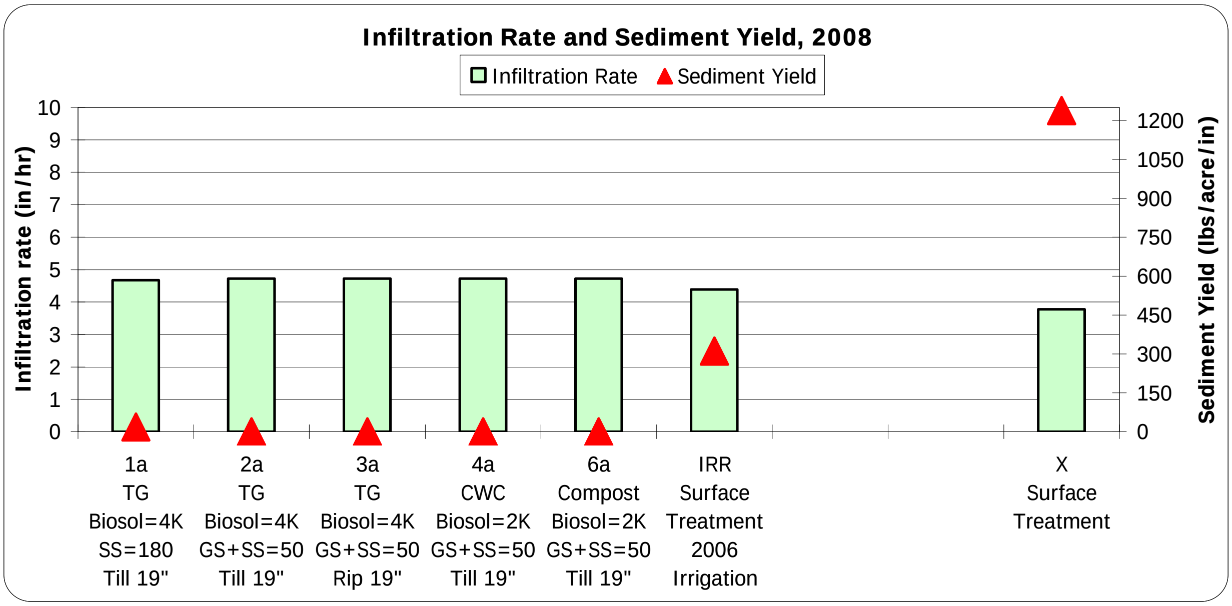

Figure 23. Infiltration Rate and Sediment Yield, 2008. The full treatment plots (1a, 2a, 3a, 4a, and 6a) produced between 0-19 lbs/acre/in (0-8.4 kg/ha/cm) of sediment and had high infiltration rates, 4.7 in/hr (120mm/hr), while the sediment for the surface treatment plots (IRR, NT, and X) ranged from 311-1,238 lbs/acre/in (137-546 kg/ha/cm), and the infiltration rates ranged from 3.8-4.4 in/hr (97-112 mm/hr). SS=shrub seed, GS=grass and forb seed, TG=tub grindings, CWC=composted woodchips, Compost= 25% compost blend.

Soil Moisture

In 2006 and 2008, there was no significant difference between the soil moisture levels at the plots with and without soil loosening, allowing for comparison of penetrometer DTRs (Figure 24, Table 6). In 2007, not enough soil moisture measurements were conducted to determine whether significant differences existed. The three-year average soil moisture at the plots with soil loosening was 6%, while the soil moisture at the native reference plot was comparable at 7%. The soil moisture was much higher in 2006 at the Caltrans surface treatment plot, a plot without soil loosening and with irrigation, because irrigation occurred during that season.

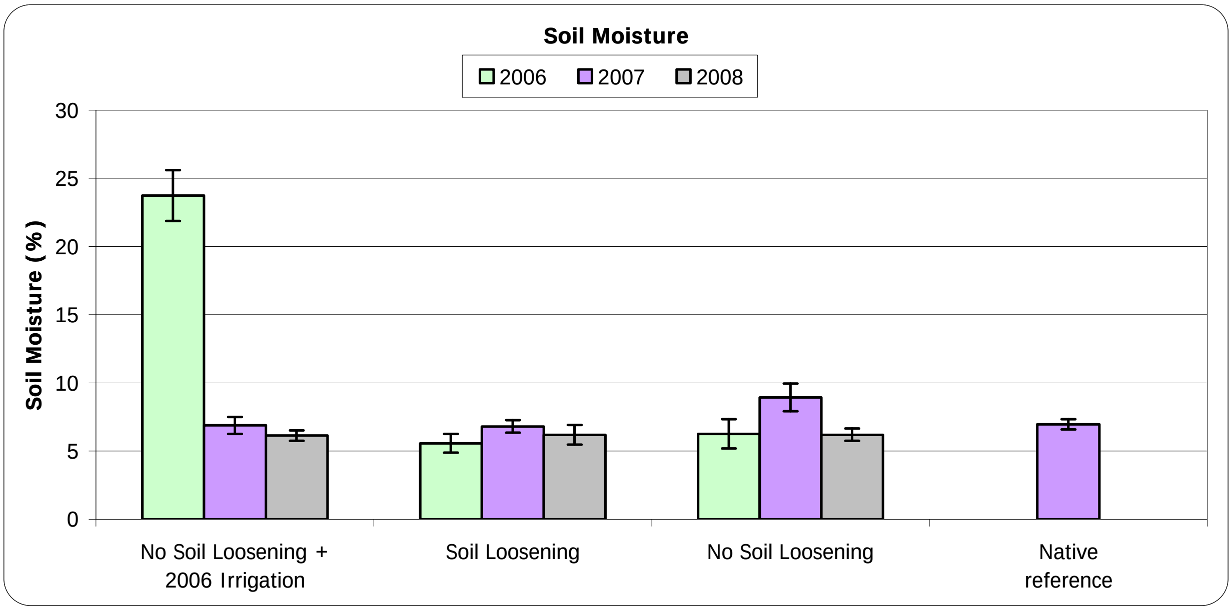

Figure 24. Soil Moisture. Soil moisture levels were similar across all plots, except in 2006 when the irrigation system was functional at the Caltans surface treatment plot without soil loosening. The no soil loosening + 2006 irrigation category includes the Caltrans surface treatment plot irrigated in 2006 only. The soil loosening category includes plots 1a-6b. The no soil loosening category includes plots NT and X. The error bars represent one standard deviation above and below the mean. Data is sorted by increasing 2008 soil moisture.

Penetrometer Depth to Refusal

Trends by Treatment Level

The three-year average DTR for the full treatment plots with soil loosening (5.0 inches or 13 cm) was significantly deeper by an average of 2.8 times when compared to the plots without soil loosening (three-year average of 1.8 inches or 4.6 cm; Figure 25, Table 6). From 2006 to 2008, the plots with soil loosening had penetrometer depths that ranged from 2.1 to 6.7 inches (5.3 to 17 cm), while the plots without soil loosening had depths that ranged from 1.6 to 2.3 inches (4.1 to 5.8 cm; Figure 25). The data from the Caltrans surface treatment plot that was irrigated in 2006 is not included in the above calculations because the number of mulch applications and mulch depths (ranging from 1 to 6 inches) are not known. Breakdown of large quantities of woodchip mulch could result in deeper DTR readings.

The DTRs measured at the plots with soil loosening (three-year average of 5.0 inches or 13 cm) are approximately 1.8 times shallower than the DTR measured at the native reference plot in 2007, 9.2 inches (23 cm; Figure 25). The DTRs at the plots without soil loosening (1.8 inches or 4.6 cm) were 5.2 times shallower than the DTR at the native reference plot. This suggests that applied concentrations of amendments at the plots with soil loosening or the lack of amendments at the surface treatment plots is not adequate to maintain deeper DTRs that would be comparable to those at the native reference plot. Higher incorporated concentrations of woody amendments may result in deeper penetrometer DTRs.

Trends by Amendment Type

Amendment type did not significantly affect the DTR for any year (Table 6).

Trends by Loosening Method

Neither loosening method (tilling/ripping) significantly affected DTR for any year (Table 6).

Trends by Year

The penetrometer depth to refusal for the plots with or without soil loosening (Caltrans surface treatment plot with irrigation in 2006 excluded) did not change significantly from 2006 to 2008 (Table 6). This indicates that re-compaction did not occur over the three-year period, although re-compaction occurred between 2005 (directly following treatment) and 2006 at the plots with soil loosening (from 19 inches or 48 cm to an average of 5 inches or 13 cm).

Effects of Irrigation

The DTR was deeper at the plot without soil loosening and with irrigation in 2006 compared to 2007 and 2008 because the irrigation system was functional during 2006 and penetrometer DTRs are known to increase with increasing soil moisture. The irrigation was not functional in 2007 or 2008.

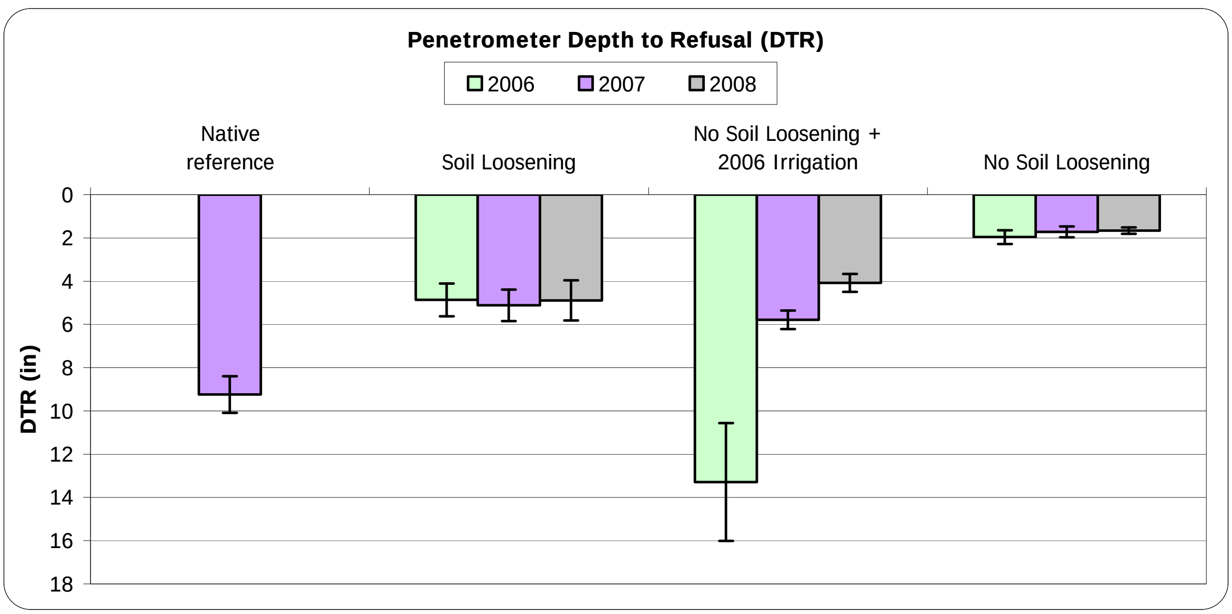

Figure 25. Penetrometer DTR. The penetrometer DTR was 3 times deeper for the plots with soil loosening (three-year average of 5.0 inches or 13 cm) compared to plots without soil loosening (three-year average of 1.8 inches or 4.6 cm). The plot without soil loosening, but with irrigation, had a deep DTR (13.3 inches or 34 cm) in 2006 because the irrigation system was functional and DTR is known to increase with increasing soil moisture. The irrigation system did not operate in 2007 or 2008. The no soil loosening + 2006 irrigation category includes the Caltrans surface treatment plot irrigated in 2006 only. The soil loosening category includes plots 1a-6b. The no soil loosening category includes plots NT and X. The error bars represent one standard deviation above and below the mean. Data is sorted by decreasing penetrometer DTR for 2008.

Cover

Ground Cover by Mulch and Bare Soil

The mulch cover at the full treatment plots (three-year average of 90%) was significantly higher by an average of 1.4 times compared to the mulch cover at the surface treatment plots (three-year average of 66%) and similar to the mulch cover at the native reference plot (95%; Figure 26, Table 6). It is possible that water erosion occurring at the surface treatment plots carried the mulch away, as in some places at Caltrans surface treatment plot, the mulch application was up to 6 inches (15 cm) deep.

Trends by Year

Ground cover by mulch was consistent over time at full treatment and surface treatment plots, with the exception of the surface treatment plot with planting, at which cover by mulch increased from 50% in 2006 and 2007 to 81% in 2008. This increase may be a result of pine needle cast from trees in the surrounding area.

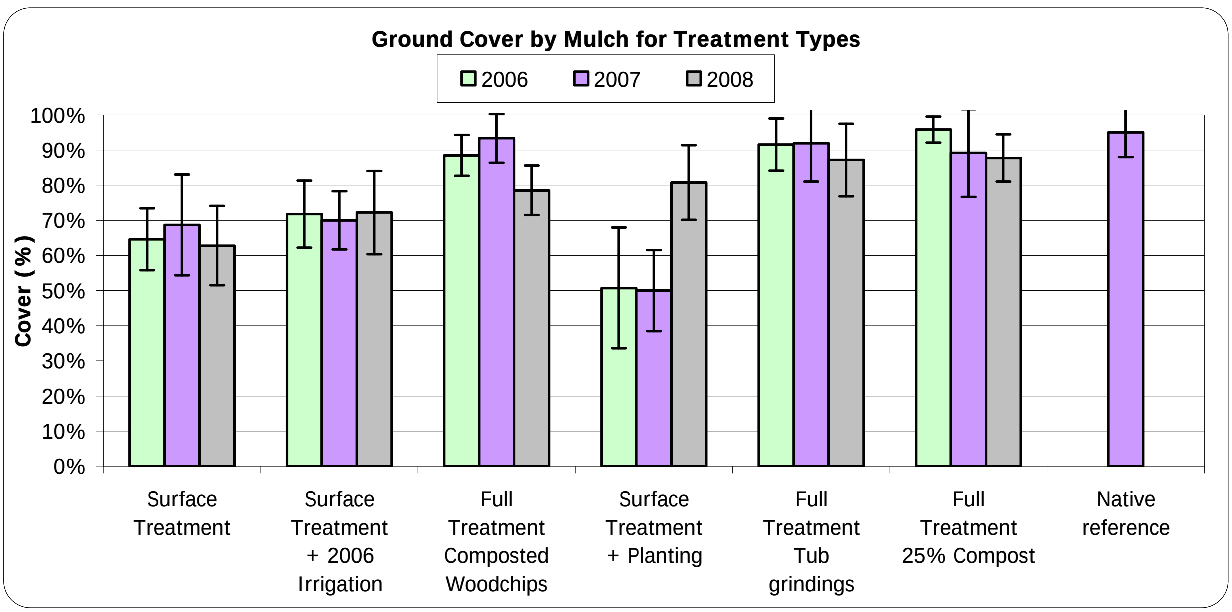

Figure 26. Ground Cover by Mulch for Treatment Types. The mulch cover at the full treatment plots (three-year average of 90%) was on average 1.4 times higher than the mulch cover at the surface treatment plots (three year average of 66%) and similar to the mulch cover at the native reference plot (95%). The error bars represent one standard deviation above and below the mean. Data is sorted by increasing 2008 mulch cover.

The cover by bare soil was significantly lower by an average 10.5 times at the full treatment plots (three-year average of 2%) when compared to the bare soil cover at the surface treatment plots (three-year average of 23%; Figure 27 and Table 6). The native reference plot did not have any bare soil when sampled in 2007.

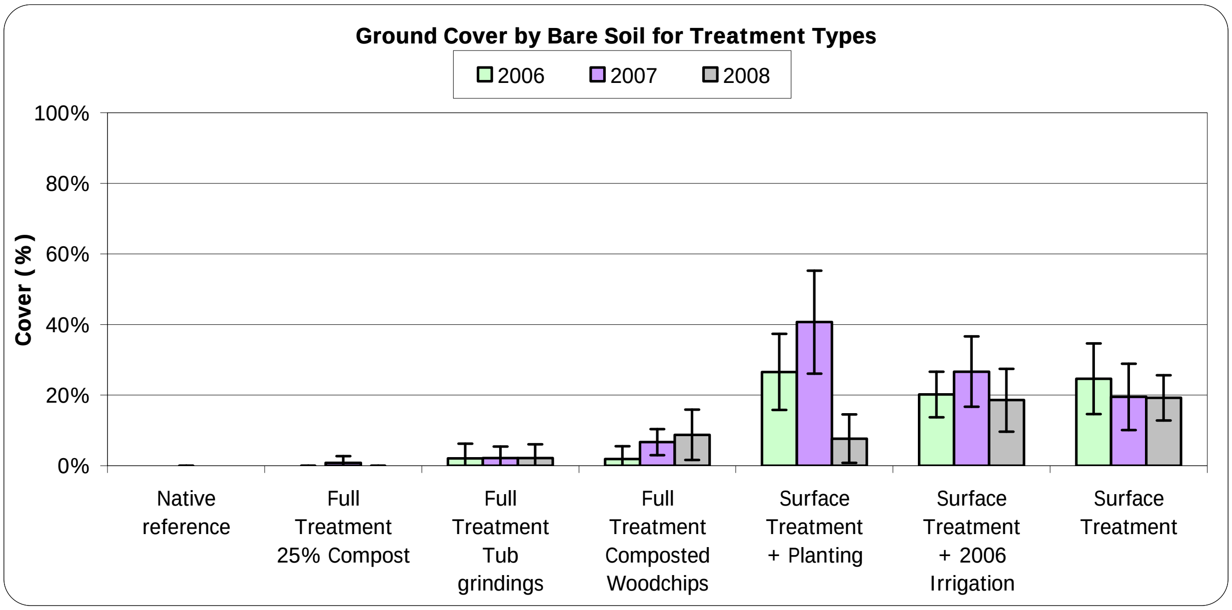

Figure 27. Ground Cover by Bare Soil for Treatment Types. The cover by bare soil was on average 10.5 times lower at the full treatment plots (three-year average of 2%) when compared to the bare soil cover at the surface treatment plots (three-year average of 23%). The native reference plot did not have any bare soil when sampled in 2007. The error bars represent one standard deviation above and below the mean. Data is sorted by increasing bare soil for 2008.

Plant Cover and Composition

Trends by Treatment Level

Foliar plant cover was significantly higher in 2006 to 2008 by an average of 2.2 times at full treatment plots with soil loosening (three-year average of 27%) when compared to surface treatment plots without soil loosening (three-year average of 13%; Figure 28 and Table 6). The perennial plant cover of full treatment plots (three-year average of 21%) was significantly higher by 2.3 times in 2006, 2007, and 2008 than the perennial plant cover of surface treatment plots (three-year average of 9%; Table 6). A graph is not presented for this result, as the data was very similar to that presented in Figure 28. It is possible that foliar and perennial plant cover was higher at the plots with soil loosening because the plant roots were able to penetrate more deeply into the soil and access more moisture and nutrients.

Trends by Amendment Type

In 2006, 2007, and 2008, foliar plant cover was significantly higher by an average of 2 times at plots amended with the 25% compost blend (three-year average of 48%) than plots amended with tub grindings (three-year average of 24%; Figure 28 and Table 6). In 2007 and 2008, the seeded plant cover at plots amended with the 25% compost blend (two-year average of 47%) was significantly higher by 2.3 times than at plots amended with tub grindings (two-year average of 20%; Table 6). Foliar and seeded plant cover was most likely higher at the plots amended with the 25% compost blend because the compost blend has a lower carbon to nitrogen ratio than tub grindings. A lower carbon to nitrogen ratio indicates more nutrients are available in the short term. It is possible that the cover will increase over time at the plots with tub grindings as more nutrients are released.

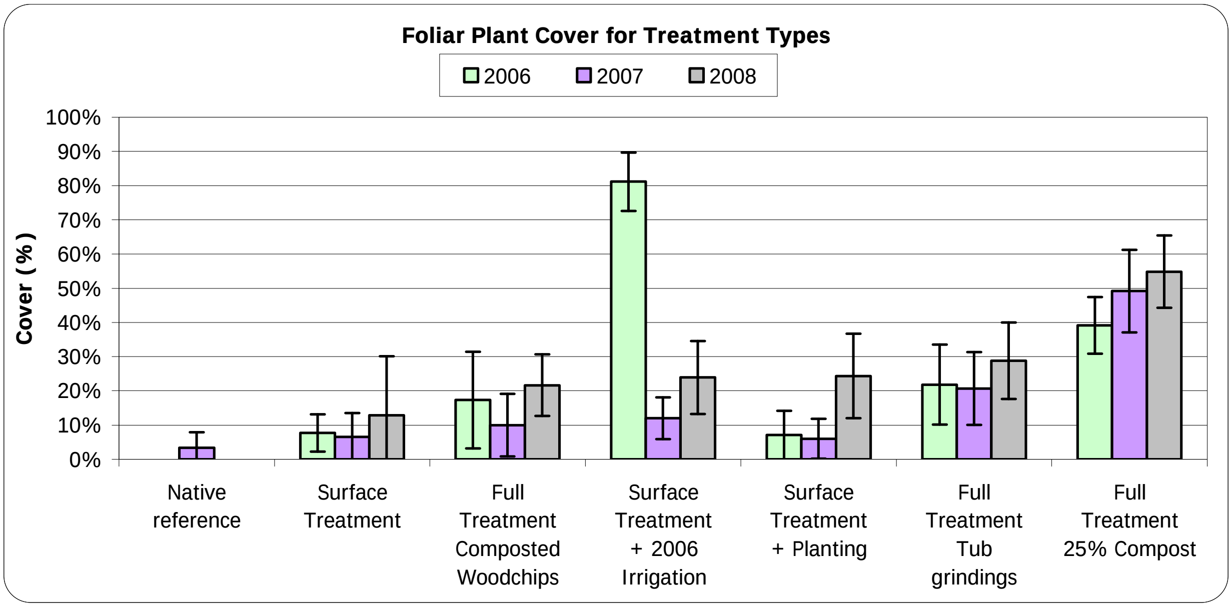

Figure 28. Foliar Cover for Treatment Types. Plant cover was significantly higher from 2006 to 2008 by an average of 2.2 times at full treatment plots (three-year average of 27%) when compared to surface treatment plots (three-year average of 13%). The error bars represent one standard deviation above and below the mean. Data is sorted by increasing foliar plant cover for 2008.

Trends by Year for Full Treatment Plots

At full treatment plots, there is a trend toward a decrease in annual plant cover over time. Annual plant cover ranged from 7 to 8% in 2006, decreased to 2-4% in 2007, and was 0-5% in 2008 (Figure 29, Figure 30, and Figure 31). In addition, there is a trend toward increasing seeded plant cover over time. The average seeded plant cover in 2007 was 20%, with a high of 45% foliar plant cover. In 2008, the average seeded plant cover was 28%, with a high of 56% foliar plant cover (Figure 29, Figure 30, and Figure 31). In the 2006-7 and 2007-8 water years, the yearly precipitation total was less than average (23 and 25 inches or 58 and 64 cm, respectively), compared to a 28-year average of 36 inches (91 cm), making the increase in seeded cover during this time noteworthy.[5] Additional years of data are necessary to confirm these yearly trends because the standard deviations are high for foliar and seeded plant cover. It is likely that as cover by seeded species increases, the seeded species are able to out-compete volunteer species.

Between 2007 and 2008 at the full treatment plots, the amount of the native grass, mountain brome (*Bromus carinatus*), decreased from 7-20% to 1-6%, while the amount of native grass, squirreltail (*Elymus elymoides*), increased from 2-12% to 18-47% (Figure 30 and Figure 31). This trend may be a result of the low initial cover generally present by squirreltail compared to mountain brome in the first season after seeding. Test plots at Homewood indicate that squirreltail does not compete well with other species during the first year of growth. When it

[5] Snotel data from: http://www.wcc.nrcs.usda.gov/snotel/snotel.pl?sitenum=834&state=ca

composed 100% of the seed mix at 125 lbs/acre (112 kg/ha), an average of 60% of the measured cover was squirreltail. In comparison, when mountain brome composed 100% of the seed mix at 125 lbs/acre (112 kg/ha), an average of 94% of the measured cover was mountain brome.[6] It also may be a result of the progressively drier conditions because of less-than-average precipitation totals during those two water years. Squirreltail generally thrives in dry, sunny conditions, while mountain brome prefers moist, shady conditions.

Trends by Year for Surface Treatment Plots

The surface treatment plots with and without planting were dominated by annual plants (7-24% cover) throughout all years and water conditions. In 2008, annual cover increased from no more than 7% in 2006 and 2007, to 10-24% in 2008.

Squirreltail, which was seeded at the Caltrans surface treatment plot, composed 13% of the plant cover in 2006 and subsequently decreased in 2007 and 2008 to amounts less than 5%. This trend is opposite of what was observed at the full treatment plots over the same time.

Effect of Irrigation

A decrease in cover from 81% cover in 2006 to 12% in 2007 was observed after irrigation was shut off in 2007 at the Caltrans surface treatment plot (Figure 29 and Figure 30). An increase to 24% was observed in 2008 (Figure 31). Annual species, which were reliant on the moist conditions created by irrigation, dominated in 2006, while lupine (*Lupinus sp.*) and yarrow (*Achillea millefolium*) dominated in 2008. Native, perennial grasses were present in trace amounts in all years (Appendix A).

In 2008, the Caltrans surface treatment plot that was irrigated in 2006 had similar plant cover to the surface treatment test plot with planting, but different composition. Lupine and yarrow dominated at the Caltrans surface treatment plot, while native annual plants such as slender phox (*Phlox gracilis*) and blue-eyed mary (*Collinsia parviflora*) dominated at the plots without irrigation.

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[6] Monitoring and Assessment of Erosion Control Treatments in and around the Lake Tahoe Basin, 2008-2009 Annual Report for Caltrans, Howewood Wedding Road. Unpublished.

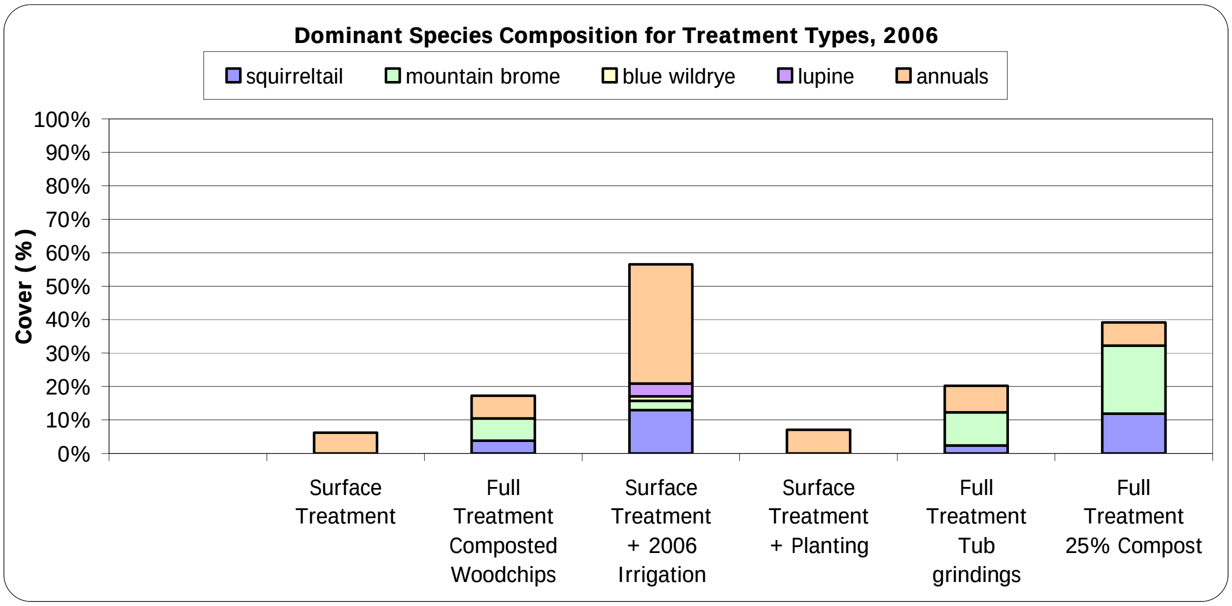

Figure 29. Dominant Species Composition for Treatment Types, 2006. Mountain brome was the dominant species at the full treatment plots.

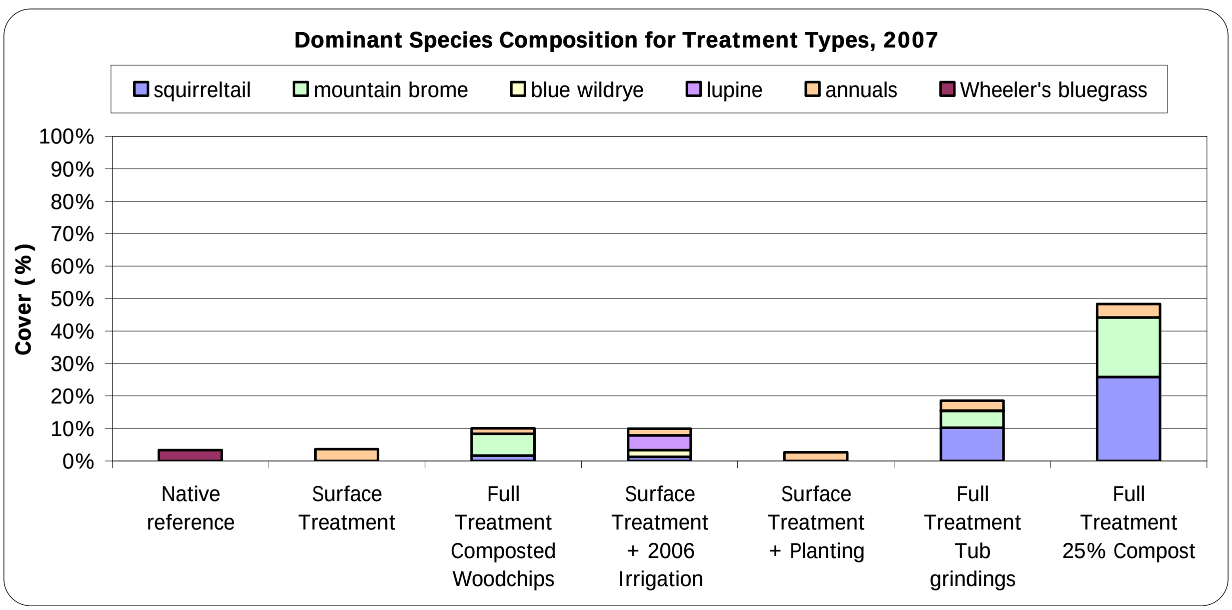

Figure 30. Dominant Species Composition for Treatment Types, 2007. Mountain brome dominated at the full treatment plots with composted woodchips, but decreased at the full treatment plots amended with the 25% compost blend or tub grindings. Squirreltail was the new dominant at the full treatment plots with the 25% compost blend or tub grindings.

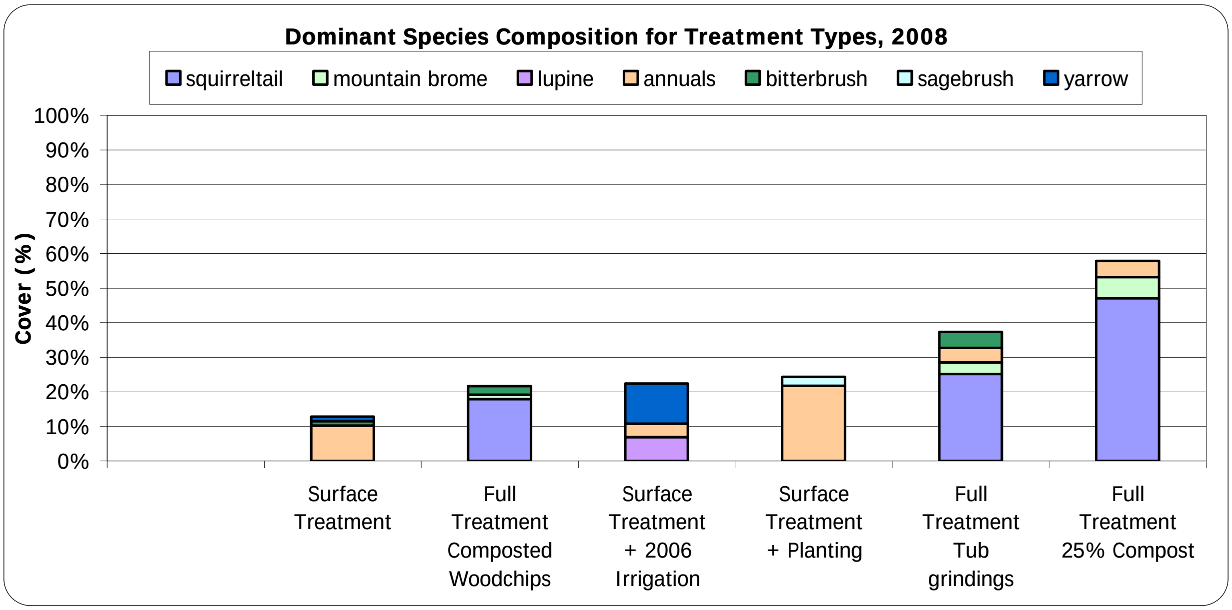

Figure 31. Dominant Species Composition for Treatment Types, 2008. Squirreltail dominated at all the full treatment plots and mountain brome continued to decrease.

Effect of Seed Rates

Seed rate did not significantly affect the seeded plant cover when comparing the combined grass, forb, and shrub seed mix rates of 50 and 150 lbs/acre (Figure 32 and Table 6). The plot with shrub seed produced less than 10% seeded plant cover (Figure 32).

Effect of Planting

Planting was not an effective means of establishing plant cover. Annual, volunteer plants rather than native, seeded plants dominated at both test areas with planting, regardless of whether soil loosening was employed. The percent annual cover at the surface treatment with planting plot as was 100% in 2006 and 2007 and 89% in 2008 (Figure 29, Figure 30, and Figure 31). The percent annual cover at plot 1b, the tilled plot with tub grindings, was 100% in 2006, 44% in 2007, and 65% in 2008 (no graph).

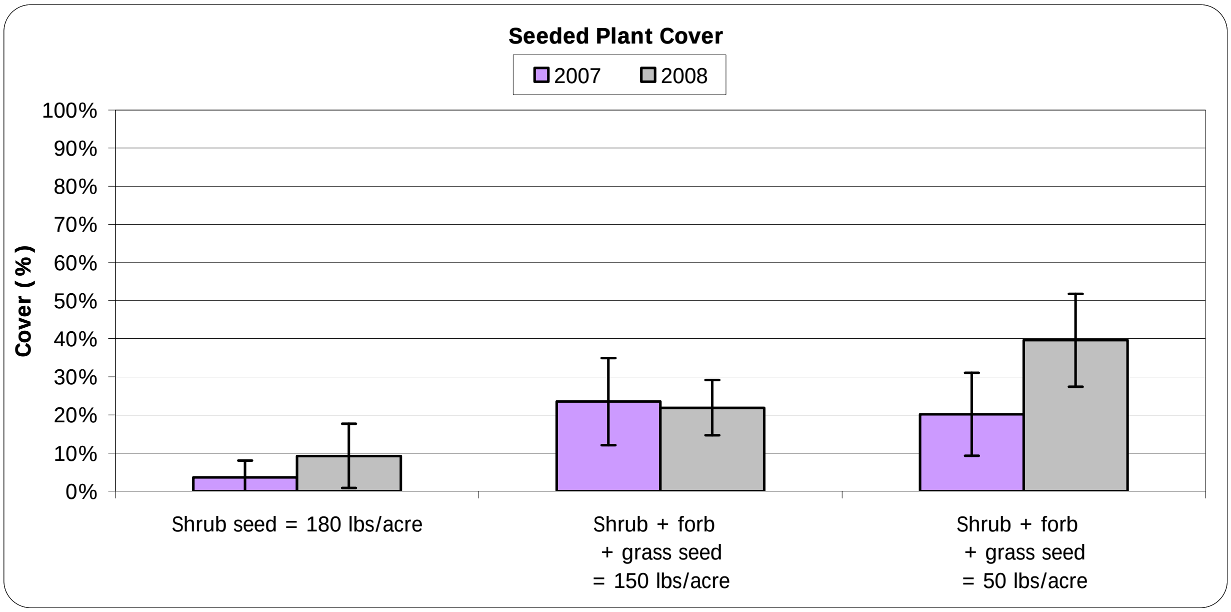

Figure 32. Seeded Plant Cover. Seed rate did not significantly affect seeded cover when comparing the plots seeded with 50 or 150 lbs/acre of shrub, forb, and grass seed. The plot seeded with shrub seed only had a seeded cover of less than 10%. The error bars represent one standard deviation above and below the mean. Data is sorted by 2008 seeded cover.

Soil Nutrients

Total Kjeldahl Nitrogen

Trends by Treatment Level

Over the three years, the surface treatment plots (three-year average of 1,156 ppm) and the full treatment plots (three-year average of 1,104 ppm) had similar average TKN levels (Figure 33). The average TKN for the surface treatment plots in 2008 (1,396 ppm) exceeded that of the full treatment plots (1,015 ppm; Figure 33). However, the full treatment plots amended with the compost blend had a TKN of 1,576 ppm, which was higher than the surface treatment plots.

Trends by Amendment Type

In 2008, the TKN for full treatment plots amended with the 25% compost blend (1,576 ppm) or composted woodchips (1,054 ppm) was similar to or higher than TKN at the native reference plot (1,176 ppm; Figure 33). The TKN at the full treatment plots amended with tub grindings decreased consistently from 1,244 ppm in 2006 to 715 ppm in 2008, which is below native reference levels (Figure 33). This suggests that tub grinding cannot produce TKN levels over time to re-capitalize the soil to native reference levels.

Trends by Year

The Caltrans surface treatment plot that was irrigated in 2006 had low TKN in 2006 and 2007 (790 and 786 ppm respectively). However, the TKN increased to 1,356 ppm in 2008, which is higher than native reference levels (Figure 33). This may be a result of the presence of many lupine plants, which are nitrogen fixers (Appendix A).

The full treatment plots did not exhibit a consistent increasing or decreasing trend over time.

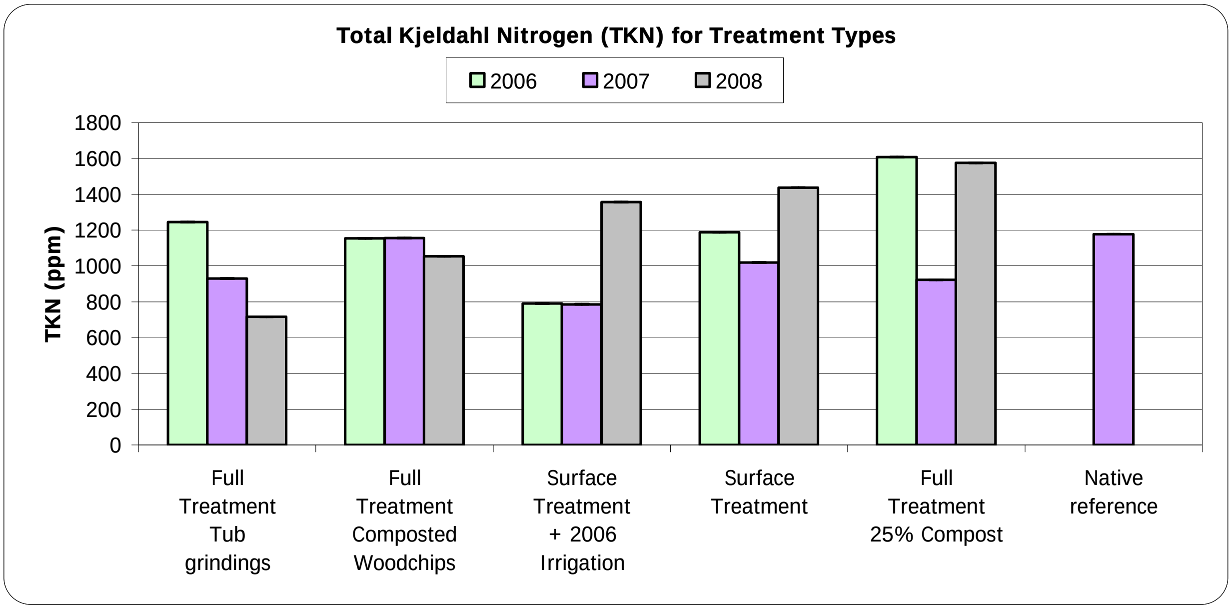

Figure 33. Total Kjeldahl Nitrogen for Treatment Types. Full treatment plots amended with the 25% compost blend (TKN range of 1,054-1,576 ppm) had TKN levels most similar to the native reference plot (TKN of 1,176 ppm) in 2008. Both surface treatment plots (TKN range of 1356-1436 ppm) had similar TKN levels to the native reference plot. Data is sorted by increasing TKN for 2008.

Organic Matter

Trends by Treatment Level

From 2006-8, the surface treatment plots (three-year average of 4.4%) and the full treatment plots (three-year average of 4.1%) had similar average organic matter levels (Figure 34). Neither of the treatment types had similar organic matter levels to the native reference plot (9%). The low organic matter level may be a result of the lack of amendments in the surface treatment plots or the low concentration of amendments used in the full treatment plots. In 2008, the full treatment (4.0%) and surface treatment plots (5.2%) also had similar organic matter levels (Figure 34).

Trends by Amendment Type

Organic matter levels were similar for plots with different amendment types and ranged from 3.4 to 4.7% for amended full treatment plots.

Trends by Year

Organic matter levels were generally consistent over time; however, there was a notable increase in 2008 at the Caltrans surface treatment plot, from 3% to 5.7%. It is unclear why this increase occurred, though it might be related to the increase in plant cover.

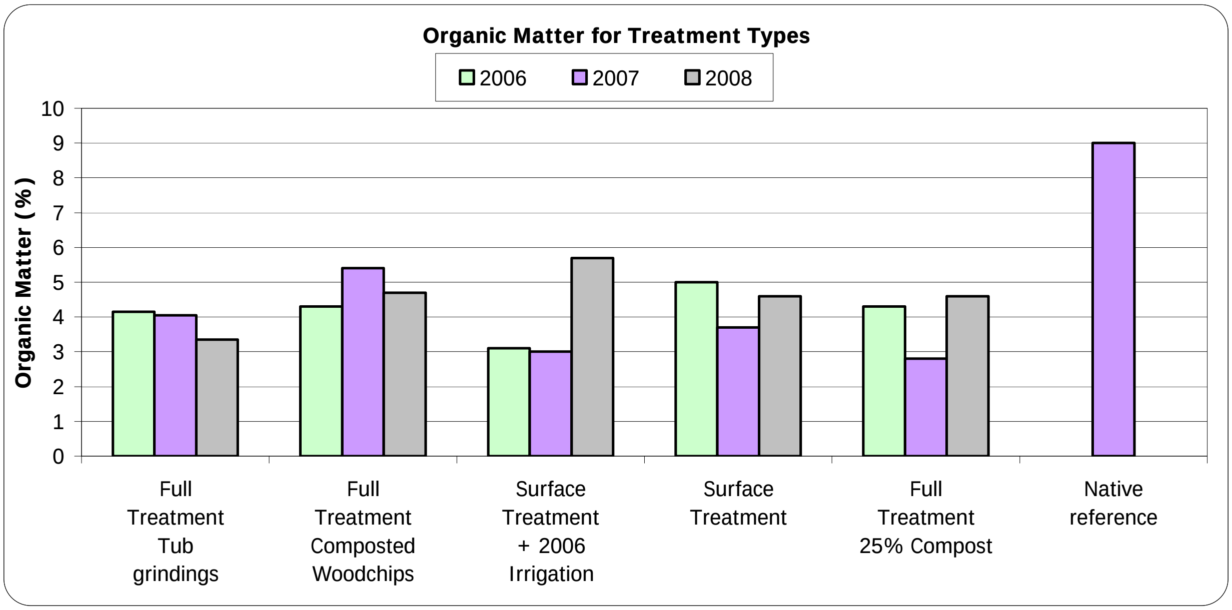

Figure 34. Organic Matter for Treatment Types. The full treatment plots and surface treatment plots had similar organic matter levels (average range of 3.0-5.4%), but both treatment types had lower organic matter levels than the native reference plot (9.0%).

Statistical Results

Statistical results are presented in the order in which they appear in the Results and Discussion section.

Table 6. Statistical Results. A probability of less than 0.1 is considered significant.

Statistical Test	Factors	Variable	Year	Result	Test Statistics	Probability
Mann-Whitney	Soil Loosening and No Loosening	Soil Moisture	2006	No difference in soil moistures for plots with or without loosening	U(12,2)=16	0.549
Mann-Whitney	Soil Loosening and No Loosening	Soil Moisture	2008	No difference in soil moistures for plots with or without loosening	U(12,2)=14	0.791
Mann-Whitney	Soil Loosening and No Loosening	Penetrometer DTR	2006	Deeper DTR at plots with soil loosening	U(10,2)=19	0.061
Mann-Whitney	Soil Loosening and No Loosening	Penetrometer DTR	2007	Deeper DTR at plots with soil loosening	U(10,2)=20	0.030
Mann-Whitney	Soil Loosening and No Loosening	Penetrometer DTR	2008	Deeper DTR at plots with soil loosening	U(10,2)=20	0.030

Statistical Test	Factors	Variable	Year	Result	Test Statistics	Probability
ANOVA	Amendment Type	Penetrometer DTR	2006	No difference in DTR with amendment type	F(1,9)=0.43	0.527
ANOVA	Amendment Type	Penetrometer DTR	2007	No difference in DTR with amendment type	F(1,9)=0.238	0.637
ANOVA	Amendment Type	Penetrometer DTR	2008	No difference in DTR with amendment type	F(1,9)=2.27	0.166
ANOVA	Ripping and Tilling	Penetrometer DTR	2006	No difference in DTR with ripping or tilling	F(1,8)=2.209	0.176
ANOVA	Ripping and Tilling	Penetrometer DTR	2007	No difference in DTR with ripping or tilling	F(1,8)=0.167	0.693
ANOVA	Ripping and Tilling	Penetrometer DTR	2008	No difference in DTR with ripping or tilling	F(1,8)=0.003	0.958
ANOVA	Year	Penetrometer DTR for Soil Loosening	N/A	No difference in DTRs between years for plots with soil loosening	F(2,33)=0.19	0.831
ANOVA	Year	Penetrometer DTR for No Loosening	N/A	No difference in DTRs between years for plots with no loosening	F(2,3)=0.73	0.553
Mann-Whitney	Surface Treatment and Full Treatment	Ground Cover by Mulch	2006	Higher ground cover by mulch at full treatment plots	U(12,3)=36	0.004
Mann-Whitney	Surface Treatment and Full Treatment	Ground Cover by Mulch	2007	Higher ground cover by mulch at full treatment plots	U(12,3)=36	0.004
Mann-Whitney	Surface Treatment and Full Treatment	Ground Cover by Mulch	2008	Higher ground cover by mulch at full treatment plots	U(12,3)=33	0.031
Mann-Whitney	Surface Treatment and Full Treatment	Ground Cover by Bare Soil	2006	Higher ground cover by bare soil at surface treatment plots	U(12,3)=36	0.004
Mann-Whitney	Surface Treatment and Full Treatment	Ground Cover by Bare Soil	2007	Higher ground cover by bare soil at surface treatment plots	U(12,3)=36	0.004

Statistical Test	Factors	Variable	Year	Result	Test Statistics	Probability
Mann-Whitney	Surface Treatment and Full Treatment	Ground Cover by Bare Soil	2008	Higher ground cover by bare soil at surface treatment plots	U(12,3)=35	0.009
Mann-Whitney	Soil Loosening and No Loosening	Foliar Plant Cover	2006	Higher foliar plant cover at plots with soil loosening	U(10,2)=20	0.030
Mann-Whitney	Soil Loosening and No Loosening	Foliar Plant Cover	2007	Higher foliar plant cover at plots with soil loosening	U(10,3)=29	0.014
Mann-Whitney	Soil Loosening and No Loosening	Perennial Plant Cover	2006	Higher perennial plant cover at plots with soil loosening	U(10,2)=20	0.030
Mann-Whitney	Soil Loosening and No Loosening	Perennial Plant Cover	2007	Higher perennial plant cover at plots with soil loosening	U(10,3)=29	0.014
Mann-Whitney	Soil Loosening and No Loosening	Perennial Plant Cover	2008	Higher perennial plant cover at plots with soil loosening	U(10,3)=27	0.049
Mann-Whitney	25% Compost Blend and Tub Grindings	Foliar Plant Cover	2006	Higher foliar plant cover at plots with 25% compost blend	U(9,2)=18	0.036
Mann-Whitney	25% Compost Blend and Tub Grindings	Foliar Plant Cover	2007	Higher foliar plant cover at plots with 25% compost blend	U(9,2)=18	0.036
Mann-Whitney	25% Compost Blend and Tub Grindings	Foliar Plant Cover	2008	Higher foliar plant cover at plots with 25% compost blend	U(9,2)=18	0.036
Mann-Whitney	25% Compost Blend and Tub Grindings	Seeded Plant Cover	2007	Higher seeded plant cover at plots with 25% compost blend	U(9,2)=18	0.036
Mann-Whitney	25% Compost Blend and Tub Grindings	Seeded Plant Cover	2008	Higher seeded plant cover at plots with 25% compost blend	U(9,2)=17	0.073
ANOVA	Seed Rate=150 lbs/acre and Seed Rate=50 lbs/acre	Seeded Plant Cover	2007	No difference in seeded plant cover at plots with 150 or 50 lbs/acre of seed applied	F(1,8)=0.858	0.381

Statistical Test	Factors	Variable	Year	Result	Test Statistics	Probability
ANOVA	Seed Rate=150 lbs/acre and Seed Rate=50 lbs/acre	Seeded Plant Cover	2008	No difference in seeded plant cover at plots with 150 or 50 lbs/acre of seed applied	F(1,8)=3.077	0.117

Recommendations

These recommendations are for sites with rocky soils on volcanic parent material, with slope angles between 20 and 25 degrees, solar exposures of 89-98% during the summer months, at 5,765 feet (1,758 m) AMSL:

Tilling: 19 inches (48 cm)

Amendment: 7 inches (18 cm) compost with 25% fines and 75% coarse overs at a nitrogen equivalent of approximately 1,908 lbs/acre (2,139 kg/ha)

Biosol: 2,000 lbs/acre (2,250 kg/ha)

Seed: 50 lbs/acre (56 kg/ha) seed with the following composition:

squirreltail: 60%
mountain brome: 30%
native forbs and shrubs: 10%

Mulch: 2 inches (5 cm) of pine needles with 99% cover

Full treatment versus Surface Treatment

Full treatment is recommended over surface treatment because full treatment plots exhibited:

- sediment yields that were on average 47 to 981 times lower than the sediment yield at the surface treatment plots (1.3 lbs/acre/in or 0.6 kg/ha/cm compared to 60-1,238 lbs/acre/in or 26-546 kg/ha/cm)
- sediment yields that were on average 4 times less than at the native reference plot (1.3 lbs/acre/in or 0.6 kg/ha/cm compared to 5.2 lbs/acre/in or 2.3 kg/ha/cm)
- no sediment yield in 29 of 30 simulations conducted and no increase in sediment yield over time
- infiltration rates that were 1.3 to 1.6 times higher than the infiltration rates exhibited by the surface treatment plots (4.7 in/hr or 120 mm/hr compared to 3.0-3.7 in/hr or 75-94 mm/hr)

- soil densities that did not change over time that were 2.8 times significantly lower than those at the surface treatment plots (5.0 inches or 13 cm compared to 1.8 inches or 4.6 cm)
- mulch cover that is significantly higher by an average of 1.4 times than the mulch cover at the surface treatment plots (90% compared to 66%) and similar to the mulch cover at the native reference plot.
- cover by bare soil that is significantly lower by 10.5 times compared to the bare soil cover at the surface treatment plots (2% compared to 23%) and similar to the bare soil cover at the native reference plot (0%).
- foliar plant cover that was significantly higher by 2.2 times in 2006 and 2007 when compared to surface treatment plots (27% compared to 13%)
- perennial plant cover that was significantly higher by 2.3 times in 2006, 2007, and 2008 compared to the perennial cover at the surface treatment plots (21% compared to 9%)
- a trend toward a decreasing annual plant cover over time (a high of 8% in 2006, compared to a high of 3% in 2008)
- a trend toward increasing seeded plant cover over time (average of 20% compared to 28%)
- similar average TKN levels to the surface treatment plots (1,104 ppm compared to 1,156 ppm)
- similar average organic matter levels to the surface treatment plots (4.1% compared to 4.4%)

Soil Loosening Method (Tilling versus Ripping)

Either tilling or ripping is recommended for the following reason:

- the loosening method did not affect the DTR for 2006, 2007, or 2008

Soil Loosening versus No Soil Loosening

Tilling or ripping is recommended to a depth of 19 inches (48 cm) for the following reasons. Plots with soil loosening exhibited:

- sediment yields that were on average 47 to 981 times lower than the sediment yield at the surface treatment plots (1.3 lbs/acre/in or 0.6 kg/ha/cm compared to 60-1,238 lbs/acre/in or 26-546 kg/ha/cm)
- sediment yields that were on average 4 times less than at the native reference plot (1.3 lbs/acre/in or 0.6 kg/ha/cm compared to 5.2 lbs/acre/in or 2.3 kg/ha/cm)
- no sediment yield in 29 of 30 simulations conducted and no increase in sediment yield over time

- infiltration rates that were 1.3 to 1.6 times higher than the infiltration rates exhibited by the surface treatment plots (4.7 in/hr or 120 mm/hr compared to 3.0-3.7 in/hr or 75-94 mm/hr)
- soil densities that did not change over time that were 2.8 times significantly lower than those at the no soil loosening plots (5.0 inches or 13 cm compared to 1.8 inches or 4.6 cm)
- mulch cover that is significantly higher by an average of 1.4 times than the mulch cover at the no soil loosening plots (90% compared to 66%) and similar to the mulch cover at the native reference plot.
- cover by bare soil that is significantly lower by 10.5 times compared to the bare soil cover at the no soil loosening plots (2% compared to 23%) and similar to the bare soil cover at the native reference plot (0%).
- foliar plant cover was that was significantly higher by 2.2 times in 2006 and 2007 when compared to no soil loosening plots (27% compared to 13%)
- perennial plant cover that was significantly higher by 2.3 times in 2006, 2007, and 2008 compared to the perennial cover at the no soil loosening plots (21% compared to 9%)
- a trend toward a decreasing annual plant cover over time (a high of 8% in 2006, compared to a high of 3% in 2008)
- a trend toward increasing seeded plant cover over time (average of 20% compared to 28%)
- similar average TKN levels to the no soil loosening plots (1,104 ppm compared to 1,156 ppm)
- similar average organic matter levels to the no soil loosening plots (4.1% compared to 4.4%)

Amendment Type (25% Compost Blend versus Tub grindings versus Composted Woodchips)

Compost, composed of 25% fine material and 75% coarse overs, is recommended for incorporation over tub grindings or composted woodchips for the following reasons. Plots with the 25% compost blend exhibited:

- sediment yields that were similar to those of composted woodchips and tub grindings (average of 1.3 lbs/acre/in or 0.6 kg/ha/cm)
- infiltration rates that were similar to those of composted woodchips and tub grindings (average of 4.7 in/hr or 120 mm/hr)
- penetrometer DTRs that were similar to those of composted woodchips and tub grindings (average of 5 inches or 13 cm)
- foliar cover that was significantly higher in 2006, 2007, and 2008 by an average of 2 times compared to plots amended with tub grindings (48% compared to 24%)

- seeded cover that was significantly higher by 2.3 times in 2007 and 2008 compared to plots amended with tub grindings (47% compared to 20%)
- TKN that was similar to that of the native reference plot in 2008 (1,576 ppm compared to 1,176 ppm)

Amendment Rate

Compost, composed of 25% fine material and 75% coarse overs, applied to a 7 inch (18 cm) depth, is recommended over the tested application depth of 3 inches (8cm) because plots with 3 inches (8 cm) of amendment exhibited:

- organic matter content (average of 4%) that was 2.3 times less than at native reference plot (9%)
- penetrometer DTRs that were (average of 4.9 inches or 12 cm) 1.9 times less than at the native reference plot (9.2 inches or 23 cm)
- increasing the concentration of amendments may increase both soil nutrients and the penetrometer DTRs

Biosol Rate

Biosol is recommended at a rate of 2,000 lbs/acre (2,250 kg/ha) rather than 4,000 lbs/acre (4,483 kg/ha). Other variables that might affect plant cover or soil nutrients, such as amendment type, were not held constant at the plots in which the Biosol rate was varied. Therefore, the lower, more standard rate is recommended, though more study on Biosol rates needs to be conducted.

Seed Mix and Rate

A native grass, forb, and shrub seed mix is recommended at a rate 50 lbs/acre (56 kg/ha), rather than at 150 lbs/acre (168 kg/ha) or 180 lbs/acre (202 kg/ha) of shrub seed only. Suggested species composition is:

squirreltail: 60%

mountain brome: 30%

native forbs and shrubs: 10%

For the following reasons:

- Seed rate did not significantly affect the seeded plant cover when comparing the combined shrub, forb, and grass seed mix rates of 50 and 150 lbs/acre (56 and 168 kg/ha)
- The plot with shrub seed only produced very little seeded plant cover, less than 10%
- mountain brome (*Bromus carinatus*) cover decreased during low water years and is recommended in smaller quantities than squirreltail (*Elymus elymoides*), which had increased cover in low water years and is therefore more drought tolerant

Mulch Type and Depth

Mulch composed of native pine needles should be applied at a depth of 2 inches (5 cm) and a ground cover of at least 99% for the following reasons. Plots with this application exhibited:

- sediment production of less than 1.3 lbs/acre/in (0.6 kg/ha/cm) on average
- mulch cover that is on average 1.4 times significantly higher than the mulch cover at the surface treatment plots (90% compared to 66%) and similar to the mulch cover at the native reference plot.
- cover by bare soil that is 10.5 times significantly lower compared to the bare soil cover at the surface treatment plots (2% compared to 23%) and similar to the bare soil cover at the native reference plot (0%).

Irrigation

Long-term irrigation, as used by Caltrans at the Caltrans surface treatment plot, is not recommended for the following reasons:

- foliar plant cover decreased from 81% cover in 2006 to 12% in 2007 at the Caltrans surface treatment plot when irrigation was removed because the dominant annual species were dependent on irrigation for growth
- one of dominant species in 2008 at the Caltrans surface treatment plot was yarrow, which responded to the increase of available water (yarrow has a shallow root system and is unlikely to improve soil stability)
- although 1-6 inches (2.5-15 cm) of mulch was applied one or more times at the Caltrans surface treatment plot, the proportion of bare ground ranged from 19 to 27%, which may be a result of increased erosion from the type of irrigation applied (a different irrigation system could prevent this)
- the mulch cover at the Caltrans surface treatment plot that was irrigated in 2006 was lower (72%) than the mulch cover at the surface treatment plot with planting, but without irrigation (81%; a different irrigation system could prevent this)
- the plant cover at the Caltrans surface treatment plot that was irrigated in 2006 was the similar to the plant cover at the surface treatment plot with planting, but without irrigation
- The cost of this two-year irrigation project was very large and measurable improvements were not apparent

Appendix A

Species list and ocular estimates for Truckee Bypass Test Plots and Caltrans Surface Treatment Plot, 2006. “T” indicates a species present in trace amounts.

Lifeform	Family	Scientific Name	Common Name	Annual / Perennial	Native / Alien	Invasive / Noxious	Plot 1A	Plot 2A	Plot 3A	Plot 1B	Plot 2B	Plot 3B	Plot 4B	Plot 5B	Plot 6B	Plot NT	Plot X	Plot IRR
Forb	Asteraceae	*Achillea millefolium*	yarrow	Perennial	Native		T	T		T	T	< 5				< 5	< 5	5
Forb	Asteraceae	*Antennaria rosea*	pussy toes	Perennial	Native													
Forb	Brassicaceae	*Arabis holboelii*	Holboel's rockcress	Perennial	Native													
Forb	Asteraceae	*Aster ascendens*	long-leaved aster	Perennial	Native													
Forb	Brassicaceae	*Capsella bursa-pastoris*	shepherd's purse	Annual	Alien	Invasive												
Forb	Asteraceae	*Chaenactis douglasii*	Douglas pincushion	Perennial	Native													
Forb	Chenopodiaceae	*Chenopodium albens*	goosefoot	Annual	Alien		T		T	T	T	T			T	T	T	
Forb	Asteraceae	*Cirsium andersonii*	Anderson's thistle	Perennial	Native													
Forb	Scrophulariaceae	*Collinsia parviflora*	blue-eyed mary	Annual	Native		T					T			T			
Forb	Polemoniaceae	*Collomia linearis*	narrow-leaved collomia	Annual	Native		T	T	< 5	T	< 5	< 5				10 - 15	5	
Forb	Polemoniaceae	*Collomia tinctoria*	staining collomia	Annual	Native									T	< 5			
Forb	Boraginaceae	*Cryptantha ambigua*	Wilke's cryptantha	Annual	Native		20	10 - 15	5 - 10	5 - 10	< 5	< 5			5 - 10	10	10 - 15	
Forb	Brassicaceae	*Descurainia sophia*	herb Sophia	Annual	Alien	Invasive												
Forb	Polygonaceae	*Eriogonum nudum*	nude buckwheat	Perennial	Native													
Forb	Polygonaceae	*Eriogonum umbellatum*	sulphur flower buckwheat	Perennial	Native		< 5			< 5	T	T		T		T	< 5	
Forb	Geraniaceae	*Erodium cicutarium*	red stem storksbill	Annual	Alien	Invasive												
Forb	Onagraceae	*Gayophytum diffusum*	groundsmoke	Perennial	Native		20 - 30	< 5	5 - 10	10	< 5		< 5	< 5	< 5	20		25
Forb	Asteraceae	*Hieracium albiflorum*	Hawkweed	Perennial	Native													
Forb	Asteraceae	*Lactuca serriola*	devil's lettuce	Annual	Alien	Invasive	T		T	T	< 5	T	< 5	< 5	< 5	T		< 5
Forb	Fabaceae	*Lathyrus latifolius*	sweet pea	Perennial	Alien													
Forb	Brassicaceae	*Lepidium campestre*	English pepperweed	Annual	Alien					T								
Forb	Asteraceae	*Leucanthemum vulgare*	ox-eye daisy	Perennial	Alien	Invasive												
Forb	Polemoniaceae	*Linanthus harkensii*	Harken's linanthus	Annual	Native			< 5				T		T	T			
Forb	Fabaceae	*Lotus purshianus*	Spanish lotus	Perennial	Native					T			T		T			60
Forb	Fabaceae	*Lupinus argenteus*	silver lupine	Perennial	Native					T						T	T	5
Forb	Fabaceae	*Lupinus lepidus (culbertsonii)*	Culberton's lupine	Perennial	Native							< 5	T			T	< 5	50
Forb	Asteraceae	*Madia glomerata*	mountain tarweed	Annual	Native		T	T			T		T					
Forb	Fabaceae	*Melilotus albus*	white sweet clover	Annual	Alien										T			
Forb	Fabaceae	*Melilotus officinalis*	yellow sweet clover	Annual	Alien													T
Forb	Lamiaceae	*Monardella odoratissima*	mountain monardella	Perennial	Native													
Forb	Polemoniaceae	*Navarretia*	navarretia	Annual	Native					T						T		
Forb	Onagraceae	*Oenethera sp.*	evening primrose	Perennial	Native													
Forb	Scrophulariaceae	*Pedicularis semibarbata*	lousewort	Perennial	Native													

Lifeform	Family	Scientific Name	Common Name	Annual / Perennial	Native / Alien	Invasive / Noxious	Plot 1A	Plot 2A	Plot 3A	Plot 1B	Plot 2B	Plot 3B	Plot 4B	Plot 5B	Plot 6B	Plot NT	Plot X	Plot IRR
Forb	Scrophulariaceae	*Penstemon laetus*	gay penstemon	Perennial	Native													
Forb	Hydrophyllaceae	*Phacelia hastata*	silverleaf phacelia	Perennial	Native													
Forb	Polemoniaceae	*Phlox gracilis*	slender phlox	Annual	Native		T											
Forb	Polygonaceae	*Polygonum arenastrum*	common knotweed	Annual	Native		20		5 - 10		T		T	< 5	< 5	35	15 - 20	5
Forb	Polygonaceae	*Polygonum douglasii*	Douglas knotweed	Annual	Native			< 5		10 – 15					T			
Forb	Ericaceae	*Pyrola picta*	wintergreen	Perennial	Native													
Forb	Brassicaceae	*Sisymbrium altissimum*	tumble mustard	Annual	Alien										T			
Forb	Apiaceae	*Sphenosciadium capitellatum*	ranger's buttons	Perennial	Native													
Forb	Asteraceae	*Taraxacum officinale*	dandelion	Annual	Alien	Invasive												
Forb	Asteraceae	*Tragapogon dubius*	false salsify	Annual	Alien											T		
Forb	Fabaceae	*Trifolium repens*	white clover	Perennial	Alien													
Forb	Scrophulariaceae	*Verbascum thapsis*	mullen	Annual	Native	Invasive												
Forb	Portulaceae	*Calyptridium umbellatum*	pussy paws	Perennial	Native												T	
Graminoid	Poaceae	*Achnatherum nelsonii*	Nelson's needlegrass	Perennial	Native													
Graminoid	Poaceae	*Achnatherum occidentalis*	Western needlegrass	Perennial	Native													
Graminoid	Poaceae	*Elytrigia intermedia (new name)*	pubescent wheatgrass	Perennial	Alien													
Graminoid	Poaceae	*Elytrigia intermedia (new name)*	intermediate wheatgrass	Perennial	Alien													
Graminoid	Poaceae	*Bromus carinatus*	mountain brome	Perennial	Native		< 5	25 - 30	30		25	25	15	30	40			5
Graminoid	Poaceae	*Bromus tectorum*	cheatgrass	Annual	Alien	Invasive	< 5	5 - 10			T	< 5	T	T	T	T		
Graminoid	Poaceae	*Dactyls glomerata*	orchard grass	Perennial	Alien	Invasive												
Graminoid	Poaceae	*Deschampsia elongata*	elongated hairgrass	Perennial	Native													
Graminoid	Poaceae	*Elymus elymoides*	squirreltail	Perennial	Native		T	10	5 - 15		10 -	10	5 - 10	15	10	T	T	< 5
Graminoid	Poaceae	*Elymus glaucus*	blue wildrye	Perennial	Native													5
Graminoid	Poaceae	*Festuca*	fescue	Perennial	Native													T
Graminoid	Poaceae	*Hordeum vulgare*	barley	Annual	Alien													
Graminoid	Poaceae	*Poa bulbosa*	bulbous bluegrass	Perennial	Alien													
Graminoid	Poaceae	*Poa secunda*	pine bluegrass	Perennial	Native											T	T	
Shrub	Ericaceae	*Arctostaphylos nevadensis*	pinemat manzanita	Perennial	Native													
Shrub	Asteraceae	*Artemisia tridentata*	common sagebrush	Perennial	Native				T					T		< 5	< 5	
Shrub	Ramnaceae	*Ceanothus cordulanthus*	buckthorne	Perennial	Native													
Shrub	Rosaceae	*Purshia tridentata*	antelope bitterbrush	Perennial	Native		T		T			T	T	T				
Shrub	Rosaceae	*Rubus parviflorus*	thimbleberry	Perennial	Native													
Shrub	Caprifoliaceae	*Symphoricarpos mollis*	trailing snowberry	Perennial	Native													
Tree	Pinaceae	*Abies concolor*	white fir	Perennial	Native			T										
Tree	Pinaceae	*Pinus jefferyi*	Jeffrey pine	Perennial	Native		T		T	T	T	T		T		T	T	T

Species list and ocular estimates for Truckee Bypass Test Plots and Caltrans Surface Treatment Plot, 2007. Ocular estimates are presented below the plot numbers/letters. “T” indicates a species present in trace amounts. OS=overstory

Lifeform	Family	Scientific name	Common name	Annual/ Perennial	Native/ Alien	Noxious	In grass/ shrub mix? (Plots 2-6)	% in grass/ shrub seed mix	Plot 1A	Plot 2A	Plot 3A	Plot 4A	Plot 5A	Plot 6A	Plot 1B	Plot 2B	Plot 3B	Plot 4B	Plot 5B	Plot 6B	Plot IRR	Plot NT	Plot X	Plot N
Forb	Asteraceae	*Achillea millefolium*	yarrow	Perennial	Native				T	T	T	T	T	T	<5	T	<5	T			<5	<5	<5	
Forb	Asteraceae	*Agoseris retrorsa*	spear-leaved mountain dandelion	Perennial	Native														T	T				
Forb	Brassicaceae	*Arabis holboellii*	Holboel's rockcress	Perennial	Native					T	T						T							T
Forb	Portulaceae	*Calyptridium umbellatum*	pussy paws	Perennial	Native																	T		
Forb	Chenopodiaceae	*Chenopodium album*	goosefoot	Annual	Alien				T		T			T	T	T	T	T	T	T	T	T		
Forb	Scrophulariaceae	*Collinsia parviflora*	blue-eyed mary	Annual	Native				<5	T	T	T	<5	<5			T	T	T	T			<5	
Forb	Polemoniaceae	*Collomia linearis*	narrow-leaved collomia	Annual	Native				T	T	<5	T	T	T	<5	<5	<5	T	T		10-15	<5	T	
Forb	Polemoniaceae	*Collomia tinctoria*	staining collomia	Annual	Native					T		T	T	<5				T	T	<5		10	<5	
Forb	Boraginaceae	*Cryptantha ambigua*	Wilke's cryptantha	Annual	Native				15	10-15	5-10	5	5	5-10	5-10	<5	<5	T	<5	5-10	10	10-15	<5	T
Forb	Polygonaceae	*Eriogonum umbellatum*	sulphur flower buckwheat	Perennial	Native		X	7%	5		T	T	T	T	<5	T	T	T	T	T	T	<5	T	
Forb	Brassicaceae	*Erysimum capitatum*	wall flower	Perennial	Native																			T
Forb	Onagraceae	*Gayophytum diffusum*	spreading groundsmoke	Annual	Native				5	T	T	T	5	T	10	<5		T	T	T	20	<5	25	T
Forb	Polemoniaceae	*Navarretia capillaris*	miniature gilia	Annual	Native				T															
Forb	Asteraceae	*Lactuca serriola*	devil's lettuce	Annual	Alien	Of concern			T		T	T	T	T	T	<5	T	T	T	<5	T		<5	
Forb	Brassicaceae	*Lepidium campestre*	English pepperweed	Annual	Alien				T			T	T		T									
Forb	Polemoniaceae	*Linanthus harknessii*	Harken's linanthus	Annual	Native					<5		T		T			T		T	T				
Forb	Fabaceae	*Lotus purshianus var. purshianus*	Spanish lotus	Perennial	Native						T		T		T			T		T			60	
Forb	Fabaceae	*Lupinus argenteus*	silver lupine	Perennial	Native				T		T			T	T					T	T	T	T	
Forb	Fabaceae	*Lupinus lepidus*	Culberton's lupine	Perennial	Native					T	T	T	5	T	T	T	<5	5		T	T	<5	T	
Forb	Asteraceae	*Madia glomerata*	mountain tarweed	Annual	Native				T	T	T	T	T	T	T	T	T	T		T				
Forb	Fabaceae	*Melilotus alba*	white sweet clover	Annual	Alien	Of concern							T	T				T		T				
Forb	Fabaceae	*Melilotus officinalis*	yellow sweet clover	Annual	Alien	Of concern																	T	
Forb	Polemoniaceae	*Navarretia capillaris*	navarretia	Annual	Native										T						T			
Forb	Scrophulariaceae	*Penstemon laetus*	gay penstemon	Perennial	Native										T									
Forb	Scrophulariaceae	*Penstemon rydbergii*	Rydberg's penstemon	Perennial	Native		X	1%																
Forb	Hydrophyllaceae	*Phacelia hastata*	silverleaf phacelia	Perennial	Native					T		T	T						T				T	
Forb	Polemoniaceae	*Phlox gracilis*	slender phlox	Annual	Native				<5	T	T	5	T		<5	T	5	5	T				10-15	

Lifeform	Family	Scientific name	Common name	Annual / Perennial	Native / Alien	Noxious	In grass / shrub mix? (Plots 2-6)	% in grass / shrub seed mix	Plot 1A	Plot 2A	Plot 3A	Plot 4A	Plot 5A	Plot 6A	Plot 1B	Plot 2B	Plot 3B	Plot 4B	Plot 5B	Plot 6B	Plot IRR	Plot NT	Plot X	Plot N
Forb	Polygonaceae	*Polygonum arenastrum*	common knotweed	Annual	Alien				<5		5-10			T		T		T	<5	<5	35	15-20	5	
Forb	Polygonaceae	*Polygonum douglasii*	Douglas knotweed	Annual	Native					T	T		T	T	T	T	T	T	T		T			
Forb	Brassicaceae	*Sisymbrium altissimum*	tumble mustard	Annual	Alien									T					T					
Forb	Asteraceae	*Tragopogon dubius*	false salsify	Annual	Alien				T			T		T	T	T					T		T	
Forb	Fabaceae	*Trifolium repens*	white clover	Perennial	Alien																			
Forb	Asteraceae	*Wyethia mollis*	mule ears	Perennial	Native					T					T								T	
Graminoid	Poaceae	*Achnatherum occidentale*	Western needlegrass	Perennial	Native		X	7%																
Graminoid	Poaceae	*Elytrigia intermedia ssp. intermedia*	intermediate wheatgrass or pubescent wheatgrass	Perennial	Alien				T	T														
Graminoid	Poaceae	*Bromus carinatus*	mountain brome	Perennial	Native		X	23%	<5	10	10	15	10-15	30	T	<5	5-10	5-10	10-15	10-15			T	
Graminoid	Poaceae	*Bromus tectorum*	cheatgrass	Annual	Alien	Invasive			25	T	5	T	T	5		5	<5	T	T	<5	T			
Graminoid	Cyperaceae	*Carex rossii*	Ross sedge	Perennial	Native																			T
Graminoid	Poaceae	*Dactylis glomerata*	orchard grass	Perennial	Alien	Invasive				T														
Graminoid	Poaceae	*Elymus elymoides*	squirreltail	Perennial	Native		X	21%	T	35	15	15-	20	30		25-	15	15-	20-	20-	T	<5	T	5
Graminoid	Poaceae	*Elymus glaucus*	blue wildrye	Perennial	Native					T														
Graminoid	Poaceae	*Festuca*	fescue	Perennial	Native																		T	
Graminoid	Poaceae	*Poa bulbosa*	bulbous blue grass	Perennial	Alien				T	T	T	T		T	T	T	T	T	T			T		
Graminoid	Poaceae	*Poa secunda*	pine bluegrass	Perennial	Native																T	T		
Graminoid	Poaceae	*Poa wheeleri*	Wheeler's bluegrass	Perennial	Native																			10
Shrub	Asteraceae	*Artemisia tridentata*	common sagebrush	Perennial	Native		X	7%	T		T	T	T	T			T	T	T	T	<5	<5	<5	
Shrub	Rhamnaceae	*Ceanothus velutinus*	tobacco brush or snowbrush	Perennial	Native		X	14%																
Shrub	Rosaceae	*Purshia tridentata*	antelope bitterbrush	Perennial	Native		X	14%	T	T	T		T	T	T	T	<5	2	T	T		T		T
Shrub	Grossulariaceae	*Ribes cereum*	wax currant	Perennial	Native		X	7%																
Tree	Pinaceae	*Abies concolor*	white fir	Perennial	Native					T	T													
Tree	Pinaceae	*Pinus jeffreyi*	Jeffrey pine	Perennial	Native				2		T	T	T	T	T	T	T	T	T					30

Species list and ocular estimates for Truckee Bypass Test Plots and Caltrans Surface Treatment Plot, 2008. Ocular estimates are presented below the plot numbers/letters. "T" indicates a species present in trace amounts.

Lifeform	Family	Scientific name	Common name	Annual/ Perennial	Native / Alien	Invasive/ Noxious	Plot 1a	In 1a seed mix ?	% in 1a seed mix	Plot 1b	In 1b seed mix ?	% in 1b seed mix	Plot 2a	Plot 2b	Plot 3a	Plot 3b	Plot 4a	Plot 4b	Plot 5a	Plot 5b	Plot 6a	Plot 6b	In 2a-6b seed mix ?	% in 2a-6b seed mix	Plot NT	In NT seed mix ?	% in NT seed mix	Plot X	Plot IRR
Forb	Asteraceae	*Achillea millefolium*	yarrow	Perennial	Native		T			2			T	T		T	T	T	T		T	T			T			1	7
Forb	Asteraceae	*Agoseris retosa*	spear-leaved mountain dandelion	Perennial	Native												T												
Forb	Brassicaceae	*Arabis holboellii*	Holboel's rockcress	Perennial	Native								T	T				T		T									
Forb	Scrophulariaceae	*Collinsia parviflora*	blue-eyed mary	Annual	Native		T			T			T	T	T	T	T	T	T		2	2			4			T	
Forb	Polemoniaceae	*Collomia linearis*	narrow-leaved collomia	Annual	Native												T	T											
Forb	Asteraceae	*Crepis occidentalis*	Western hawk's beard	Perennial	Native																							T	
Forb	Boraginaceae	*Cryptantha ambigua*	Wilke's cryptantha	Annual	Native					T				T			T								T			T	
Forb	Polygonaceae	*Eriogonum umbellatum*	sulphur flower buckwheat	Perennial	Native		7	Yes	14%	T	Yes	7%	T	T	T	T	T	T	T	2	2	2	Yes	17%	T	Yes	14%	T	T
Forb	Onagraceae	*Gayophytum diffusum*	groundsmoke	Annual	Native					3					T			T	T	T					T				T
Forb	Asteraceae	*Lactuca serriola*	devil's lettuce	Annual	Alien	Of concern				T								T			T	T							1
Forb	Brassicaceae	*Lepidium campestre*	English pepperweed	Annual	Alien					T																			
Forb	Fabaceae	*Lotus purshianus var. purshianus*	Spanish lotus	Perennial	Native																								T
Forb	Fabaceae	*Lupinus argenteus*	silver lupine	Perennial	Native		T						T		T		T				T				T			T	7
Forb	Fabaceae	*Lupinus lepidus*	Culberton's lupine	Perennial	Native		T			T			T		T	T	T	2	2	2	T	T			T			T	T
Forb	Asteraceae	*Madia glomerata*	mountain tarweed	Annual	Native												T								T				
Forb	Fabaceae	*Melilotus alba*	white sweet clover	Annual	Alien	Of concern																							T
Forb	Fabaceae	*Melilotus officinalis*	yellow sweet clover	Annual	Alien	Of concern				T																			
Forb	Scrophulariaceae	*Penstemon sp.*	penstemon				T																						

Lifeform	Family	Scientific name	Common name	Annual / Perennial	Native / Alien	Invasive / Noxious	Plot 1a	In 1a seed mix ?	% in 1a seed mix	Plot 1b	In 1b seed mix ?	% in 1b seed mix	Plot 2a	Plot 2b	Plot 3a	Plot 3b	Plot 4a	Plot 4b	Plot 5a	Plot 5b	Plot 6a	Plot 6b	In 2a-6b seed mix ?	% in 2a-6b seed mix	Plot NT	In NT seed mix ?	% in NT seed mix	Plot X	Plot IRR
Forb	Scrophulariaceae	*Penstemon newberryi*	mountain pride	Perennial	Native			Yes	32%																	Yes	32%		
Forb	Scrophulariaceae	*Penstemon rydbergii*	Rydberg's penstemon	Perennial	Native						Yes	1%											Yes	17%					
Forb	Hydrophyllaceae	*Phacelia hastata*	silverleaf phacelia	Perennial	Native		T			T							T		T		T								
Forb	Polemoniaceae	*Phlox gracilis*	slender phlox	Annual	Native					T			T	1	T	T	T	T	T	T		T			12			7	
Forb	Polygonaceae	*Polygonum arenastrum*	common knotweed	Annual	Native																							T	
Forb	Brassicaceae	*Sisymbrium altissimum*	tumble mustard	Annual	Alien											T													
Forb	Asteraceae	*Tragopogon dubius*	false salsify	Annual	Alien					T			T	T	T	T	T	T	T	T	T	T			T				
Forb	Fabaceae	*Trifolium pratense*	red clover	Perennial	Alien														T										
Forb	Asteraceae	*Wyethia mollis*	Mule ears	Perennial	Native		T	Yes	13%																T	Yes	13%	T	T
Graminoid	Poaceae	*Achnatherum occidentale*	Western needlegrass	Perennial	Native		T				Yes	7%	T		T		T		T										
Graminoid	Poaceae	*Elytrigia intermedia ssp. intermedia (new name)*	pubescent wheatgrass	Perennial	Alien																T								
Graminoid	Poaceae	*Elytrigia intermedia ssp. intermedia (new name)*	intermediate wheatgrass	Perennial	Alien										T	T	T								T				
Graminoid	Poaceae	*Alopecurus pratensis*	meadow foxtail	Perennial	Alien																								T
Graminoid	Poaceae	*Bromus carinatus*	mountain brome	Perennial	Native		T			T	Yes	23%	2	2	4	2	5	3	5	5	7	2			T			T	T
Graminoid	Poaceae	*Bromus tectorum*	cheatgrass	Annual	Alien	Invasive	18			6			4	T	2	T	T		T	T	5	2							1
Graminoid	Poaceae	*Dactylis glomerata*	orchard grass	Perennial	Alien	Invasive	T						T																
Graminoid	Poaceae	*Elymus elymoides*	squirreltail	Perennial	Native		T				Yes	21%	35	17	31	15	14	7	23	23	45	40			T			T	T
Graminoid	Poaceae	*Elymus glaucus*	blue wildrye	Perennial	Native		T						T	T							T	T							T
Graminoid	Poaceae	*Festuca rubra*	red fescue	Perennial	Native																								1

Lifeform	Family	Scientific name	Common name	Annual / Perennial	Native / Alien	Invasive / Noxious	Plot 1a	In 1a seed mix?	% in 1a seed mix	Plot 1b	In 1b seed mix?	% in 1b seed mix	Plot 2a	Plot 2b	Plot 3a	Plot 3b	Plot 4a	Plot 4b	Plot 5a	Plot 5b	Plot 6a	Plot 6b	In 2a-6b seed mix?	% in 2a-6b seed mix	Plot NT	In NT seed mix?	% in NT seed mix	Plot X	Plot IRR
Graminoid	Poaceae	*Hordeum brachyantherum*	meadow barley	Perennial	Native		T								T			T											
Graminoid	Poaceae	*Poa bulbosa*	bulbous blue grass	Perennial	Alien		T			T			1	1	T	2	T	T	T						T			T	
Graminoid	Poaceae	*Poa pratensis*	Kentucky bluegrass	Perennial	Alien		T																						
Graminoid	Poaceae	*Poa secunda*	pine bluegrass	Perennial	Native		T												T		2	T							T
Shrub	Asteraceae	*Artemisia tridentata*	common sagebrush	Perennial	Native		1				Yes	7%	T	T	T	T	T	T	T	T	2	2	Yes	17%	5			T	T
Shrub	Rhamnaceae	*Ceanothus velutinus*	tobacco brush or snowbrush	Perennial	Native		T				Yes	14%											Yes	17%					
Shrub	Rosaceae	*Purshia tridentata*	antelope bitterbrush	Perennial	Native		5			4	Yes	14%	T	T	T	9	2	9	7	5	T		Yes	17%	T			T	
Shrub	Fagaceae	*Quercus vaccinifolia*	huckleberry oak	Perennial	Native			Yes	14%																	Yes	14%		
Shrub	Grossulariaceae	*Ribes cereum*	wax currant	Perennial	Native						Yes	7%											Yes	17%					
Tree	Pinaceae	*Abies concolor*	white fir	Perennial	Native										T														
Tree	Pinaceae	*Pinus jeffreyi*	Jeffrey pine	Perennial	Native		T	Yes	28%	T			T	T	T	T	T	T	T	T	T				T	Yes	28%	T	T
Tree	Pinaceae	*Pinus contorta*	lodgepole pine	Perennial	Native																								T
TOTAL COVER (transects)							31%			12%			48%	22%	37%	22%	22%	19%	38%	31%	61%	49%			24%			13%	23%
TOTAL COVER (ocular estimate)							36%			18%			46%	23%	41%	31%	26%	24%	38%	39%	67%	52%			25%			11%	20%