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Use of Organic Amendments for Revegetation of Disturbed Sites with Adverse Soil Conditions

Final Report

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Final Report

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Use of Organic Amendments for Revegetation of Disturbed Sites with Adverse Soil Conditions

June 30, 2005

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I. EXECUTIVE SUMMARY:

Decomposed granite (DG) substrates are notorious for their ability to erode and produce sediment. This occurs because the granite particles that crumble out of a weathering rock have low cohesion and low pore space and low organic matter content. When wet, they settle into a dense mass with low infiltration. Rainwater runs over the top and cuts deep gullies. When dry, the materials form crusts or they hard-set. When they are rewetted and saturated, they can liquefy and slump. As a result of these characteristics, these substrates are erosive and unstable when wet, and when dry they are droughty, and restrict root growth. They typically have low nitrogen content for plant growth. As a result, revegetation success on DG substrates is poor.

Serpentinitic substrates weather from rock with high magnesium and very low calcium content. On this material, many plant species cannot grow well because of the low calcium availability. These substrates typically have low clay content, and often have shallow soil depths, meaning that they are easily saturated and non-cohesive. For these reasons, serpentinitic substrates are also very erosive.

In this project, soil characteristics were evaluated for two barren, eroding cut slopes on these two geological materials. Each was compared to a vegetated reference site. The DG sites compared a barren, eroding cut slope with a regraded and revegetated slope that was about 15 years old and is stable against erosion. Both sites were located near Buckhorn Summit on the Shasta/Trinity County line west of Redding, CA. Using the characteristics of the revegetated slope as examples of “adequate” soil characteristics for plant growth in this environment, the barren cut slope was treated and amended. Study plots were constructed with an uncompacted, 50 cm deep surface layer that was amended with a 24 % (by volume) mixture of coarse (unscreened) yard waste compost blended with the DG substrate. Native perennial grasses grew and set seed the first year without irrigation. Sediment loss was reduced from an estimated 200 to 300 cubic yards per year from the site to a minimal amount that required no maintenance attention.

Soil infiltration and water content data from monitoring plots were used to estimate sediment losses using various storm scenarios. After treatment, infiltration was increased until no surface runoff was produced for storms of approximately 5 year return frequency (47 mm/hr, 15 min duration), whereas the unamended DG substrates produced runoff in storms of less than 2 year return frequency. Sediment production in a 25 year return frequency storm was reduced on the compost amended treatments to

35% of that on the unamended (DG) treatments. Sediment production in a 50 year return frequency storm was reduced on the compost amended treatments to about half of that on the unamended (DG) treatments. Several soil characteristics continued to improve in subsequent seasons after construction, suggesting that the treatments were sustainable for the local climatic and geological conditions.

The constructed soil treatment for the overall cut slope at SHA299 mile 0.06 (Buckhorn Summit) involved creating a compacted bench, covered by an uncompacted surface layer of a 24 % volumetric mixture of coarse, unscreened yard waste compost to the DG substrate, creating a 50 cm uncompacted rooting depth. The uncompacted soil mixture was covered with a 900 g/m^2 coir flap over the surface of each lift (bench) and continuing down the slope face, overlapping the fabric on the next lift below.

Amendment with this much compost provides more total N than is needed for plant growth on the site, so a modified amendment should be used for future projects. This modified amendment should include higher proportions of wood shreds to yard waste compost, such as a 50:50 mixture of woods shreds with coarse unscreened yard waste compost applied to a 10 cm (4 inch) depth and tilled to 40 or 50 cm. Whether additional N fertilizers need to be mixed with the compost materials to support plant growth depends on the production history of the compost. A previous Caltrans study indicated that composts produced by 15 days thermophilic treatment but no curing time (were not held and turned after the thermophilic stage) tended to not release N for plant growth or leaching losses. These may best be used as surface mulch application. Well-aged composts (composts held and turned for 70 to 90 days or more after the 15 day thermophilic stage) will need little or no amendment since they release a steady supply of N. In some areas, the treatments could be reduced in scale with adequate results, depending on the infiltration needs of the site and the residual fertility. Also, such large compost amendments would not work for dry climates because of the salt load from the compost. Adding excessive compost to serpentine substrates alters calcium availability so that they resemble sedimentary materials, with a resulting increase of weed growth.

On the serpentinitic substrate along Colusa 20, mile 1.5, more effort was needed for developing methods to get plants to grow successfully and for creating adequate plant available moisture to grow through the dry summer season. A range of native species was successfully established on tilled plots, but no large-scale plot construction was done at this site.

II. Introduction
A. Previous approaches for revegetation of harsh sites

Highway cut slopes and some fill slopes often remain barren or poorly vegetated for long periods after construction (Clary, 1983; Nakao, Hatano, Howell, Shirley, 1976; Parks, and Nguyen, 1984). These studies typically showed that, on harsher sites, application of fertilizers and erosion control seedings may have generated initial plant cover, but that plant densities often steadily declined within 3 to 5 years and the site returned to a generally barren condition with chronic sediment losses. The research reported here was intended to evaluate the reasons contributing to poor plant establishment on harsh disturbed substrates on right-of-way cut and fill slopes, keeping a focus on providing adequate soil resources.

Through the last several decades, the approach to revegetation of harsh sites often emphasized identification of plant species, ecotypes or cultivars that could grow on the rigorous site conditions of disturbed sites (Conaway and Thayer, 1981). The idea was to use a "super" plant that could grow abundant biomass even under stressful site conditions. These plants, because they were widely utilized for erosion control or revegetation on numerous projects throughout the state, constitute many of the widespread, overly aggressive species we view today as "weeds" (Kay, 1974). While it is true that many of these plants have enhanced survival characteristics for harsh sites, their invasive characteristics and aggressive growth have also contributed to current weed management problems, including production of large amounts of biomass leading to accumulated fuels and increased fire frequency, herbicide damage from weed control activities, and loss of native plant habitat.

A final consideration is that many weeds do not build soil as well as deeper-rooted native species. This is because weeds commonly have an annual growth form, with small root systems and lack of secondary tissue. Their tissues are easily decomposed and contribute little to soil regeneration. Since root growth and organic matter deposition into the soil are critical processes to repair disturbed substrates, weeds would not be expected to be as desirable as perennials for soil regeneration.

The approach taken in this study was not to search for plants with aggressive growth habits, but to ameliorate the harsh substrate conditions found on impacted substrates following road construction or erosion, so that the native plants surrounding the site can survive on the site. These native species already embody several other characteristics necessary for sustained revegetation, including tolerance to the local climatic conditions, tolerance of herbivory, and ecological (competitive) stability within that environment.

Because we do not know all the target conditions of each substrate that are required for plant growth, we use the levels measured on "disturbed-but-revegetated" reference sites as examples of adequate soil characteristics. Undisturbed, native sites are not preferred as reference site examples because these soils took hundreds of years to develop and accumulate their soil resources. Undisturbed sites would be an unrealistic model for short term (3 to 10 year) revegetation objectives.

Therefore, this project addresses the task of identifying the various plant growth limiting conditions of impacted or degraded substrates by soil analysis and by comparison to a relevant revegetated reference site, followed by evaluation of potential amendments to correct limiting conditions if they occur. Two common erosion control problem substrate (geological) types in Northern California were selected to evaluate for growth limiting conditions, including decomposed granites (DG) and hydrothermally altered ultramafic (serpentinitic) substrates.

B. Soil evaluation process

A soil-based approach to revegetation involves improving the disturbed substrates so that they are adequate to support plant growth at this location. These required soil conditions have been developed and described in previous Caltrans reports (listed in Appendix B). In general, the conditions evaluated involve slope geotechnical stability, infiltration and water holding capacity, nutrients, biological activity and surface erosion control. Each condition needs to be measurable by a testing method that is technically correct, is relevant to wildlands systems and is easily applied to numerous, heterogeneous field sites. Because plant available moisture is the most critical element for plant growth during California's dry summer season, this review starts by addressing soil hydrology, including both water movement and water retention in the soil profile.

Hydrologic problems are often generated by road cuts and fills as they cross hilly landscapes. Natural, undisturbed soils in well vegetated areas have surface horizons with well developed soil structure. Typically, these soils have high pore volumes with extensive interconnections and they have high infiltration rates. When heavy or extended rainfall occurs, water infiltrates rapidly, then flows laterally through the porous surface soil horizons near the soil surface, generally within the top 30 cm (1 foot) or so.

When the lateral flows intersect a road cut, they emerge to the surface and run down the cut slope face, causing rill erosion or slumps. Surface flows then often collect along the ditch on the cut bank side of the road and flow laterally until they cross the road surface or run through a culvert. The flows then spill out onto the unconsolidated material used to construct the fill slope. Loose substrate materials erode away, exposing the underlying compacted subgrade materials.

On non-vegetated areas, the plant litter, duff, soil aggregates and root channels are not present to help protect against raindrop erosion and to infiltrate rainfall. If the substrate has gone many years without vegetation inputs, the individual soil particles start to disaggregate and pack closely together (hard-set) or they form surface crusts. Infiltration decreases to very low levels and excess rainfall is shed off as overland flow. As particles pack, a greater proportion of water from rainfall moves across the surface rather than infiltrating. As surface water flows gain volume and momentum, rills, gullies and sheet erosion are formed.

To reduce overland flow, infiltration rates into the soil must exceed rainfall rates. Infiltration can be measured by rainfall simulator or by ring infiltrometer. Ponded ring infiltrometers (cylinders pushed into the soil with standing water inside) are easier to use, but these may provide excessively high flow rates in fractured soils or where there are burrows, open root channels or animal burrows. Infiltration rate capacities of the soils are compared to the rainfall intensity estimates from long-term meteorological records. If a site is to be designed to withstand a 25 year return frequency storm, for example, the rainfall associated with this storm event would provide the target infiltration rate that the soil must attain to avoid overland flow. Although slope stability is critical for sustainable revegetation, geotechnical issues are not evaluated here except as they interact with soil and plant growth processes. All geotechnical issues should be referred to Caltrans structural engineers.

Secondly, the water holding capacity of the soil or substrate is tested to evaluate if sufficient moisture is held within the soil and is available for plant growth. Target levels are set by comparison to the amounts measured in the revegetated reference site, which is assumed to represent a viable soil condition. The amount of water holding capacity is primarily a function of the clay content of the soil. In substrates with low clay content, organic matter can be added to increase water holding capacity.

Reestablishment of the revegetation community requires several years of nutrient inputs in order to complete development of root systems, accumulate plant litter at the soil surface, and to develop a functioning soil microbial community. Chemical fertilizers provided alone during the first year are often not enough to regenerate all components of the revegetation community. Even if several year's supply is added initially, too much nutrient is typically available the first year and too little is available in the later years. Weedy invasion is encouraged by the abundant initial nutrient amendment, especially of nitrogen. An alternative method is to provide large total amounts of nutrients, but to select materials that have a low level of availability and a steadily release rate over extended periods of time.

Well stabilized, organic amendments can provide this type of nutrient availability pattern. The decomposition of the carbon component of an organic amendment also helps regenerate the microbial biomass as well. In this study, unscreened yard waste compost was used as a common, inexpensive form of organic amendment. Decomposition of organics within the compost supplies C and N, as well as non-N nutrients (P, K, Ca, Mg, S, micronutrients). The impacted substrates were evaluated for nutrients and chemical characteristics (pH, CEC, EC, bulk density) and appropriate amendments were selected to remediate deficiencies.

The microbes needed for decomposing plant materials are ubiquitous in the environment and need no inoculation or stimulation other than providing decomposable substrates to grow on. Some specialized microbes, however, may need to be inoculated to barren sites. These may include some types of mycorrhizal fungi, N fixing bacteria or actinomycetes. If these microbes do not move in from surrounding soils, they may be supplied as inoculants from local areas or as commercial products. The need for these inoculants needs to be decided on a site-by-site basis.

Finally, after the site has been amended or treated so that soil function is similar to the revegetated reference site, the site surface should be protected from rain drop impact, excessive rainfall, or snowmelt, and against heat and cold extremes and evaporative losses. This is best done by a mulch layer of pine needles or shredded wood fibers. Short-term cover can be obtained for one season using straw or hydromulch.

Within this list of potential plant growth limiting conditions, the two most common limitations are of plant available water and of a long-term supply of N. If these are provided, plants will gradually acquire adequate levels of the remaining nutrients or will adjust plant growth accordingly (by decreasing plant size or increasing plant-to-plant spacing). Conversely, if water or N is not made sufficient, the correction of most of the remaining characteristics will have little long-term effect and vegetative cover on the site will decline.

C. Project sites

Two substrate types that commonly form chronically erosive slopes in California are decomposed granites and hydrothermally altered ultramafic rocks (serpentines). One experimental site was selected for each of these geological types. Both sites were very erosive and had remained barren for over ten years previous to this project. The decomposed granite site was located at Buckhorn summit (SHA 299 mile 0.06) just east of the Shasta Trinity county line. The Buckhorn summit site was estimated to produce 200 to 300 cubic yards of sediment per year, requiring frequent removal by maintenance crews (personal communication, Milt Apple, District 2 maintenance supervisor). The serpentine site was located a short distance east of the Lake / Colusa county line (COL 20 mile 1.56). This site had experienced several massive failures, and finally, a large reconstruction project was undertaken to stabilize the slope. The face material of the final slope surface was deep subgrade material with no organic matter and relatively unweathered serpentine mineralogy.

Plant species selected for each site were a combination of early successional species (adapted to rapid colonization and growth) as well as locally occurring climax species. Plant type was restricted to grasses and forbs for experimental measurement. Grasses, forbs and shrubs were out-planted on the sites after the experimental phase to increase plant diversity.

In this document, the sites are summarized separately in the two following sections. Details of the experimental layout and analysis are included in the research papers listed in Appendix C.

III. Revegetation of decomposed granite (Buckhorn Summit, SHA 299 0.06)

A. Site conditions

The Buckhorn Summit site (SHA 299 0.06) is located 25 km (30 mi) west of Redding on State Route 299 just east of the summit at the Shasta/Trinity county line. Elevation at the site is approximately 1008 m (3300 feet). Vegetation in this region is mixed conifer (Sawyer and Keeler-Wolf, 1995). The average monthly temperature is 36.7 °C and the average annual precipitation is 1669 mm. This site is located in decomposed granite that varies greatly in competency from Weathering Class (WC) 4, to 5 or 6 on the exposed cut slopes (Clayton and Arnold, 1972). These WC categories correspond to rock that is hard enough that it rings when struck with a hammer (WC 1 and 2), to rock that is soft enough to dig with a shovel or break apart by hand, even though it retains the original rock-like appearance before excavation (WC 5 and 6). The DG on this site could be easily dug by hand or shovel and individual feldspar and mica minerals were highly decomposed.

Two sites were evaluated as part of this project. The impacted site was heavily gullied and had retreated 5 to 7 m (15 to 21 feet) rearward into the preexisting slope from the original constructed surface. This extensive erosion occurred because the surface of the weathered DG forms a seal crust across the surface that reduces infiltration. Water runs off the surface, cutting channels and mobilizing sediment. After the rains stop, the site becomes droughty because little water is retained for plant growth. In addition, root growth is reduced because the substrate is too dense or too dry. Although the DG substrates have generally adequate levels of non-N nutrients for plant growth, the availability of nitrogen (N) and plant available moisture are extremely low. Since N and water are the nutrients or conditions needed in the greatest amount, these are significant limitations. As a result, revegetation on these materials is difficult.

The revegetated reference site, in contrast, was previously a barren logging landing that was regraded about 15 years previously. It is now completely vegetated, with no signs of erosion. This site is made of the same DG material, at a similar slope angle, aspect and elevation, so it provides a good example of a model for treatment of the barren, impacted site. At the reference site, DG materials were pushed by bulldozer up against a cut slope in a south facing 2:1 to 3:1 slope. The infiltration rate of the reference site was used as a target for the impacted slope.

Part of the ability of these foothills and mountains to stand up to erosion through the millennia is attributed to their abundant vegetative cover and thick duff layers, and also to the relatively rapid drainage in the decomposed granite geological materials that underlie the landscape. As these rocks weather, the minerals expand, increasing their porosity and increasing their hydraulic conductivity. (The expanded vermiculite soil amendment sold by gardening stores is a larger scale example of the same process that expands the small, black biotite mica minerals in the granite rock matrix.) As these mineral crystals expand, they increase the porosity of the rock and allow water to percolate through, as long as the substrates are not disturbed by construction or landslide. When this physical disturbance occurs, however, the porous structure of the mineral matrix collapses and the small pores fill with powdered silt and clay sized particles. The infiltration of these crusts or seals is a small fraction of the original material, potentially only 10 % of infiltration in the undisturbed rock matrix. Erosion on bare, exposed DG slopes is typically high because most of the rainfall water runs overland. At the start of this project, the face of the Buckhorn (SHA 299 0.06) site was a series of deep gullies interspaced between prominent ridges with little or no vegetative cover except a cluster of willows in a low seep area (upper left cover photo). The face of the field site was also impacted by active slumping at midslope from perched water table flow that probably was connected with an abandoned logging landing immediately above and behind the cut slope. Infiltration on the undisturbed material exceeded 100 mm/hr, meaning that water infiltrating from the landing area could emerge along the cut slope face within a week or two. Repeated slumping had oversteepened the top 3 m (10 feet) of the slope, which then failed and fell down the slope. Since construction, the exposed cut face had retreated an estimated 5 to 7 m (15 to 21 feet) rearward into the slope. About 200 to 300 cubic yards per year of sediment were removed by maintenance crews from this site (Milt Apple, District 2 maintenance supervisor, personal communication).

The revegetated reference site is located in Trinity county about 5 miles west of the project site along along 299. The site was a logging landing until about 1985, when the roads were retired as part of a Forest Service project. A track-mounted backhoe was used to exhume the boulder-strewn path of the previous stream channel. Then the final slope contours of the site were then reestablished by pushing the old fill material up against the previous cut face. The soil profile beneath the revegetated cover was non-differentiated (with no soil horizon development and an obviously disturbed soil matrix), with a thin accumulated layer of organic duff. The site was therefore representative of a disturbed substrate rather than a well developed soil.

B. Site treatments

During the year previous to reconstruction of the larger slope, a series of 16 experimental plots (2 m x 2 m) were constructed along the foot of the eroding slope. Treatments were constructed at a 2:1 (run:rise) slope angle with 1 to 1.5 m depth of fill material behind a gabion rock wall. The top 50 cm of DG substrate (from the SHA 299 1.0 cut) was mixed with 0, 6, 12 or 24 % by volume coarse unscreened yard waste compost from the Redding municipal composting facility. This is equivalent to 0, 2, 4, or

8 % by dry weight. *Elymus mulitsetus* plugs (50 mm deep) were planted on 200 mm centers in an 8 x 8 plant grid pattern on the top half of each plot (upper right cover photo, lower portion of slope). These plants were allowed to grow one year before biomass measurements were taken. The bottom half of the plot was left unplanted. Infiltration measurements were measured on top and bottom halves to contrast the contribution of plant growth to infiltration in interaction with the various compost amendment amounts. The bottom half of the plots were planted one year later with *E. multisetus* to test if plant establishment was more difficult after the DG had settled and set-up (hardset) during one winter season. This was intended to be a test for ease of plant establishment on existing barren slopes, in contrast to freshly tilled or constructed fill materials. All plots were covered with a surface mulch of rice straw.

Moisture content of the plots was measured with time domain transmissivity (TDT) probes to give a picture of soil saturation and drain down patterns through time. Probes were placed at 20 and 40 cm depths. This information described how the soils handle rainfall inputs from storm events, how close to saturation they got during storms, and how much moisture was retained for plant growth.

When infiltration is adequate for the design storm event (both infiltration rate and infiltration capacity), overland flow is eliminated and the need for other surface erosion control is eliminated. Results from the infiltration plots suggested that the 24 % by volume compost amendment was needed to match the infiltration of the revegetated reference site. This research finding, however, needed to be translated into a constructable specification for application to the whole cut slope. A construction process was designed cooperatively between Chris Cummings (Caltrans District 2 Project Manager, Redding), Chris Cross (Cross Construction, Inc.), John McCullah (Salix Applied Earthcare, Redding), and Matt Curtis (soil scientist, University of California, Davis). This design was intended to provide structural stability for the slope as well as provide adequate rooting depth along the face of the slope. The 1.5 :1 (run:rise) slope was constructed in 1.25 to 1.5 m (4 to 6 foot) lifts of DG from the slope face, compacted with crawler tractor tracks to 0.85 % Proctor. The surface 30 cm (1 foot) (vertical measurement) was filled with a mix of 3 parts DG to 1 part unscreened yard waste compost that was mixed on a bench by loader bucket and then bladed across the lift surface onto the face. A coir fabric (900 g/m^2) was draped over the bench and down the face. The lower flap of the fabric was held under a 2 x 2 inch x 8 foot bat with 14 inch long nails driven into the slope surface. Plant establishment was excellent, with 100 %

cover within a year. The slope, which previously had produced 200 to 300 cubic yards of sediment per year now produces very little (no maintenance cleanout activity required during the years following construction). Shrubs and trees were planted through the coir fabric the year after construction to increase plant diversity.

C. Summary of Research findings: Buckhorn Summit (SHA 299 mile 0.06)

<u>Soil / hydrology findings</u>

1. The well weathered but undisturbed DG saprolite under the cut slope has 100 – 125 mm/hr infiltration rates. Subsurface flow on undisturbed geological materials is rapid and may account for water piping through the geological substrates from up-slope positions to the exposed cut slope surfaces. For example, the transit time from the ponded water above the slope to the slope face was estimated to be between one and two weeks. This time-delayed pattern may mean that water-related erosion and slumping may occur sometime after the rainfall event as the water percolates and flows laterally through the rocks. Local, undisturbed landforms in this region are erosion resistant because they have a thick duff and vegetative cover to sorb short bursts of rainfall and because they drain rainfall well to subsurface layers, both of which reduce overland flow and erosion. Any disruption to this soil hydrologic system in an area with this rainfall amount (1,600 mm/yr) will result in increased erosion unless the original soil hydrology is regenerated.
2. The slurry seal that forms at the substrate surface has infiltration rates less than 15 mm/hr. The slurry seal forms quickly with rain-drop impact on newly exposed saprolite. Reduced infiltration sheds precipitation overland as surface flow, increasing erosion. Mulch application to the soil surface prevents crust or seal formation, and tilled compost provides infiltration to ameliorate reduced infiltration rates. This is a physical process, so wood shreds (from a tub grinder rather than a chipper) would work as well, although they would not provide nutrients for revegetation. Wood shreds have longer fiber length than wood chips, so they are expected to be more effective at forming continuous pores for drainage down through the profile.
3. Compost amendments of 24 % (by volume) coarse unscreened yard waste compost tilled to 50 cm increases surface infiltration of DG fill to that of the revegetated reference site (about 50 mm/hr saturated hydraulic conductivity). Fine (1 cm (3/8 inch) screened)

compost has less effect on infiltration at equivalent amendment loading rates because it creates fewer continuous pores.

4. Compost incorporation was shown to provide faster internal drainage (percolation) than the unamended DG treatments. Root growth provides some of the function of developing internal drainage after the first year of growth. Infiltration of first year non-vegetated (24 %) plots declined to 37 mm/hr from 46 mm/hr at construction. The vegetated plots (24 %) remained at 47 mm/hr and in the second year of growth they increased to 60 mm/hr of infiltration. (Curtis and Claassen in prep Appendix C.).

5. Compost incorporation into DG substrates generates greater water holding capacity at saturation (45 % volumetric water content) compared to untreated substrates (32 %). Moisture content at field capacity (when drained by gravity) is also higher in the compost amended plots (about 40 %) compared to the unamended plots (30 %). This means the compost amended soils imbibe and hold more water during peak storm events. Water content also drains faster from compost incorporated DG treatments compared to unamended DG (steeper slope of green/blue (amended) water content line when draining after rain event compared to the red / magenta lines (unamended), Figure 1). The net result for field plot performance during rain events is that less surface runoff is produced. The danger of this design is that the higher moisture content may cause liquefaction of the saturated soil volume. Placement of the compost amended volumes on separate horizontal benches is important so that any slumps that form are isolated to single benches and do not spread to the whole slope. The compost amended volumes should have enough drainage that water freely percolates out of them without building up positive internal pore pressure. These aspects of the design should be reviewed by geotechnical engineers. Any design solutions must include unrestricted rooting volume of between 30 and 100 cm depth.

6. The "infiltration capacity" (IC) of a soil is the maximum rate at which a given soil at a given moisture condition can adsorb rain as it falls (Horton, 1933). The performance of the amended soil treatments at Buckhorn is evaluated on the basis of the return frequency storm intensity and the moisture content of the soil at the time of the rain event. If the storm comes in the summer when the soil is air-dry, the IC is about 25 % (40 % saturation capacity minus 15 % air dry capacity, Figure 1). This means that the rainfall volume in a 15 minute storm of 2, 5, 10 and 50 year return frequencies is estimated to be 10, 13, 15 and 20 mm. If the soil holds 25 % of its volume in moisture, this provides an estimate of adequate soil depth needed for the design infiltration

capacity. This volume is estimated as (mm precip / 25 % soil infiltration capacity volume =) 40, 52, 60 and 80 mm (1.6, 2.0, 2.4 and 4 inches soil depth) for the 2, 5, 10 and 50 year return frequency storms. As long as the surface infiltration rate is high (no surface sealing or hard packing), all of the rainfall should imbibe into the soil and no runoff should occur.

But, in the condition that the rain comes as a mid-winter storm, the soil IC is then only 10 % because the soil is partially filled with moisture (38 % saturation capacity minus 28 % field capacity (Figure 2, year 2). The estimated rainfall volumes of 2, 5, 10, and 50 year storms (10, 13, 15, and 20 mm rain) now require larger soil volumes to imbibe moisture and avoid runoff, since the wetter soil has less IC. The estimated soil volumes required are now (mm precip / 10 % soil infiltration capacity volume =) 100, 130, 600 and 800 mm (3.9, 5.1, 23.6 and 31.5 inches soil depth) for the 2, 5, 10 and 50 year return frequency storms. This suggests soil treatments should extend to these indicated soil depths.

These target values are for short (15 minute) rainfall intensities. If the objective is to imbibe a 24 hour storm with a steady rate of rainfall, the target values for 2, 5, 20, and 50 year return frequency storms are 86, 117, 135, 173 mm rainfall per 24 hrs (3.4, 4.6, 5.3, and 6.8 inches)(Trinity Center weather data). In a simple, static example, the soil volume needed to imbibe this moisture with no runoff is 860 to 1730 mm (34 to 68 inches) of soil depth during the wet season (10 % IC), but only 344 to 692 mm (14 to 27 inches) during the dry summer months (25 % IC). Although the soil volume needed to imbibe these amounts is calculated as a static model with no internal drainage in this example, it is realistic to expect that during the 24 hr rainstorm, water will percolate in a lateral or vertical direction within and out of the profile. Thus, a realistic, integrated infiltration capacity is a combination of surface infiltration rate, moisture retention capacity and percolation rate. For threshold limits, however, the static calculations provide estimates of adequate soil depth requiring treatment in different storm scenarios.

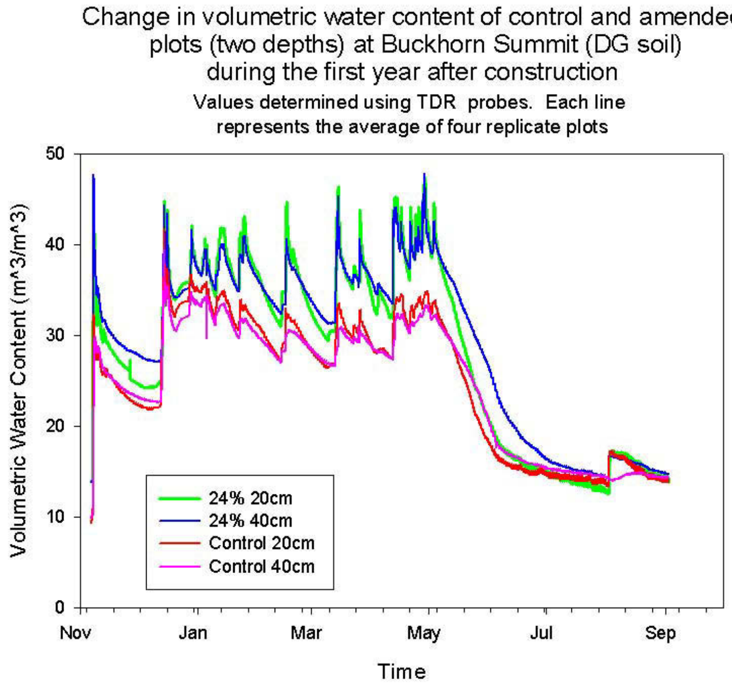

Figure 1. Volumetric water content of amended and unamended DG soils for the 01-02 water year.

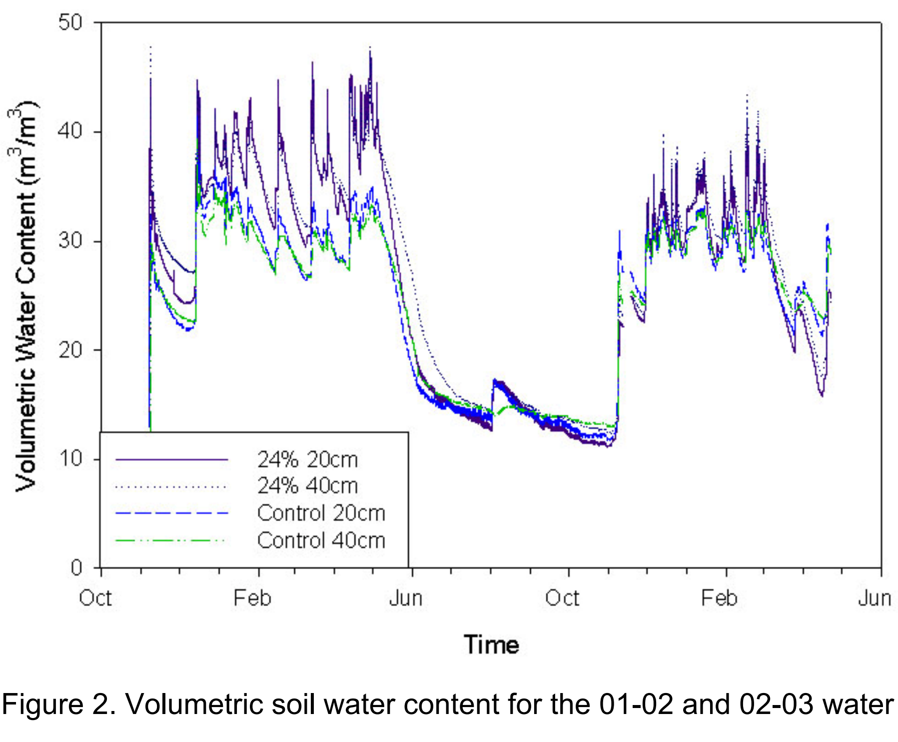

Figure 2. Volumetric soil water content for the 01-02 and 02-03 water years, Buckhorn Summit site, SHA 299 0.06 .

Table 1. Rainfall volume (mm/15 minute interval and mm/24 hr) for various return frequency storm intervals, using weather data from a station at a lower elevation.

Return Frequency Interval (yrs)	Buckhorn SHA 299 DG mm/15 min	Buckhorn SHA 299 DG mm/24 hr	Colusa COL 20 serp mm/15 min	Colusa COL 20 serp mm/24 hr
	Whiskytown data	**Trinity Center data**	**Clear lake data**	**Clear lake data**
2	10	86	5	71
5	13	117	6	96
10	15	135	7	112
50	20	173	10	145

7. Soil infiltration capacity is distinct from water holding capacity and total rootable volume. Infiltration relates to water movement into the soil during rains. Rooting volume and water holding capacity relate to moisture stored within the soil, providing plant available moisture needed for growth through the summer drought. Target levels for water use by plants is being evaluated in the Alternatives to Irrigation project (RTA 65A0182).

8. Most of the intense storms at Buckhorn occur in August or September when the soil is driest and the infiltration capacity is the greatest. During summer drought, even uncomposted substrates can handle more rainfall than a 10 year storm, as measured on the unamended plots.

9. During the rainy season, compost incorporation changes the threshold of runoff from a 2 year return frequency storm to nearly a 10 year storm (Table 2). Amounts of sediment loss for a given month or storm intensity were also reduced by over half by compost amendment. The time interval between storms also influences the capacity of the soil for greater infiltration capacity by allowing more complete profile drainage (Figure 1).

Table 2. Estimated sediment loss (kg/ha) during a 15-miute storm throughout the year (2003) at Buckhorn Summit on the a) control and b) compost treatments.

	RF † (yrs)	RI ‡	Jan.	Feb	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Average
a)	2	40	10.5	4.5	3.9	6.8	0.8	0	0	0	0	0	0	4.9	2.6
	5	47	30.5	19.6	18.4	24.0	11.0	0	0	0	0	0	1.9	24.5	10.8
	10	55	56.5	42.8	41.1	48.6	30.6	0	0	0	0	0	14.8	43.8	23.2
	25	64	85.0	71.8	69.6	78.3	56.8	9.5	5.3	6.2	3.4	1.2	37.0	73.1	41.4
	50	70	103.8	91.9	89.9	97.8	75.8	21.4	15.4	16.8	12.5	8.3	54.0	93.1	56.7
b)	2	40	0	0	0	0	0	0	0	0	0	0	0	0	
	5	47	0.5	0.1	0.1	0.5	0	0	0	0	0	0	0	0	0.1
	10	55	12.2	9.5	9.2	12.3	5.8	0	0	0	0	0	0	6.3	4.6
	25	64	30.3	27.4	27	30.4	21.3	3.1	1.1	2.2	0.8	0.2	6.3	22.3	14.4
	50	70	42.2	39.8	39.4	42.3	34.2	9.8	6.2	8.4	5.3	3.8	14.9	35.2	23.5

RF-Return Frequency, ‡ RI-Rainfall Intensity (mm/hr), Rainfall duration and intensity data from the Coffee Creek rain gauge.

10. Rainfall data for these estimates comes from areas either at lower elevations (Weaverville or Whiskeytown, both in valley positions) or from locations at similar elevations but greater distances (Trinity Center). In either case, better weather data would allow more accurate estimation of the slope performance under different rainfall intensities. Orographic effects caused by elevation changes strongly influences weather behavior, so more intensive weather analysis is needed for improved design of these slope treatments and erosion potentials.

Plant growth / nutrition findings

11. *Elymus multisetus* (squirreltail) roots grew past 2 m depth within the first year following a fall planting of grass plugs. Plots that were tilled but had no compost amendment showed the deepest root growth, as plants tried to acquire adequate moisture and nutrients. Root growth in compost amended plots was less deep but more dense, evidently because less rooting volume was required for plant establishment. Plants growing on untilled DG substrate (the undisturbed saprolite matrix of the cut slope) did not put roots any farther than the planting hole, and remained small or died.

12. At one year following construction, *E. multisetus* planted as seeds on compost treated plots during the second year (soil not freshly tilled) grew nearly as large (55 g/m^2 or 2.2 g/plant) as when planted as plugs directly after construction (68 g/m^2 or 2.5 g/plant; $p = 0.15$). Grasses grown for two years increased biomass to 354 g/m^2), which was non-significantly different from the revegetated reference site (292 g/m^2). If soil resources are adequate, these site-adapted plants can establish from seed in their first year without irrigation on compost amended substrates. On unamended substrates, seedling growth after a year of hardsetting was 23 % of first year growth immediately following construction. This is interpreted to mean that a site could be reseeded the second year if there were a failed stand establishment if the site had been compost amended. If the site were unamended, the second attempt would be much less productive than the attempt immediately after construction, due to residual tillage effects.

13. *E. multisetus* plants became dormant during the summer even though they did not show drought stress. Adequate moisture in the soil (about - 0.5 MPa) suggests that dormancy is internally regulated by these plants, and is not externally imposed by summer drought. More moisture was available at this site than was needed by these

plants. This suggests that soil treatments may possibly be scaled down for cost effectiveness, although only regarding this aspect of soil moisture and plant availability.

14. *E. multisetus* plants installed on non-composted substrates survived but produced little biomass. (88 and 79 g/m^2 for the first and second years of growth). Plant survival should be distinguished from plant health.

15. Compost amendment amounts that are needed for soil hydrology (24 % by volume) provided more N than is needed for plant growth. Combinations of wood chips and compost may provide both functions with a lower total N dosage, but this was not tested.

16. DG has adequate nutrient availability except for N availability (and perhaps S) and water, so compost amendment completes the suite of required conditions for plant growth on these DG substrates. No other fertilizers are necessary.

17. Compost physical effects may start to decline by three years or so, so plant root growth needs to be established by then to take over the infiltration function of tillage and compost fragments. Measurements showed that vegetated plots actually increased their infiltration rates to faster rates than measured on the reference sites, showing recovery and improvement of soil infiltration function. The treatments at the Buckhorn site appear to be successfully making the transition between construction and ambient soil processes for this characteristic.

18. About 50 % of the willow poles leafed out.

19. *Ceanothus prostrates* (squawmat), *Ceanothus lemmonii* (Lemmon's ceanothus), and *Arctostaphylos viscida* (whiteleaf manzanita) seedling transplants all survived for three or more years. Native manzanita and ceanothus planted as seed (treated to break dormancy and then hand broadcast) did not germinate. Forb seeds were successfully broadcast seeded into the grass-legume mix during the second season, including *Achillea millefolium* (yarrow), *Eriophylluim lanatum* (woolly sunflower), and *Wyethia angustiflia* (mule's ears).

20. Problem species at the site included *Bromus hordeaceus* (soft chess), *Bromus diandrus* (ripgut brome) and *Centaurea solstitialis* (yellow starthistle).

Implementation / construction related findings.

21. Compost incorporation increases water holding capacity only for substrates that have less than 10 % or so WHC (field capacity minus permanent wilting point moisture contents). In soils with greater WHC levels, the compost volume merely displaces soil material with comparable WHC, so there is no net gain in moisture availability. For all

soil types, rooting density goes up when compost is incorporated at depth, so plant available moisture may increase because of greater root volume and health. The expense and benefit of deeper incorporation (to 30 cm) or deeper ripping (to 50 or 100 cm) needs to be evaluated relative to the substrate type at the project site.

22. Within several seasons, a dense layer was observed to form in the soil at 10 to 20 cm depth, even without external compaction (Figure 3). We hypothesize that particles from compost or from DG minerals settled into pore spaces at this depth when they are carried by the average depth of the wetting front by rainfall from repeated storms. Penetration resistance peaked in this area on both composted and non-treated plots. Eventually, this layer may impact rooting or infiltration, but this was not observed during the first two years.

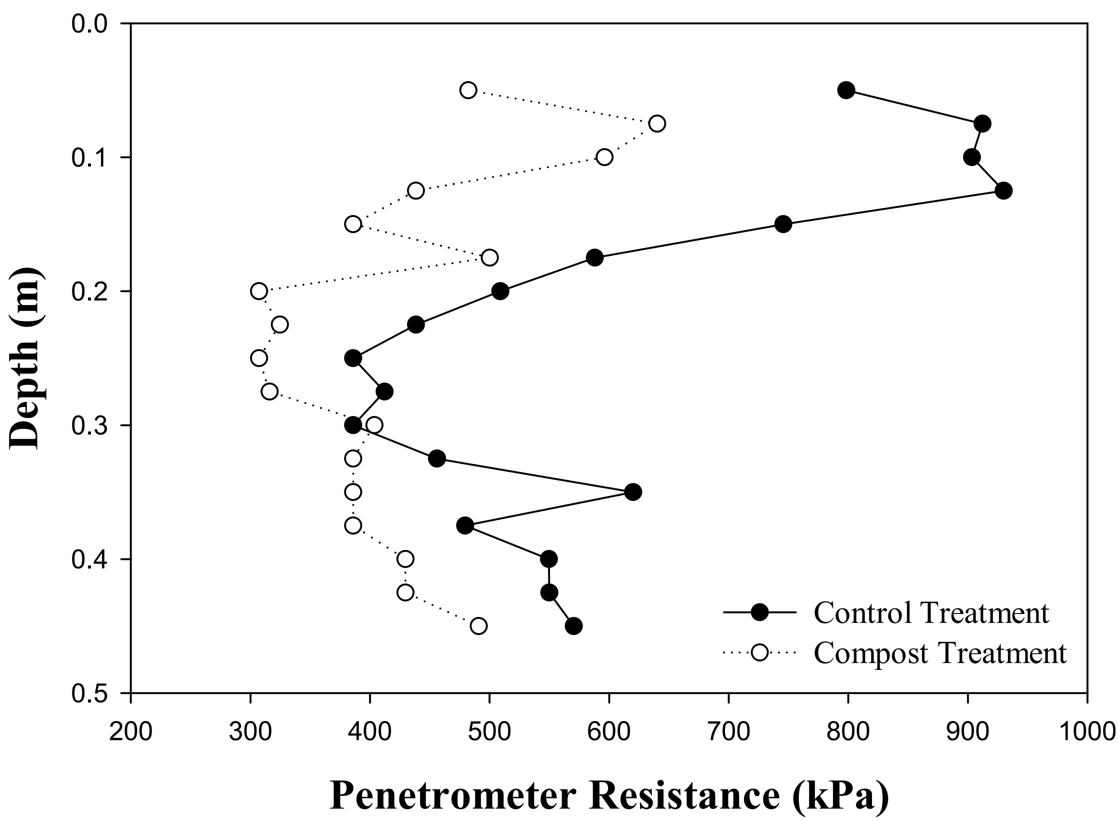

Figure 3. Penetration resistance at Buckhorn summit site (n = 4).

23. Site construction expenses were high on this particular site because the small working area restricted the use of more cost-effective (larger) equipment, and because

the spoil had to be moved to the top of the slope and then back down again. Slopes that are longer in the horizontal direction would be more easily and efficiently constructed.

24. When planning slope reconstruction, a distinction should be made between “fill-cut” slopes (at which a rough cut has been made and then benches are cut at the finish grade and filled from above on competent geological material), versus slopes like the SHA 299 0.06 site that did not have competent material for bench construction. In this case, benches had to be built, compacted and faced with compost blended material.

25. A geosynthetic soil reinforcement grid may need to be used on the flat bench before the next lift is applied, to provide structural integrity in case sections of the slope start to fail. The 900 g/m^2 coir fabric would not be strong enough and would decompose with time.

26. The 900 g/m^2 coir fabric allowed plant shoots to come up but stopped surface erosion due to the coarse fiber and relatively small (2 cm) mesh size. The fabric shrunk as it dried, pulling some plugged plants out of the ground during the first period of drying. Add folds into the lay of the blanket to compensate for shrink-swell movement during wet-dry cycles.

27. A small amount of weed seed contamination in the native seed mix resulted in the introduction of several invasive annuals to the sites. These were hand pulled the first two years in spring before seed set. Clean seed is important when using heavy seeding rates.

28. The gabion baskets were lined with a lighter fabric (600 g/m^2), which will eventually rot and may allow the fines in the baskets to drain from the baskets.

IV. Revegetation of serpentine subgrade material (COL 20 1.5)

A. Site conditions

The serpentine field site is located along Colusa State Route 20, mile 1.5, just east of the Lake / Colusa county line. This site is located on detrital (remnant of a prehistoric geological landslide process) serpentine composed of a brecciated (broken into small angular fragments) matrix of hydrothermally altered ultramafic minerals. The terms “detrital” and “brecciated” are significant and indicate that the rocks at this site are extensively fractured, as opposed to having large, solid, continuous rock structures many meters in size. This fractured rock matrix allows water to infiltrate deeper in the soil surface and contributes to the vigorous, dense plant community found on undisturbed soils at this site. The terms “hydrothermally altered ultramafic” indicates rocks that contain high concentrations of heavy metals (iron, manganese, cobalt, chrome, nickel, magnesium) that have been reformed under high temperature and water pressure to form the lighter, low calcium content rock type called “serpentine.” Since this process occurs to greater and lesser degrees at different locations, these rock types and substrates should be viewed as “serpentinized,” indicating a wide range of alteration from nearly undetectable to nearly complete obliteration of the original mineral types. As a result, serpentinized substrates can be expected to have widely variable physical and chemical behavior. Serpentinized substrates are typically deficient in nitrogen, phosphorus, and potassium, have exceedingly low Ca:Mg molar ratios (calcium deficiency, magnesium excess), and have elevated plant-available heavy metal content. Due to the unusual chemical features, serpentinized substrates typically support a high proportion of endemic species which are adapted to the stressful conditions. As mentioned before, this site is densely covered with chaparral vegetation, whereas many serpentinized areas with thin soils have sparser vegetative cover. This phenomenon may be used by Caltrans to increase plant cover above that of the native reference site because of the simple process of improving soil moisture availability.

B. Site history

This site has had a series of failures of the cut slope during the 1980’s culminating in a large project in 1992 to stabilize the site by removing the material above the cutslope. Excavated material was trucked to a valley fill site half a mile to the south at the head of Lynch Creek. The bottom half of the remaining slope was cut back to a 2:1 (run:rise) slope constructed of compacted lifts, with a subdrain system underneath and concrete interceptor ditches constructed across the face of the slope. The upper half of the cut exposed the undisturbed country rock at the site and is at a 1.5:1 slope (run:rise) angle (Figure 4). The finished surface was amended with gypsum and fertilizer, and was seeded with native and introduced nonserpentine revegetation species. These plant materials died out within a few years, leaving the slope essentially barren. Parts of the top two benches received a thin overlay of topsoil that had been harvested from the native soil at the top of the cut before excavation. This layer amounted to only a centimeter or two of thickness, but resulted in a greater level of revegetation than with the fertilizer only treatments.

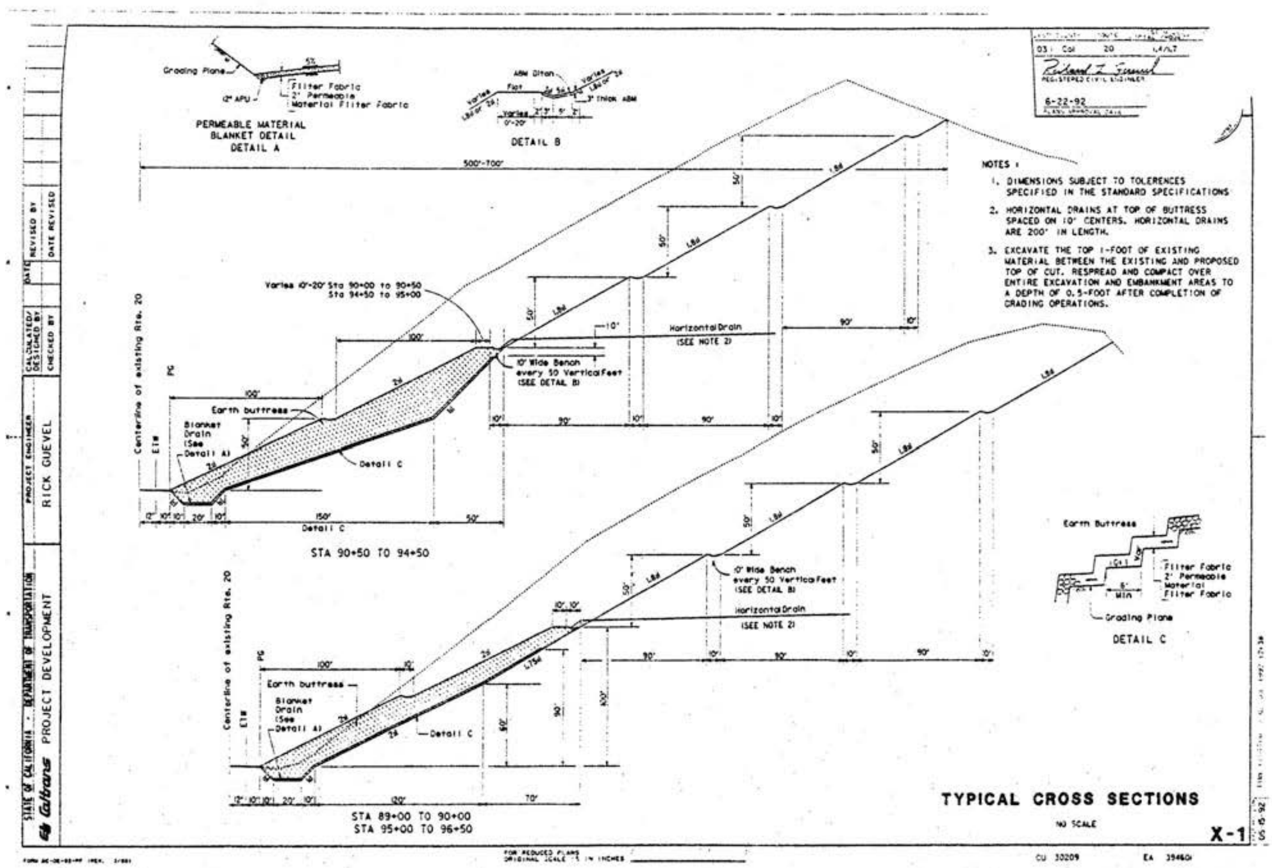

Figure 4. Cross sectional diagrams of COL 20 mile post 1.5 (from Caltrans job file).

C. Site treatments

Two types of plots were constructed on this site. The first set were excavated plots 1 m x 1 m x 0.6 m deep. These plots contained treatments of non-tilled, tilled only, tilled plus 12 % (by volume) mixed to 60 cm, and tilled plus 24 % (by volume) mixed to 60 cm. These compost amendment rates are equivalent to 270 and 540 Mg/ha (dry weight). The non-tilled treatment provided a zero control. Plants of site-collected *Elymus elymoides* (squirreltail) were plug planted in a 5 x 6 place grid on 20 cm centers. Approximately 1.2 g of resin-coated slow-release (9-6-12) fertilizer was placed below each plug in order to provide sufficient nutrients so that the plant growth on the plots reflected water availability. All plots were covered with weed free wheat straw, and replicated four times.

Rainfall and soil moisture were measured in an attempt to understand soil moisture availability for these plants. Two components of soil moisture were measured, water content (by TDT probes) and matric potential (by thermocouple psychrometers).

This allows measurement of soil moisture in the profile (content) and how tightly the moisture was held (matric tension). Soil water content was measured in the lab by conventional pressure plate extraction, as well as by a modified technique (salt equilibration with moisture evaluation by dewpoint hydrometer) that was more appropriate for these substrate materials.

D. Summary of Research findings: Serpentines (COL 20 mile 1.5)

<u>Soil / hydrology findings</u>

1. Infiltration of the COL20 1.5 face material is adequate for storms up to over a 100 year return frequency storm. This may account for the relative lack of deep gullies on this site, even though it has been barren of vegetation for 15 years. Rills and small gullies are small but regularly distributed across the slope face. The slope surface has been reduced by an estimated 5 to 10 cm from chronic erosion (estimated from lag gravels, exposed stones and stakes, berm erosion). Sizable volumes of slope material appear to be lost from the site, even though the face appears to be relatively stable (lack of deep gullies).
2. Rocks increase infiltration rates if the fine soil fraction of the substrate has high shrink-swell properties. These serpentines have “severe” shrink-swell potential (by NRCS standards), meaning that when they dry, the substrate pulls away from the rock surfaces, creating cracks and drainage channels. When hydrated, infiltration may drastically decrease. Substrate mineralogy influences infiltration behavior through shrink/swell properties and higher rock content interacts with the fines to facilitate infiltration.
3. Compost amendment does not statistically increase infiltration compared to the tilled-only treatment. Compost amendment does not always result in increased infiltration.
4. Compost amendment (24 % by volume) doubled plant available water and increased biomass more than four times over the untilled control treatment. On these substrates, compost amendment grows bigger plants. Because of the attenuation of low calcium levels by compost amendment, increased weed growth may also occur.
5. Serpentine substrates require modified, non-traditional methods for measuring water holding capacity (WHC). The conventional pressure plate method failed to draw down moisture content to the target matric tension, and so, gave erroneously high estimates of water content. An alternate method (salt equilibration with dew point psychrometer measurement) is now used. Evaluation of coarse, rocky field sites must take into

account the rock content in order to accurately estimate plant available moisture for revegetation performance. Rocks may or may not hold water available to wildlands plants, depending on their porosity.

6. Compost amendments improve soil water holding capacity on substrates with less than about 10 % plant available water. If soils have over this amount, amendment with compost does not generally result in a net increase in plant available water, although infiltration and plant growth may be greatly improved.

7. Native plants inoculated with serpentine-collected mycorrhizal fungi grow smaller than with commercial mycorrhizae or non-inoculated plants. This may suggest that mycorrhizal fungi may have fast growing (weedy) forms and slow growing (climax) forms analogous to plant growth strategies. In this case, native fungi may grow more hyphae and withdraw more carbon from the plant, making them smaller, but potentially more hardy. Many of the tested plant species grew the same size when colonized with commercial inoculum versus being non-colonized, but the results were plant-species specific.

Plant growth / nutrition findings

8. Serpentine substrates typically have high total metal contents (Cr, Ni, Co, Mn, Fe) but the plant-available levels are rarely high. Plant growth limitations at this site appear to not be due to toxicities, but primarily due to deficiencies of water, nitrogen, phosphorus, potassium and calcium.

9. The native reference soil has a vibrant, multistory shrub/forb/grass community and adequate fertility for tolerant plant species. The Ca:Mg ratio of the native soil is 0.2 molar Ca:Mg ratio, which is even lower (more stressful for plant growth) than that of the face material (0.4). Because of the deep rooting volume, however, a greater total amount of Ca is available for plant uptake in the native soil, even though the concentration of Ca in each volume of soil is much lower. Not all serpentine substrates are thinly vegetated and droughty. This serpentine community formed on brecciated (broken rock) parent materials is diverse, erosion resistant and almost uninvaded by annual weeds.

10. Roots of the perennial *Achillea millefolium* serpentine ecotype and the two native perennial grasses *Bromus laevipes* (woodlands brome) and *Elymus elymoides* (squirreltail) root directly into unamended serpentine subgrade material. Roots of the

granite accession *Achillea millifolium* (yarrow), *Vulpia microstachys* (native six weeks fescue), and *Bromus madritensis* (invasive red brome) do not. This pattern of restricted growth on serpentine substrates with thin surface amendments may potentially be used as a revegetation technique to exclude the invasive red brome from colonizing this substrate.

11. *Achillea millefolium* plants grown from granite accession seed or a commercial seed source died from root-tip necrosis (calcium deficiency) in non-amended serpentine. *A. millefolium* plants grown from serpentine site-collected seed are tolerant but grow slowly. With slight soil amendment it is able to grow to maturity and set seed. Plant tissue from serpentine ecotype seeds has a higher calcium content than the granite or commercial accessions when all plants were grown on amended serpentine substrates. Site-adapted plant accessions are more critical to use on atypical substrates like serpentines, than on typical substrates like coast range sediments or valley fill materials. The more extreme the substrate, the more care needs to be taken in selecting plant materials.

12. Average maximum rooting depth of *Elymus elymoides* grown on the barren face increases 30 % with tillage alone, indicating a root-restricting condition from compaction during construction. Amendments with both tillage and compost addition increase average rooting depth 70 % compared to the untilled control. Greater rooting volume allows average evapotranspiration to increase over 300 %, which is well correlated with increased plant biomass (r^2 = 0.96). Compost + tillage treatments increase plant growth because they provide greater plant available water.

13. Promising revegetation species at COL 20 1.5 include *Elymus elymoides* (squirreltail), *Bromus laevipes* (woodland brome), *Lotus humistratus* (hill lotus), *Achillea millefolium* (serpentine accession), *Eriophyllum lanatum* (woolly sunflower) , *Quercus durata* (leather oak), *Ceanothus jepsonii* (muskbrush), *Pinus sabiniana* (foothill pine), *Melica californica* (California snowdrop bush), *Melica torreyana* (Torrey melic), *Vulpia microstachys* (six-weeks fescue), and S*tyrax officinalis* (snowdrop bush). *Eriogonum nudum* (buckwheat) and *Streptanthus drepanoides* (jewel flower) are present on the site but appear to be easily outcompeted in denser plantings.

14. Fitness ratios of *Bromus madritensis* (red brome), *B. laevipes*, *V. microstachys* are between 1 and 10 (seeds produced per seed planted) in greenhouse treatments amended with between 0 and 30 % compost amendment. With 30 % compost and NPK amendment, seed production of *B. madritensis* jumps to 70. *Aegilops triuncialis* (goat grass) remains less than 4 at all treatments. In the field, *V. microstachys* produces twice

as much seed as *B. madritensis* and about 4 times as much seed as *A. triuncialis* in 30 % amendment treatments. These data suggest that the native *Vulpia* may be competitive in field conditions from a seed production stand point. It is, however, lower statured, so there may be other aspects to plant competition that need to be included, such as tolerance to shading. At low amendment rates, *V. microstachys* may have a competitive edge over weeds.

15. Plants may be categorized as intolerant, tolerant or endemic (restricted to growth on this substrate). Tolerance to serpentines may be by ecotype or accession, not only at the species level. This means that only certain seed sources of the same species may acceptable for use at an atypical site. The more atypical the substrate, the more likely it will be that local or site-adapted plants are needed to successfully revegetate the site.

16. A suitable reference site for revegetated serpentine tolerant species was not located. Either the substrates were disturbed and had no vegetative cover, or the less disturbed (moderately vegetated) sites had different mineralogy. Comparisons were made to the adjacent, undisturbed, well vegetated plant community. Additional serpentinized revegetation sites are needed to determine the range of plant species and soil treatments that can be used. Because of the variety of mineralogy and soil chemistry in serpentine sites, results from this site may not be applicable to other sites that appear to be "serpentinized."

<u>Implementation / construction related findings.</u>

17. When viewing the overall slope at the field site, areas with thin vegetation at COL 20 1.5 are sandstone inclusions (center of third slope from bottom) or areas with a 1 to 2 cm overlay of serpentine topsoil (left half of top two benches). Unamended subgrade serpentine materials are so thinly vegetated as to appear bare. If the area is visibly vegetated, it is not serpentine face material, except for our trial plots.

18. The COL 20 1.5 site does not form deep gullies because of its relatively high infiltration rate, but an estimated 10 cm has been lost from the slope surface during the last 15 yrs.

19. Due to the uniform loss of substrate, boulders have been partially exposed that create tractionless areas for tracked equipment. Contractors observe that it would be very difficult to work the slope now without "tearing it up" as the tracks dig deeply or "skate" on the exposed rocks.

20. Future amendments are recommended to include blends of wood shreds with yard waste compost that have a lower total N load, while providing adequate plant available water. A thin surface layer of this material (approximately 2 cm) would provide a modest nutrient amendment and mulch function, while restricting plant growth to only those species that can root directly into the unamended face material (*Achillea millefolium* (yarrow; serpentine ecotype), *Bromus laevipes* (woodland brome) and *Elymus elymoides* (squirreltail)). A preliminary ripping treatment may be needed to expand rooting volume.

21. Because of the heavy metal and asbestos content, as well as the tendency of these substrates to not revegetate well after construction disturbance, these types of sites may attract increased attention from air and water quality regulators. Because they are difficult to research and identify treatments for, several years lead time are recommended to identify options before a robust, field ready solution will be available.

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Appendix B. Previous Caltrans studies

Claassen, VP and Hogan, MP. 1999. Revegetation and monitoring in the Upper Truckee watershed. RTA: 9-043-256-0 USEPA 319(h) program with matching funds from Caltrans RTA # 03A0433

Project Summary:
Plant responses to amendment of decomposed granite cut slopes with composts and surface mulches were evaluated. Agency-appropriate plant and soil monitoring methods were developed.

Claassen, VP. 1998. Use of municipal yard waste compost and co-compost as a primary erosion control material. RTA # 59A0100. California Department of Transportation.

Project Summary:
Nitrogen release rates of green materials composts from producers throughout the state of California were compared. Lab methods for rapid evaluation of the nutrient release behavior of composts in field conditions were developed.

Claassen, VP, Hogan, MP. 1995. Generation of Water Stable Aggregates for Improved Erosion Control and Revegetation Success. RTA # 53X451

Project Summary:
The process of generating water stable aggregates in degraded soils was reviewed. The levels of organic matter bound nitrogen that are associated with sustained revegetation cover in degraded soils of the Tahoe Basin were measured. Nitrogen release rates of potential amendments were measured in long term incubation tests.

Claassen, VP, Zasoski, RJ, Southard, RJ. 1992. Soil Conditions and Mycorrhizal Infection Associated with Revegetation of Decomposted Granite Slopes. RTA # 65T385 California Department of Transportation

Project Summary:
Reductions in plant growth on decomposed granite slopes were shown to result primarily from water and nitrogen limitations. Other macro- and micro-nutrient levels did not differ significantly between vegetated and nonvegetated slopes. Sieved inoculum from native soils brought endomycorrhizal colonization of revegetated slopes to levels measured on native soils.

Claassen, VP, Zasoski, RJ. 1989. Effect of Topsoil Reapplication on Revegetative Success and Mycorrhizal Colonization. RTA # 54H666 California Department of Transportation.

Project Summary:
Topsoil harvested from construction of a freeway interchange retained its fertility and microbial activity even after storage for five months in a stockpile . Growth of native grasses was enhanced relative to equivalent rates of chemical fertilizer.

Mycorrhizal colonization of plant roots was not decreased by the stockpiling treatment.

Appendix C. List of published articles related to this research

Curtis, M.J. and V.P. Claassen. 2005. Compost incorporation increases plant available water in a drastically disturbed serpentine soil. Soil Science. 170(12): 939-953

Curtis, M. J., and V. P. Claassen. 2006. Using compost to increase infiltration and improve revegetation of a decomposed granite roadcut. Journal of Geotechnical and Geoenvironmental Engineering. in press

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O'Dell, R.E., and V.P. Claassen. 2006. Relative performance of native and exotic grass species in response to amendment of drastically disturbed serpentine substrates. Journal of Applied Ecology. 43:898-908.

O'Dell, R.E., and V.P. Claassen. 2005. Vertical distribution of organic amendment influences the rooting depth of revegetation species on barren, subgrade serpentine substrate. Plant and Soil. in press

O'Dell, R.E., V.P. Claassen. 2005. Serpentine and nonserpentine Achillea millefolium accessions differ in serpentine substrate tolerance and response to organic and inorganic amendments. Plant and Soil 279:253-269.

Rider, D.E., R.J. Zasoski and V.P. Claassen. 2005. Ammonium fixation in sub-grade decomposed granite substrates. Plant and Soil. 277:73-84.

DeGrood, S.B., V. P. Claassen, and K.M. Scow. 2004. Microbial community composition on native and drastically disturbed serpentine soils. Soil Biology and Biochemistry. 37:1427-1435.