FINAL

Soil Resource Evaluation II

RTA # 43A0168
Task order 19

Soils and Revegetation Lab
University of California, Davis

Soil Resource Evaluation II
Research Findings and Generic Recommendations (cover sheet):

Research Findings:

Task 1. This Task demonstrated the ability to upscale treatments from research sized plots to whole slope sized plots using existing contractor equipment and personnel. The Soil Resource Evaluation process was used to evaluate three construction-impacted sites and to generate recommendations for sustainable revegetation and erosion stabilization. Substrate treatments increased infiltration capacity of an example site from approximately a 2 year return frequency storm event to greater than a 1000 year return frequency event. These improvements in infiltration converted these chronically eroding sites to stable slopes with no surface runoff and, along with improvements in rooting depths and available nutrients, are expected to establish sustainable plant cover over the next two years. Construction information is included in Soil Resource Evaluation Task Order # 40 Technical Memorandum, July, 2008. Some recommended treatment methods need further optimization (such as techniques for deep incorporation of coarse organics), but current results are adequate for common site conditions.

Task 2. Construction-impacted sites with incorporated compost show substantial increases in infiltration and rooting depth, but these benefits decline in time as the organic matter decomposes. Soil aggregation or treatments that prevent the soil particles from resealing are needed to support plant growth on these raw, mineral soils until they regenerate sustainable vegetation and erosion resistance. This task evaluated the amount of organics that accumulated in isolated areas of stabilized soil under scattered shrubs and grasses on construction-impacted sites (10-15 years old) to understand soil processes taking place to allow sustainable plant establish, with the goal of recreating and speeding this process. Some, but not all of, these soils were documented to have significantly improved infiltration, nutrient content and soil aggregation compared to adjacent barren soils. The formation of soil aggregation in these sandy, low organic matter soils over such a short period of time is an unexpected and previously undocumented finding. With this information we now know that soil aggregation can develop in degraded substrates. Until aggregates are reformed, however, sites need to be treated to improve infiltration. Five soil amendments were tested for their ability to immediately increase infiltration (Ksat) of dense, hard packed substrates at the time of treatment. Fine (< 3/8 minus) compost amendments increased infiltration at the time of amendment, but lost much of the improvement after several wet/dry cycles, simulating natural drying events in field situations. Sawdust (non-composted) and very fine compost (< 2 mm) behaved similarly. These materials are recommended to be replaced with several inches of either whole compost or coarse shred materials, tilled to a foot. Two other materials (fungal biomass product and lignite humates) plugged pores initially, but then proceeded to inprove infiltration after the wet /dry cycles. These materials hold promise for field application, if they can perform at lower loading rates, required to reduce salt loading. These results show us that physical treatments (tillage and organic amendments) can provide immediate improvements, even if they are not permanent. Manipulation of these laboratory trials now need to be taken to the field to optimize their use for erosion control specifications.

Task 3. One of the critical effects of the organics measured in Task 2 is the formation of soil aggregates, which improves infiltration and increases erosion resistance on construction-impacted sites. Although organics were shown to accumulate under scattered plant cover, the strength (durability) and method (whether inorganic bonding or biological processes) of formation of these aggregates was not known and was first described in these tests. This task documented that ambient plant growth and organic inputs created naturally-occurring, durable, water stable aggregates on several measured construction impacted sites of about 15 years of age. Aggregation was modest (only to about ~20 % of total soil volume) but functioned to significantly increase infiltration. Analysis of the carbon in the aggregates provides signs of being formed, at least in part, by organics from mycorrhizal fungi. This finding suggests that some combination of native mycorrhizal fungi and site adapted plants can, in fact, regenerate soil and aggregation on the site and return it to an erosion-resistant condition. Field trials of these combinations would provide recommendations for suitable plants and mycorrhizae. The more intensive effort to establish this plant cover allows the site to be reclaimed to an erosion-resistant condition with little further input, using plants growing on site and mycorrhizal fungi associated with them. Inoculation should be checked in the growing season after planting to assure colonization. A major component of this aggregation process involves stabilizing organics on mineral surface through humification, which varies with type of organic material and mineral type. The way that this process occurs on degraded mineral substrates of construction-impacted sites is a major remaining limiting factor for sustainable soil regeneration. Treatments developed for improved organic stabilization have the greatest potential for improved slope rehabilitation and erosion-resistance, but require additional lab and field work.

<u>Generic Substrate Treatment Recommendations:</u>
While the details of these recommendations are not yet known for different climates, plant types and geological materials, the general soil characteristics needed for adequate plant growth on barren, construction impacted sites include (in sequence of site treatment):

<u>1) Rooting depth</u>
In California's summer dry environment, perennial plants must have approximately 3 or 4 feet (approximately 1 m) rooting depth to survive the summer season. Many sites have deep, rootable fractures in the underlying geology. Rooting patterns are observable in existing road cuts or excavated soil pits, and if deep enough, require no tillage. Constructed and compacted fills or dense geological formations (unfractured siltstones, lahars, competent granites) are often not rootable. These areas require tillage (ripping, or excavation and replacement ("digouts"), or backfilled benches, or fracturing with a hydraulic hammer). Slopes over 3:1 (18°) require geotechnical assistance such that the treatment is both structurally stable and erosionally stable, including adequate infiltration for target rain events. Disturbed or amended material should be placed on a level excavated bench floor so that the amended substrate does not slip downhill when saturated. If the slope is geotechnically unstable (such as with out-sloped bedding planes), the fracture treatments should be more widely spaced so that the slope has large areas of undisturbed substrate sufficient, in order to retain ambient slope stability. The base of the excavated volumes should intercept the slippage plane. In the fractured or tilled areas, coarse organics (wood shreds or coarse chips) should be deeply incorporated if the substrate is single grain sands or decomposed granites that are non-cohesive such that they will rapidly resettle when saturated. Finer textured substrate materials (loams and clays) may not need incorporation of organics if the fractures will remain open for several years until roots are well established.

<u>2) Infiltration</u>
Surface runoff from construction-impacted sites can be avoided by increasing surface infiltration until it exceeds the rate of a design storm event. This can be achieved in many areas by amending the slope surface with an overlay of yard waste compost (1 inch (25 mm) thickness; 3/8 inch (10 mm) minus) plus wood shreds or chips (additional 2 inch (50 mm) thickness, for a combined total of 3 inches (75 mm)), which is then tilled to 12 inches (300 mm). These general amounts can be increased or decreased according to the tendency of the substrate to disperse, hard set or compact and on the rainfall intensity of the area. Higher incorporated proportions of

woody material can, however, make the soil droughty to young plants by reducing root contact with mineral soil, which holds more water when dry. Run-on to the site from up-slope should be controlled separately from these treatments or taken into account in the infiltration treatments.

3) Nutrient levels

Nitrogen (N) available for uptake into plant tissues should amount to between 35 and 55 lb N/ac/yr (40 and 60 kg N/ha/yr). This can come from several sources, but the sum should not be much greater except in vigorous growth conditions so that the excess does not encourage weed growth or promote N losses to the watershed. Atmospheric N deposition may amount to between 4 and 40 lb N/ac (5 and 45 kg N/ha/yr), being higher within a few dozen feet (10's of meters) of major roadways or in urban areas. This amount should be subtracted from soil amendments added to the site. An additional objective of N amendments is that they provide the modest amounts of plant available N for multiple years after site treatment, in order to support continued establishment of the plant community (including woody tissue, soil organics, a duff layer, microbial populations, in addition to plant roots and shoots). Examples of organic amendments that generally provide adequate yearly amount and multi-year duration include screened yard waste composts (3/8 inch (10 mm) minus) amended at 1 to 2 inches (25 to 50 mm) depth or commercial, slow release organic soil amendments (applied at approximately 900 lb/ac (1000 kg N/ha) if at 7 % N content). Residual N in the ambient soil material, if it occurs after disturbance, can be expected to release N at approximately 1 % of the total N content per year. Coarse wood shreds utilize soil N when they decompose, as is often reported, but this is a relatively small amount and can generally be ignored.

Feedlot, dairy, or biosolids composts are not recommended because they have higher N levels and salts. In dry areas (Eastern Sierra and Mohave), commercial organic soil amendments and composts should be used sparingly because of their additional salt content.

Composts and commercial organic N amendments generally contain a complete suite of non-N macro-nutrients and micronutrients. Amendment with these organic materials generally eliminates the need to amend other nutrients separately.

Serpentinitic substrates should not be amended with high-calcium content amendments such as yard waste composts or gypsum if they are to retain their serpentinitic (low calcium content) character or if invasive weeds are a threat to the site.

3) Mycorrhizal fungi

Endomycorrhizal fungal inocula for grasses, forbs and shrubs should applied to the site surface and immediately disked or tilled to the depth of compost incorporation (10 to 12 in; 250 to 300 mm), or to only 2 to 3 in (50 to 75 mm) if only the inoculum is to be to incorporated. If surface organic duff is collected from vegetated areas along with several inches of mineral topsoil, mycorrhizal fungi will be included and can be used as inocula. Alternatively, place a cup of local topsoil in the planting holes of container stock. Another inoculum source onto the site may be from adjacent, up-slope soils where plants are growing. Local inocula may be more effective than commercial inocula, especially for shrub species. In some conditions, commercial inocula are adequate and may serve as a start-up amendment, but the conditions where this would be true or false are not well known. The most dramatic growth effects have been described in fumigated soils, but this growth increase generally does not occur on weedy sites or sites with imported soil from other rooted substrate. Ectomycorrhizal fungi (associated with oaks and pines) commonly blows in from adjacent areas, so inoculation is not necessary.

4) Plant materials

Seed materials can be applied by broadcast and harrowing, seed drill, or in a light hydroseed application. No-till drills should be used with minimal (2 inch; 50 mm) surface preparation on hard, non-soil substrates to break up surface crusts and disrupt matted thatch. As soil conditions become more extreme in elevation, temperature, salt, moisture, or chemistry, the use of locally adapted native plants, as well as microbial inocula, becomes more imperative. Seeded plants are often better able to adapt to the amended substrates than container plants.

5) Mulch

Apply a 2 inch (50 mm) layer of woody shredded material, pine needles or coarse duff as a surface mulch. This amendment should have few fines to reduce smothering of seedlings at this higher rate. Straw should be amended only to 1 inch (25 mm) and hydromulches half of that to avoid suppressing seed germination.

6) Supplemental Moisture

The treatments recommended above will provide adequate moisture for plant growth through the summer without supplemental irrigation in normal rainfall years. In low rainfall years, wet up the entire rootable profile (to field capacity) perhaps during the dry part of the winter if needed, but mainly just before the summer drought begins, after which the plant growth can grow without further irrigation. This often amounts to an irrigation amount of 4 to 10 inches, depending on substrate texture and soil structure.

7) Weeds

Weeds must be controlled for the first three years to reserve soil moisture for summer growth of native species.

Project overview

Task 1. Demonstration plot construction:

The Soil Resource Evaluation (SRE) system was used to evaluate three barren, eroding field sites in Lake, El Dorado and Los Angeles counties and to use the SRE findings to generate treatment recommendations for sustainable, erosion resistant revegetation. These Task 1 activities demonstrated the ability to upscale treatments from research sized plots to whole slope sized plots, using existing contractor equipment and personnel. Issues of slope stability (out-sloped bedding planes, fractured substrates) were addressed by geotechnical evaluation. Soil treatment methods were modified to obtain both revegetation and surface erosion resistance as well as geotechnical stability.

Ripping and surface tillage treatments were sized to create infiltration capacity (both rate and amount) that was adequate to prevent runoff from a 25 year return period storm event. Infiltration depth was generated by fracturing the slope substrate by dozer blade, ripper shank, track-hoe bucket excavation and replacement (dig-outs) or by creating clusters of hydraulic hammer holes, typically to depths of approximately three feet (1 m). The treatment method varied according to slope steepness (1.5:1 or 2:1 or 4:1 horiz:vert), geological characteristics and geotechnical evaluation. Tillage-disturbed areas were distributed across the slope but undisturbed areas were retained in between so that adequate ambient slope stability remained. Steeper and more fractured slopes had greater spacing between treatment areas, up to 30 feet or more. Steeper slopes were accessed by track-hoe boom. Out-sloped bedding planes were intercepted and stabilized by locating a bench across the slippage plane. Flatter sites were ripped by crawler tractor, allowing large scale, cost effective substrate remediation.

Surface infiltration was improved by tillage and incorporation of compost materials to reduce crusting and hardsetting. This was achieved by amending the slope surface with an overlay (1 inch (25 mm) thickness; 3/8 inch (10 mm) minus) of yard waste compost mixed with wood chips or shreds (additional 2 inch (50 mm) thickness, 1 - 3 in (25 - 75 mm) fragment length) for a total of 3 inches (75 mm) depth, which was then tilled to 12 to 18 inches (300 to 450 mm). These coarse woody materials function to keep infiltration high, so that no surface runoff occurs. Single grain substrates (sands, decomposed granite, hard setting substrates) require coarse wood incorporation into the throat of the ripping slot to prevent resettling, but substrates with higher organic matter content or non-dispersive substrates (more weathered or higher clay content) do not require deep incorporation of organics. Naturally fractured (and rootable) substrates do not need tillage deeper than 12 to 18 inches (300 to 450 mm), depending on rainfall intensity.

Slopes treated in Task 1 were tested by rainfall simulator and confirmed to infiltrate rainfall at the target rates delivered by a 25 year return frequency / 15 minute storm event or greater with no runoff. Infiltration capacity (both rate and amount) following treatment was actually much greater than the target levels. The Los Angeles county Templin site infiltrated 1.1 in/hr (28.7 mm/hr) on the undisturbed shale geological material, while a previously treated area infiltrated 1.2 in/hr (30.4 mm/hr). The rip treatment recommended by SRE infiltrated 8.0 in/hr (204 mm/hr). The target threshold for a 25 year return storm (15 min) is 1.7 in/hr (43.2 mm/hr), while a 5 day event (25 year return period) is 7.8 inches (198 mm) total. These data confirm that a 25 year, 15 minute storm would produce runoff from the pre-existing site, as observed in the field (1.7 in/hr rainfall exceeds 1.1 or 1.2 in/hr). In contrast, the ripped treatment has a great excess of infiltration capacity (1.7 in/hr is much less than 8.0 in/hr infiltration capacity). In fact, the volume from a 5 day storm event is estimated to be infiltrated within less than a one hour period on the treated site, giving a large factor of safety for intense, pulsed precipitation events. With no runoff, we assume there will be no sediment production. The treated Lake county site infiltrated more than 9.4 in/hr compared to a target 25 year return, 15 min storm intensity of 1.3 in/hr. The treated El Dorado 49 site infiltrated 4.6 in/hr compared to a target value of 2.4 in/hr. None of these sites is anticipated to produce surface runoff after treatment, according to these static evaluation methods. Subsurface flow dynamics were not measured as part of this project. Task 1 provides recommendations for tillage treatment that are adapted to slope conditions and recommendations for amendment type and amount. These recommendations can be used to generate construction specification by Caltrans designers. The evaluated sites provide examples for treatment of other similar sites on similar geology and topography and climate.

Substrate fracturing and surface amendment treatments also provided adequate rooting depth, infiltration and moisture availability for plant growth through the summer drought without irrigation. Plants were estimated to require approximately three feet of moisture retaining soil. The fine compost (3/8 inch (10 mm) minus) provided adequate plant available nutrients. This amendment may be reduced at sites with residual soil nutrients or areas with high atmospheric deposition out. A surface mulch amendment (additional 2 inch (50 mm) layer of wood chips or shreds not tilled into the substrate) was applied to protect against raindrop impact and to reduce evaporation.

Because California has many types of geologies and climates, additional site evaluations are needed to determine if generic site treatments can be identified for different substrates, regions and plant types. Some substrates are very susceptible to resettling, thus reducing infiltration and increasing overland flow. Tillage equipment should be modified to incorporate coarse organic matter on some substrates. Additional work on aggregation and prevention of hard setting is needed, particularly the process of coating mineral surfaces with organic films to regenerate soil aggregates. Cumulative effects of water movement within a slope during rain events should be modeled with dynamic pedotransfer functions rather than the static methods used currently. The occurrence of cumulative water flow laterally and downslope within the substrate points out the need to know thresholds of soil strength necessary to resist formation of shallow slips when saturated.

Task 2. Organic matter characterization of field substrates:
Regeneration of soil infiltration is an effective alternative to hard-scaped steep slopes and can provide a sustainable and self-improving treatment that reduces non-point source sediment production. The process is based on accumulation of organics on barren mineral substrates. Substrates with low clay and organic matter contents tend to hard set and chronically erode. Substrates such as those found at Conway summit, Bullion Bend and Blue Canyon are difficult aggregate, based on existing information about generation of water-stable soil aggregates. In spite of this expectation, Task 2 of this project documented the presence of significant aggregate formation on these high elevation sites. The substrates occurring under shrub and grass canopies had significantly greater aggregation, infiltration and water holding capacity than the inter-canopy “gap” samples, as a result of the process of forming erosive clays and silt sized particles into larger, sand sized aggregates. These processes were shown to occur within the 15 years since construction, rather than the hundreds of years normally associated with natural soil formation. This suggests that revegetation of barren, harsh sites can actually begin the process of creating a stable erosion resistant system. Not all sites showed this degree of regenerated aggregation, however, including decomposed granite substrates near Placerville and volcanic lahar near Blue Canyon. These sites point out that additional work needs to be done on organic stabilization on mineral surfaces, on plant and mycorrhizal organic production, and on integrating these soil responses to target rainfall events. Current results show that soil regeneration can actually occur in relatively short time spans on substrates that were thought not able to be aggregated.

In the absence of aggregation, constructable treatments are needed to immediately provide infiltration on recently completed, degraded substrates. Incorporation of wood shreds (10 to 20 % by volume) is shown to be an effective way to improve infiltration. Shreds works to a greater extent than fine (3/8 minus) composts. Two non-compost related products, fungal biomass and humates (10 % and 1 % loading rates), gave surprising results. They both showed that initial infiltration is first decreased, but then after several experimental wet/dry cycles simulating field drought conditions, very large increases in infiltration occur. Additional work is needed to identify modified treatments that would work without the initial decrease under field conditions. This could include pre-leaching of salts, combining the amendment with calcium, or blending it with compost amendments, depending on mineral type at the site.

Task 3. Aggregate regeneration:

Task 3 of this project documented that soil aggregates begin to be reformed in the substrate within months after revegetation, as plant roots and mycorrhizal fungi colonize and add carbon to the soil. These results show that mycorrhizae have an important function in soil infiltration and erosion resistance, even if they are not needed to compensate for soil nutrient deficiencies. Native inocula appear to be more beneficial than commercial accessions, especially for forbs.

The strength of these aggregates was evaluated using sonication energy to determine whether they were formed by simple crust-forming processes or whether they were strong enough to resist water disruption. They were, in fact, shown to be assembled from finer clay and silt sized particles into larger, erosion-resistant sand sized particles that were held together by organics from mycorrhizal fungi. These organics appear to be characteristic of a compound called "glomalin," a sticky fungal glycoprotein exudate that degrades slowly, and is long-lasting in soils. This work showed significant aggregation in substrates with very low clay, surface oxide or ambient organic content. This suggests that intensive efforts for revegetation can be expected to be able to regenerate erosion-resistant soils on currently barren slopes. This work also showed that aggregates begin to re-form from dispersed substrates within four months under experimental greenhouse conditions. These findings are documentation that the aggregates detected under isolated plants on barren slopes are regenerated, in part, by mycorrhizal fungi as well as plant organics. They suggest that harsh, construction-impacted slopes can be treated to increase infiltration by ambient processes of plants and microbes.

Field evaluation indicated, however, that the extent of aggregation was variable on different mineralogical substrates. The process of aggregation is expected to vary under different plant types (lower under manzanita than oak; higher under perennial grass than annual grass). The process is observed on natural soils, but additional work is needed to induce and facilitate these aggregation processes on degraded sites so that they occur fast enough to avoid erosive losses from the site as compost amendments decompose. This work should involve testing different plant types and different mineral types to be able to recommend combinations that speed regeneration of aggregates.

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Objectives:

This project has three Tasks, each listed in its own section: 1) demonstration plot construction, 2) organic matter characterization of field sites, and 3) aggregate regeneration.

Task 1 - Demonstration plot construction was intended to use existing information and commercial contractors to demonstrate the product that could currently be generated on problem soils. A limited number of field measurements would still be needed in order to generate appropriate treatments. Valuable information is gained from contractor experience on soil treatment methods, available equipment, generation of specification verbiage and costs.

Task 2 - Organic matter characterization of field substrates involves sampling of construction impacted sites that have naturally revegetated over several decades and testing of amount and quality of organics and aggregates. These tests are designed to evaluate whether drastically disturbed sites are, in fact, actually recovering, or if plant growth has no verifiable impact on soil regeneration (organic accumulation and infiltration).

Task 3 - Aggregate regeneration involves evaluation of selected organic amendments and testing of their function (aggregate strength, infiltration, water holding capacity) in amended, degraded substrates.

Task 1. Demonstration plot construction

1.1. Field site locations

Three sites were selected from five preliminary investigation sites. The Lake County Highway 20 mile 46.0 (LAK 20 mile 46.0) is located 0.25 miles west of the Lake / Colusa county line, directly across from a rest area facility. The El Dorado County Highway 49 mile 24.5 (ELD 49 mi 24.5) is located 0.5 miles north of the intersection of state route 49 and the Lotus Road, or immediately north of the intersection of state route 49 and Marshall Road. The third site was located at the intersection of I-5 and Templin highway about 11 miles north of Castaic Junction in Los Angeles County.

1.2. Substrate and site evaluation

Overview of site evaluation components.
Site geology and landform. The mapped geology of an area indicates the general geological mineralogy that the soils or cut slopes will be derived from. This suggests the kinds of substrate treatments that may be needed, and the long term outcome of soil development on the site.
Site landform evaluation describes the site aspect and slope. From this information, issues relating to drainage (whether there is upslope drainage onto the slope, seepage piping out onto the slope face), or geotechnical stability can be addressed.

Infiltration rate. This value is the speed at which water can be imbibed into the soil. This parameter helps evaluate whether the soil will have overland flow during short, intense rainfall events. Low infiltration rates will result in overland flow during intense storms. During longer rain events, the amount of rainfall that can be imbibed becomes important. This is determined by soil depth and structure. The infiltration *capacity* represents the combined effects of the *rate* and the *amount* of water that can be imbibed into the soil.

Water holding capacity. The ability of a soil or substrate to hold onto water after gravity has drained it for several hours is known as water holding capacity or plant available water. This means that water in the larger pores has been drained away, leaving moisture retained in smaller pores. Water holding capacity is determined by developing moisture tension (suction) values between 1/3 bar and 15 bar negative pressure.

Nutrient treatments. In general, compost incorporation is an appropriate treatment for barren slopes. Remaining challenges for compost acquisition are to match the nutrient release from the compost to the site conditions. More fertile or warmer sites will require more total nutrients, but at slower rates, in order to avoid weed invasion. Nutrient release is determined by compost feedstock and curing time after the composting process. Also, the mix of compost fines to coarse woody material is variable between producers and batches, so each load must be inspected.

1. LAK 20 46 (Lake County State Route 20 mile 46.0).
Site description.
This south-facing, 2:1 (H:V) site is located on low organic matter content, fractured residuum weathered from siltstone, mudstone and shale with scattered out sloped bedding planes. The site was cut and surface amended (hydroseed, hydromulch and straw wattles) one year previous, but during the first winter season some medium sized (20 x 50 foot) surface slips developed. Surface infiltration rates of the weathered

siltstone material was lower than subsurface infiltration rates. With continued weathering of these substrates at exposed, earth-surface conditions, the rock structure will continue to decompose into a silty clay loam texture material. Without organic inputs and aggregate regeneration (initially by compost amendment, later by plant organic matter inputs), this surface layer will have decreased infiltration and increased overland flow, creating surface rills and sediment mobilization. In addition, the fine-over-coarse textural distribution of the near-surface substrates means that surface substrates may saturate with rainwater and not drain readily into subsurface horizons. This, in combination with the geological characteristics of the site (out sloped bedding planes) and surface or subsurface run-on from undisturbed soils upslope from the site, create conditions for slips, as observed at several locations across the site.

Initial infiltration measurement indicated that infiltration was high enough to imbibe an intense rain event (15 min 100 year storm intensity of 41.9 mm/hr). But, several shallow slips were observed on the surface. Geotechnical assistance was requested to interpret the slope and recommend treatments that would also allow deep rooting for improved revegetation.

Figure 1. Lake county site (LAK 20 mile 46.0). This site had been constructed and revegetated one growing season earlier and had sparse vegetation, few natives, and decreasing erosion control cover from blankets and wattles. A shallow slip in the center of the slope resulted from subsurface seepage and outsloped bedding planes.

Table 1. Surface infiltration data measured by rainfall simulator.

Replicate Plot Location	Surface Infiltration in / hr (mm / hr)	Sub-surface (35 cm) Infiltration in / hr (mm / hr)
east	4.7 (119.3)	11.0 (279.5)
middle	3.0 (75.4)	3.4 (86.5)
west	3.8 (96.7)	26.2 (665.5)

Table 2. Plant available nutrients for Lake County 20 mile 46.0.

SAMPLEID	OM	ENR	P1	HCO3_P	PH	K	MG	CA
M 10-20	2.2	34.4	0.6	6.2	7.5	124.3	558.0	3067.0
E 10-20	2.1	34.2	0.3	4.2	8.1	146.4	761.9	3346.0
W 10-20	2.2	34.3	8.2	8.1	7.7	179.2	806.3	3006.0

SAMPLEID	NA	H	CEC	K_PCT	MG_PCT	CA_PCT	H_PCT	
M 10-20	73.3	0.0	20.5	1.5	22.4	74.5	0.0	
E 10-20	48.9	0.0	23.5	1.6	26.6	70.9	0.0	
W 10-20	91.8	0.0	22.5	2.0	29.5	66.7	0.0	

SAMPLEID	NA_PCT	NO3_N	S	ZN	MN	FE	CU	B
M 10-20	1.6	1.5	2.8	0.3	1.5	11.0	0.4	0.8
E 10-20	0.9	0.9	11.9	0.2	4.7	8.6	0.5	0.8
W 10-20	1.8	0.8	3.2	0.2	5.7	7.5	0.6	1.0

SAMPLEID	EX__LIME	S__SALTS	SAND	SILT	CLAY	TEXTURE
M 10-20	L	0.3	32.4	24.4	43.2	CLAY
E 10-20	H	0.4	24.4	40.4	35.2	CLAY LOAM
W 10-20	L	0.3	36.4	26.4	37.2	CLAY LOAM

Tillage treatments.

Because all infiltration rates were relatively high relative compared to 20 year storm events or greater, the main objective was to increase flow of the surface horizons relative to subsurface horizons. This was proposed to be done with incorporation of unscreened yard waste composts into the top foot of the existing slope. Larger pores and deeper tillage was accomplished by ripping on contour to two feet to intercept and disrupt continuous out sloped bedding planes, and to reach the same objective by excavating a soil volume and replacing it with organics incorporation using a track mounted excavator. Overland flow run-on from upslope soils was routed off the site by a 2 foot deep head ditch that was lined with silt fence fabric and rocked, utilizing an existing rock lined drop ditch to the level of the road edge. The slope surface was then hydroseeded with appropriate seeds and covered with a 2 inch layer of coarse wood chips.

Geotechnical evaluation of the site generated a recommendation to till substrates to a horizontal base that runs across (intersects) the bedding plane where failure occurred within the last year. This allows a tilled surface volume of soil to be placed on a horizontal base so lateral, down slope slippage is less likely. In addition, increased infiltration of the surface horizons allows moisture to drain downward or down slope through tilled horizons without reaching saturation levels that bring the soil nearer to liquefaction. When soils were less competent, spacing of rip slots or excavations was increased to leave more of the ambient slope intact.

Three mechanical methods for breaking up out sloped bedding planes were tried on LAK 20 mile 46, including excavation and replacement (“dig-outs”), contour ripping with crawler tractor shanks, and hydraulic hammer hole clusters. Because the underlying geology was actually more porous than the overlying, decomposed siltstones, this site was not a rigorous test of the efficiency of these methods. The site, did, however, provide a realistically steep (2:1) test environment for mechanical tillage methods.

Surface incorporation of organics with tillage was relatively inefficient with tines or ripper shanks. Surface applied composts tended to remain at the surface. Side hill sliding (crabbing) resulted in uneven slope surfaces following crawler tractor work. Contour tillage may need to be restricted to slopes flatter than 2:1. A technique generated by the contractor was to skim 6 inches (150 mm) of slope surface, including both compost overlay and mineral substrate, and backblade or push it to blend. A modification of this method was to push out a slightly deeper cut (1 foot; 300mm) and then to skim, mix and blade a blend of mineral and organic materials back into the deeper cut. Uniform, blanket treatments of organics and mineral soil over a smooth interface to the subsurface horizons was to be avoided during these combinations of surface and subsurface tillage.

At this site, an initial material that was too coarse (predominantly composted overs) was reground, producing a material that was now finer, but had exposed organic surfaces of uncomposted materials. This would have immobilized excessive N, reducing plant growth. A third material was created from blending of fine compost and the ground overs.

Seed and container materials.

Seed materials for the Lake County site, Lake 20 mile 46.0.

Seeded plants	Achillea millifolium	1.0 lb PLS / ac
	Eriophyllum lanatum	2.0
	Lupinus bicolor	5.0
	Elymus multisetus	2.0
Seeded plants	Elymus glaucus	8.0
	Nassella pulchra	5.0
	Poa secunda	2.0
	Melica californica	6.0
	Lotus purshianus	2.0

<u>2. ELD 49 21 (El Dorado County State Route 49 mile 21).</u>

Site description.

This east-facing, 1.5:1 (H:V) site is located on low organic matter content, decomposed granite (DG) saprolite. The site was graded and seeded one season previously by application of 15 cm (6 inches) of mineral fines and duff over a planar DG subsurface that was cut and smoothed by excavator bucket. This surface overlay had since slipped and re-exposed the subsurface DG. About 50 % of the slope face slurried down slope. Plant growth was adequate within the surface duff materials, but roots did not penetrate into the underlying DG. The surface and subsurface horizons were not structurally keyed together. Because the surface infiltration rates were much higher than subsurface infiltration rates, the surface horizons became saturated slurried down slope. Surface rills are probably not going to be a problem at this site because surface infiltration is relatively high and little or no slope run-on will occur from the relatively flat area behind the cut slope. Geotechnical evaluation of the site generated a recommendation to key surface substrates into the subsurface DG material but without fracturing the underlying DG saprolite material by mechanical tillage. Mechanical disturbance of the DG saprolite by digging, however, can generate infiltration problems when the dis-articulated DG packs tightly after saturation. For this reason a blend of mineral substrate, fine compost and coarse wood chips was applied to the surface soil in a rate equivalent to approximately 3 inches (75 mm) depth, and was variously tilled in as described in the next section.

Photo 2. Decomposed granite cutslope in Placer county (PLA 49 mile 21). This site had been constructed one year earlier with shallow topsoil overlay over dense decomposed granite substrate. Vertical teeth marks from the backhoe, a steep slope and a low infiltration rate in the subsurface contributed to saturation and slumping of the surface amendment.

The listed rainfall amount for a 100 year event (15 minute storm) is 2.9 in/hr (74.1 mm/hr). This decomposed granite material was estimated to have a saturated conductivity of 3.6 in/hr (91 mm/hr) when tilled. Therefore, the treatment selected was to use coarse organics to hold pores open after tillage so that the DG material would not pack tight and decrease infiltration. Deep tillage was recommended for two reasons, first to key the loose surface horizons into the underlying rock and secondly to provide adequate rooting depth for summer active shrubs.

Tillage treatments.
Tillage to key the surface into the subsurface material was accomplished with a combination of digouts with a track mounted excavator and hydraulic hammer hole clusters scattered across the face. No crawler tractor ripping was done on this slope. Fine yard waste compost was blended with coarse wood chips in a 50:50 mixture and was spread across the slope by backhoe bucket reaching down from the top. The DG and compost blend was mixed into the digouts to the full excavated depth (approximately 3 feet at the back of the pit), using a rate equivalent to 3 inches (75 mm) of surface applied material. The blended material was also surface applied in areas to be hammered, which were first dug out one foot below grade. The organic blend was placed on the dug out area and was subsequently incorporated by disturbance from hammering the cluster to 2 foot (600 mm) depth (the length of the hammer moil).

The organic / soil blend was mixed into non-tilled areas of the slope by shallow raking with the backhoe bucket teeth. The slope surface was then hydromulched and hydroseeded. Container plants were placed in locations that would indicate growth on tilled versus non-tilled treatments. The site was then covered by a 0.06 lb/sq ft (900 g/m^2) woven coir fabric that fastened using wire staples. A shallow, unlined head ditch protected the slope surface from possible overland flow from above.

Nutrient treatments.
All nutrient availability was supplied by the equivalent of 1.5 inches (37 mm) of fine yard waste compost applied on the surface and tilled in according to the tillage treatment. Decomposed granite is nutrient rich in all requirements except water and N, which are provided through increased infiltration and the compost material.

Seed and container materials for the Coloma site, El Dorado 49.

Container plants	Ceanothus cuneatus	liner
	Juglans californica	liner
	Rhamnus californica	liner
	Sambucus mexicana	liner
Seeded plants	Elymus glaucus	5.97 lb PLS / ac
	Nassella pulchra	5.97
	Bromus carinatus	4.03
	Leymus triticoides	5.97
	Muhlenbergia rigens	4.03

<u>3. LA 15 at Templin</u> (Los Angeles County Interstate 5 at Templin Highway interchange, then south 1/2 mile on frontage road on west side of right-of-way). The complete description of site evaluation is placed in Appendix A.

Site description.
This large site has two types of demonstration sites, termed “slopes” and “flats”.

The “slopes” portion of the site has east-facing, 2:1 (H:V) slopes on shale and sandstone geological materials. These slopes have out-sloped bedding planes making these sites geotechnically unstable.

The “flats” portion of the site was located between the sloped area at the west end of the site and the chain link fence running out toward the midline of the site. This area had south-facing 5:1 slopes made of 8 to 10 in (200 to 250 mm) of loose siltstone fill over undisturbed shale. Infiltration on the untilled area of the site was 1.1 in/hr (28.7 mm/hr), while on the area with the loose overlay it was 1.2 in/hr (30.4 mm/hr). The water storage capacity on the overlay portion would be approximately 1.6 inches (41 mm) based on textural analysis. Although rainwater may infiltrate fast enough for some storm conditions, the thin overlay soil will soon fill with water and overland flow will start. These measurements were made with a portable rainfall simulator and may be higher than true equilibrium rates because of they were not run for a typical full measurement time needed due to lack of water on site and because site conditions at the time of measurement were dry and took extra water to reach equilibrium.

All sites were covered with a thick (3/8 inch; 10 mm) layer of hydromulch through which young grass plants were germinating.

Photo 3. Templin site in Los Angeles county. The site was deeply excavated and 8 to 10 inches of loose ground substrate was bladed over low permeability shale. The area was revegetated during the previous winter and grass was just emerging from seed. Container plantings were installed near irrigation lines.

Table 3. Nutrient analysis data for I-5 at Templin Highway

Templin Hwy revegetation				LA I-5	REPORTNUM													
2/11/2008					08-042-036													
SAMPLEID		OM	ENR	P1	HCO3_P	PH	K	MG	CA	NA	CEC	K_PCT	MG_PCT	CA_PCT	H_PCT	NA_PCT		
SCUT1	sandstone cut	0.3	30.5	0.5	2.8	7.7	62.4	185.5	1184.0	24.0	7.7	2.1	19.8	76.8	0.0	1.4		
SCUT2		0.8	31.5	0.9	2.9	7.3	79.4	265.7	1647.0	29.5	10.7	1.9	20.4	76.6	0.0	1.2		
SCUT3		0.7	31.5	0.8	2.5	7.8	95.7	308.3	1681.0	41.2	11.3	2.2	22.3	73.9	0.0	1.6		
ACUT1	shale cut	1.0	32.1	0.7	4.0	8.0	254.2	1126.0	2451.0	356.5	23.7	2.7	39.1	51.6	0.0	6.5		
ACUT2		1.1	32.1	0.6	2.3	8.4	258.8	932.8	2600.0	331.1	22.7	2.9	33.7	57.0	0.0	6.3		
ACUT3		1.2	32.4	0.4	4.6	7.7	252.2	970.7	3013.0	344.4	25.2	2.6	31.7	59.8	0.0	6.0		
UPSL1	upperslope	1.7	33.4	2.1	4.4	7.8	223.3	1125.0	3112.0	254.2	26.5	2.2	35.0	58.7	0.0	4.2		
UPSL2		1.6	33.1	0.8	4.6	7.9	321.1	1475.0	3663.0	182.6	32.0	2.6	37.9	57.1	0.0	2.5		
UPSL3		2.1	34.1	2.0	6.4	7.7	248.0	1092.0	4250.0	199.9	31.7	2.0	28.3	66.9	0.0	2.7		
TNAT1	native ref site	6.3	42.7	26.7	26.4	7.4	513.8	508.5	4715.0	29.7	29.2	4.5	14.3	80.7	0.0	0.4		
TNAT2		4.4	38.8	24.2	24.5	7.3	720.6	736.4	5137.0	26.4	33.6	5.5	18.0	76.2	0.0	0.3		
TNAT3		4.0	38.0	24.1	24.4	6.9	508.3	640.6	5004.0	25.6	32.1	4.0	16.4	77.7	1.5	0.3		
BUTR1	buttress	1.0	32.0	8.0	2.0	8.8	275.3	477.9	2105.0	2624.0	26.5	2.7	14.8	39.6	0.0	43.0		
BUTR2		1.1	32.3	0.1	4.1	9.2	311.0	690.4	2161.0	1868.0	25.4	3.1	22.4	42.5	0.0	32.0		
BUTR3		1.3	32.7	10.0	2.5	9.2	250.8	503.4	1993.0	2123.0	24.0	2.7	17.3	41.5	0.0	38.5		
																	Ca:Mg	
SCUT	sandstone cut	0.6	31.2	0.7	2.7	7.6	79.2	253.2	1504.0	31.6	9.9	2.1	20.8	75.8	0.0	1.4	3.6	
ACUT	shale cut	1.1	32.2	0.6	3.6	8.0	255.1	1009.8	2688.0	344.0	23.9	2.7	34.8	56.1	0.0	6.3	1.6	
UPSLOPE	upperslope	1.8	33.5	1.6	5.1	7.8	264.1	1230.7	3675.0	212.2	30.1	2.3	33.7	60.9	0.0	3.1	1.8	
NATIVE	native ref site	4.9	39.8	25.0	25.1	7.2	580.9	628.5	4952.0	27.2	31.6	4.7	16.2	78.2	0.5	0.3	4.8	
BUTTRESS	buttress	1.1	32.3	6.0	2.9	9.1	279.0	557.2	2086.3	2205.0	25.3	2.8	18.2	41.2	0.0	37.8	2.3	
SAMPLEID		NO3_N	S	ZN	MN	FE	CU	B	EX__LIM	S__SALT	CL	MO	SAND	SILT	CLAY	TEXTURE		
SCUT1	sandstone cut	0.9	121.7	1.2	3.4	30.2	0.8	0.7	H	1.2			73.2	18.4	8.4	SANDY LOAM		
SCUT2		1.2	214.4	2.1	10.6	52.3	2.1	0.7	H	1.8			57.2	26.4	16.4	SANDY LOAM		
SCUT3		6.0	168.7	2.4	7.7	43.4	2.4	0.8	H	1.0			51.2	30.4	18.4	LOAM		
ACUT1	shale cut	3.6	34.4	1.4	25.6	42.3	2.3	9.4	H	1.0			41.2	36.4	22.4	LOAM		
ACUT2		2.4	52.7	2.9	20.4	34.1	3.0	8.0	H	0.9			35.2	40.4	24.4	LOAM		
ACUT3		2.0	421.0	3.0	24.0	48.7	4.7	10.3	H	2.1			37.2	40.4	22.4	LOAM		
UPSL1	upperslope	1.2	625.2	2.9	8.3	35.2	3.6	3.2	H	2.5			37.2	34.4	28.4	CLAY LOAM		
UPSL2		3.5	259.1	4.0	5.5	28.6	4.2	2.7	H	1.5			17.2	50.4	32.4	SILTY CLAY LOAM		
UPSL3		13.9	905.6	2.3	6.2	21.3	5.0	2.5	H	2.2			35.2	32.4	32.4	CLAY LOAM		
TNAT1	native ref site	5.0	41.2	2.5	10.3	23.4	1.6	2.6	L	0.5			33.2	34.4	32.4	CLAY LOAM		
TNAT2		6.7	6.7	1.6	12.9	20.5	1.9	1.2	L	0.3			21.2	36.4	42.4	CLAY		
TNAT3		9.6	7.1	1.9	12.1	19.7	2.2	0.9	L	0.5			19.2	34.4	46.4	CLAY		
BUTR1	buttress	4.3	388.0	4.2	13.5	43.2	4.0	10.5	H	2.7								
BUTR2		2.9	77.6	4.7	9.7	41.3	3.8	7.1	H	0.8								
BUTR3		1.5	177.5	4.9	14.5	42.1	4.5	10.0	H	1.2								

Tillage treatments.

For these mineral substrates, fine compost (1 inch (25 mm) thick) and coarse wood chips (2 inches; 50 mm) were applied to the surface soil in a rate equivalent to approximately 3 inches (75 mm) depth, that was then variously tilled in by ripping, excavating or hammer clusters. After tillage, a hydromulch / hydroseed layer was applied. Following this a one or two inch layer (25 to 50 mm) was added as a surface mulch.

The slope area was geotechnically evaluated and found to be inherently unstable. To address the need for rooting depths on such unstable material, the center-to-center spacing of the excavated or hammered holes is increased to be approximately ten times the depth of excavation. Special care was taken to not till at such frequent distances that the surface disturbance becomes continuous and behaves like a blanket treatment of porous unconsolidated material. When porous material overlies undisturbed material with a planar interface between the two types of material, this planar interface allows lateral slippage when saturated during winter rains.

Both sandstone and shale areas of the slope were treated similarly, although water availability will be less on the sandstone substrates due to lower water holding capacity. Excavated areas were arranged in a diamond pattern so that overland flow on non-tilled (low infiltration) areas is captured by excavated areas within about 30 feet (10 m) of slope length. This pattern is intended to reduce overland flow during normal rain periods and to capture increased rainfall for plant utilization during dryer than normal periods.

This area had three tillage treatments: none, excavating and hammer hole clusters. The excavation treatments involved digging to a depth of three feet (1 m) at the back wall of the pit. Organics were mixed to depth. Then another layer of organics was applied to the surface and tilled to 1 foot (300 mm) as part of a general soil surface treatment.

The hammer hole clusters involving hammering into the shale or sandstone beds with a hydraulic hammer with a 2 foot (600 mm) moil. After pushing the hammer some distance into the broken substrate, a cluster of 3 foot (1 m) deep holes was created for rooting. The holes were clustered together so that one hole collapsed the previous hole, making a fractured zone for root growth while moving less soil than with the excavation method. The last hole was backfilled by hand using local loose material.

The surface of the tilled area was then recovered with 3 inches (75 mm) of blended organics (one inch (25 mm) compost and two inches (50 mm) wood chips).

The “flats” area was uniformly ripped, and then selected areas were also excavated.

While nontilled shale areas infiltrated water at a rate of less than 1.1 in/hr (28.7 mm/hr), and previously graded material on the 4:1 slope was approximately 1.2 inches (30.4 mm) of moisture, areas amended with compost and tilled by ripping infiltrated water in excess of 8.0 in/hr (204 mm/hr). In addition, the ripped area rapidly infiltrated water down to 2 feet (600 mm) during the rainfall simulation, indicating a much higher infiltration amount than the untilled material.

The 25 year 15 minute storm rainfall volume is 1.72 in/hr (44 mm/hr). While the bare geological material will only infiltrate about 60% of this amount, the loose soil overlay, which infiltrates 2.0 in/hr (50 mm/hr), brings the slope into the target range of infiltration. But, excess water will pool in the soil during a multi-day event, since rainfall volume for a 5 day storm event (25 year return period) is 7.75 inches (197 mm) total. This volume of water will saturate the loose soil overlay, which has a water holding capacity estimated at only 1.6 in (41 mm) if there were no additional infiltration. The excess water volume from this storm would flow overland and create the volumes of overland flow and rills as was observed at the site.

The ripped soil treatment, in contrast, was able to retain all of this rainfall volume and more with no overland flow. The true capacity of these soil treatments will be larger than the maximum measured infiltration of 8.0 in/hr (204 mm/hr), but the exact amount was not determined because the rainfall simulator equipment could not go high enough. No surface saturation or overland flow was observed at the highest settings of the rainfall simulator. Therefore, this surface tillage is expected to imbibe a 25 year 15 minute storm event as well as a 5 day storm event with no surface runoff. This implies that the site would also produce no runoff or sediment. Given the shallow slope of the ”flats” area, no geotechnical instability is expected, even when the substrate is uniformly ripped.

Seed and container materials for Templin Hwy site.

Container plants	Baccharis pilularis	1 gal (3.8 L)
	Eriogonum fasciculatum	liner
	Leymus condensatus	1 gal
	Nassella pulchra	liner
	Salvia leucophylla	1 gal
	Salvia mellifera	liner
Seeded plants	Artemisia tridentata	0.50 lbs PLS/ac
	Leymus condensatus	1.00
	Nassella pulchra	4.00
	Nassella lepida	2.00
	Poa secunda	1.00
	Eriogunum fasciculatum	1.00
	Lotus scoparius	3.00
	Lotus purshianus	2.00
	Isomeris arborea	4.00
	Malacothamnus fremonti	0.20
	Baccharis pilularis	0.10
	Atriplex lentiformis	1.00
	Artemesia californica	0.50

Nutrient treatments.
Given the proximity to the Los Angeles basin, with its high rates of atmospheric N deposition, the amount of fine compost was kept at a low level and a relatively high proportion of woody material was mixed into the organics blend. No other fertilizer materials were used. Complete nutrient information is contained in the Site Evaluation in Appendix A.

1.3. Site treatments
Site construction methods and treatments are detailed in the Technical Memorandum from the contractor consultant.

1.4. Interim summary
These site evaluations show that rapid evaluation of site conditions can be used to generate target thresholds for site treatments that will imbibe target rainfall amounts (static model conditions only; no dynamic flow). They provided opportunity for the soils lab to work with an experienced contractor to develop methods that were implementable in field conditions. All sites are expected to grow vegetative cover without erosion losses. Development of deeper moil for hammering, where needed, is recommended. For large, flatter slopes, a ripper shank that can incorporate organic material is recommended. This is not particularly the case at the Templin site because of the siltstone geology, but it would certainly be the case at decomposed granite sites in the Tahoe basin, or in the sorted fine sands along Hwy 99 in the San Joaquin valley, to name specific examples. These materials are all single grain substrates that have no particle to particle cohesion, and so need organic material to maintain open pores for drainage. Dynamic modeling and field truthing of these recommendations using carefully constructed and instrumented field plots is needed to assure reduction of sediment generation under various mineralogical and climatic conditions.

Task 2. Organic matter characterization of field substrates

2.1. Site locations and descriptions

Soil conditions and organic matter accumulations were evaluated from four field site locations that showed sparse or clumped but sustainable revegetation when starting from a barren, construction-impacted substrate. Sites were sampled under the plant canopy of long-term vegetative cover. Between these widely spaced canopies, the unvegetated "gap" substrates were collected from areas that had few or no roots, no overland flow from vegetated slopes above the cut occurred, and no litter inputs from the scattered plant canopies. Both substrates were sampled from 0 to 100 mm depth, starting with the mineral soil under the accumulated organic horizon material, if any.

Site descriptions included Conway summit (MON 395 mile 62.5), Bullion Bend (ELD 50 mile 32.0), and Blue Canyon (PLA 80 mile 53.5).

Site Descriptions

The Conway Summit site (MON 395 mile 62.5) is the first cut north of the retaining wall about a mile north of the maintenance station at Virginia Lakes road at the summit. This west facing cut slope was constructed in 1993 and was benched at approximately 2 foot by 1 foot (600 x 300 mm) (horizontal:vertical) intervals. These benches have since eroded or filled to the extent that a horizontal pattern is still slightly visible under tangential morning light. Revegetation is currently consists of scattered *Purshia tridentata* shrubs with a few percent of *Leymus cinerus* grasses or Idaho Fescue. Total plant cover is approximately 26 %. Snowmelt and rain creates small slurry flows at a few meter intervals down the face to the road shoulder, where it is routinely removed by maintenance crews.

Site geology is mapped as terrace landforms cut into glacial outwash from mixed sources, primarily volcanic. Rainfall is approx 14.46 inches (367 mm) per year with about 60 % coming as rain or snow in winter months. This site is extremely windy and arid, being on the east side of the Sierra. The substrate is glacial till from volcanics, metamorphosed materials. The material disperses when wet and hardsets when dry. Texture is sandy silt loam.

The Bullion Bend site (ELD 50 mile 32.0) is located about a mile east of Pollack Pines overcrossing. This site is a spoil pile consisting of the decomposed granite or granodiorate material that slurried down during the Mill Creek slide in 1993. The material was amended with compost and planted to native grasses the following year, but plant take was poor. Although weeds invaded the site initially, a uniform stand of blue wildrye (*Elymus glaucus*) and purple needlegrass (*Nassella pulchra*) was eventually able to establish. A non-vegetated reference material was not available at the slope surface because of the uniform stand of grasses, so the deep (C horizon) material below the rooting zone was used as the control (non-vegetated) substrate. This material was easily visible in soil pits because it was non-rooted and more compacted.

The Blue Canyon site is on volcanic andesitic mudflows (lahar) at east bound mile 53.5 on I-80. The site is a shallow 3:1 (H:V) slope with a NW aspect.

Site organic matter was evaluated using the work plan outlined in Task 2.3 below.

2.2. Organic matter evaluation background information

Organic matter contributes many critical characteristics to soil function that improve revegetation success. Organic matter stores and releases nutrients, supports microbial growth, retains moisture, and improves infiltration by reducing bulk density and dispersion of mineral particles. These many functions occur partly because soil organic matter is not a single, uniform pool, but is made up of many different types or qualities of organic matter.

One of these small pools is made of plant litter that is rapidly degraded and replaced, steadily converting recognizable plant leaves and roots into fine dusty organic within a few seasons. This rapid decomposition drives much of the soil's microbial activity. The residues from the microbes, as well as less decomposable plant parts then support slower decomposition by different microbes, often more dominated by fungal groups. The byproducts from these processes gradually form a second pool of organic matter that degrades over several decades. These are materials that could be degraded by microbes, but get covered by clay films, hidden in soil pores, or adsorbed onto mineral surfaces. Tillage and wet/dry or freeze/thaw weather cycles can make this pool degrade faster. Eventually, organics form that are so slow to decompose that they remain in the soil for centuries, creating the aggregated, granular texture of "topsoil." The majority of soil organic matter in native, undisturbed systems is formed by this very stable or "humified" pool. Most of the smaller pools found on recently disturbed sites is of the first, more decomposable type. The challenge of soil treatment on degraded sites is to facilitate the transition from the degradable to stable types of soil organic matter.

For modeling purposes, soil organic matter pools are conceptualized as having different stabilities or C residence times (Parton et al., 1987). This approach provides an understanding of the quality or characteristic of the pool's source material that can guide management decisions. The least stable pools with the most rapid turnover are generalized as containing "metabolic" C (such as plant or microbe cellular contents) or "structural" C (such as woody plant tissues) with average C residence times of 6 months or 3 years, respectively. A greater proportion of C from perennial shrubs or grasses flows into the slower, structural pool, whereas C from annual plant systems flows to a greater extent into the faster metabolic pool, which also decomposes more quickly. This difference explains some of the long term revegetation patterns caused by weedy annual vegetation versus perennial plant types. The plant type alters the speed that this pool loses C as CO_2 during decomposition, and the amount of the remaining residues that gradually transition into soil organic matter pools, again having various levels of stability. The "active" soil organic matter pool contains microbial cell wall biomass (average residence time of 1.5 years), while "slow" pools are thought to consist of less biodegradable materials (plant lignins, waxes) with residence times of about 25 years. Well protected or very non-decomposable soil organic matter is grouped into a general group of "passive" soil organic matter with residence times of thousands of years. Even these passive materials may be decomposable if they are exposed to microbial activity by tillage, burning or increased enzyme activity. An individual molecule of organic matter may end up in any one of these pools, and does not necessarily go through each pool in sequence. But, as C is released through respiration, the amount of N that is also released depends on the proportion of these two elements, and on the speed by which plants or microbes resorb the N. These dynamics and the size and stability of the nutrient pools helps explain changes in C and N cycling when a plant community is converted from perennial to annual growth forms.

This substrate-based approach (CENTURY model; Parton et al., 1987) explains why annual vegetation may influence the site differently (less carbon stabilization) than perennial vegetation. But it does not explain why a sandy substrates derived from glacial or beach sands or granites do not stabilize or retain as much soil organic matter as clayey substrates derived from volcanics or sedimentary or very weathered granite sources. For help understanding this approach, the chemical mechanics of soil organics and minerals is needed. This approach cites three different ways that organics are stabilized in soil, which allows interpretation of site geological or mineralogical conditions (Christensen, 1995). Organic matter is stabilized, or protected against further decomposition because it becomes so heterogeneous (with an unorganized mixture of chemical bonds) that microbial enzymes become very inefficient at decomposition (chemical stabilization), or because it becomes closely bound to a mineral surface by bonding of cations (Al^{3+}, Fe^{3+}, Ca^{2+}) between the organic molecule and the mineral (cation bridging), or because the organic is covered on a mineral surface by a thin layer of clay (clay shielding). In either of these cases, microbial enzymes are rendered ineffective and the soil organic matter, even if decomposable, becomes stabilized. Tillage, excavation, freezing or weathering can increase the decomposition rate (decrease stability) while burning or drying may increase stabilization.

The application of this approach is that some degraded sites with low organic matter inputs, low clay content, and low levels of mineral weathering can be expected to have very low levels of organic matter stabilization, and that amendment with organics can be much less effect and have a shorter duration compared to sites with more clay (finer texture), more plant growth and duration of biological activity (lower, moisture sites) or mineral weathering (redder or browner soils compared to gray or light tan soils). Understanding of the process of organic matter stabilization can guide site treatment, either through different plant materials (annual versus perennial with more complex leaf chemistry) or through different substrate treatments (segregation of different excavated materials as fill, compensatory treatment for less responsive substrates, such as coarse woody shreds for non-aggregated substrates).

In the case of the task of stabilized organics and regeneration of aggregates evaluated here, the question is whether, on substrates of low organics, low clay and low mineral weathering, soil organic pools and aggregates form at all, as is observed on less harsh soil conditions.

2.3. Work plan

Several distinct measurements of organic matter were undertaken.

Total Carbon and Nitrogen (TCN)

Soil organic matter levels are evaluated by total carbon and nitrogen analysis (TCN), which shows the amount of C and N retained in the soil. This total organic matter pool does not distinguish between very well stabilized pools (turnover times over one hundred years) and more decomposable (labile) pools (turnover times less than 5 years). But, in developed soils, the actively decomposing pools are small, the TCN value indicates a more or less “permanent” pool of organic matter that can stabilize aggregates, retain nutrients, hold water, reduce thermal conductivity, etc.

Saturated conductivity (Ksat)
Changes in conductivity with organic content or amendment indicate whether a soil or substrate will imbibe rainfall. Secondarily, they indicate whether the soil or substrate is susceptible to hardsetting, which compresses the soil with drying and reduces its pore volume and infiltration.

Water holding capacity (WHC)
The ability of a soil or substrate to retain water after drainage (set at 1/3 bar tension against water removal) and before wilting (set at 15 bar tension for further water removal) indicates whether a soil will supply moisture for plant growth. Wildland plants can withdraw additional water (to 30 to 50 bar tensions) but this tightly held moisture is not conventionally counted as “plant available” water.

Mycorrhizal-source carbon
The amount carbon associated with mycorrhizal activity is evaluated by two methods, one easier and more rapid but not specific to mycorrhizal carbon and one more laborious but more exacting. Each test is used depending the priority of speed or accuracy in the assay.

Particle size distribution
For each pair of soil samples (4 to 6 total), subsamples of ~1g (<2mm) were placed in 20ml vials and rapidly inundated with 15 ml of DI water, capped, and allowed to sit for at least 2 hours prior to analysis.

Particle-size analysis of subsamples was performed using a Coulter LS230 Laser Diffraction Particle-Size Analyzer. Particle-size distribution data were obtained for the following particle-size subgroups: 1000-2000 μm, 250-1000 μm, 63-250 μm, 20-63 μm, 2-20 μm, and 0.04-2 μm.

Subsampling was performed in triplicate, and results were averaged.

Statistics
All statistical analysis was performed using JMP® statistical software (JMP, version 6, SAS Institute, Inc., 1989-2005). Particle-size distribution data was analyzed according to a randomized complete block design model with mixed factor effects, using the restricted maximum likelihood (REML) method. Soil Type (“Canopy” or “Gap”) was considered to have fixed effects, and each set of paired soil samples was treated as a block (3 blocks total) with random effects. Post-hoc comparison of least-squares means representing the two soil types was performed using the Student’s *t*-test, with significance determined at the $\alpha = 0.05$ confidence level unless otherwise noted.

2.4 - 6. Substrate organic matter evaluation, amendment and results

Methods citations - technical methods
The ambient or control field treatment is to evaluate organic matter accumulation under canopies of shrubs existing for a decade or more on an otherwise barren cut slope.

Total C and N

Total C and N content of paired soils sampled from under gap and canopy, with probability (p) of significance listed below each pair of means. Bullion Bend non vegetated soils were from beneath the root zone rather than from a surface "gap" soil. The two right columns indicate the total C and N in the surface 6 in (150 mm).

site plant type	soil type	%N	%C	N/C	kgN/haD15	kgC/haD15
Bullion Bend	unveg	0.000	0.063	---	0.0	1221.4
Elymus, Nassella	canopy	0.006	0.096	15.152	124.2	1881.1
p =		0.374	0.071			
Blue Canyon	gap	0.028	0.545	19.269	551.9	10633.4
Arctostaphylos	canopy	0.057	1.602	28.127	1110.5	31236.1
p =		0.060	0.128			
Conway	gap	0.035	0.239	6.906	675.4	4663.8
Artemesia	canopy	0.057	0.959	16.734	1117.4	18697.9
p =		0.000	0.001			
Conway	gap	0.035	0.239	6.906	675.4	4663.8
Elymus	canopy	0.061	0.783	12.915	1182.4	15269.8
p =		0.000	0.007			
Conway	gap	0.017	0.035	2.101	328.9	691.0
Purshia	canopy	0.086	1.511	17.485	1685.5	29470.4
p =		0.005	0.002			

Infiltration

Particle size distribution: Canopy versus Gap samples
Conway Purshia tridentata (PUTR)(Antelope bitterbrush)

Soil samples obtained from under the canopy of *Purshia tridentata* (PUTR) had a significantly ($p<0.05$) greater fraction of soil macroaggregates (>250 μm) relative to samples obtained from nearby exposed soil. Canopy soils had 130% greater volume of 1000-2000 μm particles, and 40% greater volume of 250-1000 μm particles, relative to the exposed soil. The greater volume of macroaggregates of the canopy soils appeared due to aggregation of clay (<2 μm) and silt (2-63 μm) particles, particularly particles 2-20 μm in size. PUTR may reduce susceptibility of road cut slopes to erosion by promoting formation of soil macroaggregates.

The results suggest that the soil samples obtained from beneath the canopy of PUTR had a significantly ($p<0.05$) greater fraction of macroaggregates (>250 μm) than those obtained from nearby exposed soil. The Canopy soils exhibited 130% and 40% greater volume of 1000-2000 μm and 250-1000 μm particles, respectively, relative to the Gap soils. As it is assumed that primary soil texture does not significantly vary between the Canopy and Gap soils, differences observed in the PSD of these soils are presumably due to differences in soil aggregation. Hence, these data suggest that conditions existing under the canopy of PUTR promote a greater degree of aggregation relative to the exposed Gap soil.

The greater fraction of >250 µm particles observed in the Canopy samples appears to be due to aggregation of both clay and silt particles, especially fine silt in the range of 2-20 µm. The Canopy soils exhibited 30%, 32%, and 39% less volume of 20-63 µm, 2-20 µm, and 0.04-2 µm particles, respectively, relative to the Gap soils. However, no significant difference in the fraction of 63-250 µm was observed between the Canopy and Gap samples. The relative increase >250 µm particles in the Canopy samples relative to the Gap samples is therefore balanced by a corresponding reduction of discrete <63 µm particles that are, presumably, bound up in >250 µm aggregates.

Soil aggregates, particularly macroaggregates (>250 µm), increase soil infiltration capacity by increasing the number of large high-conductivity pores, and reduce soil susceptibility to soil detachment and transport by wind, rain splash and overland flow. The soil conditions associated with PUTR may therefore improve soil resistance to erosion by promoting the formation of soil macroaggregates. Further research investigating both the stability of soil aggregates and the biogeochemical mechanisms contributing to aggregate formation under the canopy of PUTR will assist formulation of BMPs for soil erosion abatement on road cut slopes.

Particle size distribution: Canopy versus Gap samples
Conway Purshia tridentata (Antelope bitterbrush)

PSD Subgroup (µm)	Texture	Volume (% of total soil) *Purshia tridentata*		p-value	Ranking	Difference (can/gap)
		Can.	**Gap**			
1000-2000	Sand	16.5	7.1	0.0199*	Can > Gap	2.32 x
250-1000		28.2	20.5	0.0071*	Can > Gap	1.38 x
63-250		19.6	20.0	0.41	N.S.D.	0.98 x
20-63	Silt	14.6	20.9	0.0285*	Can < Gap	0.70 x
2-20		17.8	26.0	0.0015*	Can < Gap	0.68 x
0.04-2	Clay	3.3	5.5	0.0061*	Can < Gap	0.60 x

* Indicates statistical significance ($p<0.05$).
N.S.D. = Not Significantly Different

The results suggest that the soil samples obtained from beneath the canopy of both *Artemisia tridentata* (ARTR) and *Leymus cinerus* (LECI) (Basin wildrye) had a significantly greater fraction of macroaggregates (250 – 1000 µm) than those obtained from nearby unvegetated soil. We assume that primary soil texture does not significantly vary between the Canopy and Gap soils, so differences observed in the PSD of these soils are presumably due to differences in soil aggregation. Hence, these data suggest that conditions existing under the canopy of ARTR and LECI promoted a greater degree of aggregation relative to the unvegetated soil. Further, the ARTR and LECI samples did not significantly differ in the fraction 250 – 1000 µm material, suggesting that conditions under the canopy of these two species promoted soil aggregation to a similar degree. However, in contrast to the effect of PUTR on soil aggregation on a nearby slope (see

PUTR summary), neither ARTR or LECI was associated with a significantly greater fraction of 1000 – 2000 µm macroaggregates.

The greater fraction of 250 - 1000 µm particles observed in the canopy samples appears to be due to aggregation of both clay and silt particles. For all particle fractions <63 µm, ARTR and LECI had significantly ($p<0.10$) less volume than that of the unvegetated soil. However, differences were not observed between the canopy and unvegetated soils in the fraction of 20-63 µm particles. The relative increase 250 – 1000 µm particles in the canopy samples relative to the unvegetated samples is therefore balanced by a corresponding reduction of discrete <63 µm particles that are, presumably, bound up in 250 - 10000 µm aggregates.

Soil aggregates, particularly macroaggregates (>250 µm) reduce soil susceptibility to soil detachment and transport by wind, rainsplash and overland flow. The soil conditions associated with ARTR and LECI may therefore improve soil resistance to erosion by promoting the formation of soil macroaggregates. Further research investigating both the stability of soil aggregates and the biogeochemical mechanisms contributing to aggregate formation under the canopy of ARTR and LECI will assist formulation of BMPs for soil erosion abatement on road cut slopes.

PSD Subgroup (µm)	**Texture**	**Volume (% of total soil) *Artemisia tridentata***		**Ranking**	**Difference (can/gap)**
		Can.	**Gap**		
1000-2000		20.4^{A}	17.1^{A}	Can = Gap	1.19 x
250-1000	Sand	33.3^{A}	26.2^{B}	Can > Gap	1.27 x
63-250		17.9^{A}	17.9^{A}	Can = Gap	1.00 x
20-63	Silt	12.7^{B}	16.3^{A}	Can < Gap	0.78 x
2-20		13.4^{B}	19.0^{A}	Can < Gap	0.71 x
0.04-2	Clay	2.4^{B}	3.5^{A}	Can < Gap	0.69 x

Values in each row followed by the same letter do not significantly differ ($p = 0.05$).

PSD Subgroup (µm)	**Texture**	**Volume (% of total soil) *Leymus cinerus***		**Ranking**	**Difference (can/gap)**
		Can.	**Gap**		
1000-2000		19.3^{A}	17.1^{A}	Can = Gap	1.13 x
250-1000	Sand	32.4^{A}	26.2^{B}	Can > Gap	1.24 x
63-250		19.3^{A}	17.9^{A}	Can = Gap	1.08 x
20-63	Silt	12.9^{B}	16.3^{A}	Can < Gap	0.79 x
2-20		13.6^{B}	19.0^{A}	Can < Gap	0.72 x
0.04-2	Clay	2.5^{B}	3.5^{A}	Can < Gap	0.71 x

Values in each row followed by the same letter do not significantly differ ($p = 0.05$).

Particle size distribution: Canopy versus Gap samples
Blue Canyon Arctostaphylos patula (Manzanita)

PSD Subgroup (µm)	**Texture**	**Volume (% of total soil) Blue Canyon**		**p-value**	**Ranking**	**Difference (can/gap)**
		Veg	**Non Veg**			
1000-2000	Sand	17.0	20.3	0.1166	NSD	n/a
250-1000		41.6	36.9	0.3859	NSD	n/a
63-250		20.9	17.8	0.1141	NSD	n/a
20-63	Silt	9.4	9.6	0.4444	NSD	n/a
2-20		9.3	12.8	0.4293	NSD	n/a
0.04-2	Clay	1.8	2.6	0.4132	NSD	n/a

NSD = Not Significantly Different; n/a = not applicable

Particle size distribution: Canopy versus Gap samples
Bullion Bend: Elymus glaucus (blue wildrye)*, Nassella pulchra* (purple needlegrass)

PSD Subgroup (µm)	**Texture**	**Volume (% of total soil) Bullion Bend**		**p-value**	**Ranking**	**Difference (can/gap)r**
		Veg	**Non Veg**			
1000-2000	Sand	3.58	4.13	0.7173	NSD	n/a
250-1000		24.18	21.43	0.6665	NSD	n/a
63-250		38.23	37.98	0.8028	NSD	n/a
20-63	Silt	21.68	22.93	0.7700	NSD	n/a
2-20		10.69	12.83	0.4027	NSD	n/a
0.04-2	Clay	1.08	1.23	0.4303	NSD	n/a

NSD = Not Significantly Different; n/a = not applicable

Summary statement of all particle size distributions:
Particle size distributions show a net increase in aggregation in sand sized particles at Conway summit of 17.1 % (*Purshia*), 10.4 % (*Artemisia*) and 9.8 % (*Leymus*). Non significant increases were measured at Blue Canyon (7.8 % for manzanita) and Bullion Bend (3 % for *Nassella* and *Elymus*). This suggests that aggregation can, in fact, occur on these substrates. But, it also suggests that not all substrates or plants or climates or interactions between them, can regenerate aggregates within the decade or so that these slopes have existed.

Ksat section:

The “canopy” soils for Conway had Ksat measurements were all higher than the non-vegetated “gap” soils. In the 14 years since the slope was constructed, *Purshia* canopies generated 4.4 times greater infiltration rates, the *Artemisia* generated 5.4 times more infiltration than the associated gap soil, while the *Leymus* grass generated 1.5 times more infiltration.

Plant type	Infiltration rate (mm/hr) Conway Summit		Difference (can/gap)
	Canopy	Gap	
Purshia tridentata	12.67 a	2.85 b	4.45
Artemisia tridentata	30.3 a	5.65 b	5.36
Leymus cinerus	8.4 a	5.65 b	1.49

Values in each row followed by the same letter do not significantly differ ($p < 0.05$).

Plant type	Infiltration rate (mm/hr) Bullion Bend		Difference (can/gap)
	Canopy	Gap	
Elymus glaucus *Nassella pulchra*	3.41 a	5.00 b	0.68

Values in each row followed by the same letter do not significantly differ ($p < 0.02$).

This substrate material was collected from a spoil pile created from landslide material recovered from HWY 50 following the Mill Creek slide. After several years of poor vegetative cover, a solid stand of perennial grasses has developed. When lower horizons (non-vegetated) were compared to surface horizons (vegetated), however, the infiltration was much lower in the surface (canopy) horizons. This is assumed to result from weathering breakdown of the crushed rock material by freeze thaw during the time since deposition. Root action and organic matter addition did not act to improve aggregation or infiltration. This example shows that not all soils can be expected to steadily improve infiltration after impacts cease.

WHC section:

Plant type	Water Holding Capacity (g water /g soil) Conway Summit				Difference (plant avail water)
	Canopy		Gap		
	1/3 bar	15 bar	1/3 bar	15 bar	
Purshia tridentata	0.175	0.049	0.154	0.042	1.12 x ($p < 0.05$)
Artemisia tridentata	0.137	0.039	0.133	0.036	NSD
Leymus cinerus	0.133	0.038	0.133	0.036	NSD

NSD = non significant difference

Plant type	Water Holding Capacity (g water /g soil) Bullion Bend				Difference (plant avail water)
	Canopy		Gap		
	1/3 bar	15 bar	1/3 bar	15 bar	
Elymus glaucus Nassella pulchra	0.122	0.035	0.104	0.034	NSD

NSD = non significant difference

Summary statement of Ksat and water holding capacity:
Conway had sign more infiltration (Ksat), with shrubs providing 4 and 5 times more under the canopy compared to the non-vegetated gap soils. At Bullion Bend, this trend was reversed, with vegetated samples having less Ksat. Whether the plant type (grass vs shrub) or the substrate (decomposed granites are susceptible to disarticulation, dispersion and close packing) is not clear.

The *Purshia* shrub canopy soils from Conway held more water than the grass or Artemisia samples. Bullion Bend vegetated samples held more water but the differences were non-significant. Changes in infiltration appear to be independent from changes in water holding capacity.

2.5. Potential amendments

Analysis of field organic matter levels in the previous section indicates that aggregates can form within decades on some soils, but others have no response in approximately the same time period. The mechanisms required to re-aggregate dispersed fines need additional study. For short term response, critical for reducing overland flow on erosive sites, several treatments were designed and tested for comparative purposes in laboratory conditions. These include: 1) fine (< 3/8 inch) compost incorporation, sawdust incorporation (2 - 4 mm), microbial biomass concentrate (Biosol) (loaded as a soil physical amendment, not a nutrient source), and a commercial lignite derived humate material. The objective of these amendments was to provide the critical functions (infiltration and water holding capacity) normally provided by aggregates, for the interim period when aggregates were not yet regenerated. The specific questions were whether the amendments increased infiltration rate or water holding capacity above that of the unamended substrate material.

Substrates used for these trials were from Conway summit (sandy loam derived glacial volcanic till), Lee Vining (loamy sandy derived from volcanic ash) and Meyers (loamy sand derived from glacial till from mixed granitic and volcanic sources). These three substrates were selected because they are single grain, dispersive, easily eroded and easily compacted, thus reducing infiltration and requiring soil amendment.

Because the bulk density of each soil and amendment differs, all are packed to the same weight per volume rate (Table 1).

Table 1.

Bulk Density	$g\ cm^{-3}$	Initial ring bulk density (soil + amendment) $g\ cm^{-3}$
Soil	1.3888	1.39
Woodshreds	0.16	1.27
Humate	0.6	1.38
Fine compost (< 2 mm)	0.48	1.29
Coarse compost (3/8" – 2 mm)	0.35	1.28
Fungal biomass	0.7	1.32

All amendments were added at 10% by volume with the exception of the humate, which was loaded at 1% by volume.

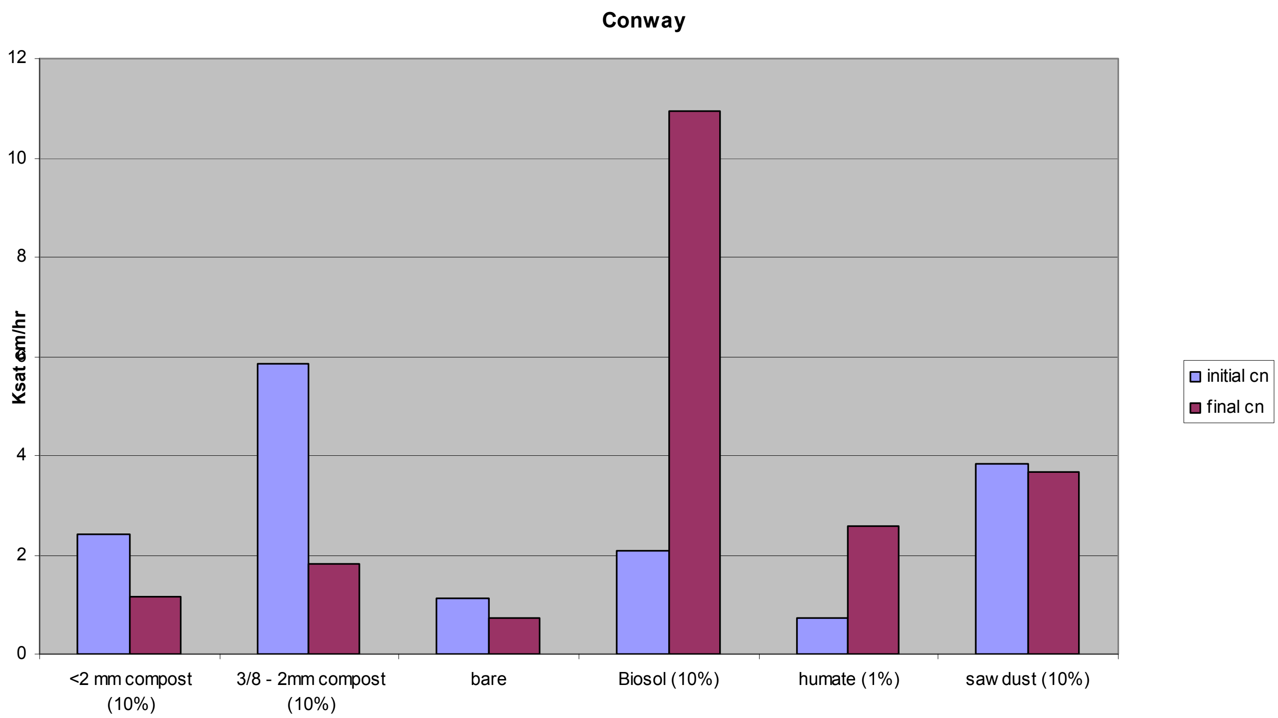
Measurement of saturated conductivity (Ksat):
Saturated conductivities were measured utilizing the constant head method. As per the method, a solution of 0.01 $CaCl_2$ was utilized for Ksat measurements. After the initial packing of the rings, the soil rings were allowed to saturate (from the bottom) overnight. After the initial measurements, the soil rings were placed in a oven at 60° C until they reached a constant mass (approximately one week). This wetting and drying procedure was performed a total of three time. The rings were then saturated a final time and Ksat was measured again.

Bulk density:
Upon completion of the final Ksat measurement the soil rings were dried a final time. Many of the soil rings had "settled" or "packed" significantly during this process. Quartz sand (bulk density equaling 1.65 $g\ cm^{-3}$) was added to the rings in order to fill the remaining volume of the rings. The sand was chosen because of its consistent bulk density and its lack of compressibility. A thin layer of plastic film was placed between the sand and the original soil sample. This allowed for an accurate measure of the final volume of the soil in the ring. Since the mass in the soil ring was not changed this allowed the measurement of the final ring bulk density, which was subsequently compared to the initial packed bulk density.

Measurement of water holding capacity (WHC):
The water holding capacities of the soil and treatment combinations were measured on pressure plates at 0.33, 3, and 15 bars of pressure.

2.6. Test amendments

2.6.1. Conway infiltration measurements



		Ksat (cm/hr) initial		final		delta	p value (initial vs final)
Conway	<2 mm compost (10%)	2.414305423	c	1.159495	cd	-1.25	0.07
	3/8 - 2mm compost (10%)	5.865966253	a	1.825945	cd	-4.04	0.00003
	bare	1.114294811	de	0.722228	d	-0.39	0.56
	Fungal biomass (10%)	2.077363897	cd	10.94397	a	8.86	0.000001
	humate (1%)	0.716332378	e	2.579386	bc	1.8	0.01
	sawdust (10%)	3.820439351	b	3.660272	b	-0.16	0.8

The initial saturated conductivity measurements showed that both compost amendments, as well as the sawdust amendment, significantly increased initial Ksat when compared to the control bare soil. The 3/8 – 2mm compost exhibited the greatest increase of Ksat being 5 times faster than the bare. The fibrous content of the organic amendments appeared to be important, since the non-fibrous materials did not significantly increase infiltration.

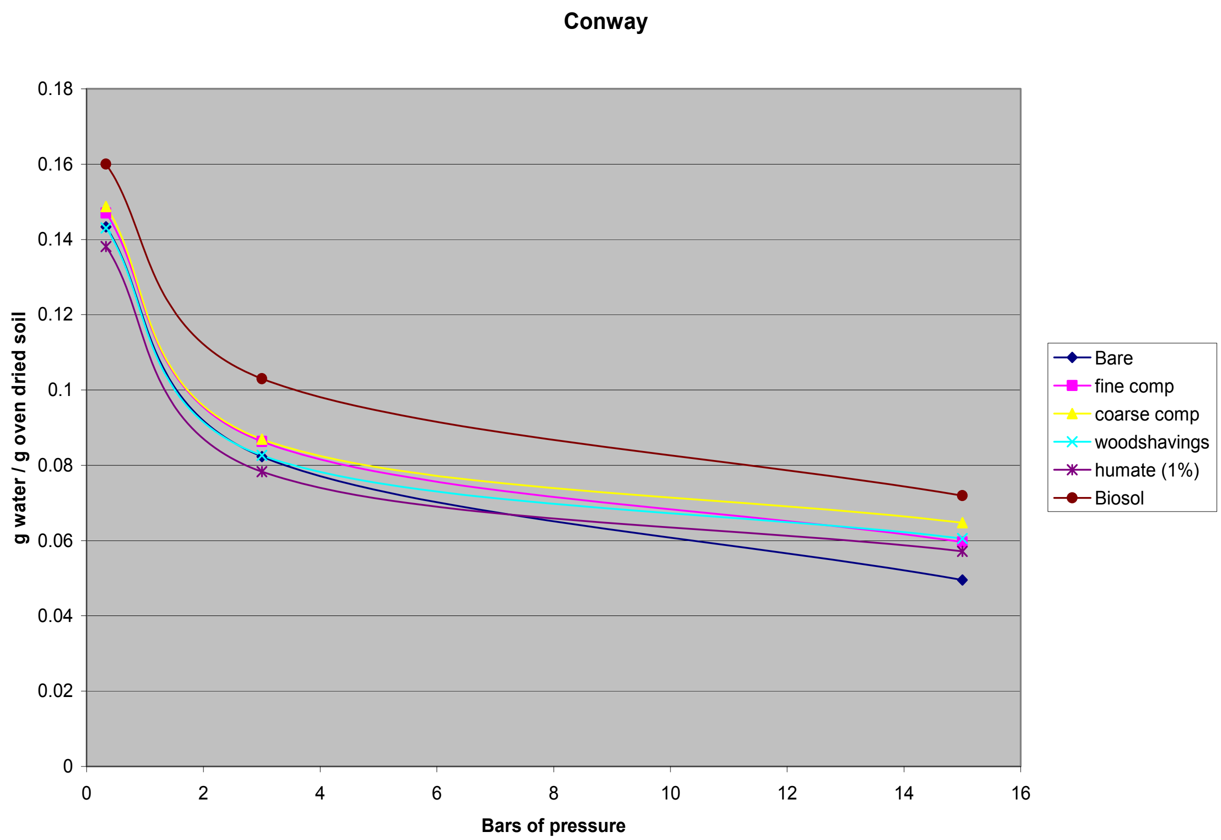
The final Ksat measurement exhibited different characteristics than the initial, however. The two compost amendments were still higher than the bare, but, after drying, neither was statistically higher. In these conditions, the fungal biomass amendment and the lignite humate significantly increased infiltration after the multiple wet/dry cycles. The process by which this happens is not known. The infiltration rate of the fibrous sawdust treatment also remained significantly higher than the bare.

The change in improvement from initial to final (the “delta” value) indicates how well the initial tillage and amendment effects on Ksat were retained after three wetting and drying events. This value indicated that the bare material was stable (did not further compact much after the initial measurements) and the sawdust treatment retained the initial higher infiltration rate. The composts tended to decrease infiltration, and the fungal biomass and humate materials tended to greatly increase. Most significant in these data is the tendency of the finer composts to lose their initially high infiltration characteristics that are induced after tillage and amendment.

The soil / amendment rings all settled (increased in bulk density) after wetting / drying events. The fungal biomass treated rings were the only treatments that “settled” less significantly than the bare soil rings. Actual settling values are listed below (g cm^{-3}).

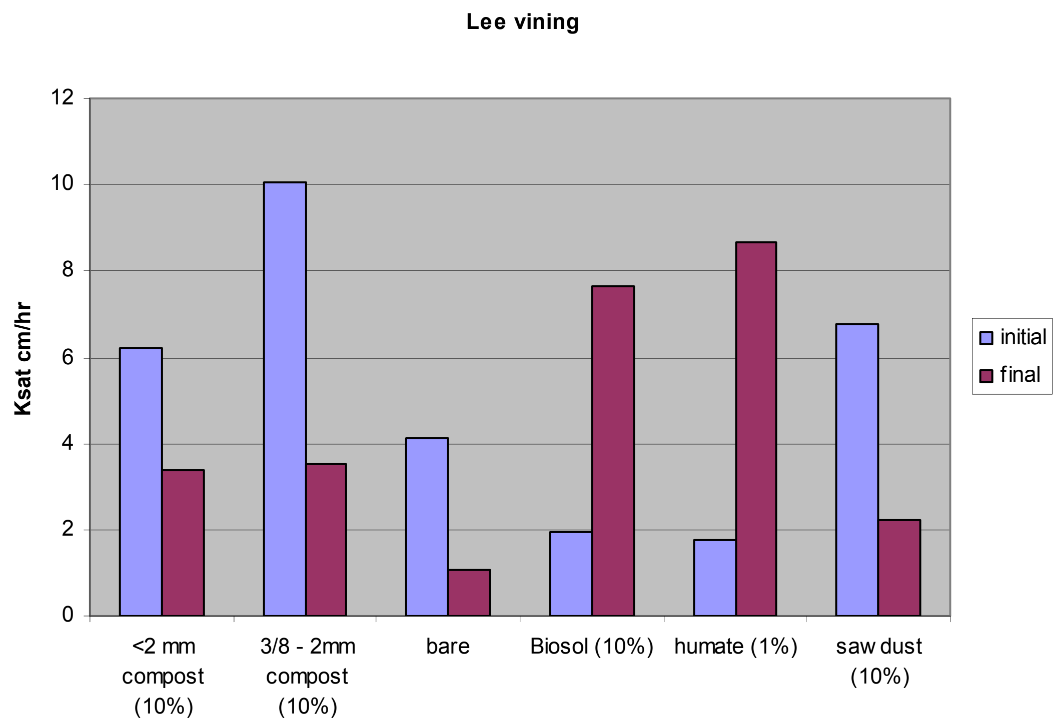
		delta Bd	
Conway	<2 mm comp.	0.318	bc
	3/8 - 2mm comp.	0.357	c
	bare	0.347	bc
	Fungal biomass	0.209	a
	humate	0.287	bc
	sawdust	0.321	bc

Conway water holding capacity data:



All soil amendments contained more water at dry (- 15 bar) conditions compared to the bare soil treatment. The fungal biomass and the composts or sawdust materials were all significantly higher. The total amount of water released between -0.33 and -15 bar pressure levels were found to be the greatest in the bare, fungal biomass, and < 2 mm compost treatments, but these treatments did not differ statistically. Compared to the beneficial increase in infiltration, soil amendment had moderate but significant functional improvement in water holding capacity. The fibrous organic amended substrates at 15 bar matric tension had 20 % (< 2 mm), 31 % (2 mm to 3/8 inch) or 22 % (sawdust) more water holding capacity compared to the bare unamended soil, all significantly greater than the unamended substrate.

2.6.2. Lee Vining infiltration measurements



		Ksat (cm/hr)					
		initial		final		delta	p value
LeeVining	<2 mm compost (10%)	6.225901164	b	3.39675	b	-2.8	0.00009
	3/8 - 2mm compost (10%)	10.04095745	a	3.511433	b	-6.5	0.000001
	bare	4.11493155	c	1.082716	c	-3.03	0.00004
	Fungal biomass (10%)	1.950811843	d	7.627613	a	5.67	0.000001
	humate (1%)	1.751034702	d	8.663974	a	6.9	0.000001
	sawdust (10%)	6.769340974	b	2.210902	bc	-4.55	0.000001

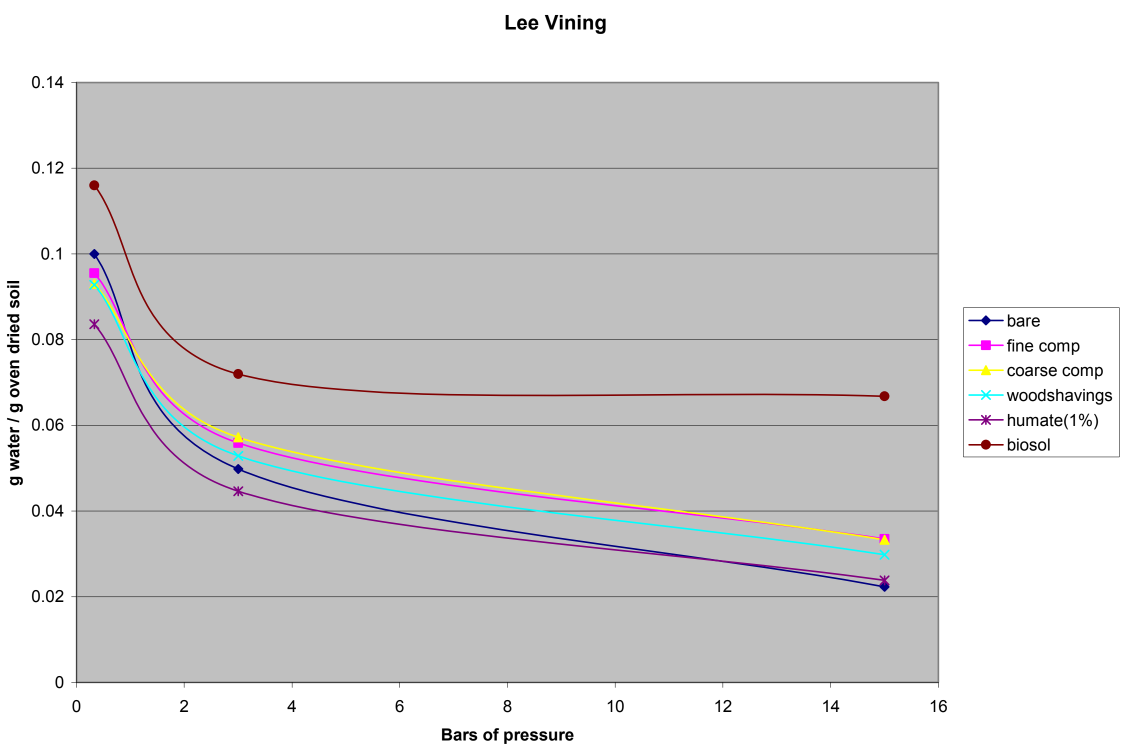
The initial saturated conductivity measurements on the Lee Vining substrate showed that both compost amendments, as well as the sawdust amendment, increased Ksat compared to the control bare soil. The 3/8 – 2 mm compost exhibited the greatest increase of Ksat, being 2.5 times faster than the bare. The fungal biomass and humate amendments reduced infiltration rates at the time of incorporation, compared to the bare substrate treatment.

The final Ksat values were again found to have different characteristics than the initial. All final Ksats were slower than the initial with the exception of the fungal biomassfungal biomass and humate treatments. Even though there was a decrease with time for fibrous amendments, the sawdust treatment was the only Ksat value that was not still significantly greater than the bare soil after the multiple wet/dry cycles. All treatments exhibited significant changes in Ksat as compared to the initial values. The 3/8 - <2mm compost showed the greatest loss in Ksat; whereas the fungal biomass and humate exhibited the greatest increase.

The soil / amendment rings all settled (increased in bulk density) after wetting / drying events. The fungal biomass treatment had the least increase of bulk density. The fungal biomass and humate treatments were the only treatments that significantly exhibited less “settling” than the bare soil. Actual settling values are listed below (g cm^{-3}).

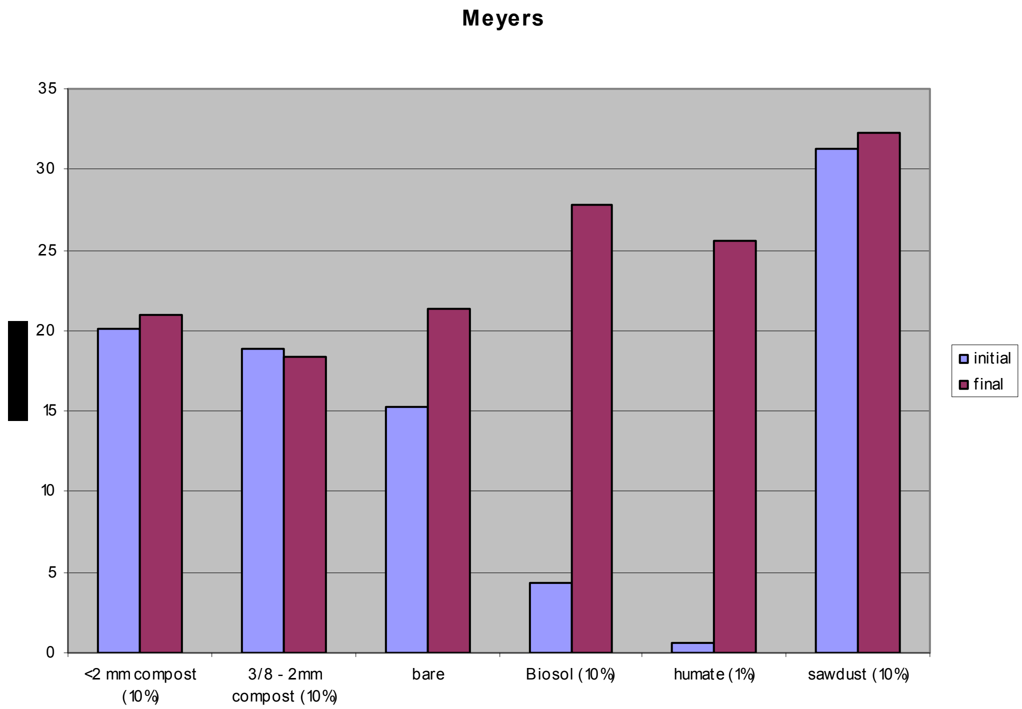
		delta Bd	
Lee Vining	<2 mm comp.	0.283	d
	3/8 - 2mm comp.	0.239	bc
	bare	0.273	cd
	Fungal biomass	0.142	a
	humate	0.227	b
	sawdust	0.277	d

Lee Vining water holding capacities:



The fungal biomass treatment significantly ($p < 0.05$) retained the most water among the treatments at all measured pressure levels. At the 15 bar level, the fungal biomass and two compost treatments contained more water than the bare soil. The total amount of water released between 0.33 and 15 bar pressure levels were found to be the greatest in the bare soil (0.078 g water / g dried soil). The least amount of water was released from the fungal biomass treatment. All other treatments were between the bare and fungal biomass, and were not significantly different from each other. At 15 bar matric tension, compost amendment resulted in a 50 % increase in WHC for < 2 mm and 2 mm to 3/8 fraction, and 34 % more water for sawdust amended samples compared to bare mineral soils. These increases were all statistically significant, but still are relatively low levels of water holding capacity (approximately 3 % v/v).

Meyers infiltration measurement



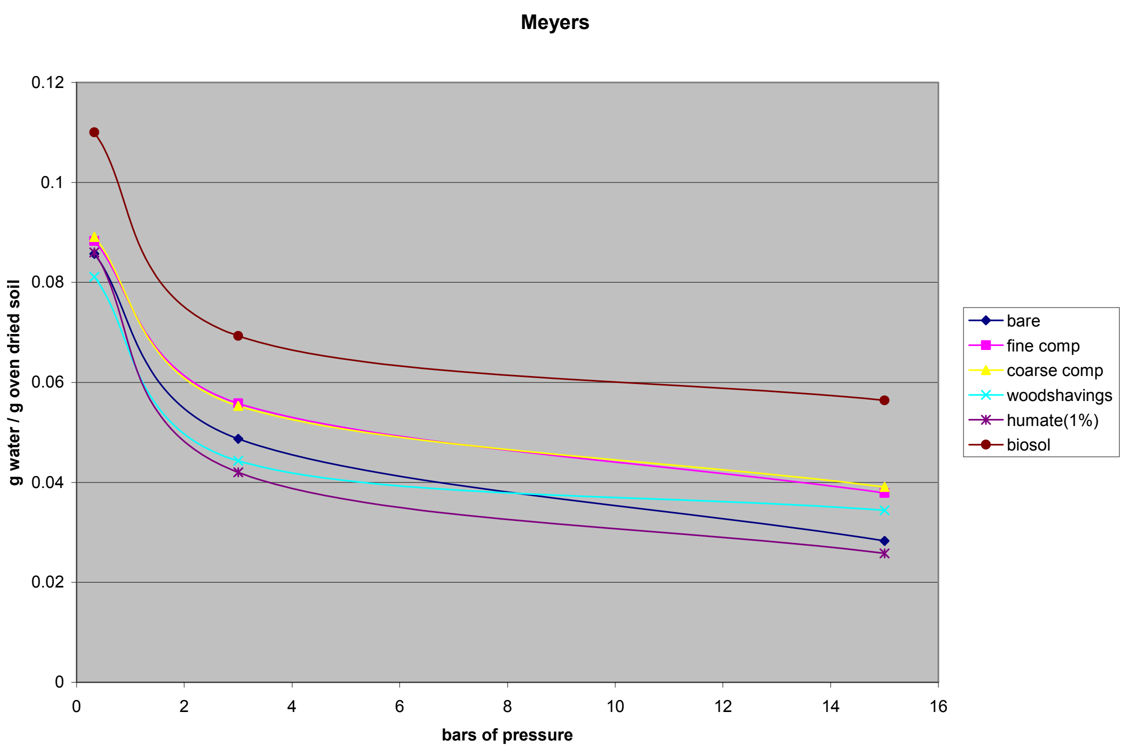
		Ksat (cm/hr) initial		final		delta	p value
Meyers	<2 mm compost (10%)	20.11289499	b	20.9962	b	0.88	0.8
	3/8 - 2mm compost (10%)	18.87478965	b	18.42419	b	-0.45	0.9
	bare	15.32155365	b	21.35732	b	6.03	0.1
	Fungal biomass (10%)	4.395627719	c	27.78773	ab	23.39	0.000001
	humate (1%)	0.65869644	c	25.61699	ab	24.9	0.000001
	sawdust (10%)	31.24005094	a	32.27918	a	1.039	0.77

The sawdust treatment was the only treatment significantly greater than the bare treatment shortly after initial Ksat measurements. Compost amendments provided non-significant increases. The fungal biomass and humate treatments had large, significant increases to Ksat after the wetting / drying process. The process that caused this increase is not known.

The soil / amendment rings all settled (increased in bulk density) after wetting / drying events. The fungal biomass treatment had the least increase of bulk density. The sawdust and two compost treatments had greater increases in bulk density than the bare soil. Actual settling values are listed below (g cm^{-3}).

		delta Bd	
Meyers	<2 mm comp.	0.374	d
	3/8 - 2mm comp.	0.365	cd
	bare	0.297	b
	Fungal biomass	0.191	a
	humate	0.33	bc
	sawdust	0.359	cd

Meyers water holding capacities:



The fungal biomass treatment significantly ($p < 0.05$) retained the most water amongst the treatments at all pressure levels. At the 15 bar level, the fungal biomass and two compost treatments contained more water than the bare soil. The total amount of water released between 0.33 and 15 bar pressure levels was statistically the same amongst all treatments, ranging from 0.046 to 0.06 g water / g dried soil. At 15 bar matric tension, the compost amended samples had 39 % (2 mm to 3/8 inch), 34 % (< 2 mm) greater water holding capacity than the bare unamended soils, while the sawdust had 21 % increase. The compost water contents were significantly greater ($p = 0.05$) but the sawdust were non-significant.

2.6.4. Discussion:

Field aggregate PSD evaluation

Amendment, soil function regeneration evaluation

In the event that a newly constructed site has no substrate particle aggregation, In general, the compost / sawdust incorporation treatments initially increase Ksat compared to a non-treated (bare) soil. But, fibrous amendments tend to decrease or have no effect on infiltration after they have been subjected to wet/dry cycles. Humate and fungal biomass treatments initially decrease Ksat compared to a non-treated (bare) soil, but they both dramatically increase in Ksat compared to their own initial Ksat and after multiple wet/dry cycles. In general, fine fibrous amendments did not have long-lasting effects on infiltration, but they did not reduce infiltration by plugging pores, which was a potential concern. The interaction of coarse compost shreds or chips and fine compost (standard Caltrans specification 3/8 minus) is not known, but the fine component of unscreened composts does not appear to clog pores and reduce infiltration.

These measurements were carefully designed and constructed lab experiments, so that bulk density was controlled and so that differences in bulk density did not dominate the infiltration effects that were to be measured. However, if a secondary aspect of these amendments occurred that also decreased bulk density, this would have an additional effect on functional infiltration. As an example, if composts do not appreciably increase long term infiltration, but they greatly increase plant growth, the treatment may still be recommended. Conversely, if a ring experiment indicated an increase from the fibrous or humate treatments, but in the field this treatment killed plants or dispersed and hard-set due to salt content, the field recommendation would differ from the lab result. A reduced set of treatments needs to be tested in field conditions to evaluate this potential interaction. At present, when effects are attributable only to infiltration at standardized bulk density levels (the only standardized method for testing different mixtures), these data stand as presented.

Compared to large, treatment-induced changes in infiltration, the changes in water holding capacity, or plant available moisture were more moderate. The composts generally did not increase total water release (1/3 bar to 15 bar tension) or decreased it, often by statistically significant amounts. But, the increase in soil water content at the droughty end of the water release curve was consistently higher than the bare substrate. These increases ranged from 20 to 50 % more water content compared to unamended substrates, although still low in total value (3 to 6 %).This finding supports previous observations that compost incorporation increases water holding capacity on soils with less than 10 % ambient water holding capacity.

The fungal biomass treated soils exhibited a greater water holding capacities in all soils at 0.33, 3, and 15 bars. Thus, it may be a better treatment for droughty conditions, especially if plants can continue to withdraw moisture drier than 15 bar matric tensions. All these materials release salts to the soil, which may be an additional consideration in droughty conditions. Salt effects were not evaluated as part of this study.

2.8. Summary for organic matter caracterization of field substrates

The general experimental results are interpreted to suggest the following recommendations for field implementation:

1. Fine compost or sawdust amendment (3/8 inch (10 mm) minus; equivalent to 1 inch (25 mm) applied, tilled to 12 inches (30 mm) depth) significantly increases infiltration compared to bare soils for the period shortly after field site construction. But, these treatments are observed to lose a large portion of their initial effect with repeated wet / dry cycles. The residual effects are still generally are better (greater infiltration) than unamended soil. This suggests that there is a limited period of beneficial effect of compost amendment and that long term focus should be on regeneration of infiltration function by soil aggregates. This same fine compost amendment provides adequate nutrients for growing conditions at many sites with little risk of N loss.

2. Plant available water is unaffected or even decreased by compost treatments when measured as the difference between 1/3 bar and 15 bar tensions (typically defined as "plant available water"). But, water is usually not a limiting characteristic when soils are wet. A more important indicator of amendment effects would be to measure total plant available water content when soils are dry. At this end of the water release curve, composts hold 20 to 50 % more water available for plants, potentially making compost amendment useful for revegetation. Also important is the tendency for composts to increase root growth, so that they are able to acquire water from a larger soil volume. Although not tested in this experiment, excessive amendment (> 30 % by volume) of compost fines is expected to decrease plant available water since the organics will decrease root contact and capillary wicking of water from mineral soil volumes that hold more water in droughty conditions.

3. Humates and fungal biomass treatments appeared to clog soil pores initially, but after several wet / dry cycles, these materials gave large increases in infiltration rates. The fungal biomass treatment also increased the amount of water held in the soil, retaining more moisture at the -15 bar tension. Plants that can with draw water in more droughty conditions can utilize this moisture. These materials were applied at rates larger than practical for nutrient loading targets, so additional tests are needed to test efficacy and lower loading rates.

4. These soil amendments can replace infiltration and water holding capacity functions of degraded soils for the short term, potentially until plant roots become established, and, to some extent, until soil aggregates are reformed.

Although total C and N tests indicate the overall pool of these elements, the active fractions of these organics is more difficult to evaluate. The striking results from the humates and commercial organic amendments, as well as the large increase in infiltration indicate that there are differences in soil characteristics that would be very helpful to be able to measure, and would guide site evaluation and treatment generation.

Task 3. Aggregate regeneration

3.1. Site locations and descriptions

Aggregate stability was calculated for samples from the Conway, Bullion Bend, and Blue Canyon sites. The Conway site was located in Mono County (MON 395 mile 62.5). This site was cut in 1993 and was a west-facing slope cut into moraine deposits at a 2:1 angle. Vegetative cover consisted of scattered *Purshia tridentata* (antelope bitterbrush) shrubs measuring approximately 18 to 36 inches (0.5 to 1 m) diameter located on 9 to 12 feet (3 to 4 m) intervals. Small (8 in; 200 mm) clumps of *Leymus cinerus* (basin wildrye) also occurred scattered widely across the slope face. The original bench steps had almost completely eroded away since construction, leaving a planar slope face of exposed glacial till or hard-set crust (when dry) of 2 to 3 in (50 to 75 mm) thick. Samples were collected from mineral soil underneath the plant canopy in a location that was not influenced by up-slope illuviation or colluviation (water flow or ravel) such that the soil at the sampling location was only influenced by that substrate type and the plant canopy. This insured that soil forming processes occurred at this location, not by washing in soil like material from up slope. The bare, or canopy, samples were collected from an adjacent area 3 to 6 feet (1 or 2 m) away at the same elevation, such that local rills or gullies routed water away from the sampling location. This assured that the substrate at that site was not affected by upslope processes and that the mineral soil was similar to that under the plant canopy, excluding plant organic effects. These sites were bare of vegetative cover or plant litter or moss or lichens. The samples were taken from ridges between the gullies, which also kept roots from the nearby plants out of this soil volume. Samples with root in-growth were discarded and nearby areas were sampled.

The Blue Canyon site was located in Placer Co (PLA 80 mile 53.5). This site was a northwest facing slope cut into volcanic lahar (hardened mudflow) at a 3:1 angle. Vegetation cover was scattered *Arctostaphylos patula* (manzanita) and ponderosa pine at spacing of roughly 5 to 10 m intervals. Samples were collected from bare areas between shrubs that were not affected by drainage from upslope and also in the mineral soil under manzanita canopy. Similar to the Conway site, soil samples were taken to assure that the only effects on the soil forming processes were from the target plant species. Gap samples were taken only from bare areas not affected by upslope processes.

The Bullion Bend site was located in El Dorado county (ELD 50 mile 32.0). This site was a north facing fill slope constructed of decomposed granite removed from the Mill Creek slide in 1993. This site is located about a mile east of Pollock Pines overcrossing. The substrate material was amended with compost and planted to native grasses the following year, but plant establishment was poor. Weeds (cheatgrass, yellow sweet clover) invaded the site initially, but a uniform stand of *Elymus glaucus* (ELGL, blue wildrye) and *Nassella pulchra* (NAPU, purple needlegrass) steadily established on the site by 5 to 8 years after construction. Because of the uniform stand and the heavy initial application of compost, uncontaminated surface substrate samples were not available. In substitution for the unvegetated "gap" samples, three soil pits were dug that penetrated the pile beneath the rooting zone. This was detectable by a sharp increase in bulk density and soil compaction of this fill substrate and a lack of root growth. Substrate below this line was used as a "non-vegetated" sample, in comparison to the substrate that was well rooted in the 100 mm horizon below the surface. Areas were sampled with little or no visible compost residue.

3.2.1. Work plan, literature review

The objective of this section was to determine the strength of the aggregates measured in Task 2, the mechanisms acting to stabilize them, and to evaluate potential substrate treatments to regenerate aggregates in degraded substrates. Before outlining the methods used, basic information will be reviewed regarding aggregate formation in substrates.

Review of aggregate formation processes

Current research on aggregates predominantly involves studies on agricultural, forest, and range soils. These soils typically have at least modest levels of organic matter and clay sized particles. These particles are thought to aggregate in a hierarchy of structures that have different types of bonds at different sizes of aggregates. Small particles < 2 um (micron) are bound by oxide (rust) bridging. Particles 2 to 20 um (silt sized aggregates) are thought to be bound by humified organic materials. Particles 20 to 250 um (fine sand sized aggregates) are thought to be stabilized by microbial mucilages and partially degraded plant parts. Particles greater than 250 um are thought to be stabilized by fungal hyphae and root hairs. Particles smaller than 250 um are all grouped under the category of "micro-aggregates," while particles greater than 250 um are grouped as "macro-aggregates."

If each general scale of aggregation is predominantly stabilized by different structures or methods, substrates that are missing one characteristic or another would be expected to be less well aggregated in that size fraction. For example, substrates with clay sized aggregates but few large macroaggregates would be expected to settle and be hard packed unless mechanically mixed. This occurs in agricultural systems that require tillage every few years. These microaggregates are very stable, so even years later, tillage and plant growth can regenerate productivity on these soils. High mountain soils such as around Lake Tahoe have the opposite characteristic. These substrates have macro-aggregate structure stabilized by roots and mycorrhizal fungi but little or no microaggregate structure. They are very susceptible to loss of structure, becoming uniformly massive and having very low infiltration. Even tillage will not induce porosity beyond the first saturating rain. These substrates are typical of Caltrans construction impacted substrates that tend to repeatedly return to a massive, low infiltration state.

Construction-impacted substrates have several deficiencies. Typically, they have very low clay and oxide contents. This reduces strength and extent of the smallest and strongest microaggregates. They typically have very low stabilized (humified) organic matter. This reduces the strength and extent of mid-sized aggregates. Since they are unvegetated, they typically have very low macro aggregates that are otherwise stabilized by fine roots and mycorrhizal fungi. The interaction of these substrate deficiencies with the processes needed to regenerate aggregates explains the low levels of aggregation in construction-impacted substrates.

Lack of clay, oxides, stabilized organics and roots or hyphae would seem to indicate that aggregates would never be observed in high elevation soils. The soils would be expected to settle and compact, infiltration would be expected to be low, bulk density high, and overland flow would be expected any time rain impinged on these surfaces. But, in fact, undisturbed high elevation soils are erosion resistant, but mainly when undisturbed. The purpose of contrasting the known processes of aggregate formation with common deficiency characteristics of high elevation soils is to point out that some process is, in fact, working on these substrates, but it is probably not the same process as occurs on agricultural or range soils that have higher clay, oxide surfaces, stabilized organic matter and greater root and hyphal growth.

Literature review
Soil structure is defined as the size and arrangement of particles and pores in the soil (Hartge and Stewart, 1995). In many soils, where organic matter serves as the main binding agent, soil aggregates are formed in a hierarchical manner from primary particles to microaggregates to macroaggregates (Tisdall & Oades, 1982). Soil structure influences the ability of a soil to maintain good water infiltration rates and adequate aeration for plant growth (Kemper and Rosenau, 1986). Water infiltration rates and plant growth, in turn, are important factors that affect soil surface erosion. Soil structure is of well known importance for the sustainability of agriculture systems, and regenerating soil structure is also important for the process of revegetating drastically disturbed lands (all topsoil and biological activity removed) or chronically erosive sites with barren substrates or patchy vegetation.

Soil aggregation is a complex process in which numerous organisms and binding agents play a role (Tisdall and Oades 1982; Jastrow et al., 1997). However, there are several factors that make arbuscular mycorrhizal fungi (AMF) of particular importance in this process. In general, AMF are beneficial fungi that live in beneficial symbiosis with roots of grasses, forbs and shrubs, generally thought to exchange plant carbon for improved nutrient uptake and delivery by the fungi from the soil to the plant rooth. Besides the fact that AMF are ubiquitous soil organisms that have direct access to plant carbon, AMF and their diversity have been shown to be important controllers of plant community productivity (e.g. van der Heijden et al., 1998). Net primary production controls how much carbon eventually enters the soil as litter, and this in turn, is an important determinant of soil aggregation. In addition, AMF have a direct mechanistic affect on soil aggregation. The AMF hyphal growth form lends itself to stabilizing structures, similar to the root system of a plant (Jastrow et al., 1997), and is hypothesized to act at the macroaggregate level (e.g. Miller and Jastrow, 2002). Finally, AMF may promote soil aggregation biochemically via glomalin, a highly stable protein produced in AMF hyphae (Wright and Upadhyaya, 1996). Glomalin is abundant in the soil and is highly positively correlated with aggregate stability in a number of different soils (Wright and Upadhyaya, 1998). In addition, glomalin persists in the soil after AMF hyphae have decayed (Rillig et al., 2001). The persistence of glomalin makes AMF important in longer-term aggregate stabilization (Miller and Jastrow, 2002).

The primary objective of this study is to look at the relationship between glomalin and aggregate stability at a variety of sites that are characterized by patchy vegetation and soil surface erosion. First, we will determine if there is a positive correlation between vegetative growth, aggregate stability and glomalin by assaying aggregate stability and glomalin levels underneath vegetation and in plant interspaces. We will also assay organic and inorganic C and N levels, water-holding capacity, and water infiltration rates since these are all positively correlated with aggregate stability. If we find that there is a positive correlation between these factors, especially glomalin and aggregate stability, we will then determine if different levels of glomalin are associated with different plant species. Bird et al. (2002) assayed the glomalin levels associated with black grama (*Bouteloua eriopoda*) and mesquite (*Prosopis glandulosa*) in a semiarid rangeland and found that glomalin levels were significantly higher under mesquite. Although it's not clear whether this was due to a difference in net plant productivity or the associated AMF community, the difference was positively correlated with soil aggregate stability.

Aggregate strength (overview)

Aggregated soils were identified from under decade-old soils forming under shrubs at several cut slope locations. These aggregates were then subjected to increasing levels of sonic energy that is designed to disrupt aggregates starting with weaker aggregates and progressing to stronger aggregates. After each increment of sonication of increasing power, the apparent particle size distribution was remeasured. Changes in particle size distribution showed the breakdown of large aggregates into smaller component particles, if they were present.

Aggregate Stability Methods

All laboratory methods, statistical analyses, and calculations were conducted according to Fristensky (2007), with the following modifications: (1) ultrasonic processing was conducted at 50% amplitude; (2) ultrasonic processing was applied at 11 separate durations between 0 and 1575 seconds; (3) sample replicates contained 3 grams oven-dry equivalent weight soil; and (4) samples were processed in 50 ml capacity round-bottom glass centrifuge tubes.

Soil samples were obtained from surface soil beneath the canopy of 3 different PUTR plants. For each soil sample obtained from vegetated soil ("Canopy"), a sample was obtained from nearby unvegetated soil ("Gap"). Each set of Canopy and Gap samples were sieved to <2mm, and homogenized.

1.5.3. Ultrasonic Processing

Ultrasonic processing of soil samples was based closely upon the method and experimental investigations presented in Raine and So (1993, 1994). The ultrasonic processor used in the analysis was a Vibra-Cell® VCX-130, operating at 20 kHz with a maximum power output of 130-watts, and using a 113mm length, 6mm diameter titanium-alloy probe. Subsamples of 4 grams oven-dry equivalent weight each were processed in 45 mL centrifuge tubes (1.5 cm radius) in 30 mL of DI water (DI water was exposed to open air for >48 hours, to obtain consistent dissolved gas concentration during processing (Raine and So, 1994). The soil wetting method consisted of rapid immersion in DI water, 30-60 minutes prior to processing. The ultrasonic probe was inserted into the soil suspension to a depth of 1.43 cm, with the probe centerline 0.6 cm from the centrifuge wall. During ultrasonic treatment, subsamples were insulated with a 0.25 cm-thick polyurethane foam sheath tightly set within an 8x9x14 cm polystyrene block, together with a polystyrene cap with holes for the ultrasonic and temperature probes.

Temperature was measured during processing with a 24.5 cm, 0.318 cm diameter bendable 3-pin RTD integral-handle temperature probe (maximum error ±1.1°C + 0.12% of reading below 300°F; alpha-coefficient 0.003850 Ω/Ω/°C; 10-second time constant), and a Digi-Sense® (Cole-Parmer Instrument Co, Vernon Hills, IL) ThermologR™ digital RTD thermometer; with a stated accuracy of ±0.03°C at 0.01°C resolution within 10-40°C. The RTD probe was bent to approximately 40 degrees, 13.97 cm from the probe tip (to allow access to the suspension during processing), and was inserted to a depth of 6.19 cm, radially located 1.2 cm from the ultrasonic probe centerline. Temperature of the soil suspension during ultrasonic treatment was recorded at 1 second intervals. Recorded data was transferred by an infrared adapter to a laptop computer via Microsoft® HyperTerminal (Version 5.1, Microsoft Corporation, Redmond, WA, 1981-2001). The cooling characteristic curve of the system (probes, suspension, centrifuge tube, insulation material) was determined by heating a soil suspension to 40°C with the ultrasonic probe, and recording temperature at 10 second intervals until the soil suspension reached 24°C (consistent ambient temperature in the laboratory was approximately 23.5°C). Using JMP® statistical software, data representing the time derivative of a sixth-order polynomial regression function describing system cooling rate was fit with a second-order polynomial function (all polynomials were centered) with respect to temperature; thereby obtaining the cooling characteristic curve as a function of suspension temperature. The prediction equation obtained by this analysis was

$$T'_c[T] = 0.00411 - 0.00017*T - 0.000002*(T-29.5032)^2 \quad \text{for } T>23.5°\text{C} \qquad [27]$$

where T'_c is the rate of cooling (°C s^{-1}) at a given level of suspension temperature T. For T<23.5°C (i.e. less than room temperature), T'_c was assumed equal to zero.

The estimated standard error for an individual prediction of system cooling rate at a level of T was conservatively estimated as the largest individual standard error calculated by JMP for the cooling characteristic curve. This value was determined to be 7.16×10^{-6} °C s^{-1}; corresponding to the standard error of a prediction at 40°C. It was assumed that the cooling characteristic curve for an incompletely dispersed suspension did not significantly differ from that of a completely dispersed suspension.

Heat capacity of the non-suspension components of the container (i.e. centrifuge tube, insulation material, probes) was determined according to method of mixtures (as used in Roscoe et al., 2000). A mass of water (m_1) of a given temperature (T_1) is combined with a mass of water (m_2) of lower temperature (T_2) already in the container, after which the equilibrium temperature (T_3) is measured:

$$m_1 c_{h2o}(T_1 - T_3) = (C_{cont} + m_2 c_{h2o})(T_3 - T_2) \quad \Rightarrow \quad C_{cont} = m_1 c_{h2o}\frac{(T_1 - T_2)}{(T_3 - T_2)} - m_2 c_{h2o} \qquad [28]$$

(heat lost from m_1) *(heat absorbed by m_2 and*

where C_{cont} is the heat capacity of the container, and c_{h2o} is the specific heat of water. The mixtures method was performed 5 times (using $m_1 = m_2 = 15$g, $T_1 \approx 55$°C, $T_2 \approx 24$°C), obtaining a calculated C_{cont} of 30.3±0.5SD J°C^{-1}. Assuming that the heat capacity of the soil mineral and organic matter fractions were equivalent to those employed by North (1976), the average heat capacity of the soil suspensions subject to ultrasonic treatment was calculated to be 129.9±0.2SD J°C^{-1}. Total system heat capacity was therefore calculated at 160.2±0.6SD J°C^{-1}.

Ultrasonic agitation of the soil suspension was conducted at constant amplitude for 12 different time periods – 0, 30, 60, 90, 150, 210, 330, 450, 690, 930, 1290, and 1650 seconds – in order to obtain a measure of the soil disruption over a wide range of applied energies. Three repetitions were performed for each period of applied energy. Processor amplitude was held constant at 60%, which was qualitatively determined to be the minimum amplitude able to produce enough turbulent mixing to maintain continuous circulation of the largest sand-sized particles. To minimize the effects of suspension temperature on applied power (Raine and So, 1994) and the susceptibility of aggregates to disruption, suspension temperature was maintained within the range of 20-35°C by cooling suspensions to 20°C in an ice bath after each 150-second period of applied energy.

Reduction in the applied power due to erosion of the titanium probe over time due to cavitation was minimized by gently abrading and polishing the probe tip with an emory cloth after each full soil sample was complete. Erosion of the probe tip with use is inevitable, occurring slowly at first, but accelerating rapidly with continued use. The effect upon applied power – and therefore upon the experimental results (Raine and So, 1997) – over time can be dramatic, due to alteration of the resonant frequency of the probe (Sonics and Materials Inc., 2002). To assess the degree of resonant frequency alteration, after each polishing, the probe was activated at 100% amplitude in the open air: if the processor watt-meter registered greater than 10 watts, or if a persistent high-pitch noise occurred (indicating an overload condition), the probe was replaced (Sonics

and Materials Inc., 2002). If the probe was found to be in good condition, the probe was then activated in pure water for 50 minutes at 50% amplitude; pursuant to observations of greater power output immediately following a polishing treatment until a very slight degree of erosion occurred. After the 50-minute period, power output was relatively consistent at a slightly lower level. In addition to probe care, consistency of results was monitored by including a reference sample with every processing cycle – results consistently different than the reference distribution prompted probe replacement.
The power of ultrasonic energy applied to the soil suspension, as well as the energy absorbed by disaggregation, was calculated according to the heat balance formula presented in Raine and So (1993). However, calculations of the rate of change of temperature (T) as a function of T differed slightly to that of Raine and So (1993). First, temperature readings were adjusted by 10 seconds to account for the measurement delay of the temperature probe. Second, for each individual continuous period of applied ultrasonic energy, a second-order polynomial was fitted to temperature (T) data as a function of time using JMP. As applied power declines with increasing suspension temperature (Raine and So, 1994), however, to facilitate comparison of the rate of change of T for the non-dispersed suspension to that of the dispersed system, dT/dt = T' needs to be calculated as a function of suspension temperature. Accordingly, a second-order polynomial was fitted to T' as a function of T. For all but the final continuous period of applied energy, the individual standard error of all predicted T' as a function of T was calculated using JMP. As JMP could not generate a prediction equation for individual standard errors at any level of suspension temperature, the individual standard error of T'(T) for all T for the final (dispersed) period of applied energy was estimated using the prediction standard error, and multiplying by 10. This generated a conservative estimate of the uncertainty of an individual prediction of T'(T) for the dispersed soil. Propagation of uncertainty for all derived statistics was calculated according to the formula presented in the *Derived Statistics* section above.

Employing this analysis approach, the average rate of ultrasonic energy applied to the soil suspension was determined to be 14.2±0.2SE W (by comparison, a power of 8.9W was used in Raine and So, 1993). Maximum energy applied to suspensions was 5838±29SE J g^{-1} soil, or 753±4SE J L^{-1} of water. Total calculated ultrasonic energy absorbed by aggregate fragmentation and dispersion (or "dispersive" energy) was 34±3SE J g^{-1}; which is comparable to values reported in Raine and So (1993). Table III lists the calculated cumulative applied and dispersive energy for each period of applied energy.

Table III. Calculated applied and dispersive energy and associated standard error (SE).

Time (s)	Energy Applied (J)	SE	Energy Applied J/g	SE	Energy Applied J/mL	SE	Dispersive Energy (J)	SE	Dispersive Energy (J/g)	SE
30	433	2	108	1	14	0	-5	0	-1	0
60	861	4	215	1	28	0	-6	0	-2	0
90	1286	6	321	2	41	0	-5	1	-1	0
150	2127	11	532	3	69	0	8	1	2	0
210	2985	15	746	4	96	0	16	2	4	0
330	4679	24	1170	6	151	1	28	3	7	1
450	6371	32	1593	8	206	1	43	4	11	1
690	9778	49	2444	12	315	2	71	6	18	1
930	13167	66	3292	17	425	2	99	8	25	2
1290	18259	92	4565	23	589	3	126	11	32	3
1650	**23355**	**117**	**5839**	**29**	**753**	**4**	**136**	**13**	**34**	**3**

1.5.4. Particle-Size Analysis

Particle-size analysis of processed soil suspensions was performed using a Beckman-Coulter LS-230 laser light diffraction particle-size analyzer. The laser light diffraction technique calculates the particle-size distribution (PSD) of a suspension of particles by measuring forward diffraction of light from particles within the path of the laser (Beuselinck et al., 1998; Eschel et al., 2004). The soil PSD is calculated (using an optical model such as the Fraunhofer diffraction model or the Mie Theory) according to diffraction angle of a 750nm monochromatic light beam: the degree of diffraction is inversely proportional to particle-size; and beam intensity is correlated with the number of particles within the beam path (Eschel et al., 2004). This technique calculates the PSD in units of volume, based upon the detected size distribution (Eschel et al., 2004). The LS-230 is capable of measuring particle-sizes within the range of 0.04 μm to 2000 μm. LS-230 software version 3.29 was used for the analysis, and the soil PSD was calculated according to the Mie Theory. Samples were analyzed with the LS-230 within approximately 4-7 hours of ultrasonic treatment (samples left overnight before analyzing tended to display an unexpected (coarser) distribution). Samples (previously sieved to <2 mm) were poured through a 2 mm sieve into the detection chamber pool (particles suspended by turbulent circulation of the chamber pool created by an internal pump), and diluted to the optimal optical obscuration and Polarization Intensity Differential Scattering (PIDS) ranges (8-12% and 40-55%, respectively). Preliminary tests (data not shown) involving multiple suspensions of varying concentration and soil texture indicated that the extent of dilution needed within the LS-230 detection chamber did not have a noticeable impact upon the measured soil PSD. Information obtained from the LS-230 PSD analysis included the volume (percent of total) of the soil particle size fractions: <1000 μm, <250 μm, <20 μm, and <2 μm. From these data, the percent volume of the discrete particle-size ranges [2000-1000 μm], [1000-250 μm], [250-20 μm], [20-2 μm], and [2-0.04 μm] was calculated. These particle-size fractions are labeled as tiers A through E, respectively.

3.3. Conceptual Flowchart for Isolation and Analysis of the [C/N] of Particles Liberated from Aggregates Disrupted by Ultrasonic Energy

-- 5 particle-size subgroups will be isolated and analyzed:
<2 µm, 2-20 µm, 20-250 µm, 250-1000 µm, and 1000-2000 µm
--Various levels of ultrasonic energy will be applied, to analyze different aggregate cohorts.
-- 3-4 complete repetitions per energy level, in order to distinguish between results at different levels of applied energy.

SONICATED SAMPLE
(3 REPS @ GIVEN ENERGY LEVEL x 4g PER REP = ***12g****)*

↓

WASH THRU 1000 µm AND 250 µm SIEVES → DRY, WIEGH, AND ANALYZE 2000-1000 µm AND 250-1000 µm FRACTIONS.

INTO 1 L GRAD. CYL

↓

MAKE UP TO 1 L WITH DI WATER, MIX AND ALLOW APPROPRIATE PERIOD FOR EITHER <2 µm OR <20 µm PARTICLES TO SETTLE
(*SEPARATE RUNS NEEDED FOR <2 AND <20 µm SAMPLES IN ORDER TO OBTAIN ESTIMATES OF 2-20 µm FRACTION*)

↓

WITHDRAW ALL SUPERNATANT ABOVE SPECIFIED LEVEL IN COLUMN. → PUT IN LARGE (1L) BEAKER

↓

FILL AGAIN TO 1 L WITH DI WATER. MIX, AND REPEAT SETTLE/WITHDRAWAL PROCEDURE UNTIL SUPERNATANT IS CLEAR. → PUT IN LARGE (1L) BEAKER

PUT IN LARGE (1L) BEAKER → CENTRIFUGE UNTIL SETTLED. WITHDRAW/DISPOSE OF SUPERNATANT. → DRY, WEIGH, AND ANALYZE <2 OR <20µm FRACTION. → Obtain estimate of 2-20 µm conc. by subtraction of the <2 µm from the 2-20 µm.

↓

<u>FOR <20 µm RUNS</u>, ALLOW REMAINING PARTICLES TO COMPLETELY SETTLE. WITHDRAW/DISPOSE SUPERNATANT.

↓

DRY, WEIGH, AND ANALYZE 20-250 µm FRACTION REMAINING IN CYLINDER.

Mycorrhizal produced organics (glomalin) evaluation

Methods
Multiple samples were selected in each of two soil types: from under a plant canopy ("canopy"), and from non-vegetated areas between plant canopies ("gap" samples). Soil samples were taken from 0 to 10 cm depths. Surface litter was included in the samples. Samples were left to air dry for to constant weight. Soil was pressed through a 2-mm sieve and stored at room temperature until analyzed.

Fractions of glomalin are extracted from 1g whole soil samples. The easily-extracted glomalin (EEG) is extracted with 8 ml of 20 mM citrate, pH 7.0 at 121C for 60 min. Supernatant containing solubilized glomalin is separated by centrifugation at 3000xg for 15 min and decanted.

Total glomalin (TG) is extracted with 8 ml of 50 mM citrate, pH 8.0 at 121C for 60 min. Supernatant containing solubilized glomalin is separated by centrifugation at 3000xg for 15 min and decanted. This process is repeated as many times as necessary until the supernatant is straw-colored indicating all of the glomalin has been removed.

Glomalin is first quantified with a Bradford protein assay after autoclave-extraction from the soil. Assay values are extrapolated to mg/g of soil using the total volume of liquid containing solubilized EEG or TG and a correction of the original weight for coarse material. Following this first approximation, glomalin is further quantified using an enzyme-linked immunosorbent assay (ELISA) and the monoclonal antibody, MAb32B11, that has been developed against glomalin. The latter step increases the accuracy of glomalin quantification since other soil proteins may survive the extraction process.

3.3. Organic matter characterization

3.3.1. Aggregate Stability Assessment
3.3.1.1. Conway *Purshia tridentata* Canopy-Gap Pairs

Average power of ultrasonic energy application was 10.3 +/- 0.3(SE) Js^{-1} and 8.4 +/- 0.3(SE) Js^{-1} for the Canopy and Gap samples, respectively (differences in power application are due to erosion of the processor horn).

Table 1: Observed volume of aggregates per particle-size group.

Parameter	Soil	Particle-Size Interval (μm)				
		0.04 - 2	2 - 20	20 - 250	250 - 1000	1000 – 2000
Volume Aggregation (% of total soil)	Gap	ND	ND	ND	13.6^{A}_{A}	8.1^{B}_{B}
	Canopy	ND	ND	ND	11.8^{B}_{A}	20.6^{A}_{A}

Note: Columns not connected by the same subscript letter are significantly different at p<0.05.
Note: Rows not connected by the same superscript letter are significantly different at p<0.05.
ND = no aggregates detected.

Table 2: Ultrasonic aggregate stability indices, according to particle-size group.

Parameter	Soil	Particle-Size Interval (µm)				
		0.04 - 2	2 - 20	20 - 250	250 - 1000	1000 - 2000
E_{50}^{*} (J/g)	Gap	ND	ND	ND	317^{B}_{A}	28^{B}_{B}
	Canopy	ND	ND	ND	2118^{A}_{A}	206^{A}_{B}
Fragmentation Rate Constant (g/J)	Gap	ND	ND	ND	0.00211^{A}_{B}	0.02335^{A}_{A}
	Canopy	ND	ND	ND	0.00032^{B}_{B}	0.00336^{B}_{A}

Note: Columns not connected by the same subscript letter are significantly different at p<0.05.
Note: Rows not connected by the same superscript letter are significantly different at p<0.05.
$^{*}E_{50}$ = Energy (J/g) required to disrupt 50% of all aggregates within the specified particle-size interval.
ND = no aggregates detected.

Table 3: Size distribution of particles liberated from aggregates of specified size.

Parameter	Soil	Aggregate Size (um)	Particle-Size Interval (µm)				
			0.04 - 2	2 - 20	20 - 250	250 - 1000	1000 - 2000
Size Distribution of Liberated Particles (% per size range)	Gap	250 - 1000	55	45	0	n/a	n/a
		1000 - 2000	0	100	0	0	n/a
	Canopy	250 - 1000	16	63	20	n/a	n/a
		1000 - 2000	20	57	23	0	n/a

The Canopy and Gap soils did not differ in the total volume of aggregation for aggregates 250 – 1000 µm (Table 1). However, Canopy had significantly (p<0.05) greater aggregation than Gap for aggregates 1000 – 2000 µm, indicating that Canopy favored promotion of large macroaggregates relative to Gap.

The Canopy aggregates also exhibited significantly (p<0.05) greater resistance to fragmentation under ultrasonic agitation than the Gap aggregates for both the 250 – 1000 µm and 1000 – 2000 µm aggregate sizes (Table 2). These results suggest that the principal aggregate bonding mechanisms differ between the two soils, favoring greater strength of the Canopy aggregates.

The particle composition of aggregates appeared to differ between the two soils (Table 1). For Gap, all aggregates appeared to be composed of <20 µm particles. However, for Canopy, all aggregates appeared to include both <20 µm and 20 – 250 µm particles that were stable under ultrasonification (i.e. the 20 – 250 µm liberated particles did not appear to include microaggregates).

Altogether, these results indicate that the mechanisms of aggregate formation differed between these two soils, favoring both greater aggregation and aggregate stability of the Canopy soil.

Findings from Conway Purshia canopy - gap pairs

Soil samples were obtained from a highway road cut slope vegetated by PUTR, and subject to 11 different levels of ultrasonic energy up to 5400 Jg^{-1}. Soil samples obtained from under the canopy of PUTR exhibited significantly ($p<0.05$) greater volume of macroaggregates (1000 – 2000 μm) as well as significantly ($p<0.05$) greater aggregate stability of macroaggregates (250 – 2000 μm) than samples obtained from nearby unvegetated soil. Also, aggregates obtained from under the PUTR canopy were found to possess larger constituent particles (20 – 250 μm) than found in aggregates of equivalent size from unvegetated soil, although aggregates from both soils were predominantly composed of clay (<2 μm) and fine silt (2 – 20 μm) particles. These results suggest that the aggregate formation processes differed between the vegetated and unvegetated soil, the former favoring increased aggregation and aggregate stability.

3.3.1.1. Aggregate Stability Assessment: Conway LECI Canopy-Gap Pairs

Average power of ultrasonic energy application was 10.3 +/- 0.3(SE) Js^{-1} and 10.1 +/- 0.8(SE) Js^{-1} for the Canopy and Gap samples, respectively.

Table 1: Observed volume of aggregates per particle-size group.

Parameter	Soil	Particle-Size Interval (μm)				
		0.04 - 2	2 - 20	20 - 250	250 - 1000	1000 – 2000
Volume Aggregation (% of total soil)	Gap	ND	ND	30.8^{A}_{A}	14.6^{A}_{B}	ND
	Canopy	ND	ND	ND	13.2^{A}_{A}	9.3_{B}

Note: Columns not connected by the same subscript letter are significantly different at $p<0.05$.
Note: Rows not connected by the same superscript letter are significantly different at $p<0.05$.
ND = no aggregates detected.

Table 2: Ultrasonic aggregate stability indices, according to particle-size group.

Parameter	Soil	Particle-Size Interval (μm)				
		0.04 - 2	2 - 20	20 - 250	250 - 1000	1000 - 2000
E_{50}^{*} (J/g)	Gap	ND	ND	1549_{A}	980^{A}_{A}	ND
	Canopy	ND	ND	ND	1486^{A}_{A}	174^{A}_{B}
Fragmentation Rate Constant (g/J)	Gap	ND	ND	0.00046_{B}	0.0007^{A}_{A}	ND
	Canopy	ND	ND	ND	0.00047^{B}_{B}	0.00398^{A}_{A}

Note: Columns not connected by the same subscript letter are significantly different at $p<0.05$.
Note: Rows not connected by the same superscript letter are significantly different at $p<0.05$.
* E_{50} = Energy (J/g) required to disrupt 50% of all aggregates within the specified particle-size interval.
ND = no aggregates detected.

Table 3: Size distribution of particles liberated from aggregates of specified size.

Parameter	Soil	Aggregate Size (um)	Particle-Size Interval (μm)				
			0.04 - 2	2 - 20	20 - 250	250 - 1000	1000 - 2000
Size Distribution of Liberated Particles (% per size range)	Gap	20-250	0	100	n/a	n/a	n/a
		250 - 1000	91	9	0	n/a	n/a
		1000 - 2000	n/a	n/a	n/a	n/a	n/a
	Canopy	250 - 1000	37	56	7	n/a	n/a
		1000 - 2000	32	68	0	0	n/a

Findings for Leymus cinerus canopy - gap pairs

The Canopy and Gap soils did not differ in the volume of aggregation of 250-1000 μm. However, Canopy had 1000-2000 μm aggregates while Gap did not have aggregates of this size; and Gap had aggregates of size 20-250 μm while no aggregates of this size were detected in Canopy. Large uncertainty was observed for the Gap, such that estimates of the volume and stability of Gap samples have low reliability and should be interpreted with a caution.

The Canopy and Gap did not differ in the ultrasonic stability of 250-1000 μm not differ in the total volume of aggregation for aggregates 250 – 1000 μm (Table 1).

The particle composition of aggregates appeared to differ between the two soils (Table 1). For Gap, aggregates 250-1000 appeared to be composed of mostly of <2 μm particles, with a small fraction (~10%) of 2-20 μm particles; and 20-250 μm aggregates were composed entirely of 2-20 μm. For Canopy, all aggregates appeared to be composed of 2-20 μm (~60%) and <2 μm (~40%) particles.

3.3.1.2. Aggregate Stability Assessment – Blue Canyon Canopy-Gap Pairs

Results and Discussion

Average power of ultrasonic energy application was 10.2 +/- 0.2(SE) Js^{-1} and 10.4 +/- 0.3(SE) Js^{-1} for the Plant and Gap samples, respectively.

Table 1: Observed volume of aggregates per particle-size group.

Parameter	Soil	Particle-Size Interval (μm)				
		0.04 - 2	2 - 20	20 - 250	250 - 1000	1000 – 2000
Volume Aggregation (% of total soil)	Gap	ND	ND	ND	10.6^{B}_{B}	15.9^{A}_{A}
	Canopy	ND	ND	ND	17.8^{A}_{A}	14.2^{B}_{A}

Note: Columns not connected by the same subscript letter are significantly different at p<0.05.
Note: Rows not connected by the same superscript letter are significantly different at p<0.05.
ND = no aggregates detected.

Table 2: Ultrasonic aggregate stability indices, according to particle-size group.

Parameter	Soil	Particle-Size Interval (µm)				
		0.04 - 2	2 - 20	20 - 250	250 - 1000	1000 – 2000
E_{50}* (J/g)	Gap	ND	ND	ND	813^{A}_{A}	813^{A}_{A}
	Plant	ND	ND	ND	966^{A}_{A}	966^{A}_{A}
Fragmentation Rate Constant (g/J)	Gap	ND	ND	ND	0.000852^{A}_{A}	0.000852^{A}_{A}
	Plant	ND	ND	ND	0.000718^{A}_{A}	0.000718^{A}_{A}

Note: <u>Columns</u> not connected by the same <u>subscript</u> letter are significantly different at $p<0.05$.
Note: <u>Rows</u> not connected by the same <u>superscript</u> letter are significantly different at $p<0.05$.
* E_{50} = Energy (J/g) required to disrupt 50% of all aggregates within the specified particle-size interval.
ND = no aggregates detected.

Table 3: Size distribution of particles liberated from aggregates of specified size.

Parameter	Soil	Aggregate Size (um)	Particle-Size Interval (µm)				
			0.04 - 2	2 - 20	20 - 250	250 - 1000	1000 - 2000
Size Distribution of Liberated Particles (% per size range)	Gap	250 - 2000	18	45	38	n/a	n/a
	Plant	250 - 2000	19	50	31	n/a	n/a

The vegetated sample exhibited significantly ($p<0.05$) greater volume of 250-1000 µm aggregates than the unvegetated sample, no other differences in aggregate volume were observed.

The vegetated and unvegetated samples did not significantly differ with respect to their resistance to ultrasonic agitation, or in the particle-size distribution of aggregate constituent particles.

<u>Summary</u>

Sample pairs were obtained from vegetated and unvegetated soil on a highway road cut slope near Blue Canyon, and subject to 11 different levels of ultrasonic energy up to 5500 Jg^{-1}. Total volume of aggregation, aggregate stability, and particle-size distribution of aggregate constituent particles were calculated with respect to 5 selected particle-size intervals. The vegetated samples had significantly ($p<0.05$) greater total volume of 250-1000 µm macroaggregates, but otherwise did not significantly differ from the unvegetated samples.

3.3.1.3. Aggregate Stability Assessment – Bullion Bend Deep-Top Pairs

Results and Discussion

Average power of ultrasonic energy application was 10.0 +/- 0.3(SE) Js^{-1} and 9.9 +/- 0.1(SE) Js^{-1} for the Top and Deep samples, respectively.

Table 1: Observed volume of aggregates per particle-size group.

Parameter	Soil	Particle-Size Interval (μm)				
		0.04 - 2	2 - 20	20 - 250	250 - 1000	1000 – 2000
Volume Aggregation (% of total soil)	Top (veg)	ND	ND	ND	6.8^{A}_{A}	2.3_{B}
	Deep (non-veg)	ND	ND	ND	7.2^{A}	ND

Note: Columns not connected by the same subscript letter are significantly different at p<0.05.
Note: Rows not connected by the same superscript letter are significantly different at p<0.05.
ND = no aggregates detected.

Table 2: Ultrasonic aggregate stability indices, according to particle-size group.

Parameter	Soil	Particle-Size Interval (μm)				
		0.04 - 2	2 - 20	20 - 250	250 - 1000	1000 - 2000
E_{50}* (J/g)	Top (veg)	ND	ND	ND	1791^{A}_{A}	1791_{A}
	Deep (non-veg)	ND	ND	ND	50^{B}	ND
Fragmentation Rate Constant (g/J)	Top (veg)	ND	ND	ND	0.000387^{B}_{A}	0.000387_{A}
	Deep (non-veg)	ND	ND	ND	0.0140^{A}	ND

Note: Columns not connected by the same subscript letter are significantly different at p<0.05.
Note: Rows not connected by the same superscript letter are significantly different at p<0.05.
* E_{50} = Energy (J/g) required to disrupt 50% of all aggregates within the specified particle-size interval.
ND = no aggregates detected.

Table 3: Size distribution of particles liberated from aggregates of specified size.

Parameter	Soil	Aggregate Size (um)	Particle-Size Interval (μm)				
			0.04 - 2	2 - 20	20 - 250	250 - 1000	1000 - 2000
Size Distribution of Liberated Particles (% per size range)	Top (veg)	250 - 2000	9	51	40	n/a	n/a
	Deep (non-veg)	250 - 1000	15	56	28	n/a	n/a
		1000 - 2000	n/a	n/a	n/a	n/a	n/a

The Top and Deep soils did not differ in the total volume of aggregation for aggregates 250 – 1000 µm (Table 1). However, Top had a small volume of 1000-2000 µm aggregates, while no aggregates of this size were observed for Gap.

The Top aggregates 250 – 1000 µm exhibited significantly ($p<0.05$) greater resistance to fragmentation relative to those of Deep (Table 2). These results suggest that the principal aggregate bonding mechanisms differ between the two soils, favoring greater ultrasonic stability of the Top aggregates.

The particle composition of aggregates did not appear to differ significantly between the two soils (Table 3), although the Top aggregates appeared to liberate a somewhat greater proportion of 20-250 µm particles than the Deep aggregates.

Summary

Soil samples were obtained from a highway road cut slope, and subject to 11 different levels of ultrasonic energy up to 5400 Jg^{-1}. A small volume (~7-10% of total soil volume) of macroaggregates (250-1000 µm) was found in soil obtained from both the surface soil (Top) and soil obtained 1 m below the surface (Deep). Only Top was found to have aggregates 1000-2000 µm (albeit a very small amount). The Top sample exhibited significantly ($p<0.05$) greater aggregate stability Deep. The particle composition of aggregates did not appear to differ significantly between the two soils (Table 3), although the Top aggregates appeared to liberate a somewhat greater proportion of 20-250 µm particles than the Deep aggregates. These results suggest the presence of different aggregate bonding processes between 250-1000 µm aggregates of Top and Deep, with those of the former favoring greater ultrasonic stability.

The remaining question, then, is how are these substrates being aggregated if they do not have the clay content or soil organic matter to do so? The answer is partly given by analysis of the soil under the plant canopy compared to the gap substrates. Differential thermal analysis is a technique to steadily heat up the sample and measure when different materials burn (give off heat) or melt (soak up heat). These tests (Fig 1) show a large peak at 350 º for the canopy substrates that is missing from the gap soil samples. Chemicals degrading at this temperature are typically straight chain (“aliphatic”), and include sugars, starches and cellulose, along with petroleum products. Absent from these spectra is a peak at 550º, which would indicate the stabilized topsoil humic materials that aggregate particles on typical soils. This information suggests that humics are not functional for aggregation in these substrates, but that some source of straight chain organic molecule is present and related to the process.

Differential Thermal analysis of organics.

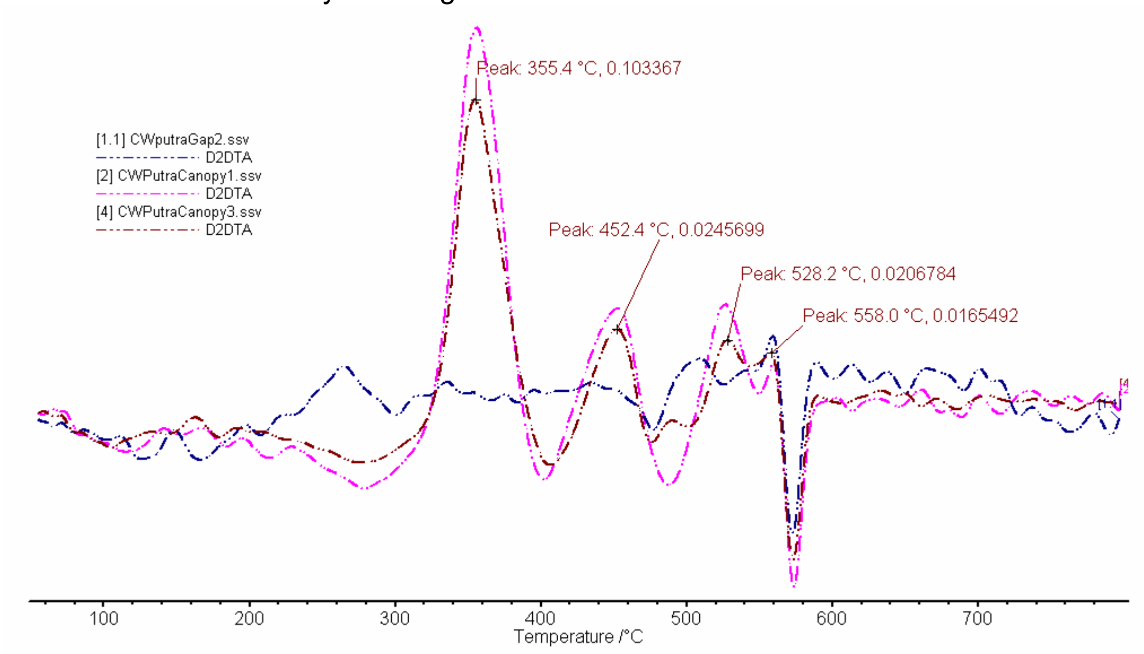


Figure 1. Differential thermal analysis of Conway summit canopy samples (magenta and brown lines) versus gap substrates (dark blue line).

The types of chemicals suspected are plant exudates, sugars and amino acids, but these sites are quite low in plant productivity compared to lower elevations, as a result of dry and cold climate conditions. Another alternative is fungal produced organics, which are much more resistant to decomposition, perhaps as a development to improve the environment of fungi, which are aerobic and must maintain soil drainage to survive. The suspect here is glomalin, a very resistant glyco-protein (sugar-protein) molecule. Two assays were used to test whether this material is accumulating in the aggregated canopy soils. First, a general protein assay was used on a wide range of soils. This expedient test identified substrates that had organics that may be glomalin. On these subsamples, a second enzyme biochemistry test (ELISA, enzyme linked immuno assay) was used that is specific to mycorrhizal produced glomalin. The results confirmed that mycorrhizal glomalin was present in these canopy samples. Secondly, when larger aggregates were sonicated and broken down into their component parts, the signal for the glomalin also came to be detected in the silt and clay products of dis-aggregation, and no longer in the sand sized fraction that remained. This indicates that, on these substrates that would not be expected to aggregate by conventional methods, the fine particles are being held together by resistant organics produced by mycorrhizal fungi without the hierarchy of formation assumed to occur in other aggregate studies. These glomalin tests are presented below.

3.3.2. Mycorrhizal-produced organics (glomalin) evaluation

3.3.2.1. Canopy - gap comparisions

Elisa assays (glomalin specific)

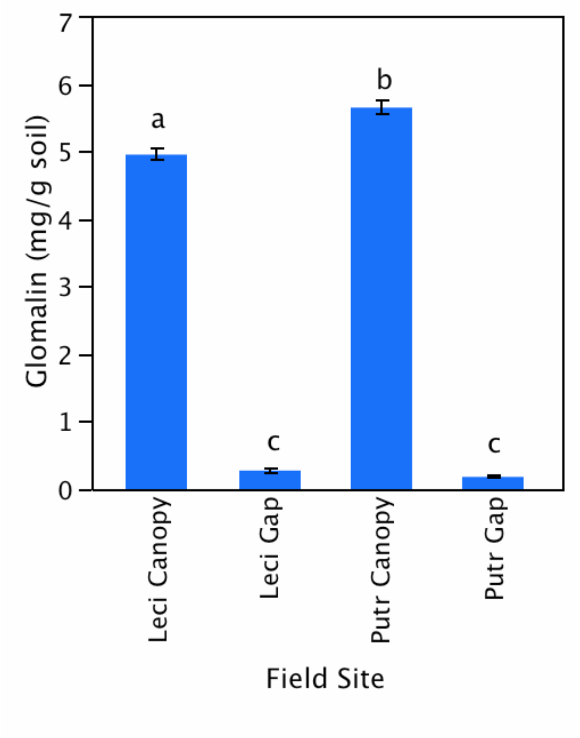


Fig 2. Content of mycorrhizal exudate (glomalin) using ELISA test method on basin wildrye (Leci) and antelope bitterbrush (Putr) vegetation samples at the Conway summit cut slope (MON 395).

Aggregates in the 1000 - 2000 um size range of the *Purshia* canopy soil comprised 20.6 % of the total soil volume compared to only 8.1 % in the gap soil. The *Purshia* canopy also had over 4 times greater infiltration rate. These canopy soils had a correspondingly greater glomalin content (Fig 2) compared to gap soils. Similarly, canopy soils under *Leymus* had 9.3 % of the soil volume formed of aggregates, while the gap had none and the *Leymus* canopy had 50% greater infiltration. Glomalin contents were also much higher in the *Leymus* canopy compared to the gap.

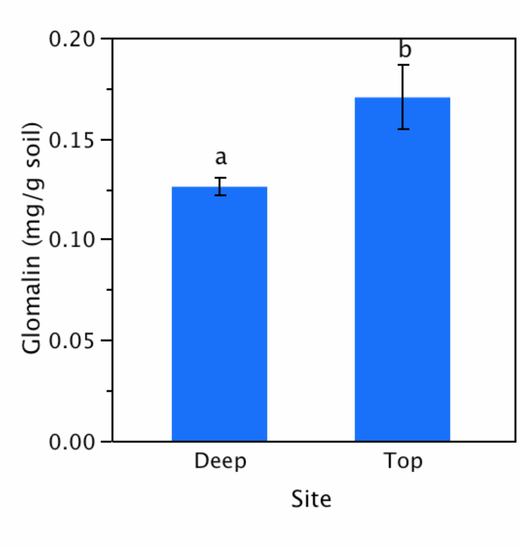


Fig 3. Content of mycorrhizal exudate (glomalin) associated with grass vegetation versus non-vegetated soils from the Bullion Bend fill site (ELD 50).

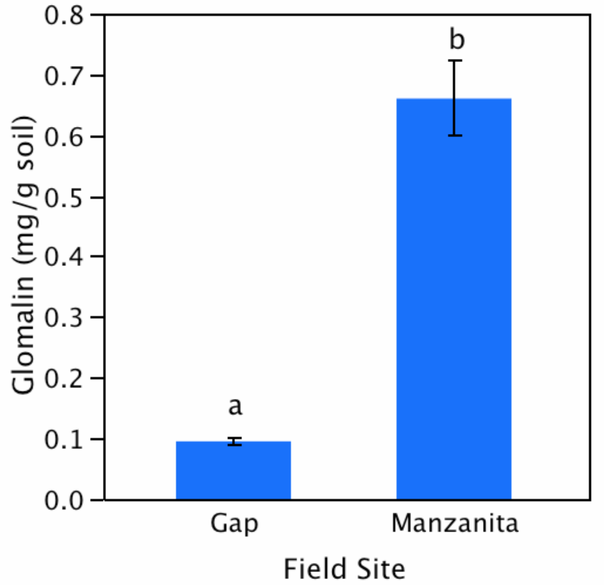


Fig 4. Content of mycorrhizal exudate (glomalin) associated with manzanita canopy soils versus non-vegetated gap soils at the Blue Canyon cut site (PLA 50).

Substrates at this site were only weakly aggregated (Table 1). Even so, the rooting of native grasses has elevated glomalin in the soil horizons with roots compared to the non-rooted (deep) volumes. However, these levels are about 2 or 3 % of those measured in the better aggregated soils at Conway Summit. Infiltration levels were less in the vegetated (top) soils than the non-vegetated (deep). Evidently, the accumulated glomalin was not functioning to increase infiltration.

Although aggregate content of the soil was similar in the 1000- 2000 um range, the 250- 1000 um range had significantly more (17.8 %) aggregates than the gap soil (10.6 %). More glomalin was isolated from the Manzanita canopy soil than from the barren gap soil. But, these glomalin levels are about 10 % of those measured at Conway Summit.

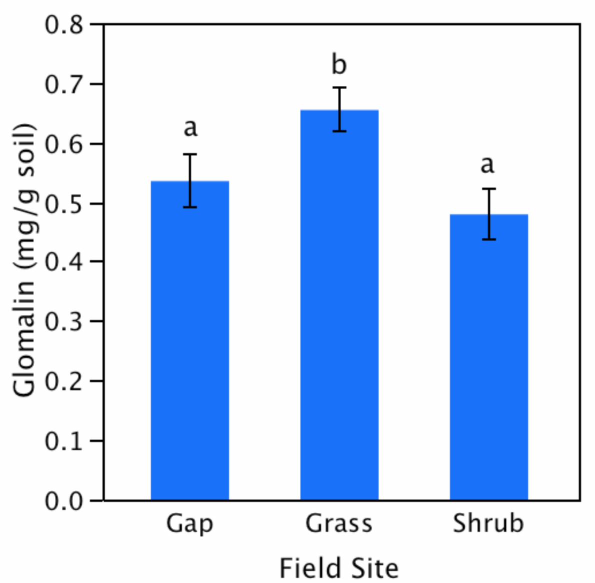


Fig 5. Content of mycorrhizal exudate (glomalin) associated with different vegetation at the Meyers chain-on (ELD 50 x 89).

The glomalin levels show slight increase under grass plants, but this is not expected to be relevant in field situations. These soils may aggregate poorly due to their decomposed granite mineralogy, or plant growth may not have occurred for a sufficient time, or the plant and mycorrhizal combination may have been suboptimal.

The summary finding for this section is that plant canopy soils consistently have higher mycorrhizal organics (glomalin) but that the levels that have accumulated differ greatly. Whether this is due to soil mineralogy or plant type or disturbance history is not known. The implemental finding is that the process occurs commonly, but may need to be optimized to become relevant to field situations, as is the situation in the Conway substrates.

3.3.2.2. Aggregate size fractions with mycorrhizal organics (glomalin)

Table 1. Key to organic matter fraction data.

1 = <2 um (clay sized particles)
2 = 2 - 20 um (silt sized particles)
3 = 20 - 250 um (fine sand sized particles)
4 = 250 - 1000 um (medium sand sized particles)
5 = 1000 - 2000 mm (coarse sand sized particles)
M = Mineral fraction of 1000 - 2000 mm
O = Organic fraction of 1000 - 2000 mm
Canopy 1-3 = non-fractionated soil
E0, E1, E2 = sonication energy levels

Data from Conway PUTR canopy samples
CANOPY

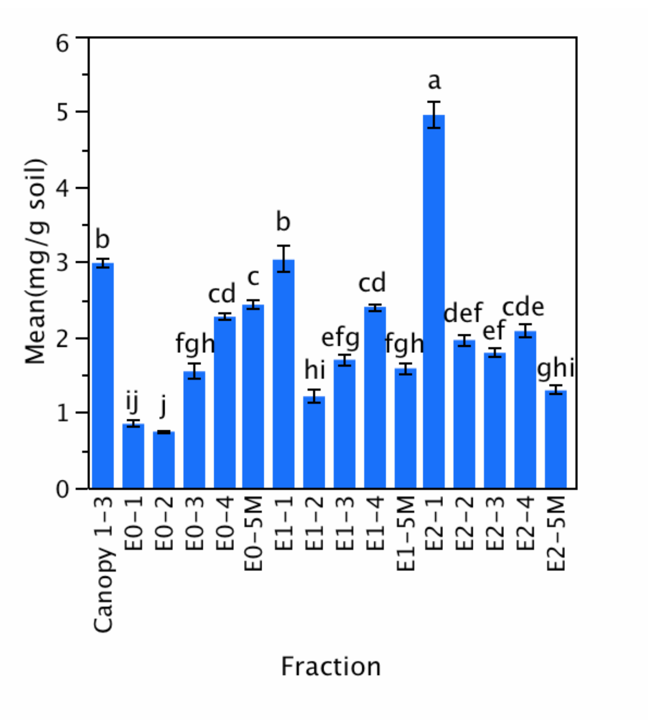


Figure 6. Canopy Samples without 1-2mm Organic Fraction

In Figure 6, the glomalin content of the canopy soil is graphed without the small organic chunks in the coarse sand fraction. This graph shows a pattern of increasing glomalin with size in unsonicated samples (E0 series) but decreasing glomalin in larger particle size fractions in samples sonicated with high energy (E2). This pattern confirms that the source of the aggregate binding strength is attributed to mycorrhizal produced glomalin and that the energy level delivered to E 2 samples is strong enough to break these larger particles down to clay sized primary particles. The process partially occurs in slightly sonicated samples (E1), indicating that some aggregates are weaker than others.

Data from Conway PUTR gap samples -- All fractions
GAP

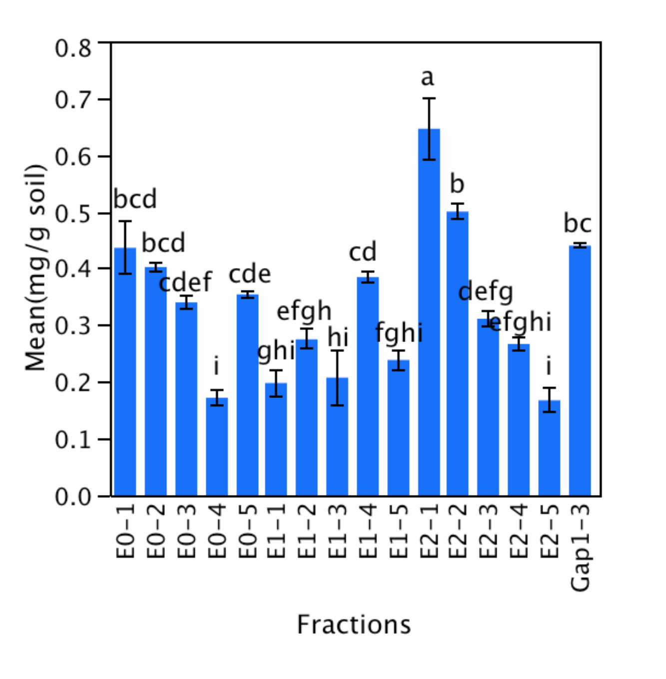


Figure 7. Gap Samples without 1-2mm Organic Fraction

The first trend observed between the Canopy (Fig 6) and the Gap (Fig 7) is that the gap samples are about 20 % as high as the canopy samples. The gap samples, collected between plant canopies with no visible organic matter content or inputs, indicate little change with energy and particle size fraction. The pattern of increased levels of glomalin content in clay sized fraction is similar whether the substrates are either not sonicated (E0) or intensely sonicated (E2). These gap samples do not show signs of soil aggregates associated with glomalin.

3.4. Aggregate regeneration

After four months growth of *Achillea millifolium* or *Elymus multisetus* with either commercial or ambient mycorrhizal inocula, plants in 0.5 L pots in growth chamber conditions on Conway summit substrate showed a significant ($p = 0.10$) increase in glomalin compared to uninoculated pots. This indicates that at least some of the components needed for aggregate generation (in this case, mycorrhizal exudation and/or glomalin production) start the first season after establishment. The application of this finding is to assure vigorous plant growth and mycorrhizal colonization soon after slope construction is completed.

Photo 4. Regeneration of small aggregates of fine soil into sand sized aggregates after four months of growth of Big squirreltail (*Elymus multisetus*) in growth chamber conditions.

3.5. Interim summary of aggregate and organic matter evaluation

The relatively unweathered ambient substrates at Conway Summit have little or no stabilized (humified) soil organic matter. With low clay and organic matter levels, aggregates would not be expected to occur. But, substrates under *Purshia tridentata* and *Leymus cinerus* canopies at Conway Summit show distinct, strong soil aggregates with increased infiltration and water holding capacity. This indicates the fundamental trend in sustainable soil-vegetation systems: a self improving, self sustaining process that assures continued plant growth. Slope water relations and stabilized organic matter for nutrient cycling and retention are key components of this process. The aggregation observed was shown to be caused by some type of aliphatic (straight chain, non-humified) carbon, as shown in the organic spectra (DTA) scans. This is interesting, because it shows that recent (< 10 years) organic inputs can substitute for the humic acid based aggregation that is typical of most existing soils. Further evaluation indicates that the source of these organics are mycorrhizal exudates or organics known as glomalin. They are sticky, resistant to decomposition, and are actively functioning to group silt and clay sized particles into sand sized particles that are more resistant to erosion and have higher infiltration rates. These organic-bound aggregates can be broken down by sonication from sand sized particles to silts and clays, with organic compounds still attached. This confirms that the aggregation process is stabilized by organics, not by inorganic bonding such as carbonates or oxide bridging. These organics are shown to begin to accumulate in growth chamber experiments with mycorrhizal *Achillea millifolium* and *Elymus multisetus* within four months of growth. This result indicates that the process starts even in the first season of growth.

The time until aggregates become functional for infiltration under field conditions is not known. Methods to improve (speed up or intensify) the process are also not known. But, these results show that the process can occur on slopes that are predominantly non-vegetated and erosive. The key treatments are to get vegetation established and prevent overland flow that removes the accumulated duff under plant canopies. Below ground, the mycorrhizal take over the process of forming erosive fines into stable sand sized particles.

Several sites had low or non-existent levels of aggregate formation (Bullion Bend and Meyers). Whether these differences reflect mineralogical or plant or climate or age-since-disturbance is not known. In addition, recent literature review and our own lab work indicates that the chemical and enzyme tests for glomalin are perhaps not as specific to this mycorrhizal-source organic as represented or as tested in our experimental conditions. Because of the large potential role that mycorrhizal organics play in site regeneration and creation of erosion resistant slope treatments, this lab test needs additional research work.

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Appendix A. Templin Demonstration

Soil Resource Evaluation: Templin Hwy Revegetation (DRAFT)

Soils and Revegetation Lab
Land, Air and Water Resources, UC Davis
February 18, 2008

Executive Summary:
A Soil Resource Evaluation (soil-based) approach was used to scope potential treatments for revegetation of the impacted site at I-5 and Templin Highway for revegetation and reduced sediment production. The more intensive of these treatments (substrate tillage to 3 feet (1 m), compost amendment of on inch (25 mm) layer that is incorporated to 10 in (250 mm), plus 2 in (50 mm) mulch cover) is expected to be able to reduce runoff to near zero under target storm conditions and to supply adequate conditions for sustainable plant growth, thereby reducing sediment production and surface erosion.

SRE Step 1. Identify impacted and relevant revegetated reference sites

Impacted site:
The Templin Hwy stabilization project is located immediately west and south of I-5 and Templin Highway in Los Angeles County (Figure 1, 2). The mass of the hill to the west of I-5 was removed for geotechnical purposes. This created 2:1 cut slopes and a large, very shallow cut slope, along with a deep valley fill area. This site was evaluated during a one day field visit by Vic Claassen, Monica Finn, Harry Clarke, and staff from District 7 on February 4, 2008. Soil samples were analyzed for nutrients and plans for soil treatment and vegetative stabilization were generated by Finn, Claassen and Clark, and constructed under a separate contract to P&D construction under Harry Clark projected for spring and summer 2008.

Geology:
The site is on sedimentary geology of fractured shales and sandstones. The general geography of the area has frequent examples of mass wasting with sparse to dense revegetation. The two soils are typical of the area are the Osito and the Trigo series soils.

The Osito series consists of shallow, well drained soils formed in material weathered from interbedded sandstone and shale. Osito soils are on uplands and have slopes of 15 to 70 percent. Mean annual precipitation is 17 inches (432 mm) and mean annual temperature is 58 ºF (14 ºC). The underlying weathered rock (Cr) horizon is light yellowish brown fine grained sandstone, highly fractured with fractures less than 1 mm wide and greater than l0 cm apart; fragments easily slake in water; easily cut with a spade, no roots (Soil Series Descriptions, NRCS).

The Trigo series consists of shallow, well drained soils formed in consolidated alluvium from mixed sources on dissected terraces. Slopes are 2 to 60 percent. The mean annual precipitation is about 10 inches and the mean annual temperature is about 61 ºF (16 ºC). The underlying weathered rock (Cr) horizon is white (10YR 8/2) softly consolidated stratified fine sandy alluvial sediments with a few lime seams in places, light gray (10YR 7/2) moist; firm when moist, does not slake in water. (Soil Series Description)

Reference sites:
An undisturbed Vegetated Reference Site is located in a coastal sage shrub community immediately north of the lower road entering Site 9 (Planting Plan 1) (Figure 3). This site has a south-facing slope, but is steeper than the main Impacted Site. No disturbed-but-revegetated reference site was identified during the site visit, but a fill slope located within the NE half of Site 9 indicates a likely erosion potential (Figure 4). The year-old, seeded portion at the north end of Site 5 indicates probable successful revegetation from seeded shrubs, forbs and grasses (Figure 5, 7, 8).

Visual evaluation of site condition:
Slope stability issues included both surface erosion and mass wasting. Surface erosion is not observed in the undisturbed vegetated slopes (Figure 3) although the surrounding geography shows historic slips and failures that have since revegetated (Figure 5). The fill slope for the access road in Site 9 (Figure 4) shows surface erosion (lag gravels, pedestalled gravels) that contribute to development of rills and gullies on the slope face. This erosion is not thought to involve runoff from the road because rills do not cut through the slope break at the road edge. The flat area comprising most of Site 5 has a shallow, construction disturbed overlay of disintegrated sedimentary rocks overlying low-permeability sedimentary rock in-place (Figures 10, 11). This appears to result in an insufficient infiltration capacity to retain rainfall amounts within the soil volume, contributing to increased overland flow. This flow was observed to break through the bonded fiber matrix hydromulch (BFM), creating head cuts around and under hardened water conveyences, and downcutting deep gullies at the outflow end of the excavated site (Figures 8 - 11) and the outflow end of the valley fill that received the excavated material (Figure 12).

The buttress slope shows surface erosion caused by low infiltration compared to the amount of rainfall received. This flow has peeled the BFM off the surface and has cut rills. Although geotechnically engineered, the slope is not surface stabilized other than through temporary BFM treatments (Figures 13, 14).

Vegetative cover:
No transects or species lists were compiled for the Impacted or Revegetated Reference Sites, since the local district was active on the site. Existing plans and plant lists were reviewed and appeared appropriate.

<u>SRE Step 2.0: Soil water relations</u>
Soil water relations involves infiltration rate, infiltration capacity and plant available water. Infiltration rate determines the ability of the substrate to imbibe intense storm events. Infiltration capacity determines the ability of the substrate to imbibe a volume of rainfall, such as from an extended, multi-storm sequence. Infiltration rates are reduced by formation of surface crusts, increased by mulch covers and soil aggregation. Infiltration capacity is increased by deep fractures that allow adequate percolation. Plant available water is the amount of moisture retained within the soil that is available for plant growth, and is determined by substrate texture, rooting depth and rock content.

SRE Step 2.1. Soil water relations: infiltration rate
The fractured sedimentary shales and siltstones on the site were observed to crumble readily when excavated, and then continue to weather and disintegrate within several

years to silt and clay sized particles upon exposure to surface weathering conditions. The textures observed in the field will become finer as the sedimentary rock fragments disintegrate, as shown by the fineness of the substrates at the Native Reference Site (Figure 3) and the exposed, graded soil/subsoil (Figure 4). Soil aggregation improves the infiltration of fine substrates, and is high enough in the native soil that no overland flow occurs even though the substrate is very clayey. In comparison, the non-aggregated exposed subsoil along the road is highly erosive (Figure 4). The addition of compost materials provides a physical approximation of aggregated soils, but composts decompose within a few years and this carbon input must be replaced by plant materials growing on site. The amount of compost needed for these site conditions was estimated, but was not measured. The speed of transition from compost function to site plant inputs is not characterized.

Preliminary storm data from a local weather station (Castiac Patrol Station Latitude 34.464º Longitude -188.616º, elevation 1066 feet (326 m) indicates that the 25 year return frequency precipitation rate for a one hour storm event is 0.97 in/hr (25 mm/hr) (Table 1). A 15 minute storm event is estimated to deliver 1.72 inches/hr (44 mm/hr). Preliminary data from our only other sedimentary geology site (LAK 20 49) indicates an infiltration rate of 3 in/hr (75 mm/hr), but this was on a one-year old slope with less sedimentary rock disintegration than at the Templin site. The Templin site substrates are expected to infiltrate more slowly.

Other infiltration data models indicate that the Templin site substrates (sandy loams, loams, clay loams or clays) will infiltrate moisture at 15, 7, 4 or 2 mm/hr (Table 2). These rates of steady state infiltration are far less than the 25 mm/hr storm event listed as an example storm. This suggests that overland flow can be expected to occur repeatedly without treatment on this site and that substrates should be treated to reduce sediment production. Aggregation of dispersed particles in these degraded substrates can increase infiltration. The native reference site has a clay soil texture, which models predict to have the lowest infiltration. But, it was the only substrate that showed NO overland flow during this season's rain events. This occurs because the soil particles are aggregated, which allows this clay textured material to function as if it is a coarse sandy loam, loamy sand or sand substrate material. These materials are modeled to have infiltration rates greater than 1 in/hr (25 mm/hr).

After treatment with compost and ripping, a maximum infiltration rate of 8.0 in/hr (204 mm/hr) was measured, compared to 1.2 in/hr (30 mm/hr) on the non-tilled areas, and 2.1 in/hr (52 mm/hr) on areas with the existing 8 to 10 inches (200 to 250 mm) of loose graded material. The interpretation of these results is that the non-ripped areas will have infiltration approximately equal to a 25 return frequency storm, depending on whether it occurs at a 15 minute (1.72 inches / hr) or 1 hour intensity (0.97 inches/hr). The treated substrate (compost and rip) infiltrated 8 in/hr (204 mm/hr), which is adequate for a 24 hour storm of 500 to 1000 year return frequency. This infiltration amount is estimated to occur within one hour. But, the *rate* of infiltration is not the limiting factor of the shallow (8 -10 inch) loose overlay, it is the *amount* of water volume that can be imbibed that becomes limiting, as discussed in the next section.

TREATMENT RECOMMENDATION: Apply a 25 mm (1 inch) yard waste compost layer, to be tilled into the top 250 mm (10 inches) of existing substrate (275 mm (11 inch) overall tillage depth). Application of a 50 mm (2 inch) layer of coarse shredded organics applied as a surface mulch is recommended. (note: the generic application of one inch compost and two inches wood shreds is not followed on this site because the substrates are clayey and less likely to settle and close pack, and because the site is droughty and the root-mineral soil contact should not be decreased by this amount of organic amendment - vpc)

SRE Step 2.2: Soil water relations: infiltration capacity.

The second component of infiltration capacity is the volume of water that can be imbibed before the substrate becomes saturated. If the crushed sedimentary rock that covers the Site 5 surface is 10 in (250 mm) thick (estimated) and has 20 % water holding capacity, then rain events greater than 2 in (50 mm) will saturate the profile and create the potential for overland flow if additional rain occurs. The Castaic Junction weather data (Table 3) indicate that this occurs within a 24 hour period every 2 years, 12 hour period every 5 years, within a 6 hour period every 10 years, or within a 4 hour period every 25 to 50 years. The soil must be able to drain and recharge its infiltration capacity within these time periods in order to avoid overland flow during subsequent rain events.

If a scenario is evaluated in which the soil is already saturated from snowmelt or steady rains (high antecedent moisture content), the additional amount of reserve infiltration capacity that needs to occur on this site can be estimated, to ensure that no runoff will occur. As an example, a 20 year, one day storm in Castaic Junction (elev 1001 feet) delivers 4.4 in (111 mm) of moisture, while a 20 year, three day storm delivers 6.6 in (168 mm) moisture and a 20 year, five day storm delivers 7.8 in (197 mm). Assuming a 30 % water holding capacity of a dry soil, this water volume can be imbibed in substrate depths of 15, 22 or 26 in (370, 560, and 657 mm). If the soil is damp, however, a lower water holding capacity is assumed, such as 20 %. In this case the soil depth required would be greater, such as 22, 33, or 39 inches (555, 840, or 985 mm) of substrate depth. Using this reasoning, a five day storm of the intensity of one in twenty years would yield no surface runoff if the substrate was ripped to 26 in (660 mm) ripped treatment (beneath the existing unconsolidated overlay) if the soil is dry, or if the substrate is ripped to 39 in (990 mm) if the soil were damp. This assumes no surface infiltration limitations. On comparable sedimentary rock substrates at LAK 20 46, subsurface infiltration was 2 to 6 times greater than the surface horizons, due to rock fragmentation. Infiltration within the zone of tilled and fractured rock is not expected to be limiting.

TREATMENT RECOMMENDATION: Increase deep infiltration by fracturing the sedimentary substrate to 39 inches (1 m) depth, either by ripping or excavating. Tilled substrate volumes must rest on a horizontal base, as with benches or steps, or on a rough surface that keys the disturbed substrates to the underlying in-place rock matrix without forming a sloped, planar surface. No other soil amendments are required for this fractured sub-soil volume. Deep rip tillage should be followed by one pass with a coarse disc to knock tilled surface down to less than 6 in (150 mm) fragments.

SRE Step 2.3. Soil water relations: plant available water

Because of the need to add organics to the soil as the sedimentary rocks weather and disintegrate, vigorous, sustained plant growth is required. When mature, plants in coastal sage scrub annually produce about 3036 lb/ac (3400 kg/ha) of organic matter litter and roots (about 6 % of a one inch (25 mm) compost amendment), and so are necessary to continue carbon inputs and soil development after initial treatments decompose.

Water use by a target plant species (coyotebush; *Baccharis pilularis*) in the San Diego area indicated that 15.3 in (390 mm) of moisture is needed to allow plant growth and survival through the summer. Although this is not the target species for this particular site, it is used as an example perennial shrub for soil remediation design purposes. If the soil is assumed to have a 30 % water holding capacity (an optimistic number), then 51 in (390 / 0.3 = 1,300 mm = 51 inches) of substrate are needed to hold this amount of moisture for plant growth. An existing 10 in (250 mm) loose substrate overlay that currently exists on the flatter areas of the site, plus an additional 3 feet (1 m) ripping treatment, provides 49 in (1250 mm) of soil rooting depth, or approximately the amount called for by the water use calculations.

TREATMENT RECOMMENDATION: Disrupt the existing in-place sedimentary rock matrix to allow 39 in (1 m) of additional rooting depth, either by excavation or by ripping or by hydraulic hammer. No other soil amendments are required for this fractured sub-soil volume on this sedimentary substrate type. Soil fracturing must be done so that the slope remains geotechnically stable.

<u>SRE Step 3: Substrate nutrient and chemical characteristics</u>

Data from nutrient and chemical analysis of the Templin substrates is included in Table 4. Organic matter is low or absent from the excavated material, compared to nearly 5 % organic matter measured on the Native Reference Site. Phosphorus amendment is the primary deficient nutrient compared to the Native Site. Other macronutrients (K, Ca, Mg, S) are adequate. Micronutrients are all adequate. The Upslope site has a somewhat elevated salt level, perhaps from existing leaching patterns in this footslope position. Established wildlands plants should not be affected, but seedling germination may be reduced or delayed. Calcium to magnesium levels are all well above 1.0, indicating non-magnesic (non-serpentinitic) mineralogy.

Phosphorus should be applied at a rate of 18 lb/ac (20 kg/ha) elemental P if no compost material is applied. If compost is used, it will provide 254 lb/ac (285 kg/ha) P amendment is added per inch of compost thickness that is applied. A one inch (25 mm) application is not an excessive application of P because it is organically bound and has low bio-availability.

Nitrogen is very low in the existing substrates, but the highly urbanized character of the greater Southern California environment means this site is probably getting additional N from atmospheric deposition. Various studies cited atmospheric deposition in this general region as contributing 4.5 to 8 lb/ac/yr (5 to 9 kg/ha/yr) of N (Fenn and Poth,1998), or 6.9 to 23 lb/ac/yr (7.7 to 25.9 kg/ha/yr) of N (Lu et al., 2007), or 40 lb/ac/yr (45 kg/ha/yr) of N (Allen et al., 1998). These nitrogen inputs amount between a tenth and a half of the annual nitrogen uptake needed for plant growth. Native soils will ultimately accumulate 4000 lb/ac (4500 kg/ha) N in soil organic matter, about 1 to 1.5 % of which is mineralized (released per year) yielding 40 to 60 lb/ac (45 to 68 kg/ha) of N annually. Yard waste compost amendments supply 3269 lb (1486 kg) N per inch of compost application, most of which is organically bound. Empirical evidence indicates that little of this nitrogen is lost, most being taken up by plants or microbes.

TREATMENT RECOMMENDATION: Plant available nutrients will be made sufficient if 25 mm (1 inch) of yard waste compost is incorporated in the top 250 mm (10 inch) overall depth, and 25 mm (2 inch) of coarse wood shreds, or coarse compost overs are applied as a surface mulch. No further soil amendments are needed. Without the compost, 18 lb/ac (20 kg/ha) elemental P and 45 lb/ac (50 kg/ha) (slow release formulations) are recommended. This can be applied with a 900 lb/ac (1000 kg/ha) amendment of Biosol Mix or the equivalent.

SRE Step 4. Soil biological constraints
Because the substrates are non-magnesic (non-serpentinitic), special ecotypic accessions are not needed for this condition other than those species that are locally adapted for coastal sage scrub conditions. Mycorrhizal fungi will be required for normal plant community function, especially given the low phosphorus levels. Duff / soil mixtures from surrounding areas (harvested from within the top foot) can be dusted on during final tillage so that they are incorporated.

TREATMENT RECOMMENDATION: No substrate-related biological constraints for plant or microbial species will exist after amendment with yard waste compost. Inoculation with local microbes can occur by harvesting duff/topsoil and applying it at a rate of 16 cu yd/ac (30 m^3/ha) followed immediately by disc tillage.

SRE Step 5. Monitoring and action thresholds.
The site should be visited after average and extreme weather events to observe erosion issues and during active grow periods to observe plant performance.

If evidence of overland flow is observed on non-drainage areas, a follow-up treatment would be to rip a slot on contour to intercept and infiltrate the flow. If overland flow is observed in shallow drainageways, berm or wattles can be used to slow flow, steep areas can be covered with coir fabric (700 or 900 g/m^2). If surface substrates become dispersed and form uniform crusts, a general mulch should be applied, or if impractical, plant growth should be improved to produce litter and mulch cover.

If plants are yellowish, add N as 14 lb/ac (15 kg/ha) elemental N fertilizer or soil amendment, using a slow release form. If plants have purple leaves add phosphorus as a 9 lb/ac (10 kg/ha) elemental P amendment with a hand operated spreader, walking over the site in a grid pattern.

If the site burns, no further action is necessary as long as plant species have established for a few years.

Note: the Buttress area with geogrid reinforcement was also sampled but is not included in this analysis. Similar surface hydrology dynamics are expected on this material, but the substrates are alkaline and sodium enriched, and so vegetative cover will be more difficult to establish on these materials.

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Appendix Data Tables

Table 1. RDDF (Ksat infiltration rates) for Castaic Patrol Station, Castaic Junction, CA. (data in inches)

		Rainfall Depth Duration Frequency for Castiac Patrol Station											
	DWR # U03 1562 11				451	Los Angeles County				Latitude 34.464°			
	Analysis By : DWR DLA									Lotitude -118.616°			
	Data From : DWR					4N/17W-1B				Elevation 1066 Feet			
Year	5 Min	10 Min	15 Min	30 Min	1 HR	2 Hr	4 Hr	6 Hr	12 Hr	24 Hr	W-Yr		
1957	0.12	0.14	0.15	0.19	0.33	0.57	0.80	1.35	2.43	2.58	11.96		
1958	0.15	0.24	0.30	0.38	0.49	0.62	0.82	1.18	2.28	2.89	**23.99**		
1959	0.13	0.25	**0.39**	0.54	0.61	0.73	0.97	1.27	1.70	1.70	6.66		
1960	0.05	0.08	0.10	0.20	0.25	0.45	0.56	0.80	1.16	1.52	8.01		
1961	0.10	0.15	0.21	0.30	0.40	0.50	0.65	0.74	0.94	0.95	5.08		
1962	0.10	0.10	0.15	0.25	0.40	0.60	0.74	1.04	2.08	3.20	17.02		
1963	0.10	0.17	0.24	0.27	0.41	0.65	0.87	1.16	1.50	1.70	9.13		
1964	0.06	0.09	0.10	0.16	0.27	0.50	0.75	1.00	1.08	1.15	6.63		
1965	0.07	0.09	0.12	0.18	0.28	0.38	0.60	0.87	1.11	1.32	10.77		
1966	0.10	0.19	0.33	**0.55**	**0.96**	**1.42**	1.90	**3.08**	**4.42**	**4.62**	17.60		
1967	0.10	0.14	0.17	0.23	0.40	0.55	0.78	1.24	2.25	2.80	16.70		
1968	**0.22**	**0.27**	0.34	0.55	0.93	1.35	**2.03**	2.28	2.75	3.25	13.31		
1969	0.08	0.11	0.14	0.23	0.50	0.80	1.05	1.50	2.87	3.50	21.85		
1970													
Average	0.11	0.16	0.21	0.31	0.48	0.70	0.96	1.35	2.04	2.40	12.98		
Max Rec	0.22	0.27	0.39	0.55	0.96	1.42	2.03	3.08	4.42	4.62	23.99		
Stdev	0.04	0.06	0.10	0.15	0.23	0.32	0.47	0.65	0.97	1.10	6.05		
Yrs Rec	13	13	13	13	13	13	13	13	13	13	13		
Z	2.19	1.51	1.74	1.58	2.05	2.09	2.27	2.63	2.38	1.89	1.93		
Coef Var	.413	.418	.472	.472	.480	.461	.483	.483	.475	.459	.466		
Reg CV	.489	.489	.489	.489	.489	.489	.489	.489	.489	.489	.439		
Reg Skew	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.0		
FIC	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
												1.3	1.0
RP 2	0.10	0.14	0.19	0.28	0.43	0.63	0.86	1.21	1.83	2.15	12.04	-0.210	-0.164
RP 5	0.14	0.21	0.28	0.42	0.65	0.95	1.30	1.82	2.76	3.24	17.30	0.719	0.758
RP 10	0.18	0.26	0.35	0.51	0.79	1.16	1.59	2.23	3.38	3.97	20.61	1.339	1.340
RP 25	0.22	0.32	0.43	0.63	0.97	1.42	1.96	2.74	4.15	4.87	24.62	2.108	2.043
RP 50	0.24	0.36	0.49	0.71	1.10	1.62	2.22	3.10	4.71	5.53	27.46	2.667	2.542
RP 100	0.27	0.40	0.54	0.80	1.23	1.80	2.48	3.46	5.25	6.16	30.20	3.211	3.023
RP 200	0.30	0.44	0.60	0.88	1.36	1.99	2.73	3.81	5.79	6.79	32.86	3.745	3.489
RP 500	0.34	0.49	0.67	0.98	1.51	2.22	3.04	4.26	6.46	7.58	36.10	**4.417**	**4.058**
RP 1,000	0.36	0.53	0.72	1.06	1.64	2.40	3.30	4.61	7.00	8.21	38.79	4.955	4.531
RP 10,000	0.45	0.66	0.90	1.32	2.04	2.98	4.09	5.72	8.68	10.19	46.92	6.640	5.957
	\Rainfall data\Rain DDF\Rain H DDF\DDF H U02-U04												

Table 2. Model estimated substrate hydraulic properties (non-aggregated)

American Hydraulic Properties calculator

		sand	shale	upslope	
		X SCUT	X ACUT	X UPSLOPE	NATIVE
pct sand	%	60.5	37.9	29.9	24.5
pct clay	%	14.4	23.1	31.1	40.4
pct silt	%	25.1	39	39	35.1
texture		SL	L	CL	C
wp	cm3/cm3	0.11	0.14	0.17	0.23
fc	cm3/cm3	0.21	0.28	0.32	0.37
bulk dens	g/cm3	1.49	1.38	1.32	1.27
sat	cm3/cm3	0.44	0.48	0.5	0.52
Ksat	mm/hr	14.6	6.5	3.7	2.4
paw	cm3/cm3	0.11	0.14	0.15	0.15
in/ft	in/ft	1.3	1.65	1.74	1.76

3. Rainfall Depth Duration Frequency (infiltration volume) for Castiac Junction

		Rainfall Depth-Duration-Frequency for Castiac Junction											
	DWR # U03 1562 21						Los Angeles County						Latitude 34.440°
	Analysis by DWR DLA												Longitude -118.606°
	Data From : DWR,												Elevation 1001 Feet
in/hr													
			Maximum Rainfall For Indicated Number Of Concecutive Days										
	1	2	3	4	5	6	8	10	15	20	30	60	W-YR
RP 2	2.13	2.73	2.96	3.16	3.26	3.44	3.75	3.98	4.27	4.57	5.37	7.05	10.97
RP 5	3.03	3.94	4.44	4.85	5.11	5.41	5.92	6.30	6.78	7.08	8.20	10.71	15.85
RP 10	3.63	4.75	5.41	5.92	6.29	6.66	7.29	7.78	8.36	8.67	9.99	13.03	18.92
RP 25	4.37	5.78	6.60	7.25	7.75	8.21	9.00	9.60	10.33	10.64	12.14	15.90	22.62
RP 50	4.92	6.53	7.46	8.17	8.76	9.29	10.19	10.87	11.70	12.01	13.68	17.90	25.27
RP 100	5.44	7.26	8.28	9.10	9.78	10.38	11.38	12.15	13.07	13.39	15.16	19.90	27.81
RP 200	5.96	7.99	9.10	9.99	10.75	11.42	12.52	13.37	14.39	14.71	16.61	21.83	30.30
RP 500	6.61	8.90	10.11	11.15	12.02	12.77	14.01	14.96	16.10	16.42	18.36	24.33	33.31
RP 1000	7.13	9.63	10.92	11.97	12.93	13.73	15.07	16.09	17.32	17.65	19.81	26.11	35.81
RP 10000	8.77	11.93	13.47	14.71	15.94	16.94	18.59	19.87	21.38	21.72	24.22	32.05	43.38
mm/hr			Maximum Rainfall For Indicated Number Of Concecutive Days										
	1	2	3	4	5	6	8	10	15	20	30	60	W-YR
RP 2	54.07	69.27	75.10	80.27	82.82	87.26	95.13	101.06	108.53	116.13	136.41	179.19	278.73
RP 5	76.93	99.95	112.67	123.18	129.90	137.41	150.28	160.06	172.09	179.80	208.37	272.02	402.48
RP 10	92.19	120.77	137.31	150.39	159.77	169.22	185.27	197.50	212.41	220.20	253.73	330.90	480.49
RP 25	111.12	146.84	167.60	184.07	196.73	208.59	228.56	243.81	262.29	270.18	308.48	403.77	574.65
RP 50	124.87	165.88	189.42	207.59	222.54	236.09	258.81	276.17	297.15	305.09	347.59	454.67	641.90
RP 100	138.26	184.50	210.42	231.12	248.36	263.59	289.05	308.53	332.00	340.01	385.13	505.57	706.47
RP 200	151.41	202.85	231.02	253.72	273.17	290.01	318.11	339.62	365.49	373.56	421.89	554.48	769.68
RP 500	167.94	226.15	256.79	283.11	305.42	324.36	355.89	380.03	409.02	417.17	466.31	618.06	846.08
RP 1000	181.18	244.60	277.47	304.01	328.35	348.79	382.75	408.77	439.98	448.19	503.23	663.27	909.57
RP 10000	222.65	303.09	342.10	373.66	404.79	430.21	472.30	504.58	543.17	551.57	615.07	813.99	1101.92
file: Rain DDF\Rain D DDF T-Z\DDF D U03 a-l													

Table 4. Substrate nutrient and chemical data from the Templin cut.

Templin Hwy revegetation				LA I-5	REPORTNUM													
2/11/2008					08-042-036													
SAMPLEID		OM	ENR	P1	HCO3_P	PH	K	MG	CA	NA	CEC	K_PCT	MG_PCT	CA_PCT	H_PCT	NA_PCT		
SCUT1	sandstone cut	0.3	30.5	0.5	2.8	7.7	62.4	185.5	1184.0	24.0	7.7	2.1	19.8	76.8	0.0	1.4		
SCUT2		0.8	31.5	0.9	2.9	7.3	79.4	265.7	1647.0	29.5	10.7	1.9	20.4	76.6	0.0	1.2		
SCUT3		0.7	31.5	0.8	2.5	7.8	95.7	308.3	1681.0	41.2	11.3	2.2	22.3	73.9	0.0	1.6		
ACUT1	shale cut	1.0	32.1	0.7	4.0	8.0	254.2	1126.0	2451.0	356.5	23.7	2.7	39.1	51.6	0.0	6.5		
ACUT2		1.1	32.1	0.6	2.3	8.4	258.8	932.8	2600.0	331.1	22.7	2.9	33.7	57.0	0.0	6.3		
ACUT3		1.2	32.4	0.4	4.6	7.7	252.2	970.7	3013.0	344.4	25.2	2.6	31.7	59.8	0.0	6.0		
UPSL1	upperslope	1.7	33.4	2.1	4.4	7.8	223.3	1125.0	3112.0	254.2	26.5	2.2	35.0	58.7	0.0	4.2		
UPSL2		1.6	33.1	0.8	4.6	7.9	321.1	1475.0	3663.0	182.6	32.0	2.6	37.9	57.1	0.0	2.5		
UPSL3		2.1	34.1	2.0	6.4	7.7	248.0	1092.0	4250.0	199.9	31.7	2.0	28.3	66.9	0.0	2.7		
TNAT1	native ref site	6.3	42.7	26.7	26.4	7.4	513.8	508.5	4715.0	29.7	29.2	4.5	14.3	80.7	0.0	0.4		
TNAT2		4.4	38.8	24.2	24.5	7.3	720.6	736.4	5137.0	26.4	33.6	5.5	18.0	76.2	0.0	0.3		
TNAT3		4.0	38.0	24.1	24.4	6.9	508.3	640.6	5004.0	25.6	32.1	4.0	16.4	77.7	1.5	0.3		
BUTR1	buttress	1.0	32.0	8.0	2.0	8.8	275.3	477.9	2105.0	2624.0	26.5	2.7	14.8	39.6	0.0	43.0		
BUTR2		1.1	32.3	0.1	4.1	9.2	311.0	690.4	2161.0	1868.0	25.4	3.1	22.4	42.5	0.0	32.0		
BUTR3		1.3	32.7	10.0	2.5	9.2	250.8	503.4	1993.0	2123.0	24.0	2.7	17.3	41.5	0.0	38.5		
																	Ca:Mg	
SCUT	sandstone cut	0.6	31.2	0.7	2.7	7.6	79.2	253.2	1504.0	31.6	9.9	2.1	20.8	75.8	0.0	1.4	3.6	
ACUT	shale cut	1.1	32.2	0.6	3.6	8.0	255.1	1009.8	2688.0	344.0	23.9	2.7	34.8	56.1	0.0	6.3	1.6	
UPSLOPE	upperslope	1.8	33.5	1.6	5.1	7.8	264.1	1230.7	3675.0	212.2	30.1	2.3	33.7	60.9	0.0	3.1	1.8	
NATIVE	native ref site	4.9	39.8	25.0	25.1	7.2	580.9	628.5	4952.0	27.2	31.6	4.7	16.2	78.2	0.5	0.3	4.8	
BUTTRESS	buttress	1.1	32.3	6.0	2.9	9.1	279.0	557.2	2086.3	2205.0	25.3	2.8	18.2	41.2	0.0	37.8	2.3	
SAMPLEID		NO3_N	S	ZN	MN	FE	CU	B	EX__LIM	S__SALT	CL	MO	SAND	SILT	CLAY	TEXTURE		
SCUT1	sandstone cut	0.9	121.7	1.2	3.4	30.2	0.8	0.7	H	1.2			73.2	18.4	8.4	SANDY LOAM		
SCUT2		1.2	214.4	2.1	10.6	52.3	2.1	0.7	H	1.8			57.2	26.4	16.4	SANDY LOAM		
SCUT3		6.0	168.7	2.4	7.7	43.4	2.4	0.8	H	1.0			51.2	30.4	18.4	LOAM		
ACUT1	shale cut	3.6	34.4	1.4	25.6	42.3	2.3	9.4	H	1.0			41.2	36.4	22.4	LOAM		
ACUT2		2.4	52.7	2.9	20.4	34.1	3.0	8.0	H	0.9			35.2	40.4	24.4	LOAM		
ACUT3		2.0	421.0	3.0	24.0	48.7	4.7	10.3	H	2.1			37.2	40.4	22.4	LOAM		
UPSL1	upperslope	1.2	625.2	2.9	8.3	35.2	3.6	3.2	H	2.5			37.2	34.4	28.4	CLAY LOAM		
UPSL2		3.5	259.1	4.0	5.5	28.6	4.2	2.7	H	1.5			17.2	50.4	32.4	SILTY CLAY LOAM		
UPSL3		13.9	905.6	2.3	6.2	21.3	5.0	2.5	H	2.2			35.2	32.4	32.4	CLAY LOAM		
TNAT1	native ref site	5.0	41.2	2.5	10.3	23.4	1.6	2.6	L	0.5			33.2	34.4	32.4	CLAY LOAM		
TNAT2		6.7	6.7	1.6	12.9	20.5	1.9	1.2	L	0.3			21.2	36.4	42.4	CLAY		
TNAT3		9.6	7.1	1.9	12.1	19.7	2.2	0.9	L	0.5			19.2	34.4	46.4	CLAY		
BUTR1	buttress	4.3	388.0	4.2	13.5	43.2	4.0	10.5	H	2.7								
BUTR2		2.9	77.6	4.7	9.7	41.3	3.8	7.1	H	0.8								
BUTR3		1.5	177.5	4.9	14.5	42.1	4.5	10.0	H	1.2								

Appendix Figures

Figure 1. Overhead view of site before removal (from area of red ellipse).


Figure 2. Overall view of the Templin Highway x I-5 site when approaching from the south on north-bound I-5.

Figure 3. Native, vegetated reference area with deep, porous soil and no surface erosion except on oversteepened roadcut slope breaks.

Figure 4. Fill slope adjacent to access road in Site 9. Most rills are initiated on the slope as indicated by the lack of channels coming over the upper road edge. Lag gravels and pedestalled gravels were commonly visible on the slope face. This indicates reduced infiltration into the weathered fines and increase overland flow. This scenario is expected to develop on the rest of Site 5 substrates within the next decade.

Figure 5. Overview of the Site 5 impacted area looking south from the north edge of the site.

Figure 6. Perennial grasses germinating well through BFM in the flat areas of Site 5.

Figure 7. Overview of the Site 5 impacted area looking north from the south edge of the site.

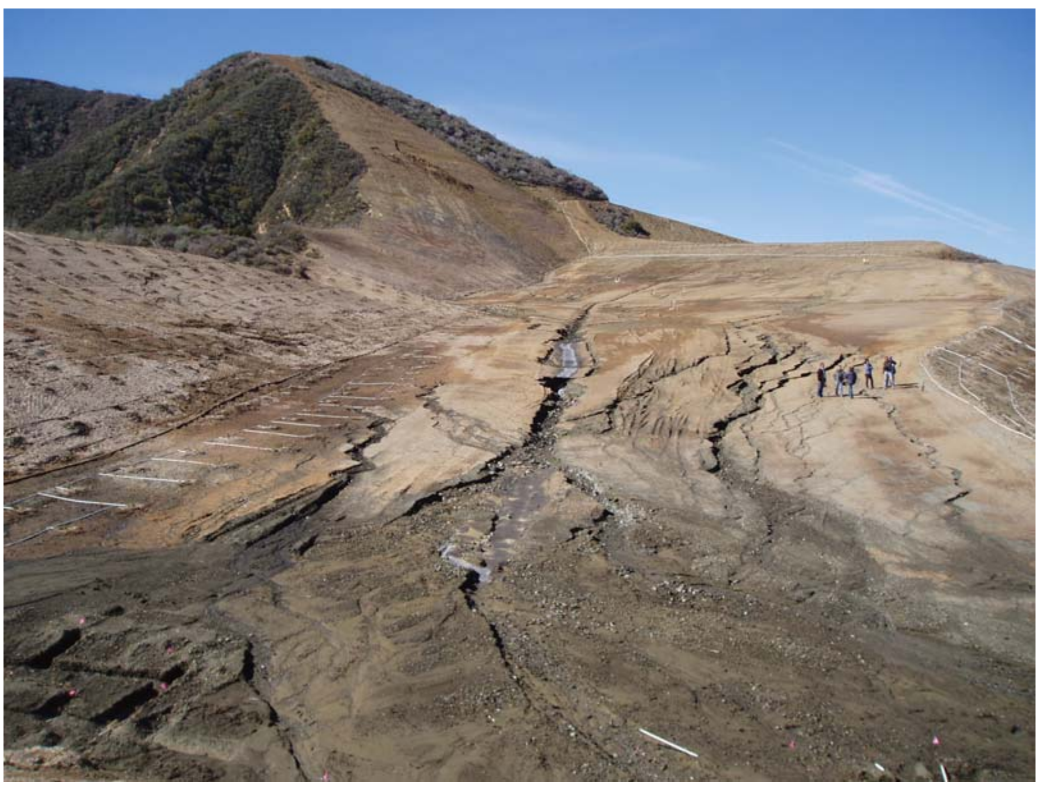

Figure 8. Overview of the Site 5 impacted area showing surface rills.


Figure 9. Head cutting under asphalt drain. Also visible in center of Figure 8.


Figure 10. Shallow depth of rootable substrate overlaying low-permeability sedimentary rock common throughout Site 5.

Figure 11. Low permeability rock in-place lying close to the substrate surface.

Figure 12. Rills and gullys from overland flow from rest of site.

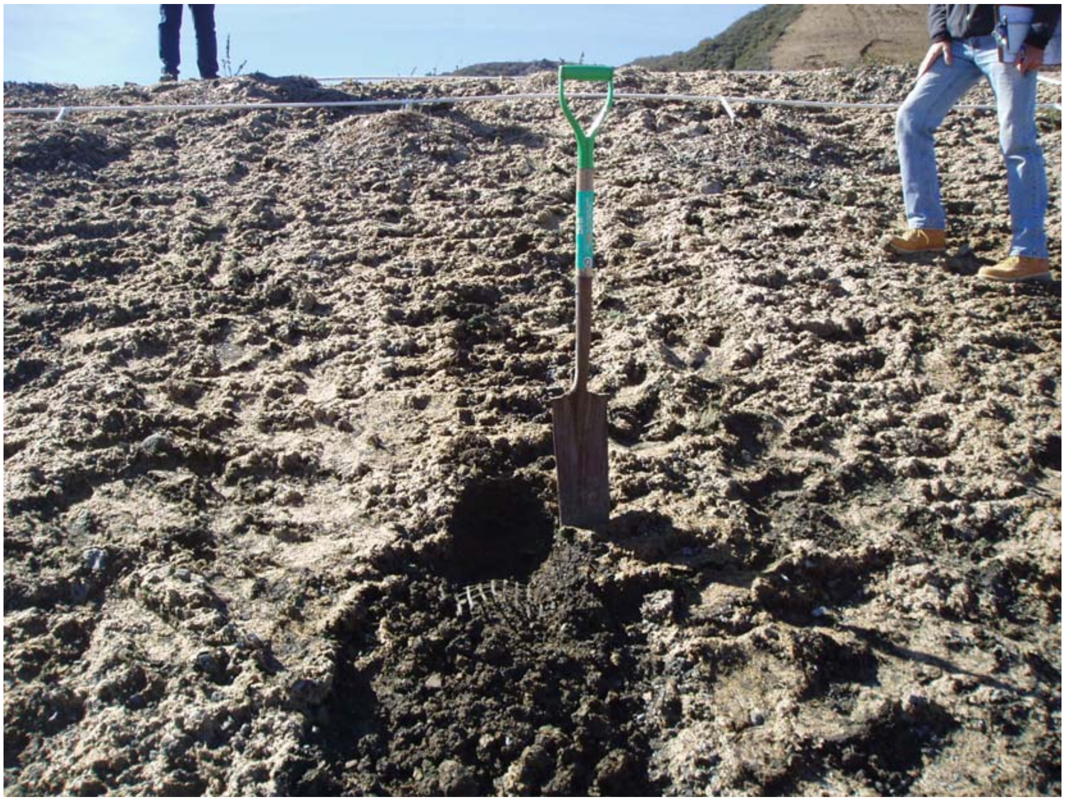

Figure 13. Exposed edge of geogrid on buttress slope.

Figure 14. Exposed geogrid on the Buttress slope, with unstabilized slope surface caused by overland flow.