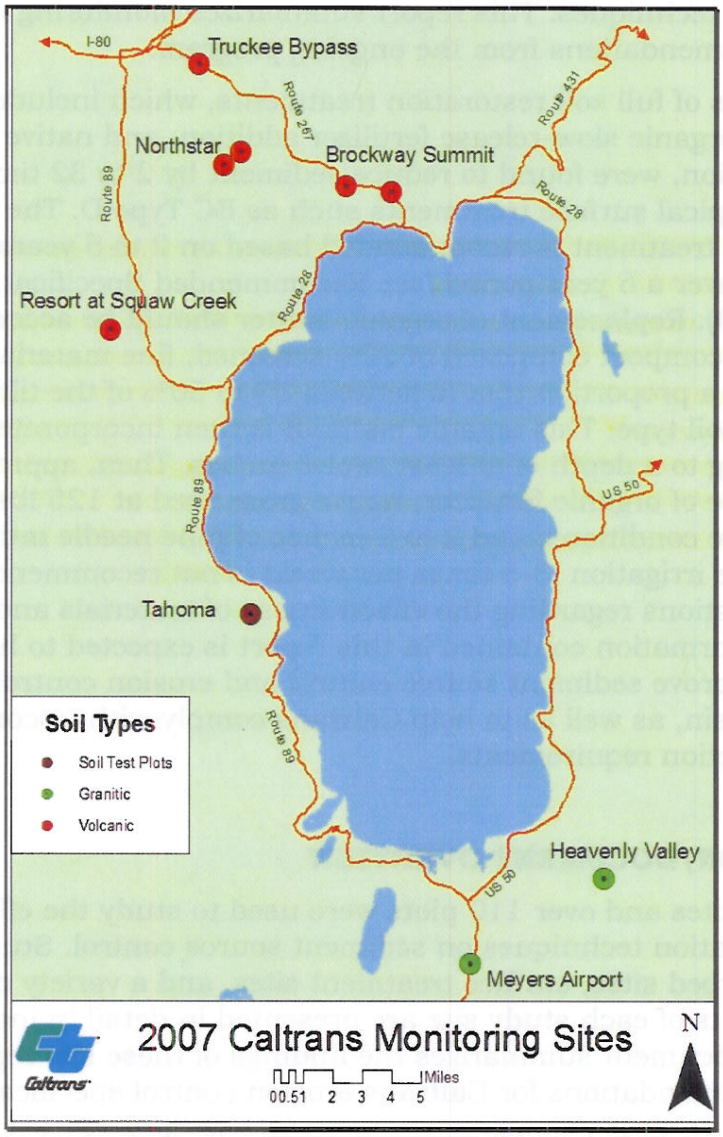
Monitoring and Assessment of Erosion Control Treatments in and around the Lake Tahoe Basin



Summary Report
May 22, 2008

EXECUTIVE SUMMARY

Caltrans is one of the largest land managers in the 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 an effort to proactively address current and upcoming water quality regulations, Caltrans has been engaged for nearly 10 years in the Demonstration and Development 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. This report summarizes monitoring results and presents recommendations from the ongoing program.

Many variations of full soil restoration treatments, which include deep tilling of amendments, organic slow-release fertilizer addition, and native seed and mulch application, were found to reduce sediment by 2 to 32 times when compared to typical surface treatments such as EC Type D. The following full soil restoration treatment is recommended based on 2 to 5 years of monitoring data collected over a 6 year period (see Recommended Specifications and Figures 3 and 4). Replacement of organic matter should be accomplished with the addition of compost composed of 25% screened, fine material and 75% coarse overs at a proportion that is between 33 to 50% of the tilling depth, depending on soil type. This organic material is then incorporated by either tilling or ripping to a depth of at least twelve inches. Then, approximately 2,000 pounds per acre of organic fertilizer, native grass seed at 125 lbs/acre, adjusted for site conditions, and 2 to 3 inches of pine needle mulch are applied. Landscape-type irrigation (3-5 times per week) is not recommended. While a number of questions regarding the effectiveness of materials and methods remain, the information contained in this report is expected to help Caltrans continue to improve sediment source control and erosion control efforts in the Lake Tahoe Basin, as well as to help Caltrans comply with upcoming TMDL sediment reduction requirements.

INTRODUCTION/DOCUMENT OVERVIEW

In 2007, nine sites and over 110 plots were used to study the effects of different restoration techniques on sediment source control. Study sites included disturbed sites, surface treatment sites, and a variety of fully treated sites. The results of each study site are presented in detail in individual site reports. This document summarizes the findings of these site reports and presents recommendations for Caltrans erosion control specifications.

The study sites included a wide range of drastically disturbed sites, including cut and fill slopes along roadsides and ski runs. 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. Further, this information and data are likely to help Caltrans meet its obligations for sediment reduction under the Tahoe Basin TMDL, which is currently being developed.

This document is laid out as follows:

The first section of the report, Section 1: "Current Level of Knowledge", gives a very brief overview of current knowledge from several years of monitoring and highlights the main findings. Each treatment component (amendment, soil loosening, fertilizing, seeding, mulch, etc.) will be discussed in terms of its effect on infiltration, sedimentation, soil density, cover, and soil nutrient status. Section 2: "Landscape Implications", gives guidance for erosion control and revegetation practices based on the monitoring findings. Section 3: "Information Gaps", discusses what we have yet to learn and gives direction for future research that will best address the needs for erosion control at Caltrans sites.

SECTION 1: CURRENT LEVEL OF KNOWLEDGE

A great deal of information has been developed over the past decade, and especially during the last five years, regarding sources of clarity loss in Lake Tahoe. For instance, fine silts (less than 63 microns and especially less than 8 microns) are now understood to have the greatest impact on lake clarity. Additionally, studies have shown that plant cover alone does not control erosion. This information has begun to change the focus of erosion control projects from conveyance and treatment, which does not capture the majority of fine particles, to sediment source control, which is designed to keep soil and sediment on site. Further, vegetation alone is no longer the primary tool used to address sediment reduction. This report, and other previous work, have shown that a combination of soil factors play a primary role in the control of erosion. These conditions include adequate infiltration capacity, low soil density, robust mulch cover, appropriate plant cover, appropriate soil nutrients, and at least a minimally developed soil structure. One of the critical missing links in our understanding of which treatments are best at controlling erosion is the fact that there are few long-term (greater than 3 years) studies available. Sustainability of most treatments is not well understood. However, the information presented here contains data from some of the only long-term erosion control monitoring in the Lake Tahoe Basin. Some of the data is based on 6 years of monitoring, although most data is short-term. However, long-term trends will continue to be studied. The following is a generalized summary of our understanding thus far.

Full Treatment

Full treatment refers to the process of restoring soil function to the greatest level possible. The process includes: replacement of soil organic matter, tilling/mixing that organic matter to a depth of 12-18 inches, addition of an organic, slow-release fertilizer, application of native meadow and forest grass seed, and application of pine needle mulch. This research has been instrumental in furthering our understanding of the types and amounts of each variable required for full soil restoration. There are a number of variations on these elements, such as seeded species mix, type of organic amendment, amount of fertilizer, etc., that are continually being refined and better understood. This report presents the latest data and information in that refinement process.

Full treatment is the best method for treating disturbed areas. When properly implemented, full treatment has been shown to improve sediment source control to stabilize soils and eliminate slope failures in the first 2 to 6 years after treatment. Further study is necessary to determine success after 6 years. Infiltration rates were similar to or exceeded those at most native sites. Sediment yields, which were greatly reduced, compared to surface treatment yields (by 7 to 32 times) or eliminated, were comparable to or less than sediments produced in most native areas. Both infiltration and sediment either remained steady or showed improvements 2 to 6 years after treatment. Soil density, which generally increased over time in volcanic soil, after 2 to 6 years, remained lower than at surface treatment plots. These volcanic soil densities were generally lower with coarser amendments versus finer amendments. Although volcanic densities were higher than at some native areas, infiltration or sedimentation was not adversely affected.

Granitic soil densities remained fairly stable over time at some sites and decreased slightly at others. Granitic soil densities remained comparable to native densities and plots with tilling, rather than ripping, maintained lower densities. Plant diversity and native plant cover was highest at most full treatment plots (without a seed source for invasive plants) and native seeded species were up to 2 to 8.8 times higher than at surface treatment sites (Figure 1 and Figure 2). Plant species diversity and composition is directly linked to the increased nutrient content from addition of fertilizer and organic amendments at full treatment plots. Soil nutrient contents were up to 4.7 to 5.6 times higher than at surface treatment plots. Many full treatment plots had soil nutrient levels that were comparable to those at native sites. For those that did not reach native levels, an increase in the proportion of organic amendments is recommended.

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 the standard treatment, easy to implement and has a low initial cost, therefore, it has been used for many years on erosion control projects. Caltrans Erosion Control Type D treatment, which is an application of light compost, seed, fertilizer, tackifier and mulch on the soil surface, has been widely used by Caltrans. Surface treatment has been shown to be inadequate in highly disturbed sites where topsoil, nutrients, and a native seed bank are absent. Re-treatments are often necessary, thereby rapidly increasing the cost per project. While initial costs are low, disturbed sites are not adequately capitalized and sustained sediment reduction is seldom achieved.

Rainfall simulations at surface treatment plots have shown that sediment yields remain high over time and although slight decreases have been observed at select sites, sediment yield at surface treatment plots have not shown a general trend toward significant improvement over time. When compared to full treatment sites, surface treatment sediment yields were 32 times higher and many 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. At native sites, sediment yields were up to 200 times lower when compared to some surface treatment sites. 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 8.8 times lower at surface treatment plots. Most surface treatment plots had low cover by mulch, which 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 low over time and was up to 3.7 times higher than at full treatment plots.

Amendment Type and Rate

Soil amendments play a fundamental role in the recapitalization of soil nutrients. There are a number of amendment types and rates currently under study, however, definitive results have not been produced. Tested amendments are described in detail in Appendix A. Different types of organic matter, such as compost, coarse overs (the woody material remaining after the composting process), woodchips, tub grindings, and various combinations of the above were all part of these tests and are in the beginning stages of study. Research results have been highly variable. Soil type, compost feedstock, and initial soil conditions all contribute to variable results.

Caltrans has recently embraced the use of compost, which is sometimes associated with the presence of invasive species, and is relatively expensive. Other types of composted, aged, or raw wood materials have been under study and show promise, but long-term results are not yet available. Ongoing study results will help determine the most economically and environmentally effective material. The following materials are under study and are discussed below:

- Compost (100% fines)
- Compost (25% fines/75% coarse overs)
- Compost (75% fines/25% coarse overs)
- Compost (50% fines/50% coarse overs)
- Compost (100% coarse overs)
- Tub Grindings
- Aged Woodchips
- Woodchips

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, 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.[1] Biosol rates between 2,000 to 4,000 lbs/acre were studied. It was found that of the tested rates and when comparing areas with Biosol to those without, 2,000 lbs/acre was most effective over the long term.

[1] Claassen, V.P. and Hogan, M.P. *Generation of Water-Stable Soil Aggregates for Improved Erosion Control and Revegetation Success*, Caltrans Report, March 1998.

Seed Type and Rate

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 of solely shrubs and/or forbs, or non-local grasses. The majority of test plots were seeded with a mix with four native bunchgrass species at a rate of 125 lbs/acre (140 kg/ha), with a range of applications from 50 to 285 lbs/acre (56 to 320 kg/ha). At several sites, native forbs and shrubs were added to the grass-dominated seed mix.

Over 2 to 6 years of sampling, seeded bunchgrasses composed a majority of plant cover at test sites that did not have a seed source for cheatgrass. Most plots seeded with bunchgrasses produced at least 25% foliar plant cover, as measured by the cover point method. Bunchgrass roots were observed up to 4 feet deep at the soil boxes. Seeded grasses did not dominate over the long term at sites with a cheatgrass seed source. More study is needed to determine appropriate seed and amendment types and rates for cheatgrass problem areas.

After 2 to 6 growing seasons, squirreltail (*Elymus elymoides*) composed the majority of cover (30 – 100%), regardless of solar exposure and soil nutrient levels. The proportion of cover by squirreltail increased, by up to 15%, even during a low precipitation year, 2007. The proportion of cover by mountain brome (*Bromus carinatus*) and blue wild rye (*Elymus glaucus*) decreased at most sites during 2007. The proportion of cover by Western needlegrass (*Achnatherum occidentale*) increased during 2007, especially on sites with lower soil nutrient levels and high solar exposure, where it often dominated. The productivity of squirreltail grass and mountain brome may be increased with the addition of nitrogen in the form of compost and/or fertilizer. Western needlegrass *(Achnatherum occidentale)* did not produce more cover with the addition of nitrogen.

The seeded native shrubs, bitter brush (*Purshia tridentata*) and sagebrush (*Artemisia tridentata*), germinated at the test plot areas, but due to their slower growth rate, did not compose more than 3% of total plant cover. Of the seeded forb species, lupines and buckwheats were the most prevalent, but still only composed a majority of cover at one test site. There are indications that plots seeded at a higher rate (150 to 296 lbs/acre) produced slightly higher cover by seeded grasses, but further study needs to be done before the higher rates are recommended.

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 downstream pollution of groundwater, 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 sites without continual disturbance and they match the native aesthetic. Pine needles also provide most of the nutrients in native forest ecosystems around the Lake Tahoe Basin and thus serve as a long-term nutrient source on erosion control projects, though the potential nutrient content is currently under study and not yet fully understood.

SECTION 2: LANDSCAPE IMPLICATIONS

Full Treatment versus No Treatment

Full treatment was compared to plots without treatment at two study sites, one with granitic parent material (Meyers Airport) and one with volcanic parent material (Brockway Summit Test Plots). Full treatment is recommended over no treatment for the following reasons. Full treatment plots exhibited the following when compared to surface treatment plots:

- no sediment production, or sediment reductions of 1.8 times
- infiltration rates that were 1.5 to 2 times higher
- soil density that was 2.3 to 5.2 times lower
- mulch cover that was up to 5 to 19 times greater

Full Treatment versus Surface Treatment

Full treatment and surface treatment were compared at four of the nine study sites, one with granitic parent material soil (Meyers Airport), and three with volcanic parent material soil (Resort at Squaw Creek, Northstar Unit 7, and Truckee Bypass Test Plots).

Full treatment is recommended over surface treatment in both soil types for the following reasons. Full treatment plots exhibited the following when compared to surface treatment plots:

- either no sediment yield, or sediment reductions of 7.5 to 32 times
- infiltration rates that were 1.3 to 1.5 times higher
- soil density that was 2.5 to 3.7 lower
- total plant cover that was up to 2 to 2.4 times higher
- seeded foliar plant cover that was up to 8.8 times higher
- mulch cover that was up to 1.2 to 5 times higher
- nitrogen (TKN) content that was up to 5.6 times higher

- organic matter content that was up to 4.7 times higher

Soil Loosening versus No Soil Loosening

To quantify the effect of soil loosening on erosion control capacity when all other variables were equal, test plots with fertilizer, native seed, and pine needle mulch, with and without tilling, were studied. The plots that did not have tilling were not similar to Caltrans EC Type D treatment, as hydroseeding techniques were not employed. Soil loosening is not recommended without incorporation of organic matter; however, plots with soil loosening and no amendments had better erosion control characteristics than plots without soil loosening. These test plots were located at two granitic sites (Meyers Airport and Heavenly Canyon) and one volcanic site (Northstar Lookout Mountain).

Plots with soil loosening exhibited the following when compared to plots without soil loosening:

- sediment yields that were up to 1.5 times lower
- infiltration that was up to 1.5 times higher
- soil densities that were 1.5 to 11 times lower
- total plant cover that was up to 1.7 to 2 times higher
- perennial plant cover that was up to 2 times higher
- mulch cover that was up to 1.4 times higher
- bare soil that was up to 2.5 times lower

Soil Loosening Methods: Tilling versus Ripping

Tilling and ripping were compared at two sites, one with granitic parent material (Meyers Airport), and one volcanic parent material (Truckee Bypass Test Plots). The two methods did not perform consistently between Meyers Airport and Truckee Bypass. Eight of the nine study sites in this project had plots with tilling that performed well, therefore tilling is recommended over ripping for new treatments. The following were observed:

- no sediment yield and similar infiltration rates for both methods at the Truckee Bypass Cut Slopes
- sediment yields were 13 times lower at ripped plots compared to tilled plots at Meyers Airport (this may be related to cover by bare soil that was 3.3 times lower at the ripped plots, rather than the soil loosening method.)
- soil densities were 1.8 times lower at tilled plots when compared to ripped plots at Meyers Airport.

Tilling Depth (18 inches versus 6 inches)

Tilling depths were compared at one volcanic parent material site: Brockway Test Plots. Tilling to 18 inches is recommended over tilling to 6 inches for the following reasons. Plots tilled to 18 inches exhibited the following over plots tilled to 6 inches:

- soil density that was 1.5 times lower

Plots with either tilling depths exhibited:

- little to no sediment production and similarly high infiltration rates

Surface Treatment with Subsequent Woodchip Ripping versus Surface Treatment

Surface treatment with subsequent ripping of woodchips is recommended for unsuccessful existing surface treatments over no re-treatment for the following reasons. The surface treatment plot with subsequent ripping exhibited the following when compared to the surface treatment plot:

- a sediment yield that was 24 times lower
- an infiltration rate that was 1.5 times higher
- organic matter content that was 1.3 times higher

Amendment versus No Amendments

Amendments in this test included coarse overs and compost. All plots in the amendment versus no amendment tests included the application of native seed 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 parent material 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:

- plant biomass that was up 1.2 to 4 times higher
- nitrogen (TKN) that was up 1.8 times higher
- cover by perennial species that was up to 2 to 9 times higher
- plant cover that was up to 2 to 10 times higher
- soil density that was up to 1.5 times lower

Amendment Type

In this study, some amendments were tested at only one area, which did not allow for comparison. 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, 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 rampant on plots with compost. Most treatment plots with amendments exhibited high infiltration rates and low sediment yields (or no sediment). A difference in soil density was not found among amendment types. A compost mix is recommended over woodchips and tub grindings in areas without a cheatgrass seed source. More research is necessary to make a recommendation for cheatgrass problem areas. Based on the results of the three different types of compost used (25% coarse, 75% coarse, or 100% coarse), the mixture composed of 75% coarse and 25% fine material is recommended. Each amendment that was tested is presented below with noteworthy monitoring results.

Compost with 25% coarse/ 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
- produced 1.3 times higher perennial plant cover than 100% coarse overs

Compost with 75% coarse / 25% fines

Plots amended with compost composed of 75% coarse and 25% fines exhibited:

- plant cover was up to 2 to 3.4 times higher than plots with tub grindings or composted woodchips
- seeded perennial cover (40%) that was 2.7 to 3.4 times higher compared to plots with tub grindings
- seeded perennial cover (40%) that was 2.2 to 2.7 times higher compared to plots with composted woodchips
- TKN that was 1.4 times higher than plots with woodchips

100% Coarse overs

Plots amended with 100% coarse over exhibited:

- TKN that was 1.2 times higher than compost and 2.1 times higher than plots with woodchips
- organic matter that was 1.3 times higher than compost and 2 times higher than plots with woodchips

Compost/woodchips mix (50/50)

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

- 1.7 times higher TKN than plots with compost alone or woodchips alone
- 1.7 times higher plant cover compared to plots with woodchips
- 1.3 times higher organic matter compared to plots with compost alone or woodchips alone
- 2.3 times higher seeded species compared to plots with woodchips

Tub grindings

Plots amended with tub grindings exhibited:

- soil densities that were15 to 40% less than plots with screened compost
- foliar cover by cheatgrass 27 times less on plots with tub grindings compared to plots with compost
- foliar cover by perennial species 7 times higher than on plots with compost and 2.8 times higher than on plots with compost and tub grindings combined

Amendment Rate (2 inches versus 6 inches)

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
- 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 year

Amendment Rates and Tilling Depths

Amendment rates are suggested only in combination with tilling depths. It is important that the proportion of amendment to tilling depth remain constant. In general, a tilling depth of 12 inches is recommended since many restoration sites have consolidated material at deeper depths. With a 12 inch tilling depth, 6 inches of amendment addition are recommended for granitic soils and 4 inches of amendment are recommended for volcanic soils. The granitic ratio of tilled soil to amendment depth is 2:1, while the volcanic ratio is 3:1. Deeper tilling requires a higher level of amendments to maintain these ratios.

Organic Slow-Release Fertilizer

Plots that compared full treatments with and without fertilizer were studied at Heavenly Canyon and the Tahoma Soil Boxes, both granitic parent material sites, as well as one volcanic parent material site: Northstar Lookout Mountain. Fertilizer application is recommended for the following reasons. Rates will be discussed in the next section. Full treatment plots with fertilizer exhibited the following when compared to full treatment plots without fertilizer:

- plant growth that was up to 2 times higher
- perennial plant cover that was up to 1.8 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 1.2 to 1.8 times higher

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

Two fertilizer rates were examined at two different sites with volcanic parent material: Brockway Test Plots and Truckee Bypass. The lower rate is recommended for the following reason. When compared to 4,000 lbs/acre, the lower rate of 2,000 lbs/acre exhibited:

- total, perennial, and seeded plant cover that was up to 2 times higher

Higher rates of fertilizer are more costly and can increase the proportion of volunteer annual species.

2000# → 140 # N/ACRE (BIOSOLIDS 7%

Seed Rate

Most plots received an application of seed close to 125 lbs/acre. Two test areas, which each compared two different seed rates, were studied to determine whether higher rates produced more desirable plant cover. The two study sites on volcanic parent material were: Truckee Bypass and Brockway Test Plots. In both cases, the higher tested seed rate (285 versus 92 lbs/acre at the Brockway Cut Slopes and 150 versus 50 lbs/acre at the Truckee Bypass) produced slightly higher cover by seeded or perennial species.

- At Truckee Bypass, the higher rate produced 1.1 times higher perennial cover and 1.2 times higher seeded plant cover.
- At Brockway Cut Slopes, the higher rate produced 4 times higher cover by seeded species (2% compared to 0.5%).

These increases were marginal compared to the relative amount of extra seed applied. The 150 or 285 lbs/acre rates are not recommended since only one test was performed on each and only a small improvement was shown. More study of seed rates is necessary, as one test is not enough to recommend a new rate. The seed rate of 125 lbs/acre, which was applied on most plots in this study, remains the recommended rate.

Seed Composition

Different plant species are more productive under certain soil conditions and in different soil types. Plant growth is also affected by the solar exposure at a site. Therefore, four different seed mixes are recommended for four different conditions: 1) volcanic soil, high solar exposure, 2) volcanic soil, low solar exposure, 3) granitic soil, high soil exposure, and 4) granitic soil, low solar exposure

Volcanic Soil – High Solar Exposure

50% squirreltail
20% Western needlegrass
20% mountain brome
5% blue wild rye
4% native forbs (lupin, buckwheat, etc.)
1% native shrubs (bitterbrush, sagebrush, etc.)

Volcanic Soil – Low Solar Exposure

40% squirreltail
30% mountain brome
15% blue wild rye
10% Western needlegrass
4% native forbs (lupin, buckwheat, etc.)
1% native shrub (bitterbrush, sagebrush, etc.)

Granitic Soil – High Solar Exposure

50% squirreltail
35% Western needlegrass
10% mountain brome
4% native forbs (lupin, etc.)
1% native shrub (bitterbrush, sagebrush, etc.)

Granitic Soil – Low Solar Exposure

50% squirreltail
30% Western needlegrass
10% mountain brome
5% blue wild rye
4% native forbs (lupin, etc.)
1% native shrub (bitterbrush, sagebrush, etc.)

The reasons for these recommendations are as follows:

- A decline in mountain brome was observed in drought years, therefore, lower quantities than applied are recommended. The percentage of cover by mountain brome decreased markedly from up to 16 to 24 times between 2006 and 2007 (drought year).
- Squirreltail was the most common dominant species and composed up to 100% of cover at some plots, and therefore is recommended as the dominant grass in all mixes.
- Blue wild rye did not germinate at some sites and therefore proportions are reduced. Blue wild rye only did well at volcanic sites with low solar exposure.
- Western needlegrass was present in higher quantities in granitic soils and therefore represents a large proportion of the recommended mix compared to the volcanic mix.

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. The reasons for the recommendations are as follows:

- Most plots with 2 inch application had greater than 89% cover by mulch after two years.
- Most plots with mulch applications of 1 inch exhibited up to 19% bare cover after three years.

- Mild disturbance can displace mulch. The effect of disturbance would not be as great with higher initial mulch application.

Irrigation

Irrigation can take many forms. Landscaping irrigation typically consists of regular, frequent application to develop a robust native plant community on sites with high soil densities (Caltrans Type D treatment sites). This type of irrigation was studied and is not recommended for the following reasons:

- The irrigated site did not perform well in rainfall simulations and produced a two-year average infiltration rate of 3.4 inches/hour (86 mm/hr) and a two-year average sediment yield of 110 lbs/acre/in (49 kg/ha/cm), compared to no sediment at fully treated sites.
- Plant cover at the irrigated site decreased from 48 to 12% after the irrigation was removed because plants at the irrigated site were dependent on artificial irrigation for growth.
- Annual species, such as Spanish clover, were dominant, rather than native, perennial bunchgrasses.
- The 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.

Biosod application

Biosod is a term that refers to a rolled sod product that is delivered to the site and applied over the surface instead of seeding. The Biosod that was studied was mostly made up of yarrow (*Achillea millifolium*). This application is not recommended for the following reason.

- Biosod reduces species diversity, which is an essential part of healthy plant communities.
- Biosod is more expensive than seeding.
- Biosod produced a shallow-rooted plant community.

Recommended Specifications

The following is a general specification for treatment or re-treatment of highly disturbed, low nutrient soils (more than 20% below native levels) and cannot be applied in all situations. Figure 3 and Figure 4 guide one through, in more detail, the important considerations in specification creation. Appendix A lists all materials and their recommended composition (size, purity, source, etc). All suggested specifications are recommendations only and based on current

research. Further research is necessary in several areas to improve upon the current recommendations.

Tilling: 12 to 18 inches

Amendment: compost (75% coarse, 25% fines) that composes 33% of tilling depth in volcanic soils and 50% of the tilling depth of granitic soils

Fertilizer: 2,000 lbs/acre of organic slow release fertilizer

Mulch: 2 to 3 inches of pine needle mulch

Seed:

For volcanic soils with high solar exposure:

50% squirreltail
20% Western needlegrass
20% mountain brome
5% blue wild rye
4% native forbs (lupin, buckwheat, etc.)
1% native shrubs (bitterbrush, sagebrush, etc.)

For volcanic soils with low solar exposure:

40% squirreltail
30% mountain brome
15% blue wild rye
10% Western needlegrass
4% native forbs (lupin, buckwheat, etc.)
1% native shrub (bitterbrush, sagebrush, etc.)

For granitic soils with high solar exposure:

50% squirreltail
35% Western needlegrass
10% mountain brome
4% native forbs (lupin, etc.)
1% native shrub (bitterbrush, sagebrush, etc.)

For granitic soils with low solar exposure:

50% squirreltail
30% Western needlegrass
10% mountain brome
5% blue wild rye
4% native forbs (lupin, etc.)
1% native shrub (bitterbrush, sagebrush, etc.)

Figure 3. Recommendations for new treatments

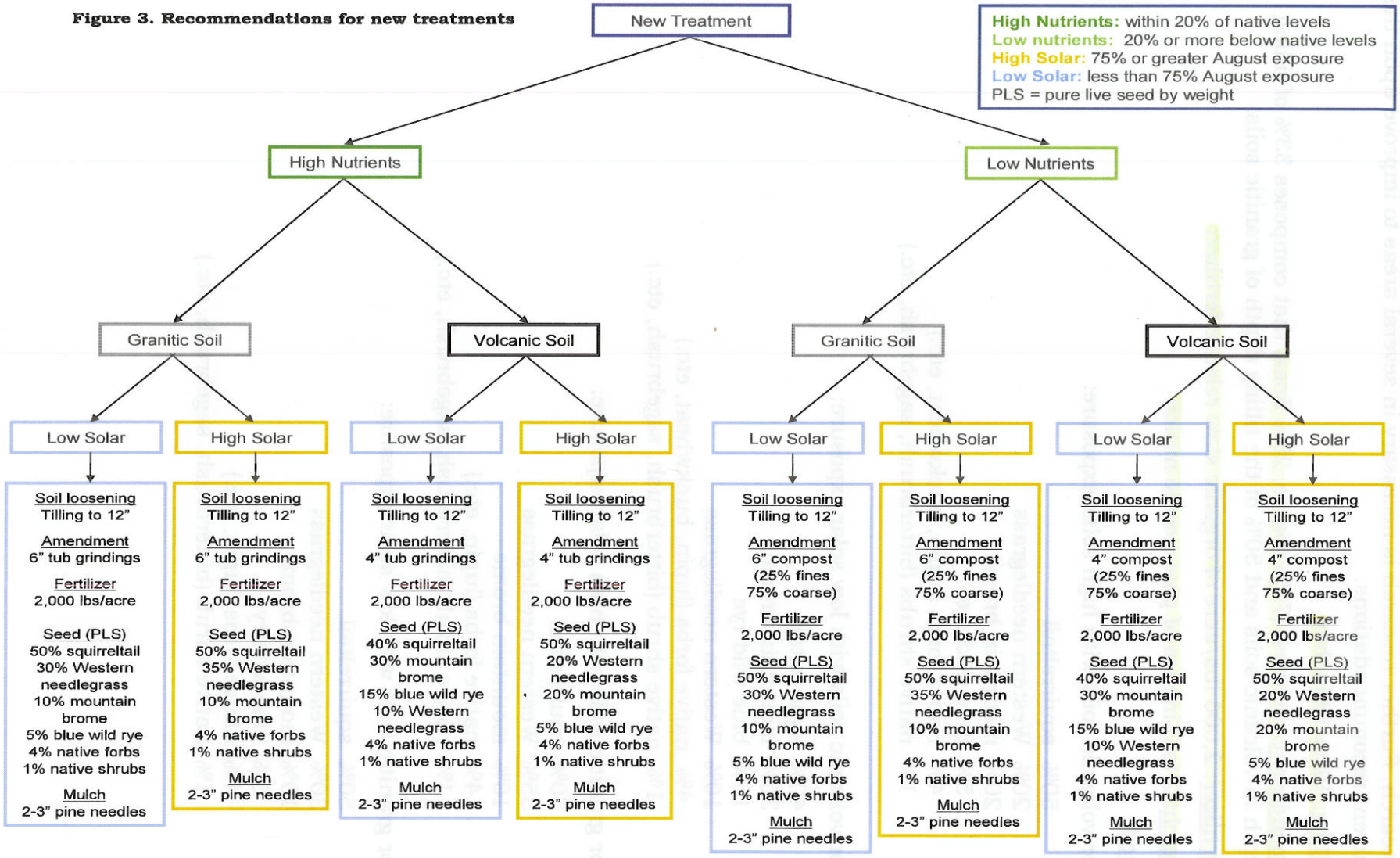
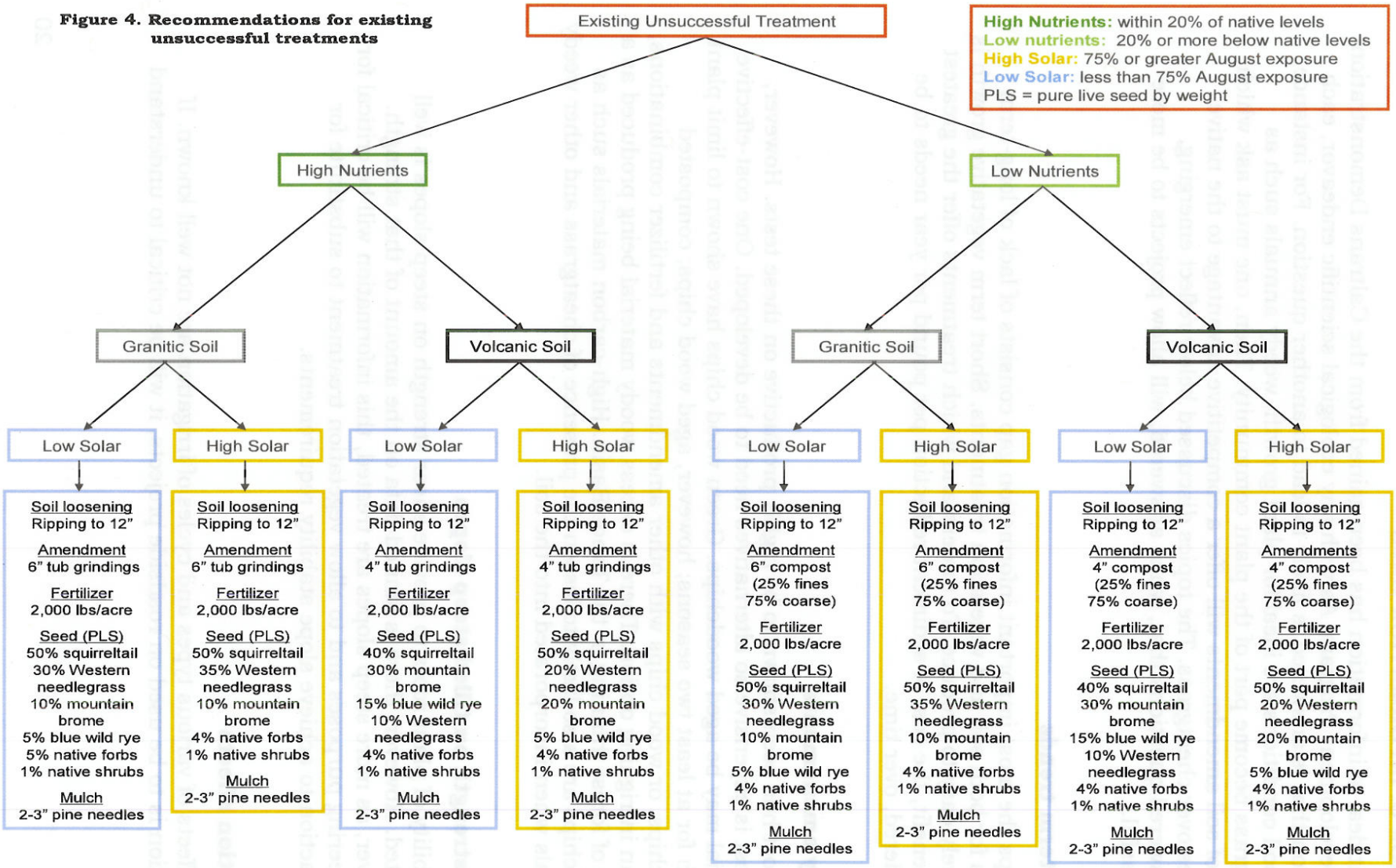


Figure 4. Recommendations for existing unsuccessful treatments



SECTION 3: INFORMATION GAPS

A great deal of information has been gained from the Caltrans Demonstration and Development Program. 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 lack of long-term trends for both soil and vegetation treatments. Short term vegetative growth is relatively easy to produce. To understand which treatments offer the greatest cost benefit, the cost of sediment reduction per pound per year needs to be considered, over time.

Woody amendments

Compost has been shown to be highly productive on these tests. However, compost is expensive so alternatives need to be developed. One cost-effective material may be aged woodchips. Green wood chips have shown to limit plant growth for at least two seasons; however, aged wood chips, composted woodchips, or wood chips with other amendments 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 wood chips 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.

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 seeding

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 that seed planting if seeding can be shown to produce a robust response.

Seeding

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 for the optimal plant growth, whether a wet season or a drought.

APPENDIX A – MATERIAL INFORMATION

Compost

The material that will be composted should consist of 50%, by volume, indigenous forest vegetation from the Lake Tahoe Basin. The predominant nitrogen sources should be cow manure, horse manure, alfalfa, grass clippings, green waste, kelp, and hydrolyzed fish protein. Green plant material for an enzyme source and up to 10% clay for the colloidal benefits are necessary to produce proper structure and nutrient holding capacity in the humus (fine material). Thermophilic temperatures should be maintained between 135 and 165 degrees Fahrenheit for a minimum. An individual row should be turned at least 15 times to complete the composting cycle. The compost also needs to be turned if carbon dioxide levels reach 11%. 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. Descriptions of compost mixtures are below:

- 100% fines
  0% coarse overs
- 25% fines
  75% coarse overs
- 75% fines
  25% coarse
- 50% fines
  50% coarse overs
- 0% fines
  100% coarse overs

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 five percent 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, since 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 five percent 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, since 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 five percent 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.

Fertilizer

Fertilizer should be slow release, have 97% organic content and an N-P-K ratio of 6-1-3. It should be derived from fermentation of soybean meal, cottonseed meal, and sulfate of potash magnesia and be sterilized and free of weed seeds.