Roadside Erosion Control and Management Studies

FINAL REPORT 2005-2008

State of California
Department of Transportation

CTSW-RT-08-067-01-1
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EXECUTIVE SUMMARY

Detailed erosion control and vegetation results have been documented previously for seven primary experiments and three secondary experiments. Based on statistical analyses of water quality and vegetation response variables, the following patterns are evident.

Soil

Reapplied topsoil from a highway environment typically contains quantities and densities of seed sufficient to produce 70 percent vegetation cover or more within the first growing season. Additional seed may not be necessary to provide rapid cover post-disturbance. However, soils obtained from coastal and interior valley locations typically contain high quantities of alien annual grasses and forbs (some considered noxious) that do not necessarily produce sufficient biomass near the soil surface where the most protection from raindrop splash and surface flow is needed to prevent sediment transport.

Compost

Type.—Fine-textured biosolids and plant materials alone or mixed with the type of fine-textured wood fiber typically applied as a hydromulch performed better overall for erosion control and seedling germination than did immature Manure Compost or immature Municipal Compost that included more coarse woody pieces.

Application Method.—Topical applications of Compost or Compost+Fiber performed better on fine-textured soils than Incorporated applications regardless of Compost source type (Commercial, Manure, or Municipal).

Function.—A 2 inch layer of compost significantly reduced germination and cover produced by naturalized alien species, and significantly increased germination of seeded species.

Physical Erosion Control Treatments

Jute Netting.—Jute application over Compost seems to be the best EC treatment over all soil types tested considering combined effects on runoff, sediment concentration, and vegetation production. Jute applied without Compost also performed well in plant cover production.

Crimped Straw.—Crimped Straw performed best with grass from either an existing seedbank or from the District 5 native mix.

Bonded Fiber Matrix.—BFM provided the best water quality overall, and best legume cover. However, BFM negatively affected grass germination and cover from both native and naturalized species.

Fertilizer (N:P:K 16:16:16)

The addition of fertilizer generally produced more plant cover; however, more naturalized alien annual grasses than native species emerged from the seed mix. The use of the commercial fertilizer increased erosion due to decreased ground cover.

Vegetation

Water

Consistency.—The frequency and consistency of rainfall greater than 0.25 in. every 3 to 5 days is more important than total annual rainfall input for production of diverse and stratified vegetation that provides both soil surface coverage and aerial plant cover.

Lifeform

Grasses.—Native perennial California Brome (*Bromus carinatus*) and native annual Small Fescue (*Festuca/Vulpia microstachys* complex) are the most consistent producers of rapid, dense cover from seedlings. Both are best seeded over a compost layer 1 to 2 inches deep. BFM negatively affects grass cover from both native and naturalized species.

Perennial Forbs.—Common Yarrow (*Achillea millefolium*) is an excellent sediment filter because of the fine, mat-like foliage at the soil surface.

Shrubs.—Seedlings of common California shrubs listed below germinated best in test boxes when seed was applied over topical compost/fiber layers using a light (1000-1500lbs/ac) fiber application to carry the seed. Topical Compost treatments applied over the Sandy Clay Loam soil resulted in very high average densities of over 10 shrub seedlings per 100 cm2 (over 90 seedlings per square foot) for Golden Yarrow (*Eriophyllum confertiflorum*) and California Buckwheat (*Eriogonum fasciculatum*).

Artemisia californica	California Sagebrush
Baccharis pilularis	Coyote Brush
Eriogonum fasciculatum	California Buckwheat
Eriophyllum confertiflorum	Golden Yarrow
Lotus scoparius	Deer Lotus

Installation Method

Hydroseeding.—The most-important factor in hydroseeding is the depth of seed burial. It is important to note seed species which are intolerant of burial, such as *Achillea millefolium*. An ideal seedbed for these species is a compost layer 1 to 2 inches deep which suppresses undesirable species and increases water infiltration and retention.

Plug-planting.—Plug-planting produces more cover of the planted material, but may cause more surface disturbance, and more sediment, than hydroseeding during installation. It is unclear if the disturbance created during installation diminishes with time.

Flats.—Flats at the top and toe of a slope, with jute netting and seed over compost, resulted in nearly no sediment loss at all (0.2g) after simulation of a 50-year storm event. Flats effectively preclude seed germination in the soil below, and effectively resist weed invasion from adjacent areas.

Ornamental Vegetation under Rainfall Simulation

In primarily urban settings, Caltrans has landscaped significant roadside areas with ground cover and low growing vegetation. The most notably used vegetation is South African "Iceplant", *Carpobrotus* spp., but Caltrans has also utilized cultivars including, but not limited to: *Acacia, Baccharis, Hedera. Lampranthus, Lantana, Myoporum,* and *Rosmarinus*. The plants vary in both lifeform and architecture. Together these factors determine density and size of shoots which collectively form the vegetation cover on the soil surface where it is most effective at filtering runoff and improving water quality.

Ground cover strip length.—Length of ground cover strip alone, whether 10%, 20%, or 100% of total box length, was not significant due to the relatively short two-meter slope run available in the soil test boxes. All ground cover strips performed significantly better compared to bare soil.

Ground cover vegetation toe strip with jute netting upslope.—Boxes with a 20% vegetative toe slopes and 80% jute netting averaged a 92% reduction in total runoff. Average total runoff from all 100% vegetation boxes exhibited a 98.6% reduction in runoff.

Ground cover vegetation compared to jute netting.—Over a short slope run, jute netting provides nearly the same soil surface protection as ground cover vegetation. Boxes with 100% jute netting over bare soil were equivalent to boxes with 20% or 100% vegetative ground cover.

Comparison among common cultivars used by Caltrans.—All of the ground cover cultivars tested at either 20% cover with 80% jute netting upslope, or 100% ground cover vegetation, were effective in reducing total runoff and total sediment by more than 90% compared to bare soil. No significant differences were observed among cultivars tested. However, observations indicate plant architecture may determine effectiveness of vegetation in filtering runoff and sediment. Plants with prostrate branches and many leaves at the soil surface may provide greater filtration than plants with arching branches that leave areas of soil uncovered and vulnerable to overland flow.

Ornamental Vegetation under Overland Flow

Overland flow erosion occurs on many roadsides, potentially transporting toxic heavy metals and other contaminants. In general, heavy metals have a high affinity for soil particles. When the soil erodes, these metals are transported to other locations. Accordingly, the best strategy for preventing this transport of heavy metals is erosion control.

Established vegetation provides the best overland flow erosion control, but only when it has cover greater than 70 %. In this study, all vegetation boxes yielded no runoff because root channels allowed the water to infiltrate faster than it was loaded on the box.

INTRODUCTION

Caltrans, in cooperation with the Sacramento State University Office of Water Programs and the Earth and Soil Sciences Department of Cal Poly State University, San Luis Obispo, and as part of the Storm Water Program, conducts ongoing research that includes the Roadside Erosion Control and Maintenance Study (as the Vegetation Establishment and Maintenance Study from 2000 to 2005). This effort is intended to improve vegetation establishment and water quality along California roadways to comply with the Clean Water Act.

In general, this study seeks to:

- Measure the effectiveness of a hydroseeded plant species in controlling runoff under varying rainfall regimes and hydroseed application methods;
- Identify and select plant species for hydroseeding that demonstrate initially fast growth and long-term erosion control under a variety of rainfall regimes;
- Characterize how various rainfall regimes affect seed germination and plant establishment;
- Characterize how various hydroseeding techniques affect seed germination and plant establishment;
- Compare the effects of plugs, flats (sod strips), and hydroseed planting techniques on minimizing erosion and improving water quality;
- Ascertain the effects of compost soil amendment on native vegetation cover, species composition, and weedy annual species suppression;
- Develop innovative tools to aid Landscape Architects in the selection of appropriate species for highway plantings, and to track contract workflow;
- Provide Expert assistance to Caltrans personnel through individual ad hoc consultations regarding individual project needs;
- Execute reviews of topics pertinent to erosion control, vegetation establishment, or vegetation management;
- Conduct training workshops to present basic erosion control and vegetation establishment theory and practice incorporating new data or techniques developed through this project.

Task Areas

The Roadside Erosion Control and Maintenance Study incorporate three major task areas. Individual sections of this report provide synoptic details about the progress and products within each task area.

Task Area 1 – Experiments

- Experiments intended to support development or modification of Standard Specifications, Standard Special Provisions, plans, guidance, policy recommendations, and training.
- Evaluation of ornamental ground cover toe treatments and their effectiveness in controlling soil detachment and improving water quality.
- Development of an overland flow system using a two-year storm and ornamental plants to determine their effectiveness as a BMP along highways.
- Native shrub germination relative to compost type, application method, and layer depth and the effect on water quality.
- Runoff relative to proportional length of slope treatments using sod strips to compare effectiveness at reducing sediment loss and improving water quality.
- Block planting flats of California native vegetation to quantify invasion of undesirable vegetation.

Task Area 2 – transPLANT Database Application

Continued development of a custom Caltrans Highway Planting Database and Specification Tool called *trans*PLANT to aid landscape architects in designing and managing highway planting specifications.

Task Area 3 - Expert Assistance

Expert assistance is provided to Caltrans personnel through individual ad hoc consultations regarding specific project needs. Below are examples of the Expert Assistance provided over the past 3 years:

Erosion Control & Revegetation Specifications

- Recommendations Regarding Erosion Control Along the Union Road Segment on SR46 Corridor Improvement Project
- Recommendations Regarding Pre-construction Erosion control Trials on US101 Prunedale Improvement Project

Plant Materials

- Literature Review for Candidate Plants for Biofilters
- Seed Vendor Quality Control to Evaluate Commercial Plant Materials
- Candidate Plants for Orange County 15 and SR 73
- Summary of Literature Review for the Scoping and Sitting of Ornamental Vegetation Types in Biostrips and Bioswales for Stormwater Treatment
- Developed appropriate seed mixes for proposed bioswales along SR 118, District 7
- A qualitative Assessment of Post-construction Revegetation Success on Cuesta Grade

Topic Reviews

- Technical Report issued July 2006: Legume Seed Inoculation for Highway Planting in California. CTSW-RT-06-167.01.2.
- Technical Report, under review, on “Nutrient Augmentation Management for Highway Planting.”
- Participated in the task order to develop details, approve specifications and consider BMP’s using compost by Caltrans.
- Advisory Regarding Identification and Provenance of Plant Materials Presently Sold in California.
- Developed a Qualitative Assessment of Post-Construction Revegetation Success on Cuesta Grade.
- Technical Memo issued July 2006: Scoping Review of Some Potential Ecological Consequences from Compost Used for Revegetation of Native Plants along California Highways.
- Assessment of Potential Sits Along SR46, District 5, to Obtain or Stockpile Topsoil for Reapplication.
- Reviewed and provided editorial peer review for “Soil Resource Evaluation – A Stepwise Process for Regeneration and Revegetation of Drastically Disturbed Soils.”

Training Programs, Conferences, and Workshops

- IECA 2006 Conference: Principles and Practices for Using Vegetation to Prevent Erosion.
- Caltrans Compost Workshops with the IWMB and US Composting Council throughout California entitled “Improving Roadside Revegetation and Stormwater Quality with Compost-Based BMP’s.”
- Presentations Posters, and demonstrations at the SuperSwat training programs.
- Participated in the RUSLE2 Beta training programs designed to incorporate Caltrans practices and principles into the field applications.
- Participating in the development of the new Landscape Architects Training Program on Stormwater Management.
- Presented paper at the CASQA Conference on “Analysis of Compost Treatments to Establish Native Shrubs and Improve Water Quality.”
- Presented paper at the CASQA Conference on “Runoff Relative to Proportional Length of Slope Toe Treatments.”

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Section 1

1.1 ABSTRACT

The literature is replete with studies quantifying erosion control effectiveness from raindrop impact on various vegetation types and erosion control products. However, there is little published overland flow research documenting the effectiveness of ornamental vegetation and erosion control products in filtering sediment and nutrients from stormwater runoff. The California Department of Transportation and the Office of Water Programs, California State University, Sacramento, conducted a study at the Erosion Control Research Facility at Cal Poly State University, San Luis Obispo. The study compared the performance of ornamental vegetation, 0.5 inches of compost, jute netting, and bare soil treatments in sandy loam soil test boxes with a southwest aspect and a 3:1 slope using simulated overland flow. Two experiments were completed: a 2-year storm (16 gal hr^{-1} box^{-1}) for 1 hour and a 2-year storm for 2 hours. Treatments were evaluated by measuring the runoff quantity, sediment load, sediment concentration, pH, electrical conductivity (EC) and turbidity of the runoff. Ornamental plant species included *Lonicera japonica, Lantana montevidenses, Carpoborotus edulis*, *Hedera helix L*., *Myoporum parvifolium, Rosmarinus officinalis L.* and *Vinca major*. Understory and overstory vegetative cover was measured by a modified transect method, and soil gravimetric moisture content was measured on soil cores representative of each test box. Compared to bare soil, compost reduced runoff, sediment, and turbidity by greater than 96 % and increased EC by 430 %. Jute netting reduced runoff, sediment, turbidity, and EC by 43 %, 99%, 97%, and 65 %, respectively when compared to bare soil. Higher pH and salt concentrations were detected in runoff from boxes treated with compost; however, levels were not substantial enough to be harmful to plants. The ornamental vegetation did not produce any runoff and, therefore, were 100% effective in controlling overland flow under test conditions as root channels and surface organic matter allowed the applied water to infiltrate through the boxes faster than it was added to the soil. Since there was no runoff, differences among vegetation types and measured parameters of water quality could not be detected. Differences among the plant species will be elucidated with future research involving steeper slopes and increased flow rates.

Keywords: Erosion, overland flow, ornamental vegetation, compost, jute netting, turbidity, sediment load, water quality.

Section 1

1.2 OVERLAND FLOW INTRODUCTION

Soils adjacent to roadways usually contain higher than normal quantities of heavy metals and other pollutants. Vehicles on the roadway deposit small amounts of metals onto the roads, and stormwater translocates these pollutants to adjacent soils and water bodies. Recent research determined vegetation filter strips remove these pollutants by acting both as a filter and a velocity dissipater, allowing sediment to settle out (Scharff, 2005).

In soils, heavy metals have a high affinity for soil particles and organic matter. Therefore, pollutants in the soil will be strongly associated with the solid phase. Accordingly, effective erosion control is the best method for reducing toxic heavy metal transport because the metals will remain in the soil. Compared to more expensive mitigation measures (e.g. pump-and-treat), vegetation filter strips can provide a very inexpensive and effective erosion control and stormwater treatment if the vegetation cover is greater than 65 percent (Scharff, 2005; Caltrans, 2003).

Previous research determined vegetation filter strips reduce erosion and associated toxic metal translocation; however, no research has quantified the effect of different species of vegetation on water quality. Additionally, there is no lab data quantifying overland flow erosion by itself.

The California Department of Transportation (Caltrans) requested this research as a pilot *ex situ* study to determine the effects of different vegetation types and erosion control products on water quality under simulated overland flow erosion, compared to bare soil. The results of this study will be used to determine the best analysis method for an *in situ* study, and eventually for developing new Best Management Practices (BMPs).

Section 2
METHODS AND MATERIALS

2.1 Experimental Design

All treatments were run in duplicate (two boxes for every treatment). There were 14 vegetated boxes total (7 treatments, **Table 2.3**). The number of non-vegetated treatments varied depending on the experiment. Table 3 shows treatments applied in the different OF experiments. **Photo 2.1** shows the setup of a vegetation treatment with rosemary (*Rosmarinus officinalis* L.).

Table 2.1. OF experiment and applied treatments.

OF Experiment	Vegetation treatments†	Non-vegetation treatments
OF 1	All	Bare , Jute, Compost and Erosion Control Blanket (straw mat)
OF 2	All	Bare
OF 3	All	None

†: See **Table 2.3** for vegetation treatments

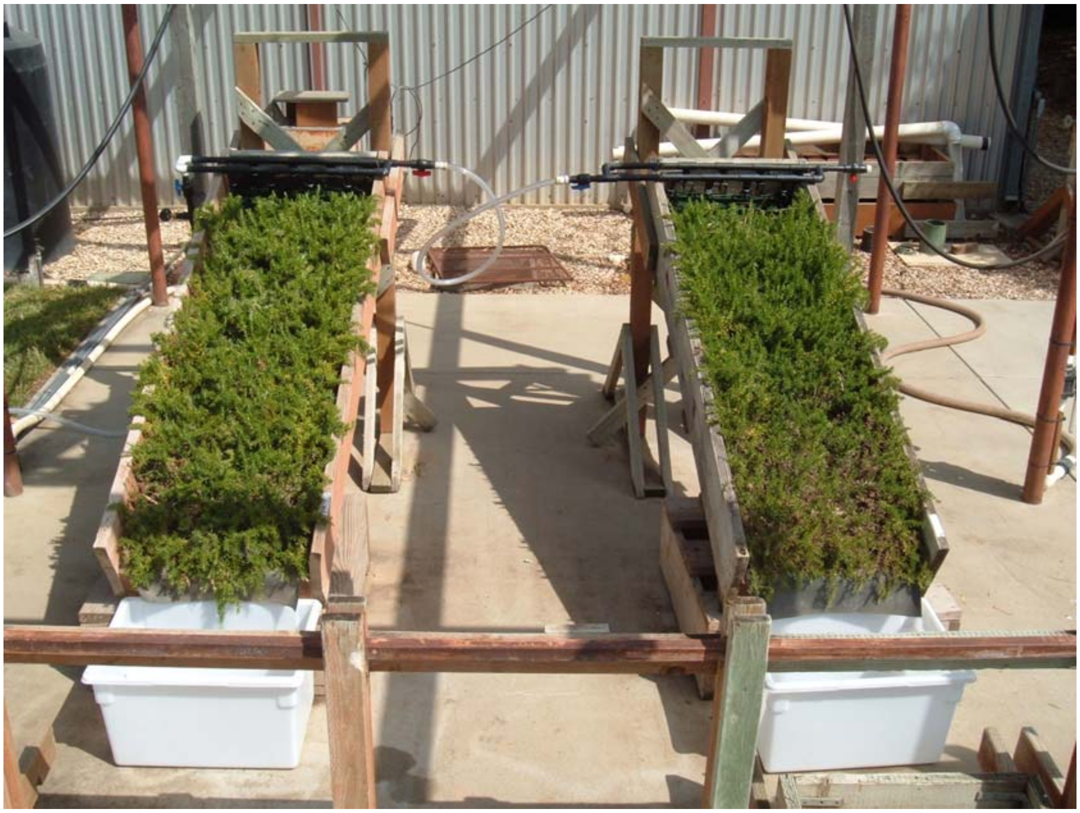


Photo 2.1. Experimental setup; *Rosmarinus officinalis* L. is vegetation shown.

2.1.1 Methods for OF-1

Overland flow simulations for OF-1 were run at a 3 to 1 slope using deionized water at 15 gallons per hour. OF-1 simulations were run for 1-hour durations. Boxes were allowed to dry for 3 days before running simulations.

2.1.2 Methods for OF-2

Overland flow simulations for OF-2 were run at a 3 to 1 slope using deionized water at 15 gallons per hour. OF-2 simulations were run for 1-hour durations. Boxes were wetted and allowed to reach field capacity before simulations were run. Soil moisture samples were obtained immediately before and after simulations were run.

2.1.3 Methods for OF-3

Overland flow simulations for OF-3 were run at a 2 to 1 slope using deionized water at 15 gallons per hour. OF-2 simulations were run for 2-hour durations. Boxes were wetted and allowed to reach field capacity before simulations were run. Soil moisture samples were obtained immediately before and after simulations were run.

2.2 Materials

2.2.1 Site Set-Up

2.2.1.1 Installation of Vegetation Treatments

For vegetated boxes soil was added and compacted to 95 % + and 16 x 16 in. flats of vegetation were placed over the compacted soil to provide complete edge-to-edge soil surface cover. ½ of soil was then sifted over the groundcover to produce a soil surface flush with the bottom edge of the box. Vegetated boxes were allowed to stabilize or grow out to 70 % cover before simulations were run. Vegetation was watered with non-deionized water. All vegetated boxes were grown out facing Vegetation was trimmed to the surface at the top of the box to make room for the overland flow apparatus just before simulations were run.

2.2.1.2 Slope

Slopes were obtained by changing the height at which the top of the test boxes rested. Adjustable wooden stands were used to obtain height.

2.2.1.3 Installation of Bare, Jute and Compost Treatments

Soil for bare, jute and compost treatments was added and compacted to a depth of 5 in, flush with the edge of the bottom of the box, before treatments were applied. ½ in. of Hydro-Post compost was applied to compacted bare soil for compost treatments. Jute netting was applied to compacted bare soil by tucking in at the toe of the box and stapling the netting to the soil surface as needed in order to ensure soil contact for the length of the box.

2.2.2 Test Boxes

Test boxes had identical construction and dimensions as those used in rain fall simulations. Test boxes were constructed of pressure-treated lumber. Box dimensions were 200 cm (79 in) *L* x 61 cm (24 in) *W* x 20 cm (8 in) *D*, conforming to field plot tests conducted by Pearce et al. (1998). Expanded steel sheets were placed in the bottom of the test boxes to allow for percolation of soil water, simulating soil depth. Landscape fabric was placed along the bottom and sides of the boxes to prevent soil loss through the expanded steel. Test boxes were positioned in rows on a concrete slab 70 ft long by 35 ft wide, and oriented such that soil surfaces faced approximately 165˚ south for adequate sun exposure.

2.2.3 Test Soils

Soil used in all overland flow simulations was collected by District 5 personnel from a road cut adjacent to SR 46 east of Paso Robles in San Luis Obispo County. Soil was compacted in the test boxes to at least 90% (calculated from bulk density). Soil properties are listed in **Table 2.2**.

Table 2.2. Basic Test Soil Physiochemical Properties.

Collection Site	USDA Type	%Sand	%Silt	%Clay	Small Gravels	Lime Nodules	pH
SR 46 East, PM 37.9	Sandy Clay Loam	58	21	21	< 2% < 1.27 cm	1-2 mm	8.1

2.2.4 Vegetation

Seven species of common ground covers were used (**Table 2.3**). Vegetation was supplied in the form of 16 x 16 inch flats purchased from wholesale growers.

Table 2.3. Ground cover species used.

Scientific Name	Common Name: English	Cultivar	Biostrips	Bioswales
Carpobrotus edulis (L.) N.E. Br.	Sea Fig		Y	Y
Hedera helix L.	English Ivy		Y	Y
Lampranthus spectabilis (Haw.) N.E. Br	Trailing Ice Plant		Y	Y
Lantana montevidensis (Spreng.) Briq.	Trailing Lantana		Y	
Lonicera japonica Thunb. Var. *repens* (Sieb.) Rehd.	Japanese Honeysuckle	'Halliana'	Y	
Myoporum parvifolium R. Br.	Myoporum	Prostratum'	Y	Y
Rosmarinus officinalis L.	Rosemary	Prostratus'	Y	

2.2.5 Overland Flow Apparatus

The overland flow simulation devices were constructed of ¾ in. PVC pipe, ¼ in. drip irrigation line and pressure regulated drip emitters. Felt covered plexi-glass was used to obtain an evenly distributed wetting front and prevent soil movement from water drop impact.

The overland flow (OF) apparatus went through many phases of development. The first tested stage was based on a drip bar and felt covered plastic (**Photo 2.2**). Uniformity of the wetting front was achieved, but regulation of gallons per hour was problematic.

Photo 2.2. First OF design test showing uniform wetting front.

The second OF apparatus design (Figure 3) used 30 pressure regulated drip emitters at 0.5 gal. h^{-1} to produce a verified application rate of 15 gal. h^{-1}. Water pressure was increased to 20 psi using an inline pressure regulator to ensure the flow rate. Water pressure was monitored using an inline fluid pressure gauge. The apparatus rested on the box and dripped water onto pre-wetted felt covered plexi-glass, producing a uniform wetting front. 30 drip emitters were used to distribute water onto the felt to help achieve the uniform wetting front (**Photo 2.4**).

Photo 2.3. Drip emitters and felt used for water application in OF simulations.

Photo 2.4. Second OF design.

The final OF apparatus consisted of the second OF design (**Photo 2.4**) and an additional unit (**Photo 2.5**).

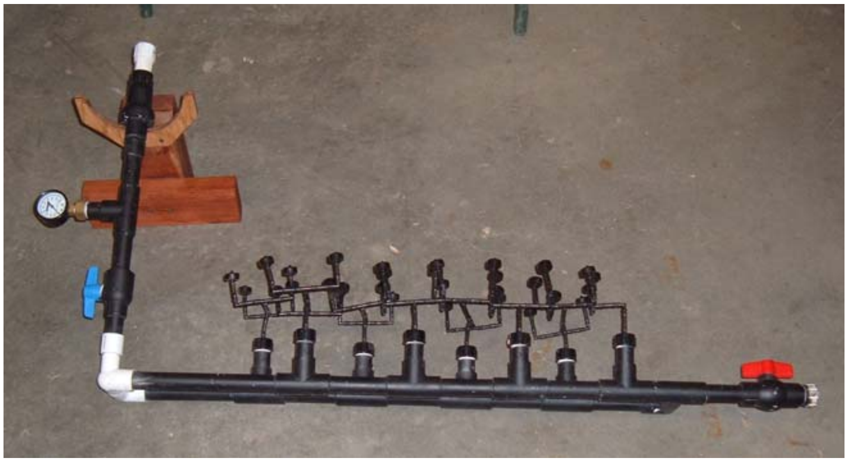


Photo 2.5. Unit 1 of final OF apparatus.

Photo 2.6. Unit 2 of final OF apparatus.

During simulations deionized water entered Unit 1 below the pressure regulator and flowed to Unit 2 through polyvinyl tubing. Air was allowed to escape the system and the end valve on Unit 2 was closed in order for the apparatus to become pressurized. Once pressure was obtained, the drip emitters began dispensing water.

2.2.6 Water

Deionized water was applied in all simulations to decrease experimental variability.

2.3 Data Collection and Analyses

2.3.1 Rainfall Regime

No natural or simulated rainfall contributed to the results of this study; boxes were covered during any natural rain events.

2.3.2 Runoff Data Collection and Analyses

Runoff from the test boxes was collected from the toe of the boxes by large, lab-grade plastic collection containers (**Photo 2.7**).

Photo 2.7. Runoff collection method.

The pH, electrical conductivity (EC) and total dissolved solids (TDS) of runoff were analyzed using a handheld PASCO Explorer GLX multi-meter. pH was determined using a double junction glass electrode. Turbidity was determined in nephelometric turbidity units (NTUs) using a HACH 2100P optical turbidity meter. Total solids were analyzed using a procedure that combined methods described by ASTM D3977-97 (ASTM 2002) and EPA method 160.2 (USEPA 2001).

After collecting and weighing, 10-20 ml .41M $CaCl_2$, a common water treatment flocculent, was added to each runoff sample. Flocculated sediments were oven dried at 105 °C for 24 to 48 hours and weighed. Total sediment mass was calculated by subtracting the mass of the oven dry soil obtained from the total water and sediment mass.

Soil water content for OF-2 and OF-3 simulations was determined by obtaining soil moisture samples from test boxes immediately before and after simulations were run. Percent soil water content was calculated by the following equation.

$$\text{Soil water content} = \frac{\text{Moist soil mass} - \text{Oven dry soil mass}}{\text{Oven dry soil mass}} \times 100\%$$ (Hillel, 1998)

2.3.3 Vegetation Data Collection and Analyses

2.3.3.1 Percent Cover

Percent canopy, ground and rock soil cover were estimated using a modified transect method.

Section 3
RESULTS

3.1 Runoff and Sediment

All treatments significantly reduced erosion compared to bare soil. All vegetation treatments yielded no runoff, and cannot be compared to the other treatments because there was no runoff for analysis. The pH, EC, turbidity, runoff, sediment load and sediment concentration for bare soil, jute netting and 0.5 inches of compost is shown below in **Table 3.1** below.

Table 3.1. Means ± standard errors for all treatments and results.

Treatment	pH	EC	Turbidity (NTU)	Runoff (L)	Sediment (g)	Sediment Concentration (g $^{L-1}$)
Bare Soil	7.07 ± 0.18	610 ± 55	1958 ± 2265	33.7 ± 5.7	725.32 ± 687.01	20090 ± 16988
Jute Neting	6.89 ± 0.18	214 ± 323	113 ± 84	19.1 ± 1.8	2.95 ± 2.03	149 ± 97
Compost (0.5 in.)	6.44 ± 0.06	2616 ± 1703	50 ± 23	1.3 ± 1.3	0.85 ± 0.11	1256 ± 1188

Compared to bare soil, compost reduced runoff by 96 %, reduced sediment load by greater than 99 %, reduced turbidity by 97 % and increased EC by 430 %. Jute netting reduced runoff by 43 %, reduced sediment load by greater than 99 %, reduced turbidity by 97 % and reduced EC by 65 % when compared to bare soil. These values are shown in **Figure 3.1** below.

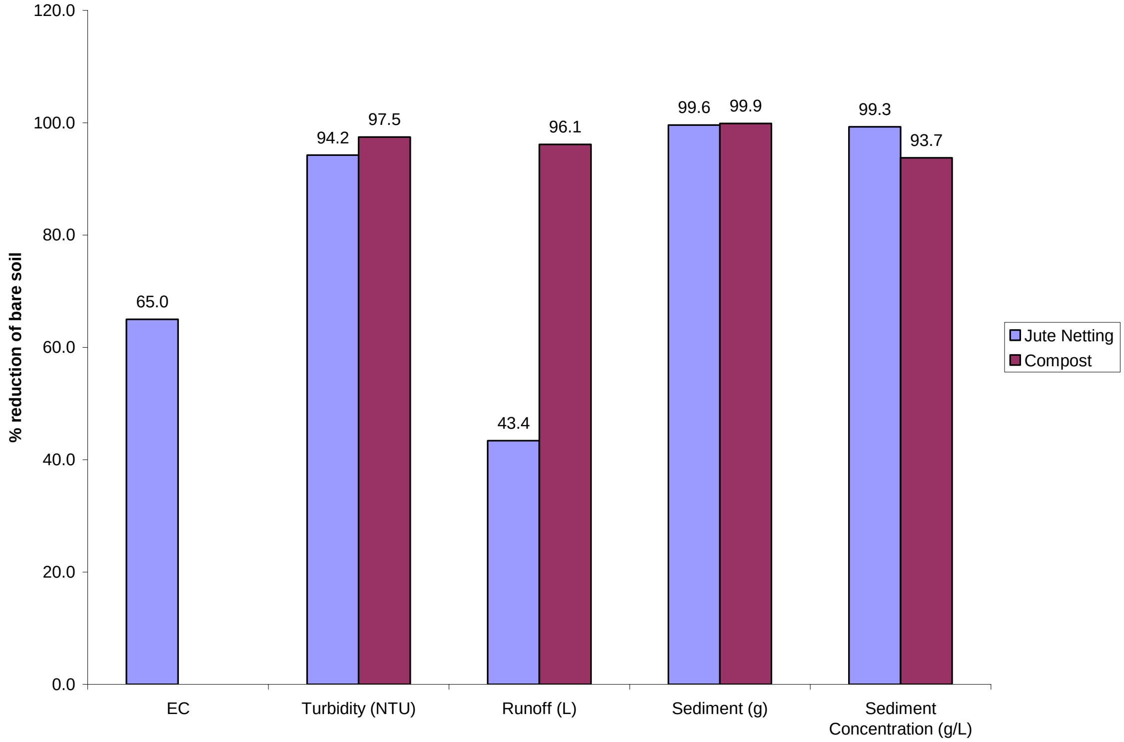


Figure 3.1. Effect of jute netting and compost on EC, turbidity, runoff, sediment and sediment concentration, expressed as a percent reduction of the bare soil values.

3.1.1 Runoff

Bare soil had significantly higher runoff than jute netting and compost. Jute netting had significantly higher runoff than compost due to the way these erosion control materials work. Jute netting slows the water and traps sediment, yielding a moderate quantity of runoff, while compost absorbs large quantities of water, transmitting it to the soil or other compost. The net result is the compost forces water to infiltrate into the soil. The jute netting holds the soil back but does not induce infiltration to the same degree as the compost. This is shown in **Figure 3.2** below.

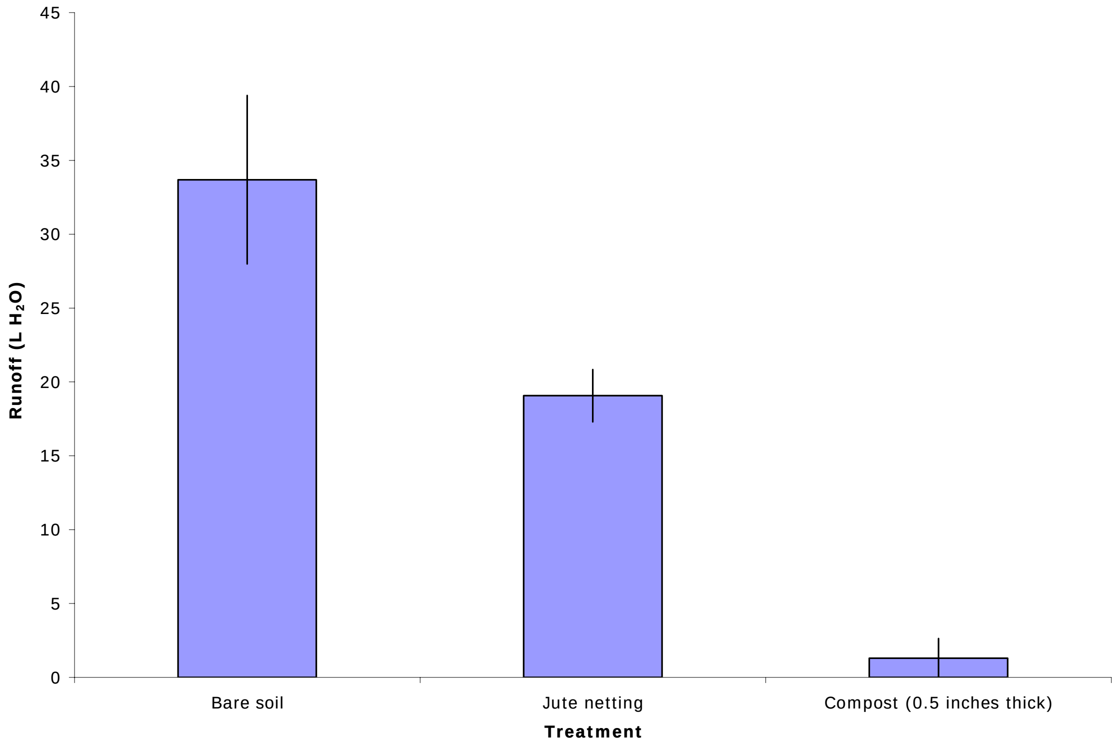


Figure 3.2. Treatment effects on runoff.

3.1.2 Total Sediment

Bare soil had significantly more sediment than both jute netting and compost. Bare soil had over 200 times more sediment than jute netting, and over 700 times as much sediment as compost. This occurs because the erosion control product slows down the water and forces it down through the soil. When the water moves slowly it lacks the energy to scour and transport sediment. Again, there was large box to box variation for the bare soil, but the differences between the bare soil and the jute and compost treatments are large enough to be significant even with this large error.

The jute netting produced significantly more (over 3 times as much) sediment than the compost. The jute netting yielded 0.41 % and the compost yielded 0.12 % of the sediment level compared to the bare box. Jute netting and compost treatments are significantly different from each other, but very similar when compared to the bare soil (**Figure 3.3**).

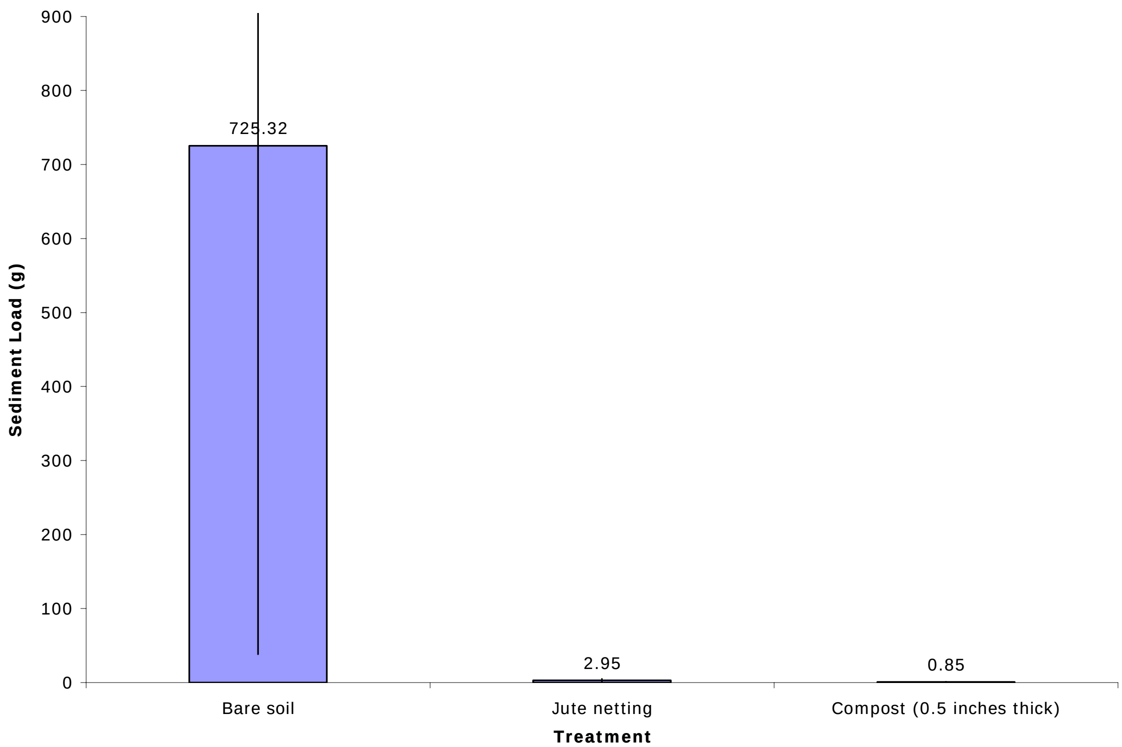


Figure 3.3. Effect of treatment on sediment load.

3.1.3 Sediment Concentration

Bare soil yielded a significantly higher sediment concentration than jute netting and compost. Compost was significantly higher than jute. This occurred due to the large difference in runoff between jute and compost. The compost forced the water to infiltrate, and decreased runoff. Sediment concentration equals the sediment load divided by the runoff. With constant sediment, as runoff decreases, concentration increases (**Figure 3.4**).

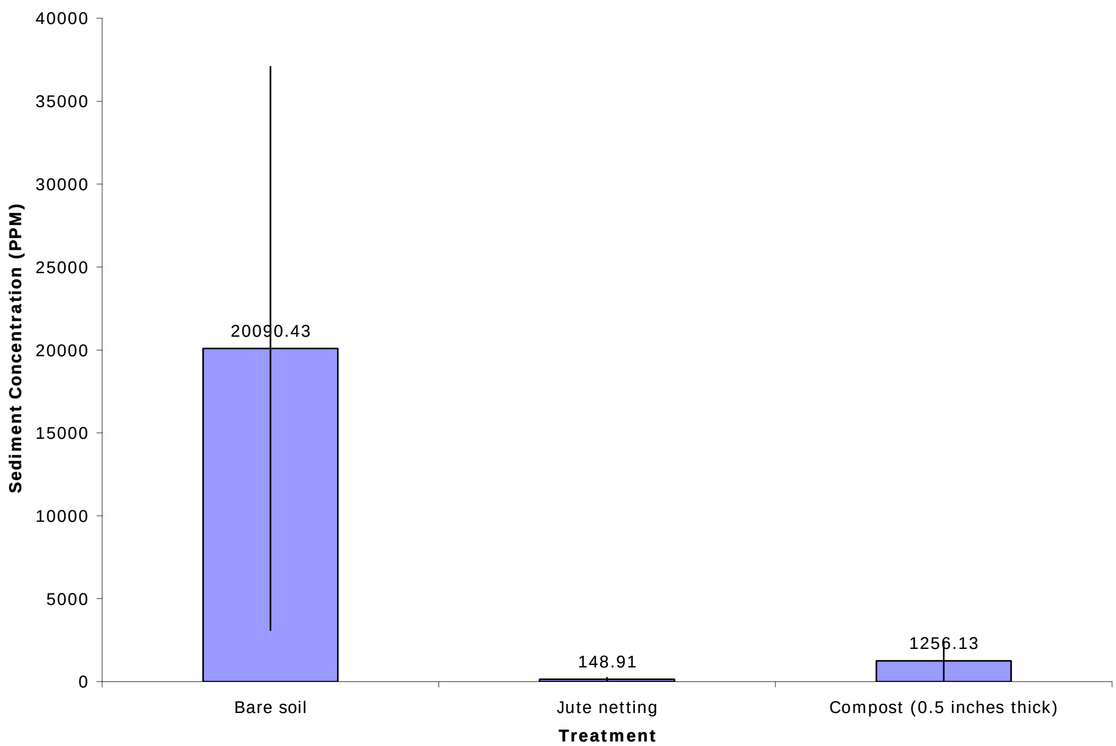


Figure 3.4. Effect of treatment on sediment concentration.

3.1.4 pH

The runoff pH for the bare soil and jute netting were near neutral and not significantly different. Compost had significantly lower runoff pH than jute netting and bare soil due to leaching of organic acids from the compost layer. This is shown in figure 1 below.

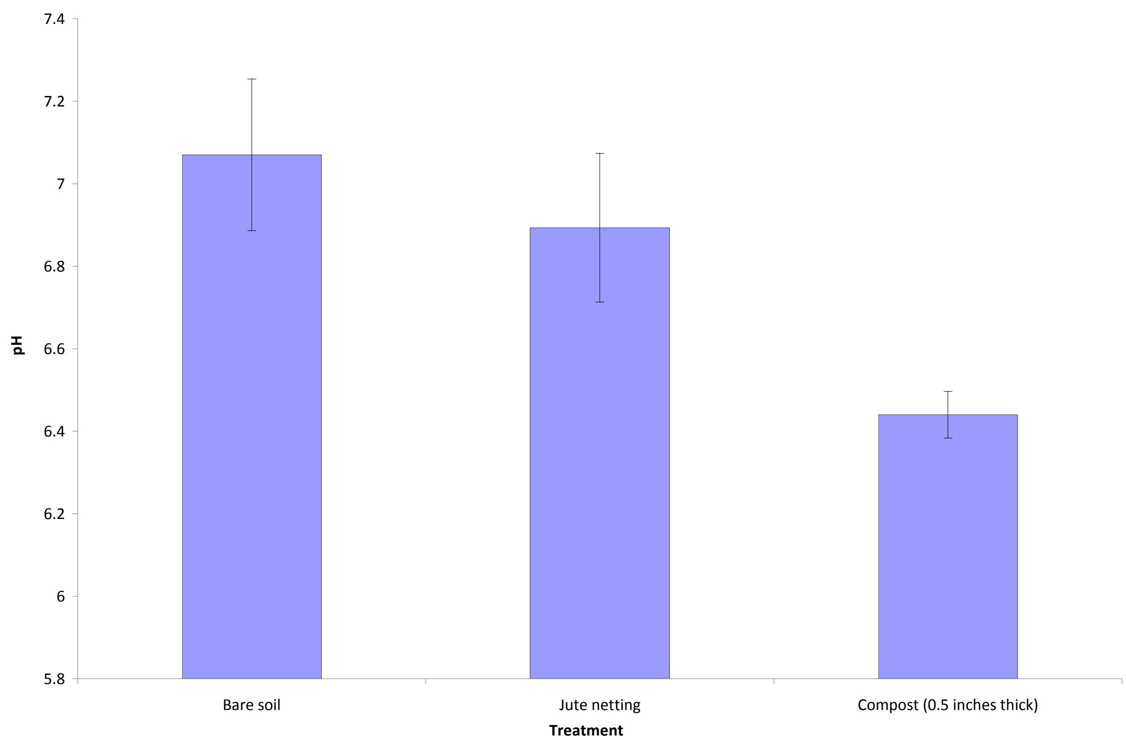


Figure 3.5. The effect of different treatments on runoff pH.

3.1.5 Total Dissolved Solids and Electrical Conductivity

Bare soil and jute netting were not significantly different from each other. The compost had a significantly higher electrical conductivity (EC) and total dissolved solids (TDS) than both bare soil and just netting since the water moving through the compost extracted all the soluble salts. Subsequent runs should yield an EC and TDS similar to the jute netting and the bare soil. Treatment effects on EC and TDS are shown in **Figure 3.6** below.

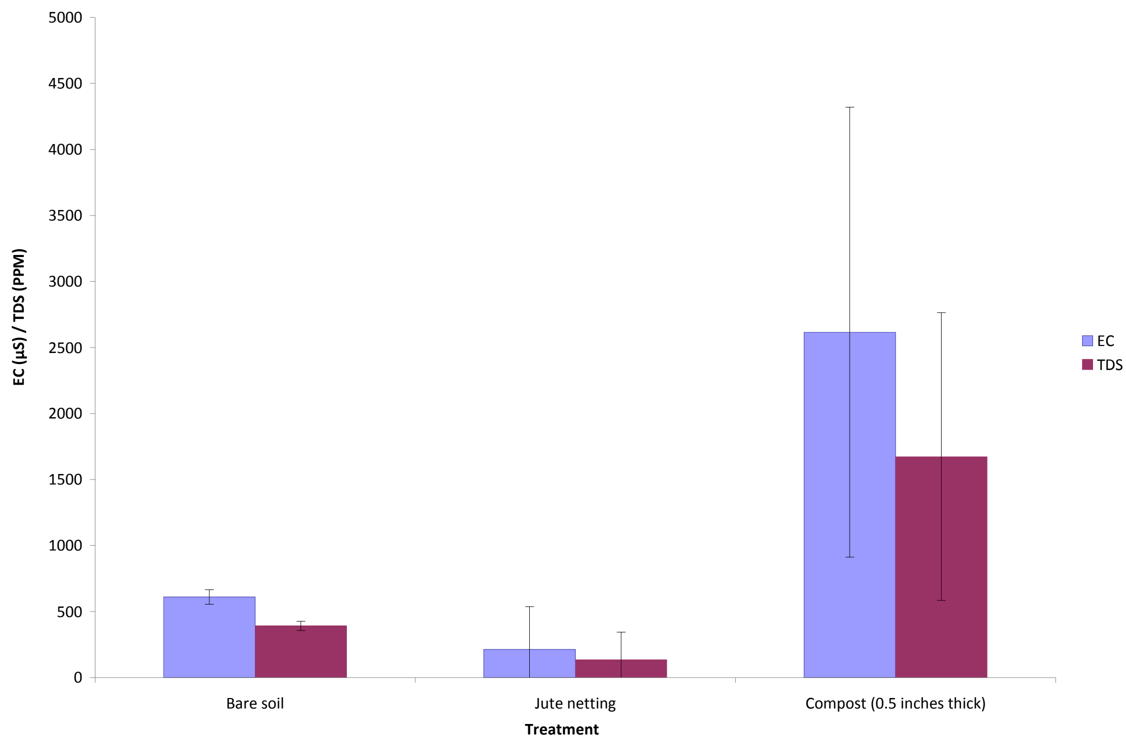


Figure 3.6. Treatment effects on EC and TDS.

3.1.6 Turbidity

There were no significant differences in turbidity among the treatments. Bare soil had a higher turbidity than the other treatments, but the large between-box variation in the bare boxes obfuscates these data through very large standard errors (**Figure 3.7**).

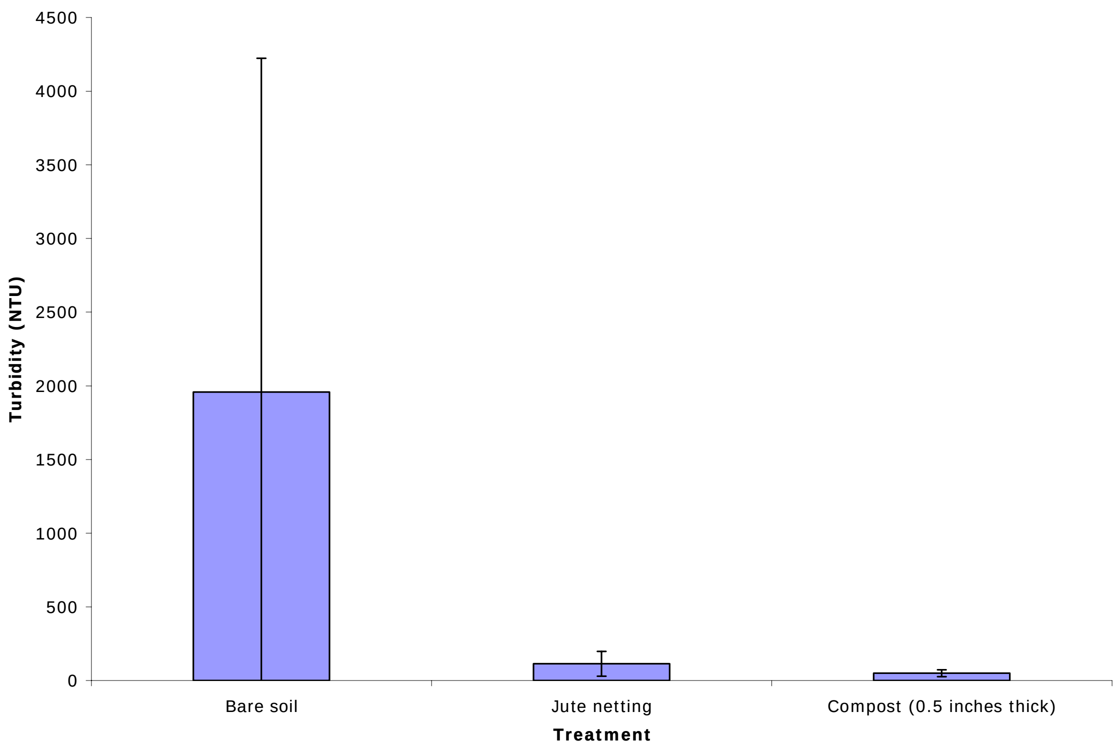


Figure 3.7. Treatment effects on turbidity.

Section 4
CONCLUSIONS

Overland flow erosion occurs on many roadsides, potentially transporting toxic heavy metals and other contaminants. In general, heavy metals have a high affinity for soil particles. When the soil erodes, these metals are transported to other locations. Accordingly, the best strategy for preventing this transport of heavy metals is erosion control.

Established vegetation provides the best overland flow erosion control, but only when it has cover greater than 70 %. In this study, all vegetation boxes yielded no runoff because root channels allowed the water to infiltrate faster than it was loaded on the box.

Compared to bare soil, jute netting and 0.5 inches of compost reduced sediment loss by over 99 %. The main difference between jute netting and compost is the way they control erosion. Jute netting holds the soil in place and allows the water to run off without scouring soil. Compost has a very high water holding capacity and absorbs the water, slowly releasing it. The net result is jute netting yielding more runoff than compost, but similar sediment loads.

No comparisons of different species are possible since none of the vegetation boxes eroded. Future research should increase the slope and flow rate until the differences between species is elucidated.

Section 5
*trans*PLANT

5.1 Introduction

5.1.1 Background

The California Department of Transportation (Caltrans) actively manages roadside rights-of-way that transect California's 41 million hectares (101 million acres) through nearly every vegetation type across elevations from sea level to over 3,000 meters in the Sierra Nevada. Personnel of the 12 Caltrans districts are typically responsible for implementing site-specific adaptations of general statewide guidelines for various categories of Highway Planting including: 1) short- to long-term erosion control following construction or storm damage; 2) long-term upland or wetland revegetation consistent with existing context vegetation; 3) phytofiltration of runoff water; 4) native wildflower seeding for aesthetic displays; and 5) ornamental plantings of trees, shrubs, and herbaceous perennials.

To enable District personnel to construct more locally accurate and consistent specifications of plant species for highway planting projects, and to minimize establishment failures requiring remedial work, a database application called trans PLANT is under development that includes plant species useful within California for erosion control, for biofilters, or for other highway plantings. This prototype uses data for Districts 4, 5, and 11, and serves as a template for all Districts.

5.1.2 Need for a Workflow Database

Development of the *trans*PLANT database was initiated following several extended discussions with Caltrans District 5 users of the Seed&Plant Calculator prototype (VEMS 2004). The Seed&Plant Calculator is a Microsoft® Excel® 97 workbook developed from the Caltrans District 5 Advisory Guide to Plant Species Selection For Erosion Control & Native Revegetation (VEMS 2002) to permit dynamic filtering of the species lists in that guide to better match species attributes with project needs, and to enable arithmetic calculation of seed quantities or of live plant materials needed for specific projects. As with the former product, this spreadsheet workbook is intended as an advisory aid to Caltrans Landscape Architects as they develop specifications for erosion control, revegetation, phytofiltration, and other highway planting projects.

Although the Seed&Plant Calculator provides users with the ability to “filter” a District-level master species list to only those species appropriate for a road segment based on user-selected options, and to rapidly calculate seed or live plant quantities in detail, the Seed&Plant Calculator was intended for single-run calculations that are not saved to a database.

As with most innovative products, once a prototype is developed that makes an abstract concept tangible, most users immediately see further to a much more elaborate or definitive product. Users of the Seed&Plant Calculator identified some key elements of a "next-generation" Seed&Plant Calculator to transform the existing product into one that better enables Landscape Architects to manage the workflow process of developing highway planting specifications, and of tracking the application and performance of such specifications.

Additional needs identified for a workflow tool include:

- Ability to rapidly access, review, and modify pre-built highway planting specifications;
- Ability to save user-developed highway planting specifications for future projects (presently specifications are saved as paper or digital files with no central indexing system);
- Ability to track application of highway planting specifications by contractors;
- Ability to track performance of highway planting specifications over time to better identify specifications that best meet intended management goals, thus reducing remedial work;
- Ability to better track availabilities and prices of plant and landscape materials for sale by vendors to both construct up-to-date specifications, and to minimize unwanted substitutions by contractors during the application phase.

Although the functional needs listed above are possible using Microsoft® Excel® 97, these functions are much better accommodated by Microsoft® Access® 97, also available to Caltrans personnel on their desktops. Microsoft® Access® databases, such as CALTREC, a Caltrans records database, or the Caltrans Storm Water Management Program for statewide analytical data about storm water chemistry, are now used routinely by some Caltrans personnel. Thus, Microsoft® Access® 97 is the application base for development of the trans PLANT database.

5.1.3 General Functions of a Workflow Database

As users query the database by county-route-mile/km, recommended seed or live plant specifications for each road mile/km segment are provided for review. Users may modify these recommended specifications as needed, make seed or live plant quantity calculations, and save new specifications to the master shared database. Reports can be output to typical spreadsheet or word processing software. Specifications are further linked to contract applications, contracts, and contractors to enable tracking as needed.

California lacks a comprehensive, ground-truthed, roadside vegetation inventory database, such as RoadVeg for Utah (Bickford et al. 1998), also developed by the designer of ***trans* PLANT**, that would provide direct georeferencing of species distributions along highways. To georeference plant species along the statewide road network, an ArcGIS Desktop™ geographic information system depicting administrative boundaries, road networks, topography, USFS Region 5 Ecoregional Subsections of California (Miles and Goudey 1997), climate, and vegetation patterns statewide is used to more narrowly define existing Ecoregional Subsections (2500+ km2) into Landtype Associations (25 to 2500 km2) more meaningful to Caltrans personnel within each District. Plant species presence within these zones is assigned using existing floras, on-line resources, herbarium specimen data, and field-based groundtruthing.

California highways are intersected with the ecoregional subunits to produce a road mile/km index to species that is a fundamental junction table of the ***trans*PLANT** database. Species and cultivar attributes also include nomenclature, provenance, lifeform characteristics, morphological traits and anticipated persistence.

5.2 General Database Model

5.2.1 Business Model

The basic business model necessary to create and track highway planting contracts and specifications is similar to that of an inventory management system. The primary elements of the ***trans*PLANT** database are compared below with a general inventory management system of a wholesale distributor. However, in the Caltrans model, Customers are Contractors, and Materials are ordered and purchased from Materials Vendors indirectly by Contractors rather than directly by Caltrans.

Wholesale Distributor	Caltrans
Employees	**Employees**
Customers	**Contractors**
Customer Invoices	Contracts
Customer Orders	Specifications
Customer Payments	Payments to Contractors
Inventory	**Materials Master Lists**
Products	Materials
Product Vendors	**Materials Vendors**
Vendor Invoices	(No Purchase Orders from Vendors directly;
Purchase Orders from Vendors	Contractors purchase from Vendors instead)

5.2.2 General Database Structure

The central focus of the ***trans* PLANT** database is the Highway Planting Contract. Contracts have Contract Applications executed by Contractors based on Materials Specifications developed by Caltrans personnel from Caltrans Approved Landscape and Plant Materials obtained by Contractors from Vendors of all Materials available on the market. **Figure 5.1** at right depicts this general structure, and a more detailed relational model follows. **Figure 5.2** shows a schematic.

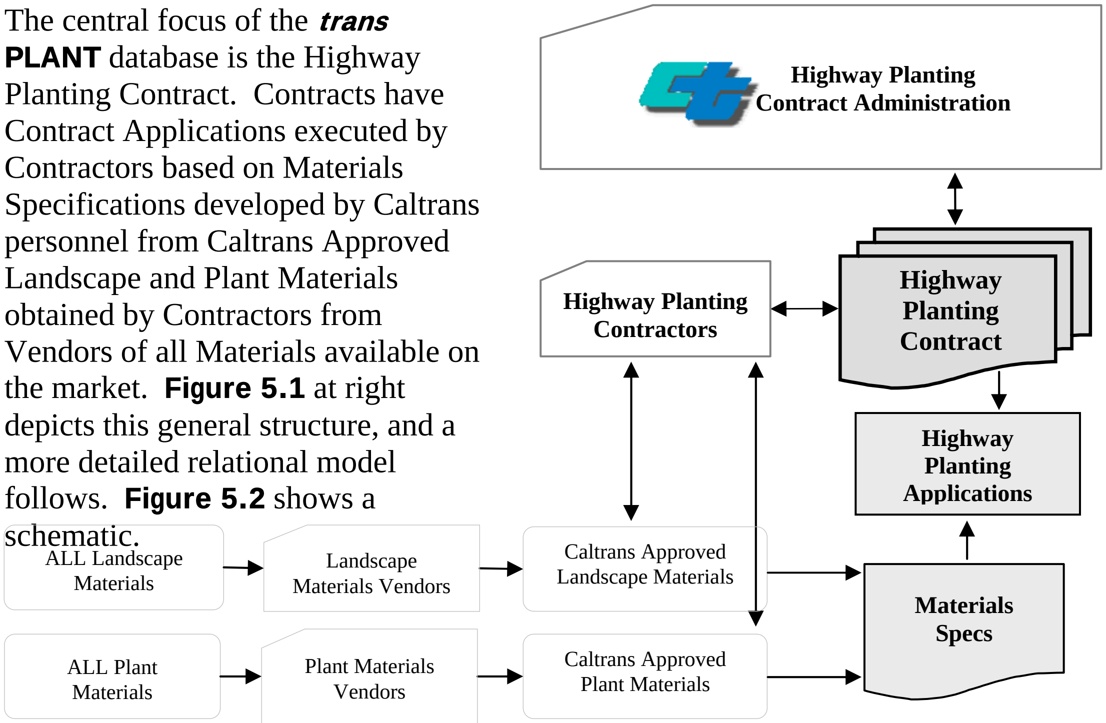


Figure 5.2. General Structure of the *trans* PLANT Database

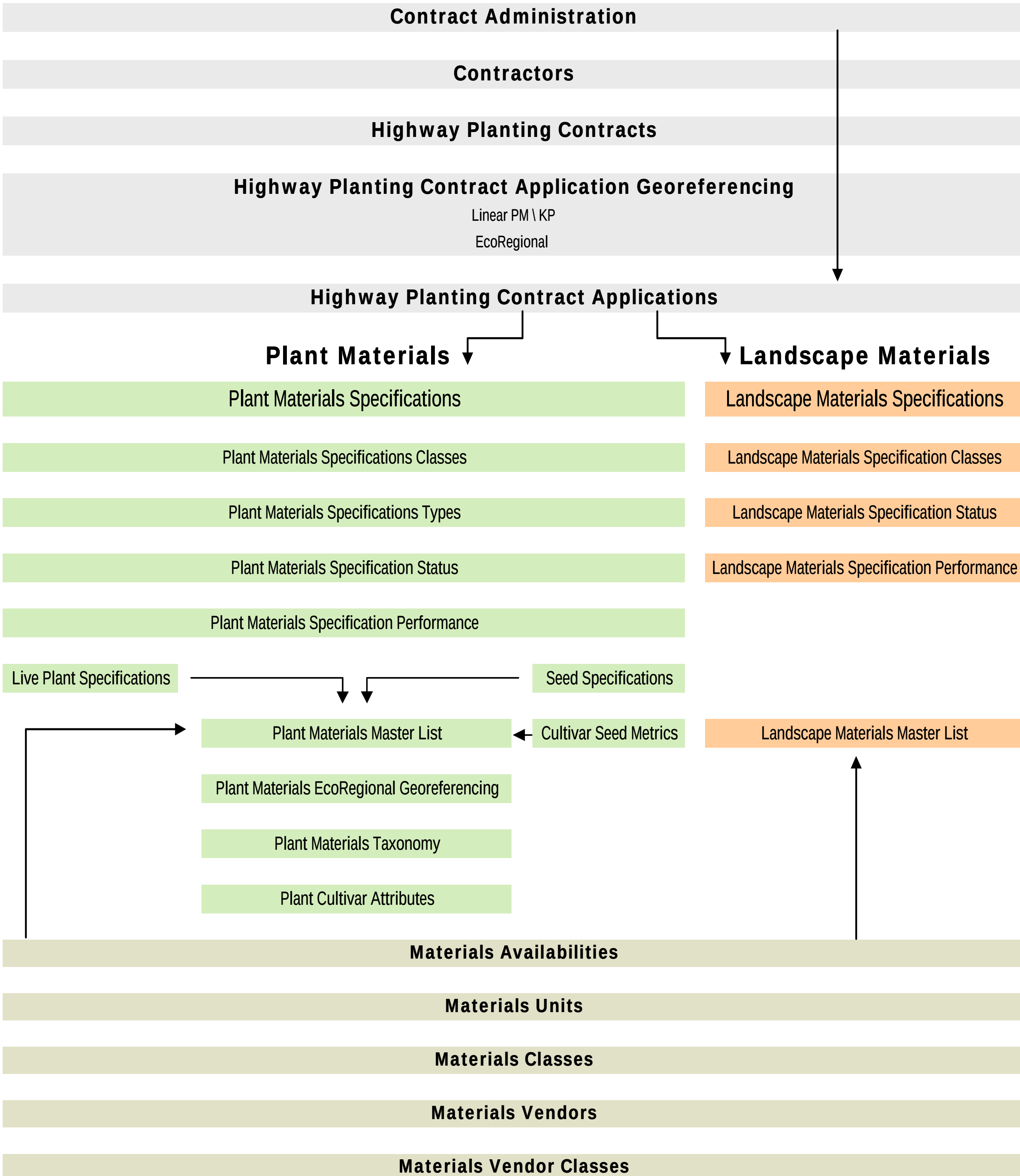


Figure 5.2. Schematic of the *trans* PLANT Database

5.3 Highway Planting Contracts

This sector of the database model allows each Caltrans District to track each Highway Planting Application assigned to a Contract and executed by a Contractor. The data tables involved are listed by category in **Table 5.1**. Data fields, a brief description of the data stored, and the source for these data, are listed below under each contract tracking category.

Table 5.1. Data tables involved in tracking Highway Planting Contracts.

Contract Administration	Contractors	Contracts	Contract Applications	Contract Application Georeferencing
tblCTDistricts	**tblContractors**	**tblContracts**	**tblContractApplications**	**tblCounties**
tblCTSpecifiers	**tblContractorInfo**			**tblRoutes**

5.3.1 Contract Administration

Contract management requires at a minimum the Caltrans District and District employees involved. Data from other databases may be linked here as needed. This sector of the database model will likely undergo modification in consultation with District personnel to ensure that a consensus model accommodates requirements of all Districts.

tblCTDistricts

Field	Key	Description	Data Source
CTDistrictID	Primary	Caltrans District identification number	Caltrans
CTDistrictName		Caltrans District Name	Caltrans
CTDistrictHQ		Caltrans District headquarters	Caltrans

tblCTEmployees

Field	Key	Description	Data Source
CTDistrictID	Foreign	Caltrans District identification number	Caltrans
CTEmployeeID	Primary	Caltrans employee identification number	Caltrans
CTEmployeeNameLast		Caltrans employee last name	Caltrans
CTEmployeeNameFirst		Caltrans employee first name	Caltrans

5.3.2 Contractors

These tables contain names and contact information for highway planting contractors.

tblContractors

Field	Key	Description	Data Source
ContractorID	Primary	Unique Contractor identification number	Database generated
ContractorName		Name of Contractor	Contractors

tblContractorInfo

Field	Key	Description	Data Source
ContractorID	Foreign	Unique contractor identification number	Database generated
ContractorAddress		Contractor street address	Contractors
ContractorPOBox		Contractor post office box (if applicable)	FIPS (NIST 1994)
ContractorCity		Contractor city name	Contractors
ContractorStateAbbr		Contractor state abbreviation	Contractors
ContractorZipCode		Contractor Zipcode	Contractors
ContractorPhone1		Contractor primary phone number	Contractors
ContractorPhone2		Contractor secondary phone number	Contractors
ContractorFAX		Contractor FAX number	Contractors
ContractorWebSite		Contractor web site address	Contractors
ContractorEmail		Contractor email address	Contractors

5.3.3 Contracts

The Contracts table stores primary data about the State Expenditure Authorization number, the District, the Contractor, the dates of issuance and bid acceptance, the cost estimated by Caltrans before bidding, and the amount bid by the contractor that was accepted by Caltrans.

tblContracts

Field	Key	Description	Data Source
EA	Primary	State Expenditure Authorization number	Caltrans
CTDistrictID	Foreign	Caltrans District number	Caltrans
ContractorID	Foreign	Unique Contractor identification number	Database generated
DateContractIssued		Date contract was issued	Caltrans
DateBidAccepted		Date contract bid was accepted	Caltrans
AmountEstimatedByCT		Contract amount estimated by Caltrans	Caltrans
AmountBid		Contract amount bid by contractor	Caltrans

5.3.4 Contract Applications

The Contract Applications table contains the primary data about each Highway Planting Application related to each contract. Multiple Highway Planting Applications may relate to the same Contract. Each Highway Planting Application is georeferenced via County\Route\Milepost. Other data include the area in square meters to be treated, the scheduled start date, the actual start date, and the date completed.

tblContractApplications

Field	Key	Description	Data Source
HPApplctnID	Primary	Highway Planting Application identifier	Database generated
EA	Foreign	State Expenditure Authorization number	Caltrans
CountyID	Foreign	Unique County identification number	FIPS (NIST 1994)
RouteID	Foreign	Identifier for Interstate, US Highway, or State Route	Caltrans
BeginPM		Beginning post-mile of road segment	Caltrans
EndPM		Ending post-mile of road segment	Caltrans
AreaTreatedM2		Area (square meters) to be treated by application	Caltrans
DateScheduledStart		Scheduled start date for contract application	Caltrans
DateActualStart		Actual start date for contract application	Caltrans
DateCompleted		Completion date of contract application	Caltrans

5.3.5 Contract Application Georeferencing

Each Highway Planting Application is georeferenced via the standard County\Route\Milepost structure. County and Route data are related to Contract Application data.

tblCounties

Field	Key	Description	Data Source
CTDistrictID	Foreign	Caltrans District number	Caltrans
CountyIDFIPS		Unique County identification number	FIPS (NIST 1994)
CountyAbbrFIPS	Primary	Unique County abbreviation	FIPS (NIST 1994)
CountyName		County name	FIPS (NIST 1994)
CountyIDCT		Unique County identification number	Caltrans
CountyAbbrCT		Unique County abbreviation	Caltrans

tblRoutes

Field	Key	Description	Data Source
CTDistrictID	Foreign	Caltrans District number	Caltrans
CountyAbbrFIPS	Foreign	Unique County abbreviation	FIPS (NIST 1994)
RouteID	Primary	Unique route identifier	FIPS (NIST 1994)
RouteINT		Unique Interstate route identifier	FHWA
RouteUS		Unique United States route identifier	FHWA
RouteCA		Unique California State route identifier	FHWA & Caltrans

5.4 Plant Materials Specifications

This largest sector of the database model contains all elements necessary to develop, classify, and georeference Plant Materials Specifications. The data tables involved are listed by category in **Table 5.2**.

Table 5.2. Data tables involved in developing Plant Materials Specifications.

Classes & Types	Specs	Plant Materials	Status	Performance	Georeferencing
tblPlantMtrlsSpecClasses	**tblSeedSpecs**	**tblPlantMtrlsMaster**	**tblSpecStatus**	**tblSpecPerformance**	**tblEcoDomain**
tblPlantMtrlsSpecTypes	**tblLiveSpecs**	**tblPlantTaxaMaster**			**tblEcoDivision**
		tblCAPlantTaxa			**tblEcoProvince**
		tblTaxonVernacular			**tblEcoSection**
		tblCultivarAttributes			**tblEcoSubSection**
		tblCultivarSeedMetrics			**tblPMSpecsEcoUnits**
					tblPlantMaterialsEcoUnits
					tjctRouteSegmentsEcoUnits

5.4.1 Plant Materials Specifications Classes

This lookup table merely identifies whether a Plant Materials Specification belongs to the "Seed" or "Live" plant materials class.

tlkpPlantMtrlsSpecClasses

Field	Key	Description	Data Source
PlantMtrlsSpecClass	Primary	Plant Materials Specification Class	Unique to database

5.4.2 Plant Materials Specifications Types

This lookup table identifies the Plant Materials Specification Type: ALL Species, Temporary Erosion Control, Long-term Erosion Control, Native Wildflower, Upland Revegetation, Wetland Revegetation, Phytofiltration, or Ornamental. Within each category, different Specification Types are identified in a series, e.g. TempEC1, TempEC2, TempEC3, etc., that specifies the percentages of lifeforms (Perennial Grasses, Annual Grasses, Legume Forbs, Other Forbs, or Shrubs) represented in that mix type. See the Example Record below.

tlkpPlantMtrlsSpecTypes

Field	Key	Description	Data Source
PlantMtrlsSpecTypeID	Primary	Plant Materials Specification Type identifier	Unique to database
PlantMtrlsSpecType		Plant Materials Specification Type	Unique to database
PlantMtrlsMixType		Plant Materials Specification Mix Type	Unique to database
%PG		Percent of mix represented by Perennial Grasses	Unique to database
%AG		Percent of mix represented by Annual Grasses	Unique to database
%LF		Percent of mix represented by Legume Forbs	Unique to database
%OF		Percent of mix represented by Other (Non-Legume) Forbs	Unique to database
%S		Percent of mix represented by Shrubs	Unique to database
PlntMtrlsSpecNotes		Comments about the applications of a specific mix type	Unique to database

Field: PlantMtrlsSpecType

Value	Description
ALLSpecies	ALL species appropriate for the EcoUnit and Application Method.
TempEC	Species best able to provide temporary rainy-season cover.
LongTermEC	Species best able to provide temporary and longer term rainy-season cover.
NativeWildflower	Native annual species best suited for a seasonal display of local wildflowers.
UplandReveg	An assemblage of local native species intended to resemble early successional stages of the context vegetation.
WetlandReveg	An assemblage of local native species intended to resemble early successional stages of local context wetlands.
Biofilter	Mostly native species intended to promote phytofiltration of unwanted chemicals potentially present in runoff water.
Ornamental	Native or non-native cultivars intended to establish longterm ornamental plantings.

Example Record

tlkpPlantMtrlsSpecTypes

Field	Value
PlantMtrlsSpecTypeID	TempEC2
PlantMtrlsSpecType	TempEC
PlantMtrlsMixType	PerGrass>AnnGrass>AnnForb>PerForb
%PG	60
%AG	20
%LF	10
%OF	10
%S	0
PlntMtrlsSpecNotes	This mix is intended as temporary rainy-season cover. These more competitive early successional species typically remain indefinitely and often inhibit establishment from seed by less competitive later successional species.

5.4.3 Plant Materials Specification Status

This lookup table identifies the status of a Plant Materials Specification so that users can see whether a specification is a "Default" design of the database, is "In Development", is "Final, But Not Yet Applied", or has been "Applied by A Contractor" previously.

tlkpSpecStatus

Field	Key	Description	Data Source
SpecStatusID	Primary	Plant Materials Specification Status identifier	Unique to database
SpecStatus		Plant Materials Specification Status	Unique to database

SpecStatusID	SpecStatus
0	Default
1	In Development
2	Final, But Not Yet Applied
3	Applied By A Contractor

5.4.4 Plant Materials Specification Performance

This lookup table identifies the known performance of a Plant Materials Specification so that users can see whether a specification "Performs Well Among Sites and Years", "Performs Well Only Under Optimum Conditions", or whether "Performance [is] Unknown".

tlkpSpecPerformance

Field	Key	Description	Data Source
SpecPerformanceID	Primary	Plant Materials Specification Performance identifier	Unique to database
SpecPerformance		Plant Materials Specification Performance	Unique to database

SpecPerformanceID	SpecPerformance
1	Performs Well Consistently Among Sites and Years
2	Performs Well Only Under Optimum Conditions
3	Performance Unknown

5.4.5 Plant Materials Specifications

The Seed Specifications and Live Specifications tables store primary data about the plant materials of each Highway Planting Specification. Table records function like a recipe for the identities, units, and quantities necessary to effect each plant materials specification. These specifications are assigned to Highway Planting Applications through junction tables, as shown by this example for Seed Specifications.

tjctContractApplicationsSeedSpecs

Field	Key	Description	Data Source

HPApplctnID	Foreign	Highway Planting Application identifier	Database generated
SeedSpecID	Foreign	Seed Specification identifier	Database generated

5.4.5.1 Seed Specifications

tblSeedSpecs

Field	Key	Description	Data Source
SeedSpecID	Primary	Seed Specification identifier	Database generated
AccptdTaxonID	Foreign	Unique identifier of the accepted taxonomic name for a species	Unique to database
TaxonID	Foreign	Unique identifier of a taxonomic synonym for a species	Unique to database
CultivarID	Foreign	Unique identifier of a specific cultivar	Unique to database
MaterialsUnitID	Foreign	Unique identifier for quantity or size of materials, e.g., kgPLS	Unique to database
Quantity		Number of product units, e.g., 20 kgPLS	Unique to database
SpecStatusID	Foreign	Plant Materials Specification Status identifier	Unique to database
SpecPerformanceID	Foreign	Plant Materials Specification Performance identifier	Unique to database
SpecifierID	Foreign	Caltrans employee identification number	Unique to database

5.4.5.2 Live Specifications

tblLiveSpecs

Field	Key	Description	Data Source
LiveSpecID	Primary	Seed Specification	Database generated
AccptdTaxonID	Foreign	Unique identifier of the accepted taxonomic name for a species	Unique to database
TaxonID	Foreign	Unique identifier of a taxonomic synonym for a species	Unique to database
CultivarID	Foreign	Unique identifier of a specific cultivar	Unique to database
MaterialsUnitID	Foreign	Unique identifier for quantity or size of materials, e.g., 4 inch or 1 gal	Unique to database
MaterialsUnitDensityM2		Density of units to be planted within the specified planting area	Unique to database
%PlantingArea		Percent of planting area to be planted by a cultivar	Unique to database
SpecStatusID	Foreign	Plant Materials Specification Status identifier	Unique to database
SpecPerformanceID	Foreign	Plant Materials Specification Performance identifier	Unique to database
SpecifierID	Foreign	Caltrans employee identification number	Unique to database

5.4.6 Plant Materials Master List

This table stores relational attribute data about Plant Materials identifying nomenclature, class, units, lots, vendor availabilities, and vendor prices. All Plant Materials Specifications are constructed from these data.

tblPlantMtrlsMasterList

Field	Key	Description	Data Source
AccptdTaxonID	Foreign	Unique identifier of the accepted taxonomic name for a species	Unique to database
TaxonID	Foreign	Unique identifier of a taxonomic synonym for a species	Unique to database
CultivarID	Foreign	Unique identifier of a specific cultivar	Unique to database
MaterialsClassID	Foreign	Materials Class identifier	Unique to database
MaterialsUnitID	Foreign	Unique identifier for quantity or size of materials, e.g., 4 inch or 1 gal	Unique to database

CultivarLotID	Foreign	Cultivar Lot identifier assigned by Vendor	Vendors
CultivarLotEcoSubSectionID	Foreign	EcoRegional SubSection origin of Cultivar Lot	Bailey 1995
VendorID	Foreign	Plant Materials Vendor identifier	Unique to database
AvailabilityID	Foreign	Availability category for Cultivar	Unique to database
UnitPrice2005		Unit price of Cultivar charged by Vendor	Vendors

5.4.7 Plant Materials EcoRegional Georeferencing

Georeferencing of Plant Materials is achieved by assigning presence/absence values to plant cultivars within the National Hierarchical Framework of Ecological Units framework (Cleland et al. 1997) as modified for California (Miles and Goudey 1997). Presence/absence values are assigned using existing floras, on-line resources, herbarium specimen data, and field-based groundtruthing. Using GIS software, California highways are intersected with these Ecological Units to produce a road mile/km index to species that is a fundamental junction table of the ***trans*PLANT** database.

tblEcoDomain

Field	Key	Description	Data Source
EcoDomainID	Primary	EcoRegional Domain code	Bailey 1995
EcoDomainName		EcoRegional Domain name	Bailey 1995

tblEcoDivision

Field	Key	Description	Data Source
EcoDivisionID	Primary	EcoRegional Division code	Bailey 1995
EcoDivisionName		EcoRegional Division name	Bailey 1995

tblEcoProvince

Field	Key	Description	Data Source
EcoProvinceID	Primary	EcoRegional Province code	Bailey 1995
EcoProvinceName		EcoRegional Province name	Bailey 1995

tblEcoSection

Field	Key	Description	Data Source
EcoSectionID	Primary	EcoRegional Section code	Bailey 1995
EcoSectionName		EcoRegional Section name	Bailey 1995

tblEcoSubSection

Field	Key	Description	Data Source
EcoSubSectionID	Primary	EcoRegional SubSection code	Bailey 1995
EcoSubSectionName		EcoRegional SubSection name	Bailey 1995

tjctRouteSegmentsEcoUnits

Field	Key	Description	Data Source

EcoSubsectionID	Foreign	Identifier for Interstate, US Highway, or State Route	Caltrans
CountyID	Foreign	Unique County identification number	FIPS (NIST 1994)
RouteID	Foreign	Area (square meters) to be treated by application	Caltrans
BeginPM		Beginning post-mile of road segment	Caltrans
EndPM		Ending post-mile of road segment	Caltrans

5.4.8 Plant Materials Taxonomy

Plant Materials nomenclature derives from a synthesis from numerous sources pertinent to California plant species and cultivars. Names largely follow *The Jepson Manual* (Hickman 1993) and updates currently in progress for a second edition. Other global, statewide, and District-level sources consulted to date are listed in section 4.1.1.

tblPlantMtrlsTaxaMaster

Field	Key	Description	Data Source
AccptdTaxonID	Primary	Unique identifier of the accepted taxonomic name for a species	IPNI 2005
TaxonID	Primary	Unique identifier of a taxonomic synonym for a species	IPNI 2005
TaxonNameLong		Scientific name including authors	IPNI 2005
TaxonNameShort		Scientific name excluding authors	IPNI 2005

5.4.9 Plant Materials Attributes

Plant Materials attribute data are fundamental to the selection of cultivars for Plant Materials Specifications. Cultivar attributes include nomenclature, provenance, lifeform characteristics, morphological traits, physiology, seed and seedling traits.

5.4.9.1 Cultivar Seed Metrics

For cultivars sold as seed, average values for seeds per pound, percent purity, and percent germination are stored for each cultivar lot.

tblPlantMtrlsMasterList

Field	Key	Description	Data Source
AccptdTaxonID	Foreign	Unique identifier of the accepted taxonomic name for a species	Unique to database
TaxonID	Foreign	Unique identifier of a taxonomic synonym for a species	Unique to database
CultivarID	Foreign	Unique identifier of a specific cultivar	Unique to database
CultivarLotID	Foreign	Cultivar Lot identifier assigned by Vendor	Vendors
Seedslb		Average number of seeds per pound (US)	Vendors
Purity%		Average percent purity of seed lot	Vendors
Germination%		Average percent germination of seed lot	Vendors

5.4.9.2 Cultivar Attributes

Forty fields store attribute data about each cultivar. These data are used to select cultivars that possess combinations of attributes desired for a particular Highway Planting Application.

tblCultivarAttributes

Field	Key	Description	Data Source
AccptdTaxonID	Primary	Unique identifier of the accepted taxonomic name for a species	IPNI 2005
TaxonID	Primary	Unique identifier of a taxonomic synonym for a species	IPNI 2005
CultivarOriginEcoSubSectionID	Foreign	EcoRegional SubSection origin of Cultivar Lot	Bailey 1995
CultivarName		Name of cultivar	Literature
Provenance		Whether a cultivar is native or alien within an EcoRegional SubSection	Literature
Duration		Whether a cultivar is perennial, biennial, or annual	Literature
Lifeform		Whether a cultivar is a grass, graminoid, forb, vine, shrub, or tree	Literature
Legume		Whether a cultivar belongs to the family Leguminosae \ Fabaceae	Literature
SeralRank		Whether a cultivar is a pioneer, mid-seral, or late-seral	Literature
WetlandID		National wetland code	USFWS 1996
Phytofilter		Whether a cultivar is useful as a phytofilter of contaminants in water	Literature
NitrogenFixer		Whether a cultivar is host to nitrogen-fixing microorganisms	Literature
PPTMinInches		Minimum amount of precipitation necessary for survival and growth	Literature
DroughtTolerance		Drought tolerance ranked as high, medium, low, none, or unknown	Literature
ActiveGrowthSeasonBegin		Season that active growth begins	Literature
ActiveGrowthSeasonEnd		Season that active growth ends	Literature
GrowthRate		Drought tolerance ranked as high, medium, low, none, or unknown	Literature
LateralSpreadRate		Drought tolerance ranked as high, medium, low, none, or unknown	Literature
SodStrips		Whether or not cultivar can be grown and used as sod strips	Literature
HeightMaxMeters		Typical maximum height in meters	Literature
Below28FTolerance		Tolerance below 28F ranked as high, medium, low, none, or unknown	Literature
Above90FTolerance		Tolerance above 90F ranked as high, medium, low, none, or unknown	Literature
FullSunTolerance		Full sun tolerance ranked as high, medium, low, none, or unknown	Literature
ShadeTolerance		Full shade tolerance ranked as high, medium, low, none, or unknown	Literature
SalinityTolerance		Salinity tolerance ranked as high, medium, low, none, or unknown	Literature
InundationTolerance		Inundation tolerance ranked as high, medium, low, none, or unknown	Literature
HedgingTolerance		Hedging tolerance ranked as high, medium, low, none, or unknown	Literature
MowingTolerance		Mowing tolerance ranked as high, medium, low, none, or unknown	Literature
FoliageRetention		Whether foliage is evergreen, dry-deciduous, or cold-deciduous	Literature
FoliageAutumnColor		Foliage color in autumn	Literature
FlowerColor		Flower color	Literature
FlowerProminence		Flower prominence ranked as high, medium, low, none, or unknown	Literature
BloomSeasonBegin		Season that flowering begins	Literature
BloomSeasonEnd		Season that flowering ends	Literature
FruitSeedProminence		Fruit prominence ranked as high, medium, low, none, or unknown	Literature
FruitSeedSeasonBegin		Season that fruit \ seed development begins	Literature
FruitSeedSeasonEnd		Season that fruit \ seed development ends	Literature
SeedAbundance		Seed abundance ranked as high, medium, low, none, or unknown	Literature
SeedPersistence		Seed persistence ranked as high, medium, low, none, or unknown	Literature
SelfSowingPotential		Self-sowing potential ranked as high, medium, low, none, or unknown	Literature
SeedBurialTolerance		Seed burial tolerance ranked as high, medium, low, none, or unknown	Literature
SeedlingVigor		Seedling vigor ranked as high, medium, low, none, or unknown	Literature

5.5 Landscape Materials Specifications

This largest sector of the database model contains all elements necessary to develop and classify Landscape Materials Specifications. The data tables involved are listed by category in **Table 5.3**.

Table 5.3. Data tables involved in developing Landscape Materials Specifications.

Classes & Types	Specs	Landscape Materials	Status	Performance
tblLndscpMtrlsSpecClasses	tblLndscpMtrlsSpecs	tblLndscpMtrlsMaster	tblSpecStatus	tblSpecPerformance

5.5.1 Landscape Materials Specifications Classes

This lookup table merely identifies whether a Landscape Materials Specification belongs to one of several Landscape Materials Specification Classes.

tlkpLndscpMtrlsSpecClasses

Field	Key	Description	Data Source
LndscpMtrlsSpecClass	Primary	Landscape Materials Specification Class	Unique to database

5.5.2 Landscape Materials Specification Status

This element is the same as element **5.4.3**.

5.5.3 Landscape Materials Specification Performance

This element is the same as element **5.4.4**.

5.5.4 Landscape Materials Specifications

The Landscape Materials Specification table store primary data about the landscape materials of each Highway Planting Specification. Table records function like a recipe for the identities, units, and quantities necessary to effect each landscape materials specification. These specifications are assigned to Highway Planting Applications through junction tables, as shown by this example for Seed Specifications.

tjctContractApplicationsLndscpMtrlsSpecs

Field	Key	Description	Data Source
HPApplctnID	Foreign	Highway Planting Application identifier	Database generated
LndscpMtrlsSpecID	Foreign	Landscape Materials Specification identifier	Database generated

tblLndscpMtrlsSpecs

Field	Key	Description	Data Source
LndscpMtrlsSpecID	Primary	Landscape Materials Specification identifier	Database generated
LndscpMtrlsSpecClass	Foreign	Landscape Materials Specification Class	Unique to database
LndscpMtrlsSqnce		Application sequence order of Landscape Materials	Unique to database
LndscpMtrlsID	Foreign	Unique identifier of Landscape Material	Unique to database
LndscpMtrlsUnit		Unique identifier for quantity or size of materials, e.g., m^3/ha	Unique to database
LndscpMtrlsQty		Number of product units, e.g., 100 m^3/ha	Unique to database
SpecStatusID	Foreign	Materials Specification Status identifier	Unique to database
SpecPerformanceID	Foreign	Materials Specification Performance identifier	Unique to database
SpecifierID	Foreign	Caltrans employee identification number	Caltrans

5.6 Materials

This sector of the database model allows each Caltrans District to track available Landscape and Plant Materials and Materials Vendors. The data tables involved are listed by category in **Table 5.4**.

Table 5.4. Data tables involved in tracking Materials and Materials Vendors.

Materials	Vendors
tblMaterialsUnits	**tblMaterialsVendorClasses**
tblAvailabilities	**tblMaterialsVendors**
	tblMaterialsVendorsInfo

5.6.1 Materials Units

Forty fields store attribute data about each cultivar. These data are used to select cultivars that possess combinations of attributes desired for a particular Highway Planting Application.

tblMaterialsUnits

Field	Key	Description	Data Source
MaterialsUnitID	Foreign	Unique Materials Unit identifier	Unique Code
MaterialsUnit		Materials Unit	FIPS (NIST 1994)

Example Units for Plant Materials

MaterialsUnitID	MaterialsUnit	MaterialsUnitID	MaterialsUnit	MaterialsUnitID	MaterialsUnit
lbPLS	pound PLS	4G	4 Gallon	TP	Treepot
lbGross	pound Gross	5G	5 Gallon	DP	Deepot
2I	2 Inch	7G	7 Gallon	TB	Treeband
4I	4 Inch	10G	10 Gallon	SC	Supercell
6IC	6 Inch Cone	15G	15 Gallon	Sod12x18	Sod Flat 12in x18in
1T	1 Trade Gallon	25G	25 Gallon	Sod18x18	Sod Flat 18in x18in
2T	2 Trade Gallon	24Box	24 Inch Box	BR	Bare Root

1G	1 Gallon	36Box	36 Inch Box	BB	Balled & Burlaped
2G	2 Gallon	48Box	48 Inch Box	Bulb	Bulb/Corm/Tuber
3G	3 Gallon			TP	Treepot

5.6.2 Materials Availabilities

Materials availabilities are ranked categorically as “Regular Stock”, “Varies Seasonally”, “Contract Collected”, “Contract Grown”, “Special Order”.

tblAvailabilities

Field	Key	Description	Data Source
Availability	Primary	Availability categories for materials	Vendors

5.6.3 Materials Vendors Classes

Materials Vendors are assigned to classes and categories to allow various queries of Materials by Materials Vendor, or vice versa.

tblMaterialsVendorClasses

Field	Key	Description	Data Source
VendorID	Foreign	Unique Vendor identification number	Database generated
MaterialsVendorClass		Materials Vendor Class	Vendors
MaterialsVendorCategory		Materials Vendor Category	Vendors

5.6.4 Materials Vendors

These tables contain names and contact information for Materials Vendors.

tblMaterialsVendors

Field	Key	Description	Data Source
VendorID	Primary	Unique Vendor identification number	Database generated
VendorName		Name of Vendor	Vendors

tblMaterialsVendorInfo

Field	Key	Description	Data Source
VendorID	Foreign	Unique Vendor identification number	Database generated
VendorAddress		Vendor street address	Vendors
VendorPOBox		Vendor post office box (if applicable)	FIPS (NIST 1994)
VendorCity		Vendor city name	Vendors
VendorStateAbbr		Vendor state abbreviation	Vendors
VendorZipCode		Vendor Zipcode	Vendors
VendorPhone1		Vendor primary phone number	Vendors
VendorPhone2		Vendor secondary phone number	Vendors
VendorFAX		Vendor FAX number	Vendors
VendorWebSite		Vendor web site address	Vendors
VendorEmail		Vendor email address	Vendors

Section 6
REFERENCES

American Society for Testing and Materials International (ASTM). 2002. D3977-97 (2002) Standard Test Methods for Determining Sediment Concentration in Water Samples.

California Department of Transportation (CalTrans). 2003. Roadside vegetated treatment study (RVTS). California Department of Transportation. CTSW-RT-03-028. November, 2003.

Hillel, Daniel. 1998. Environmental soil physics. Academic Press, New York, NY.

Pearce, R.A., G.W. Frasier, M.J. Trlica, W.C. Leininger, J.D. Stednick, and J.L. Smith. 1998. Sediment filtration in a montane riparian zone under simulated rainfall. Journal of Range Management. 51: 309-314.

Scharff, M. E. 2005. Comparison of RUSLE and RUSLE2 to determine water quality treatment of vegetated strips. International Erosion Control Association Preeedings of Conference 36.

United States Environmental Protection Agency (USEPA). 2001. Method #160.2 Residue, Non-Filterable & total Suspended Solids 600/4-79-020.

6.1 Transplant

Abrams, L. 1904. *Flora of Los Angeles and Vicinity*. Stanford: Stanford University Press.

Abrams, L. 1923. *Illustrated Flora of the Pacific States*. Vol. **1**: Ophioglossaceae to Aristolochiaceae. Stanford: Stanford University Press.

Abrams, L. 1944. *Illustrated Flora of the Pacific States*. Vol. **2**: Polygonaceae to Krameriaceae. Stanford: Stanford University Press.

Abrams, L. 1951. *Illustrated Flora of the Pacific States*. Vol. **3**: Geraniaceae to Scrophulariaceae. Stanford: Stanford University Press.

Anderson, M.; Bourgeron, P.; Bryer, M.T.; Crawford, R.; Engelking, L.; Faber-Langendoen, D.; Gallyoun, M.; Goodin, K.; Grossman, D.H.; Landaal, S.; Metzler, K.; Patterson, K.D.; Pyne, M.; Reid, M.; Sneddon, L.; Weakley, A.S. 1998. International Classification of Ecological Communities: Terrestrial Vegetation of the United States. Vol. II. The National Vegetation Classification System: List of Types. Arlington, VA: The Nature Conservancy.

ArcGIS Desktop™. 2002. Geographic information system software. Version 8.3. **R**edlands, CA: Environmental Systems Research Institute (ESRI®), Incorporated. Licensed to Cal Poly State University, San Luis Obispo.

Avers, P.E.; **Cleland, D.T.**; **McNab, W.H. 1994.** National Hierarchical Framework of Ecological Units. pp. 48-61. In L.H. Foley (ed.), Silviculture: From the Cradle of Forestry to Ecosystem Management. *USDA–Forest Service Southeastern Experiment Station* **GTR SE-88**.

Axelrod, D.I. 1979. Age and origin of the Sonoran Desert. *Occasional Papers of the California Academy of Sciences* **132**: 1-74.

Axelrod, D.I.; **Demere, T.A. 1984**. A Pliocene flora from Chula Vista, San Diego County, California. *Transactions of the San Diego Society of Natural History* **20**: 277-300.

Bailey, R.G. 1995. Description of the Ecoregions of the United States. ed. 2. *USDA–Forest Service Miscellaneous Publication* **1391/995** (with map supplement at 1:7,500,000). Washington, D.C.: U.S. Department of Agriculture, Forest Service.

Bailey, R.G. 1996. *Ecosystem Geography*. New York: Springer-Verlag.

Section 6: REFERENCES

Baldwin, B.G.; **Boyd, S.**; **Ertter, B.J.**; **Patterson, R.W.**; **Rosatti, T.J. 2002.** *The Jepson Desert Manual: Vascular Plants of Southeastern California.* Berkeley: University of California Press.

Barbour, M.B. 1970. The flora and plant communities of Bodega Head, California. *Madroño* **20**: 289-313.

Bauer, H.L. 1930. Vegetation of the Tehachapi Mountains. *Ecology* **11**: 262-280.

Beauchamp, R.M. 1986. *A Flora of San Diego County, California*. National City, CA: Sweetwater River Press.

Beetle, A.A. 1947. Distribution of the native grasses of California. *Hilgardia* **17**: 309-357.

Benson, L. 1969. *The Native Cacti of California*. Stanford: Stanford University Press.

Best, C.; **Howell, J.T.**; **Knight, W.**; **Knight, I.**; **Wells, M. 1996**. *A Flora of Sonoma County: Manual of the Flowering Plants and Ferns of Sonoma County, California*. ed. 1. Sacramento: California Native Plant Society.

Bickford, I.; **Curto, M.**; **Glazier, C.**; **MacMahon, J.A. 1998**. ROADVEG: Utah Department of Transportation Roadside Vegetation Inventory and Geographic Information System. *Transportation Research Record* **1650**: 13-18.

Bossard, C.C.; **Randall, J.M.**; **Hoshovsky, M.C. (eds.). 2000.** *Invasive Plants of California's Wildlands.* Berkeley: University of California Press.

Bowcutt, F. 1996. A Floristic study of Delta Meadows River Park, Sacramento, California. *Madroño* **43**(1): 417-431.

Bowerman, M.L. 1944. *The Flowering Plants and Ferns of Mt. Diablo, California*. Berkeley: Gillick Press.

Boyd, S.; **Ross, T.S.**; **Mistretta, O.**; **Bramlet, D. 1995**. Vascular flora of the San Mateo Canyon Wilderness Area, Cleveland National Forest, California. *Aliso* **14**: 109-139.

Boyd, S.; **Ross, T.S.**; **Roberts, F.M., Jr 1995**. Additions to the vascular flora of the Santa Ana Mountains, California. *Aliso* **14**: 105-108.

Brenzel, K.N. (ed.) 2001. *Sunset Western Garden Book.* ed. 8. Menlo Park, CA: Sunset Publishing.

Caicco, S.L. 1998[1999]. Current status, structure, and plant composition of the riparian vegetation of the Truckee River, California and Nevada. *Madroño* **45**(1): 17-30.

CDFF. 1999. California Watersheds (CALWATER 2.2). Computer file. Sacramento: California Department of Forestry and Fire. http://frap.cdf.ca.gov/data.html

Clark, C. 1990. Vascular Plants of the Undeveloped Areas of California State Polytechnic University, Pomona. *Crossosoma* **16**(4): 1-8.

Clark, C.; **Charest, N. 1992**. Vegetation survey of the Antelope Valley Poppy Reserve. *Crossosoma* **18**(1): 15-24.

Clark, G.M.; **Magney, D.L. 1994.** Vascular plants of Bear Valley, Walker Ridge, and surrounding areas, Colusa and Lake counties, California. *Four Seasons* **9**(4): 25-32.

Cleland, D.T.; Avers, P.E.; McNab, W.H.; Jensen, M.E.; Bailey, R.G., King, T.; Russell, W.E. 1997. National Hierarchical Framework of Ecological Units. pp. 181-200. *In* Boyce, M. S.; Haney, A. (eds.) *Ecosystem Management Applications for Sustainable Forest and Wildlife Resources*. New Haven, CT: Yale University Press.

Coffen, M. 1993. *Central Coast Wildflowers: Monterey, San Luis Obispo, and Santa Barbara Counties of California*. San Luis Obispo: EZ Nature Books.

Conservation Committee of The Nature Conservancy. 1997. Conservation By Design: A Framework For Mission Success. Arlington, VA: The Nature Conservancy.

Cooke, W.B. 1940. Flora of Mt. Shasta. *American Midland Naturalist* **23**: 497-572.

Cooke, W.B. 1962. On the flora of the Cascade Mountains. *The Wasmann Journal of Biology* **20**: 1-68.

Cooper, J.G. 1874. The botany of the Cuyamaca Mountains. *The American Naturalist* **8**: 90-98.

Cowardin, L.M.; **Carter, V.**; **Golet, F.C.**; **LaRoe, E.T. 1979.** Classification of Wetlands and Deep Water Habitats of the United States. FWS\OBS 79-31. Washington, D.C.: U.S. Department of Interior, Fish and Wildlife Service.

Curto, M. 1993. *Grasses of San Luis Obispo County, California*. Robert F. Hoover Herbarium, Cal Poly State University, San Luis Obispo. Technical Report. 120pp.

Curto, M.; **Hallock, B.**; **Rein, S.**; **Scharff, M. 2002.** A GIS to Select Plant Species for Erosion Control Along California Highways. Proceedings of the 33rd Annual Conference and Expo of the International Erosion Control Association, 25 February-1 March 2002, Orlando, FL.

Dale, N. 1986. *Flowering Plants: The Santa Monica Mountains, Coastal & Chaparral Regions of Southern California*. Santa Barbara: Capra Press.

Dallman, P.R. 1998. *Plant Life in the World's Mediterranean Climates*. Sacramento: California Native Plant Society.

Davidson, C. 1980. A brief floristic account of the Orocopia Mountains, western Riverside County. I. The northwest end of the mountains. *Crossosoma* **6**(4): 34374.

Davis, F. W.; **Stoms, D.**; **Hollander, M.A.D.**; **Thomas, K. A.**; **Stine, P.A.**; **Odion, D.**; **Borchert, M.I.**; **Thorne, J.H.**; **Gray, M.V.**; **Walker, R.E.**; **Warner**, **K.**; **Graae, J. 1998**. Gap Analysis of Mainland California. CD-ROM. University of California, Santa Barbara, CA.

Dedecker, M. 1984. *Flora of the Northern Mojave Desert, California*. Berkeley: California Native Plant Society.

Derby, J.A.; **Wilson, R.C. 1979**. Phytosociology of pavement plains in the San Bernardino Mountains. *Aliso* **9**(3): 463-474.

Driscoll, R.S.; **Merkel, D.L.**; **Radloff, D.L.**; **Snyder, D.E.**; **Hagihara, J.S. 1984.** An ecological classification framework for the United States. *USDA–Forest Service Miscellaneous Publication* **1439**.

Ertter, B. 1997. *Annotated Checklist of the East Bay Flora: Native and Naturalized Vascular Plants of Alameda and Contra Costa Counties, California*. Berkeley: California Native Plant Society.

Ertter, B.; **Bowerman, M.L. 2002**. *The Flowering Plants and Ferns of Mt. Diablo, California*. Sacramento: California Native Plant Society, East Bay Chapter.

Fabulous Force Database Designer 4. 2003. Version 4.0.5.6 Beta (freeware). Boston: Free Software Foundation, Inc.

Ferlatte, W.J. 1974. *A Flora of the Trinity Alps of Northern California*. Berkeley: University of California Press.

Ferris, R.S. 1960. Bignoniaceae to Compositae. In: Abrams, L., *Illustrated Flora of the Pacific States*. Vol. **4**. Stanford: Stanford University Press.

Franklin, J. 2003. Clustering versus regression trees for determining ecological land units in the Southern California mountains and foothills. *Forest Science* **49**(3): 354-368.

Gillett, G.W.; **Howell, J.T.**; **Leschke, H. 1961**. A flora of Lassen Volcanic National Park. *The Wasmann Journal of Biology* **19**: 1-185.

Gillett, G.W.; **Howell, J.T.**; **Leschke, H. 1995**. *A Flora of Lassen Volcanic National Park, California*. Sacramento: California Native Plant Society Press.

Goudey, C.B.; Smith, D.W. (eds.) 1994. Ecological Units of California: Subsections. USDA Forest Service Pacific Southwest Region. Printed Map. Scale 1:1,000,000.

Graf, M. 1999. *Plant of the Tahoe Basin: Flowering Plants, Trees, and Ferns*. Berkeley: University of California Press.

Griffin, J.R.; **Critchfield, W.B. 1976**. *The distribution of forest trees in California*. USDA Forest Service Pacific Southwest Experiment Station. General Technical Report **PSW 82**: 1-118.

Grossman, D.H.; Faber-Langendoen, D.; Weakley, A.S.; Anderson, M.; Bourgeron, P.; Crawford, R.; Goodin, K.; Landaal, S.; Metzler, K.; Patterson, K.D.; Pyne, M.; Reid, M.; Sneddon, L. 1998. International Classification of Ecological Communities: Terrestrial Vegetation of the United States. Vol. I. The National Vegetation Classification System: Development, Status, and Applications. Arlington, VA: The Nature Conservancy.

Hall, H.M. 1902. A botanical survey of San Jacinto Mountain. *University of California Publications in Botany* **1**: 1-140.

Hansen, D.J.; **McKell, C.M.**; **Clark, S.L.**; **Hobbs, L. 1991**. *Native Plant Establishment Techniques for Successful Roadside Revegetation*. Weber State University for the Utah Department of Transportation. Unpublished Report. 266 pp.

Hardman, C.B.; **True, Jr, G.H. 1972**. A floristic study of Point Arena. *Madroño* **21**: 499-504.

Heckard, L.R.; **Hickman, J.C. 1985**. Vascular plants of Snow Mountain, North Coast Ranges. *The Wasmann Journal of Biology* **43**: 1-42.

Heise, K.L.; **Merenlender, A.M. 1999**. Flora of a vernal pool complex in the Mayacmas Mountains of southeastern Mendocino County, California. *Madroño* **46**(1): 38-45.

Hektner, M.M.; **Foin, T.C. 1977**. A flora of the coastal terraces of Sea Ranch, Sonoma County, California. *The Wasmann Journal of Biology* **35**: 26-53.

Hickman, J.C. 1993. *The Jepson Manual: Higher Plants of California*. Berkeley: University of California Press. updates at http://ucjeps.herb.berkeley.edu/jeps-list.html

Higgins, E.B. 1949. Annotated distributional list of the ferns and flowering plants of San Diego County, California. *San Diego Society of Natural History Occasional Paper* **8**: 1-174.

Hirshberg, J.; **Clemons, D. 1996**. Vascular plants of the Cuyamaca and Laguna Mountains, California. *Phytologia* **81**(2): 69-102.

Hitchcock, A.S. 1923. *Poaceae*. Pp. 103-255. In: Abrams, L., *Illustrated Flora of the Pacific States*. Vol. **1**. Ophioglossaceae to Aristolochiaceae. Stanford: Stanford University Press.

Holdridge, L.R. 1947. Determination of world plant formations from simple climatic data. *Science* **105**: 367-368.

Holdridge, L.R. 1967. *Life Zone Ecology*. San. Jose, Costa Rica: Tropical Science Center.

Holton, B., Jr.; **Johnson, A.F. 1979**. Dune Scrub communities and their correlation with environmental factors at Point Reyes National Seashore, California. *Journal of Biogeography* **6**: 317-328.

Hoover, R.F. 1970. *The Vascular Plants of San Luis Obispo County, California*. Berkeley: University of California Press.

Hornbeck, D.; **Phillip, K.**; **Fuller, D.L. (design and cartography) 1983**. *California Patterns: A Geographical Atlas*. Palo Alto: Mayfield Publishing.

Howell, J.T. 1929. The flora of the Santa Ana Canyon region. *Madroño* **1**: 243-253.

Howell, J.T. 1970. *Marin Flora: Manual of Flowering Plants and Ferns of Marin County, California*. ed. 2. Berkeley: University of California Press.

Howell, J.T.; **Raven, P.H.**; **Rubtzoff, P. 1958**. A flora of San Fransisco, California. *The Wasmann Journal of Biology* **16**: 1-157.

Howitt, B.F.; **Howell, J.T. 1964**. The vascular plants of Monterey County. *The Wasmann Journal of Biology* **22**: 1-184.

Howitt, B.F.; **Howell, J.T. 1973**. *Supplement to the Vascular Plants of Monterey County, California*. Pacific Grove, CA: Pacific Grove Museum of Natural History Association.

The International Plant Names Index (IPNI). 2005. Internet database at http://www.ipni.org.

James, J.W. 1966. A modified Koeppen classification of California's climates according to recent data. *California Geographer* **7**: 1-12 + map.

Jepson, W.L. 1951. *A Manual of the Flowering Plants of California*. Berkeley: University of California Press.

Jonsson, E.G. 1988. Some interesting floristic finds in the Coyote Mountain and Volcanic Hills Area (San Diego Co. and Imperial Co.). *Crossosoma* **14**(1): 1-9.

Keeler-Wolf, T. 1988. An Ecological Survey of the Proposed Millard Canyon Research Natural Area, San Bernardino National Forest, Riverside County, California. : 47 pp.

Keeler-Wolf, T. 1990. Ecological surveys of Forest Service Research Natural Areas in California. *USDA Forest Service Pacific Southwest Research Station General Technical Report* **PSW-125**: .

Keil, D.J. 1988. *List of the Vascular Flora of the Arroyo de la Cruz Region, San Luis Obispo County, California*. California Polytechnic State University. Unpublished Report.

Keil, D.J.; **Allen, R.L.**; **Nishida, J.H.**; **Wise, E.A. 1985**. Addenda to the vascular flora of San Luis Obispo County, California. *Madroño* **32**: 214-224.

Kesseli, J.E. 1942. The climates of California according to the Koppen Classification. *Geographical Review* **32**(3): 476-480.

Kimball, M.H.; **Brooks, F.A. 1959**. Plantclimates of California. *California Agriculture* **13**(5): 7-12.

Knight, W.; **Knight, I.**; **Howell, J.T. 1970**. A vegetation survey of the Butterfly Botanical Area, California. *The Wasmann Journal of Biology* **28**: 1-46.

Köppen, W.; **Geiger, R. 1936**. *Handbuch der Klimatologie*. Vol. 1, Part C. Berlin: Gerbrüder Borntraeger.

Kozloff, E.N.; **Beidleman, L.H. 1994**. *Plants of the San Francisco Bay Region, Mendocino to Monterey Bay*. Pacific Grove: Sagen Press.

Krantz, T.P. 1981. Rare plant species in the Big Bear Lake Basin, San Bernardino Mountains. *Crossosoma* **7**(1): 1-4.

Küchler, A.W. 1964. Potential natural vegetation of the conterminous United States. *American Geographical Society Special Publication* **36**. Map Supplement 1:3,168,000.

Lanner, R. 1999. *Conifers of California*. Los Olivos: Cachuma Press.

Lathrop, E.W.; **Thorne, R.F. 1968**. Flora of the Santa Rosa Plateau of the Santa Ana Mounatins, California. *Aliso* **6**: 17-40.

Lathrop, E.W.; **Thorne, R.F. 1978**. A flora of the Santa Ana Mountains, California. *Aliso* **9**: 197-278.

Lathrop, E.W.; **Thorne, R.F. 1983**. A flora of the vernal pools on the Santa Rosa Plateau, Riverside County, California. *Aliso* **10**: 449-469.

Lathrop, E.W.; **Thorne, R.F. 1985**. A flora of the Santa Rosa Plateau. *Southern California Botanists Special Publication* **1**: 1-39.

Leatherman, T. 1996. *A Checklist of Plants of Pinnacles National Monument*. Southwest Parks and Monument Association. Unpublished Report. 12 pp.

Lloyd, R.M.; **Mitchell, R.S. 1973**. *A Flora of the White Mountains, California and Nevada*. Berkeley: University of California Press.

Mason, H.L. 1969. *A Flora of the Marshes of California*. Berkeley: University of California Press.

Matthews, M.A. 1997. *An Illustrated Field Guide to the Flowering Plants of Monterey County and Ferns, Fern Allies, and Conifers*. Sacramento: California Native Plant Society.

Mayor, S.; **Bamberg, S.A. 1963**. Some Cordilleran plant species new for the Sierra Nevada. *Madroño* **17**: 93-109.

McArthur, E.D.; **Ott, J.E. 1996**. *Potential natural vegetation in the 17 conterminous western United States*. In: Barrow, J.R.; McArthur, E.D.; Sosebee, R.E.; Tausch, R.J. (eds.), *Proceedings: Shrubland ecosystem dynamics in a changing environment, 23-25, 1995, Las Cruces, NM*. USDA Forest Service Intermountain Research Station. General Technical Report **INT-338**: 16-28.

McAuley, M. 1996. *Wildflowers of the Santa Monica Mountains*. ed. 2. Canoga Park: Canyon Publishing Company.

McClintock, E.; **Knight, W. 1968**. A flora of the San Bruno Mountains, San Mateo County. *Proceedings of the California Academy of Sciences, 4th series* **32**(20): 587-677.

McClintock, E.; **Reeberg, P.**; **Knight, W. 1990**. *A Flora of the San Bruno Mountains*. Sacramento: California Native Plant Society Press.

McLaughlin, S.P.; **Bowers, J.E. 1984**. Flora of Picacho State Recreation Area and Vicinity, Imperial County, California. : 5 pp.

McLaughlin, S.P.; **Bowers, J.E.**; **Hall, K.R.F. 1987**. Vascular plants of eastern Imperial County, California. *Madroño* **34**: 359-378.

McMahon, G.; Gregonis, S.M.; Waltman, S.W.; Omernik, J.M.; Thorson, T.D.; Freeouf, J.A.; Rorick, A.H.; Keys, J.E. 2001. Developing a spatial framework of common ecological regions of the conterminous United States. *Environmental Management* **28**(3): 293-316.

McMinn, H.E. 1939. *An Illustrated Manual of California Shrubs*. Berkeley: University of California Press.

McMinn, H.E.; **Maino, E. 1973**. *An Illustrated Manual of Pacific Coast Trees*. ed. 2. Berkeley: University of California Press.

Microsoft® Office Access®. 2003. Database software. Version 2003. Redmond, WA: Microsoft® Corporation. Licensed to Cal Poly State University, San Luis Obispo.

Microsoft® Office Excel®. 2003. Spreadsheet software. Version 2003. Redmond, WA: Microsoft® Corporation. Licensed to Cal Poly State University, San Luis Obispo.

Miles, S.R.; **Goudey, C.B. 1997.** Ecological Subregions of California: Section and Subsection Descriptions. USDA Forest Service Pacific Southwest Region Technical Report R5-EM-TP-005

Miller, D.R. 2000. Species List for a Flora of the Rocky Butte/Pine Mountain Region of San Luis Obispo County. San Simeon, CA: Author published.

Millspaugh, C.F.; **Nuttall, L.W. 1923**. Flora of Santa Catalina Island. *Publications of the Field Museum of Natural History* **5**: 1-413.

Moe, L.M.; **Twisselman, E. 1995**. *A Key to Vascular Plant Species of Kern County, California, and A Flora of Kern County, California*. Sacramento: California Native Plant Society Press.

Munz, P.A. 1935. *A Manual of Southern California Botany*. Claremont: Claremont Colleges Scripps Publishing Fund.

Munz, P.A. 1974. *A Flora of Southern California*. Berkeley: Univeristy of Califrornia Press.

Munz, P.A.; **Keck, D.D. 1959**. *A California Flora*. Berkeley: Univeristy of Califrornia Press.

Murphy, A.H.; **Heady, H.F. 1983**. Vascular plants of the Hopland Field Station, Mendocino County, California. *The Wasmann Journal of Biology* **41**: 53-96.

National Institute of Standards and Technology (NIST). 1994. Guideline: Codes for Named Populated Places, Primary County Divisions, and Other Locational Entities of the United States, Puerto Rico, and the Outlying Areas. Federal Information Processing Standards Publication **55-3**. Washington, D.C.: U.S. Department of Commerce, National Institute of Standards and Technology.

Norris, L.L. 1982. *A Checklist of the Vascular Plants of Death Valley National Monument*. Death Valley: Death Valley Natural History Association.

Ornduff, R.; **Vasey, M.C. 1995**. The vegetation and flora of the Marin Islands, California. *Madroño* **42**(3): 358-365.

Oswald, V.; **Ahart, L. 1994**. *Manual of the Vascular Plants of Butte County, California*. Sacramento: California Native Plant Society Press.

Parish, S.B. 1903. A sketch of the flora of southern California. *Botanical Gazette* **36**: 203-222; 259-279.

Parish, S.B. 1917. An enumeration of the Pteridophytes and Spermatophytes of the San Bernardino Mountains. *Plant World* **20**: 163-178; 208-223; 245-259.

Patton, C.P. 1962. A note on the classification of dry climates in the Koppen system. *California Geographer* **3**: 105-112.

Peñalosa, J. 1963. A flora of the Tiburon Peninsula, Marin County, California. *The Wasmann Journal of Biology* **21**: 1-74.

Peterson, P.M. 1986. A flora of the Cottonwood Mountains, Death Valley National Monument, California. *The Wasmann Journal of Biology* **44**: 73-126.

Plumb, T.R.; **Gomez, A.P. 1983**. *Five Southern California Oaks: identification and postfire management.* USDA Forest Service Pacific Southwest Experiment Station. General Technical Report **PSW-71**.

Plummer, A.P.; **Christensen, D.R.**; **Monson, S.B. 1968**. *Restoring Big-Game Range in Utah*. Utah Division of Fish and Game Publication 68-3. Ephraim, UT: Utah Division of Fish and Game.

Prigge, B. 1981. Botany and History of the Whitewater Marsh Area. *Crossosoma* **7**(3): 1-9.

Pyšek, P.; **Richardson, D.M.**; **Rejmánek, M.**; **Webster, G.L.**; **Williamson, M.**; **Kirschner, J. 2004.** Alien plants in checklists and floras: toward better communication between taxonomists and ecologists. *Taxon* **53**(1): 131-143.

Raven, P.H.; **Axelrod, D.I. 1978**. Origin and relationships of the California Flora. *University of California Publications in Botany* **72**: 1-134.

Raven, P.H.; **Thompson, H.J.**; **Prigge, B.A. 1986**. Flora of the Santa Monica Mountains, California. ed. 2. *Southern California Botanists Special Publication* **2**: 1-181.

Rivas-Martínez, S.; **Penas, A.**; **Luengo, M.A.**; **Rivas-Sáenz, S. 2004.** Worldwide Bioclimatic Classification System. Centro de Investigaciones Fitosociológicas, Madrid. www.globalbioclimatics.org.

Rivas-Martínez, S.; **Sánchez-Mata, D.**; **Costa, M. 1999.** North American Boreal and Western Temperate Forest Vegetation (Syntaxonomical synopsis of the potential natural plant communities of North America II). *Itinera Geobot.* **12**: 5-316.

Roberts, F.M., Jr. 1990. Plants of the Crystal Cove [State Park, Orange County, California] Back Country. *Crossosoma* **16**(3): 3-8.

Roberts, F.M., Jr. 1990. Rare and endangered plants of Orange County. *Crossosoma* **16**(2): 3-12.

Roberts, F.M., Jr. 1995. *The Oaks of the Southern Californian Floristic Province*. Encinitas: F.M. Roberts Publications.

Roberts, F.M., Jr. 1998. A checklist of the vascular plants of Orange County. ed. 2. Encinitas: F.M. Roberts Publications.

Rockwell, J.A.; **Stocking, S.K. 1969**. *Checklist of the Flora of Sequoia and Kings Canyon National Parks*. Three Rivers, CA: Sequoia Natural History Association.

Rundel, P.W.; **Sturmer, S.B. 1998[1999]**. Native plant diversity in riparian communities of the Santa Monica Mountains, California. *Madroño* **45**(2): 93-100.

Russell, R.J. 1926. Climates of California. *University of California Publications in Geography* **2**(4): 73-84.

Russell, R.J. 1931. Dry climates of the United States. I. Climatic map. *University of California Publications in Geography* **5**(1): 1-41.

Sampson, A.W.; **Jespersen, B.S. 1963(1981)**. *California Range Brushlands and Browse Plants*. California Agricultural Experiment Station Publication 4010. Berkeley: University of California.

Sawyer, J.O.; **Keeler-Wolf, T. 1995**. *A Manual of California Vegetation*. Sacramento: California Native Plant Society.

Sharsmith, H.K. 1945. Flora of the Mount Hamilton Range, California. *American Midland Naturalist* **34**: 289-367.

Sharsmith, H.K. 1982. *Flora of the Mount Hamilton Range of California*. California Native Plant Society Special Publication 6. Berkeley: California Native Plant Society.

Shierenbeck, K.A.; **Jensen, D.B. 1994**. Vegetation of the Upper Raider and Hornback Creek Basins, South Warner Mountains: Northwestern limit of Abies concolor var lowiana. *Madroño* **41**(1): 53-64.

Shreve, F.; **Wiggins, I.L. 1964**. *Vegetation and Flora of the Sonoran Desert*. Stanford: Stanford University Press.

Simpson, M.G.; **McMillan, S.C.**; **Stone, B.L.**; **Gibson, J.**; **Rebman, J.P. 1995**. Checklist of the Vascular Plants of San Diego County. *San Diego State University Herbarium Press Special Publication* **1**: 1-84.

Sinnott, Q.P.; **Sinnott, K.A.**; **Stanton, M.W. 1979**. An annotated list of the vascular plants of Sky Ranch, Alameda County, California. *The Wasmann Journal of Biology* **37**(34350): .

Skinner, M.W.; **Pavlick, B.M. 1994**. *Inventory of Rare and Endangered Vascular Plants of California*. California Native Plant Society Special Publication 1. ed. 5. Sacramento: California Native Plant Society.

Smith, C.F. 1952. *A Flora of Santa Barbara: An Annotated Catalogue of the Native and Naturalized Plants of Santa Barbara, California, and Vicinity*. Santa Barbara: Santa Barbara Botanic Garden.

Smith, C.F. 1976. *A Flora of the Santa Barbara Region, California*. Santa Barbara: Santa Barbara Museum of Natural History.

Smith, G.L. 1973. A flora of the Tahoe Basin and neighboring areas. *The Wasmann Journal of Biology* **31**: 1-231.

Smith, G.L.; **Wheeler, C.R. 1990-1991**. A flora of the vascular plants of Mendocino County, California. *The Wasmann Journal of Biology* **48/49**: 1-387.

Smith, J.P. 2001. California Floras: Literature on the Identification and Uses of California Vascular Plants. Humboldt State University Herbarium Miscellaneous Publication 1. ed. 14. Arcata: Humboldt State University Herbarium.

Stuart, J.D.; **Worley, T.**; **Buell, A.C. 1996**. Plant associations of Castle Crags State Park, Shasta County, California. *Madroño* **43**(2): 273-291.

Thomas, J.H. 1961. *Flora of the Santa Cruz Mountains, California*. Palo Alto: Stanford University Press.

Thorne, R.F.; **Prigge, B.A**; **Henrickson, J. 1981**. A flora of the higher ranges and the Kelso Dunes of the eastern Mojave Desert in California. *Aliso* **10**: 71-186.

TOPO!® 2002. California State Series 1:24000 USGS Maps and 30 meter Digital Elevation Models. San Francisco: National Geographic Maps.

TOPO!® for ArcGIS™. 2003. Multilayer edition. San Francisco: National Geographic Maps.

Trewartha, G.T.; **Horn, L.H. 1983**. *An Introduction to Climate*. ed. 5. New York: McGraw-Hill.

Twisselman, E.C. 1956. A flora of the Temblor Range and the neighboring part of the San Joaquin Valley. *The Wasmann Journal of Biology* **14**: 161-300.

Twisselman, E.C. 1967. A flora of Kern County, California. *The Wasmann Journal of Biology* **25**(1-2): 1-395.

UCCE (University of California Cooperative Extension). 1989. Generalized Plant Climate Map of California. [ca 1 : 1,500,000]. San Francisco: Pacific Gas & Electric Company.

USDA, Natural Resources Conservation Service. 2002. Land Resource Regions and Major Land Resource Areas of the United States. USDA Agriculture Handbook 296 (revised).

US Fish and Wildlife Service (USFWS). 1996. National list of vascular plant species that occur in wetlands. Draft revision. Available at http://wetlands.fws.gov/bha

USGS 1978. *Hydrologic Unit Map–State of California*. Reston, VA: United States Department of the Interior, Unites States Geological Survey.

Vegetation Establishment and Maintenance Study (VEMS). 2002. Caltrans District 5 Advisory Guide to Plant Species Selection for Erosion Control and Native Revegetation. CTSW-RT-01-079.

Vegetation Establishment and Maintenance Study VEMS. 2004. Seed and Plant Calculator and User Manual. Prototype for Caltrans District 5. ver. 2.0 Beta. Technical Report. Prepared for Caltrans by Cal Poly State University, Earth and Soil Sciences.

Viescas, J.L. 2004. *Microsoft® Office Access® 2003*. Redmond, WA: Microsoft Press.

Viescas, J.L. 2005. *Building Microsoft® Access® Applications*. Redmond, WA: Microsoft Press.

Vogel, K.P.; Schmer, M.R.; Mitchell, R.B. 2005. Plant Adaptation Regions: ecological and climatic classification of plant materials. *Rangeland Ecology and Management* **58**: 315-319.

Vogl, R.J.; **Miller, B.C. 1968**. The vegetational composition of the south slope of Mt. Pinos, California. *Madroño* **19**: 225-234.

Waring, R.H. 1969. Forest plants of the eastern Siskiyous. *Northwest Science* **43**(34350): .

Weeden, N.F. 1996. *A Sierra Nevada Flora*. ed. 4. Berkeley: Wilderness Press.

Whittaker, R.H. 1960. Vegetation of the Siskiyou Mountains, Oregon and California. *Ecological Monographs* **30**(3): 279-338.

Wiggins, I.L. 1980. *Flora of Baja California*. Stanford: Stanford University Press.

Yahr, C.C. 1961. Climate fluctuations along the Pacific Coast. *California Geographer* **2**: 45-54.

York, D. 1997[1998]. A fire ecology study of a Sierra Nevada foothill basaltic mesa grassland. *Madroño* **44**(4): 374-383.

6.1.1 Plant Materials

6.1.1.1 Taxonomy and Phytogeography

Abrams, L. 1904. *Flora of Los Angeles and Vicinity*. Stanford: Stanford University Press.

Abrams, L. 1923. *Illustrated Flora of the Pacific States*. Vol. **1**: Ophioglossaceae to Aristolochiaceae. Stanford: Stanford University Press.

Abrams, L. 1944. *Illustrated Flora of the Pacific States*. Vol. **2**: Polygonaceae to Krameriaceae. Stanford: Stanford University Press.

Abrams, L. 1951. *Illustrated Flora of the Pacific States*. Vol. **3**: Geraniaceae to Scrophulariaceae. Stanford: Stanford University Press.

Axelrod, D.I. 1979. Age and origin of the Sonoran Desert. *Occasional Papers of the California Academy of Sciences* **132**: 1-74.

Axelrod, D.I.; **Demere, T.A. 1984**. A Pliocene flora from Chula Vista, San Diego County, California. *Transactions of the San Diego Society of Natural History* **20**: 277-300.

Baldwin, B.G.; **Boyd, S.**; **Ertter, B.J.**; **Patterson, R.W.**; **Rosatti, T.J. 2002.** *The Jepson Desert Manual: Vascular Plants of Southeastern California*. Berkeley: University of California Press.

Barbour, M.B. 1970. The flora and plant communities of Bodega Head, California. *Madroño* **20**: 289-313.

Bauer, H.L. 1930. Vegetation of the Tehachapi Mountains. *Ecology* **11**: 262-280.

Beauchamp, R.M. 1986. *A Flora of San Diego County, California*. National City, CA: Sweetwater River Press.

Beetle, A.A. 1947. Distribution of the native grasses of California. *Hilgardia* **17**: 309-357.

Benson, L. 1969. *The Native Cacti of California*. Stanford: Stanford University Press.

Best, C.; **Howell, J.T.**; **Knight, W.**; **Knight, I.**; **Wells, M. 1996**. *A Flora of Sonoma County: Manual of the Flowering Plants and Ferns of Sonoma County, California*. ed. 1. Sacramento: California Native Plant Society.

Bowcutt, F. 1996. A Floristic study of Delta Meadows River Park, Sacramento, California. *Madroño* **43**(1): 417-431.

Bowerman, M.L. 1944. *The Flowering Plants and Ferns of Mt. Diablo, California*. Berkeley: Gillick Press.

Boyd, S.; **Ross, T.S.**; **Mistretta, O.**; **Bramlet, D. 1995**. Vascular flora of the San Mateo Canyon Wilderness Area, Cleveland National Forest, California. *Aliso* **14**: 109-139.

Boyd, S.; **Ross, T.S.**; **Roberts, F.M., Jr 1995**. Additions to the vascular flora of the Santa Ana Mountains, California. *Aliso* **14**: 105-108.

Caicco, S.L. 1998[1999]. Current status, structure, and plant composition of the riparian vegetation of the Truckee River, California and Nevada. *Madroño* **45**(1): 17-30.

Clark, C. 1990. Vascular Plants of the Undeveloped Areas of California State Polytechnic University, Pomona. *Crossosoma* **16**(4): 1-8.

Clark, C.; **Charest, N. 1992**. Vegetation survey of the Antelope Valley Poppy Reserve. *Crossosoma* **18**(1): 15-24.

Clark, G.M.; **Magney, D.L. 1994.** Vascular plants of Bear Valley, Walker Ridge, and surrounding areas, Colusa and Lake counties, California. *Four Seasons* **9**(4): 25-32.

Coffen, M. 1993. *Central Coast Wildflowers: Monterey, San Luis Obispo, and Santa Barbara Counties of California*. San Luis Obispo: EZ Nature Books.

Cooke, W.B. 1940. Flora of Mt. Shasta. *American Midland Naturalist* **23**: 497-572.

Cooke, W.B. 1962. On the flora of the Cascade Mountains. *The Wasmann Journal of Biology* **20**: 1-68.

Cooper, J.G. 1874. The botany of the Cuyamaca Mountains. *The American Naturalist* **8**: 90-98.

Curto, M. 1993. *Grasses of San Luis Obispo County, California*. Robert F. Hoover Herbarium, Cal Poly State University, San Luis Obispo. Technical Report. 120pp.

Dale, N. 1986. *Flowering Plants: The Santa Monica Mountains, Coastal & Chaparral Regions of Southern California*. Santa Barbara: Capra Press.

Dallman, P.R. 1998. *Plant Life in the World's Mediterranean Climates*. Sacramento: California Native Plant Society.

Davidson, C. 1980. A brief floristic account of the Orocopia Mountains, western Riverside County. I. The northwest end of the mountains. *Crossosoma* **6**(4): 34374.

Dedecker, M. 1984. *Flora of the Northern Mojave Desert, California*. Berkeley: California Native Plant Society.

Derby, J.A.; **Wilson, R.C. 1979**. Phytosociology of pavement plains in the San Bernardino Mountains. *Aliso* **9**(3): 463-474.

Ertter, B.; **Bowerman, M.L. 2002**. *The Flowering Plants and Ferns of Mt. Diablo, California*. Sacramento: California Native Plant Society, East Bay Chapter.

Ertter, B. 1997. *Annotated Checklist of the East Bay Flora: Native and Naturalized Vascular Plants of Alameda and Contra Costa Counties, California*. Berkeley: California Native Plant Society.

Ferlatte, W.J. 1974. *A Flora of the Trinity Alps of Northern California*. Berkeley: University of California Press.

Ferris, R.S. 1960. Bignoniaceae to Compositae. In: Abrams, L., *Illustrated Flora of the Pacific States*. Vol. **4**. Stanford: Stanford University Press.

Gillett, G.W.; **Howell, J.T.**; **Leschke, H. 1961**. A flora of Lassen Volcanic National Park. *The Wasmann Journal of Biology* **19**: 1-185.

Gillett, G.W.; **Howell, J.T.**; **Leschke, H. 1995**. *A Flora of Lassen Volcanic National Park, California*. Sacramento: California Native Plant Society Press.

Graf, M. 1999. *Plant of the Tahoe Basin: Flowering Plants, Trees, and Ferns*. Berkeley: University of California Press.

Griffin, J.R.; **Critchfield, W.B. 1976**. *The distribution of forest trees in California*. USDA Forest Service Pacific Southwest Experiment Station. General Technical Report **PSW 82**: 1-118.

Hall, H.M. 1902. A botanical survey of San Jacinto Mountain. *University of California Publications in Botany* **1**: 1-140.

Hardman, C.B.; **True, Jr, G.H. 1972**. A floristic study of Point Arena. *Madroño* **21**: 499-504.

Heckard, L.R.; **Hickman, J.C. 1985**. Vascular plants of Snow Mountain, North Coast Ranges. *The Wasmann Journal of Biology* **43**: 1-42.

Heise, K.L.; **Merenlender, A.M. 1999**. Flora of a vernal pool complex in the Mayacmas Mountains of southeastern Mendocino County, California. *Madroño* **46**(1): 38-45.

Hektner, M.M.; **Foin, T.C. 1977**. A flora of the coastal terraces of Sea Ranch, Sonoma County, California. *The Wasmann Journal of Biology* **35**: 26-53.

Hickman, J.C. 1993. *The Jepson Manual: Higher Plants of California*. Berkeley: University of California Press. updates at http://ucjeps.herb.berkeley.edu/jeps-list.html

Higgins, E.B. 1949. Annotated distributional list of the ferns and flowering plants of San Diego County, California. *San Diego Society of Natural History Occasional Paper* **8**: 1-174.

Hirshberg, J.; **Clemons, D. 1996**. Vascular plants of the Cuyamaca and Laguna Mountains, California. *Phytologia* **81**(2): 69-102.

Hitchcock, A.S. 1923. *Poaceae*. Pp. 103-255. In: Abrams, L., *Illustrated Flora of the Pacific States*. Vol. **1**. Ophioglossaceae to Aristolochiaceae. Stanford: Stanford University Press.

Holton, B., Jr.; **Johnson, A.F. 1979**. Dune Scrub communities and their correlation with environmental factors at Point Reyes National Seashore, California. *Journal of Biogeography* **6**: 317-328.

Hoover, R.F. 1970. *The Vascular Plants of San Luis Obispo County, California*. Berkeley: University of California Press.

Howell, J.T. 1929. The flora of the Santa Ana Canyon region. *Madroño* **1**: 243-253.

Howell, J.T. 1970. *Marin Flora: Manual of Flowering Plants and Ferns of Marin County, California*. ed. 2. Berkeley: University of California Press.

Howell, J.T.; **Raven, P.H.**; **Rubtzoff, P. 1958**. A flora of San Fransisco, California. *The Wasmann Journal of Biology* **16**: 1-157.

Howitt, B.F.; **Howell, J.T. 1964**. The vascular plants of Monterey County. *The Wasmann Journal of Biology* **22**: 1-184.

Howitt, B.F.; **Howell, J.T. 1973**. *Supplement to the Vascular Plants of Monterey County, California*. Pacific Grove, CA: Pacific Grove Museum of Natural History Association.

The International Plant Names Index (IPNI). 2005. Internet database at http://www.ipni.org.

Jepson, W.L. 1951. *A Manual of the Flowering Plants of California*. Berkeley: University of California Press.

Jonsson, E.G. 1988. Some interesting floristic finds in the Coyote Mountain and Volcanic Hills Area (San Diego Co. and Imperial Co.). *Crossosoma* **14**(1): 1-9.

Keeler-Wolf, T. 1988. An Ecological Survey of the Proposed Millard Canyon Research Natural Area, San Bernardino National Forest, Riverside County, California. : 47 pp.

Keeler-Wolf, T. 1990. Ecological surveys of Forest Service Research Natural Areas in California. *USDA Forest Service Pacific Southwest Research Station General Technical Report* **PSW-125**: .

Keil, D.J. 1988. *List of the Vascular Flora of the Arroyo de la Cruz Region, San Luis Obispo County, California*. California Polytechnic State University. Unpublished Report.

Keil, D.J.; **Allen, R.L.**; **Nishida, J.H.**; **Wise, E.A. 1985**. Addenda to the vascular flora of San Luis Obispo County, California. *Madroño* **32**: 214-224.

Knight, W.; **Knight, I.**; **Howell, J.T. 1970**. A vegetation survey of the Butterfly Botanical Area, California. *The Wasmann Journal of Biology* **28**: 1-46.

Kozloff, E.N.; **Beidleman, L.H. 1994**. *Plants of the San Francisco Bay Region, Mendocino to Monterey Bay*. Pacific Grove: Sagen Press.

Krantz, T.P. 1981. Rare plant species in the Big Bear Lake Basin, San Bernardino Mountains. *Crossosoma* **7**(1): 1-4.

Lanner, R. 1999. *Conifers of California*. Los Olivos: Cachuma Press.

Lathrop, E.W.; **Thorne, R.F. 1968**. Flora of the Santa Rosa Plateau of the Santa Ana Mounatins, California. *Aliso* **6**: 17-40.

Lathrop, E.W.; **Thorne, R.F. 1978**. A flora of the Santa Ana Mountains, California. *Aliso* **9**: 197-278.

Lathrop, E.W.; **Thorne, R.F. 1983**. A flora of the vernal pools on the Santa Rosa Plateau, Riverside County, California. *Aliso* **10**: 449-469.

Lathrop, E.W.; **Thorne, R.F. 1985**. A flora of the Santa Rosa Plateau. *Southern California Botanists Special Publication* **1**: 1-39.

Leatherman, T. 1996. *A Checklist of Plants of Pinnacles National Monument*. Southwest Parks and Monument Association. Unpublished Report. 12 pp.

Lloyd, R.M.; **Mitchell, R.S. 1973**. *A Flora of the White Mountains, California and Nevada*. Berkeley: University of California Press.

Mason, H.L. 1969. *A Flora of the Marshes of California*. Berkeley: University of California Press.

Matthews, M.A. 1997. *An Illustrated Field Guide to the Flowering Plants of Monterey County and Ferns, Fern Allies, and Conifers*. Sacramento: California Native Plant Society.

Mayor, S.; **Bamberg, S.A. 1963**. Some Cordilleran plant species new for the Sierra Nevada. *Madroño* **17**: 93-109.

McAuley, M. 1996. *Wildflowers of the Santa Monica Mountains*. ed. 2. Canoga Park: Canyon Publishing Company.

McClintock, E.; **Knight, W. 1968**. A flora of the San Bruno Mountains, San Mateo County. *Proceedings of the California Academy of Sciences, 4th series* **32**(20): 587-677.

McClintock, E.; **Reeberg, P.**; **Knight, W. 1990**. *A Flora of the San Bruno Mountains*. Sacramento: California Native Plant Society Press.

McLaughlin, S.P.; **Bowers, J.E. 1984**. Flora of Picacho State Recreation Area and Vicinity, Imperial County, California. : 5 pp.

McLaughlin, S.P.; **Bowers, J.E.**; **Hall, K.R.F. 1987**. Vascular plants of eastern Imperial County, California. *Madroño* **34**: 359-378.

McMinn, H.E. 1939. *An Illustrated Manual of California Shrubs*. Berkeley: University of California Press.

McMinn, H.E.; **Maino, E. 1973**. *An Illustrated Manual of Pacific Coast Trees*. ed. 2. Berkeley: University of California Press.

Miller, D.R. 2000. Species List for a Flora of the Rocky Butte/Pine Mountain Region of San Luis Obispo County. San Simeon, CA: Author published.

Millspaugh, C.F.; **Nuttall, L.W. 1923**. Flora of Santa Catalina Island. *Publications of the Field Museum of Natural History* **5**: 1-413.

Moe, L.M.; **Twisselman, E. 1995**. *A Key to Vascular Plant Species of Kern County, California, and A Flora of Kern County, California*. Sacramento: California Native Plant Society Press.

Munz, P.A. 1935. *A Manual of Southern California Botany*. Claremont: Claremont Colleges Scripps Publishing Fund.

Munz, P.A. 1974. *A Flora of Southern California*. Berkeley: Univeristy of Califrornia Press.

Munz, P.A.; **Keck, D.D. 1959**. *A California Flora*. Berkeley: Univeristy of Califrornia Press.

Murphy, A.H.; **Heady, H.F. 1983**. Vascular plants of the Hopland Field Station, Mendocino County, California. *The Wasmann Journal of Biology* **41**: 53-96.

Norris, L.L. 1982. *A Checklist of the Vascular Plants of Death Valley National Monument*. Death Valley: Death Valley Natural History Association.

Ornduff, R.; **Vasey, M.C. 1995**. The vegetation and flora of the Marin Islands, California. *Madroño* **42**(3): 358-365.

Oswald, V.; **Ahart, L. 1994**. *Manual of the Vascular Plants of Butte County, California*. Sacramento: California Native Plant Society Press.

Parish, S.B. 1903. A sketch of the flora of southern California. *Botanical Gazette* **36**: 203-222; 259-279.

Parish, S.B. 1917. An enumeration of the Pteridophytes and Spermatophytes of the San Bernardino Mountains. *Plant World* **20**: 163-178; 208-223; 245-259.

Peñalosa, J. 1963. A flora of the Tiburon Peninsula, Marin County, California. *The Wasmann Journal of Biology* **21**: 1-74.

Peterson, P.M. 1986. A flora of the Cottonwood Mountains, Death Valley National Monument, California. *The Wasmann Journal of Biology* **44**: 73-126.

Plumb, T.R.; **Gomez, A.P. 1983**. *Five Southern California Oaks: identification and postfire management*. USDA Forest Service Pacific Southwest Experiment Station. General Technical Report **PSW-71**.

Prigge, B. 1981. Botany and History of the Whitewater Marsh Area. *Crossosoma* **7**(3): 1-9.

Raven, P.H.; **Thompson, H.J.**; **Prigge, B.A. 1986**. Flora of the Santa Monica Mountains, California. ed. 2. *Southern California Botanists Special Publication* **2**: 1-181.

Roberts, F.M., Jr. 1990. Plants of the Crystal Cove [State Park, Orange County, California] Back Country. *Crossosoma* **16**(3): 3-8.

Roberts, F.M., Jr. 1990. Rare and endangered plants of Orange County. *Crossosoma* **16**(2): 3-12.

Roberts, F.M., Jr. 1995. *The Oaks of the Southern Californian Floristic Province*. Encinitas: F.M. Roberts Publications.

Roberts, F.M., Jr. 1998. A checklist of the vascular plants of Orange County. ed. 2. Encinitas: F.M. Roberts Publications.

Rockwell, J.A.; **Stocking, S.K. 1969**. *Checklist of the Flora of Sequoia and Kings Canyon National Parks*. Three Rivers, CA: Sequoia Natural History Association.

Rundel, P.W.; **Sturmer, S.B. 1998[1999]**. Native plant diversity in riparian communities of the Santa Monica Mountains, California. *Madroño* **45**(2): 93-100.

Sampson, A.W.; **Jespersen, B.S. 1963(1981)**. *California Range Brushlands and Browse Plants*. California Agricultural Experiment Station Publication 4010. Berkeley: University of California.

Sharsmith, H.K. 1945. Flora of the Mount Hamilton Range, California. *American Midland Naturalist* **34**: 289-367.

Sharsmith, H.K. 1982. *Flora of the Mount Hamilton Range of California*. California Native Plant Society Special Publication 6. Berkeley: California Native Plant Society.

Shierenbeck, K.A.; **Jensen, D.B. 1994**. Vegetation of the Upper Raider and Hornback Creek Basins, South Warner Mountains: Northwestern limit of Abies concolor var lowiana. *Madroño* **41**(1): 53-64.

Shreve, F.; **Wiggins, I.L. 1964**. *Vegetation and Flora of the Sonoran Desert*. Stanford: Stanford University Press.

Simpson, M.G.; **McMillan, S.C.**; **Stone, B.L.**; **Gibson, J.**; **Rebman, J.P. 1995**. Checklist of the Vascular Plants of San Diego County. *San Diego State University Herbarium Press Special Publication* **1**: 1-84.

Sinnott, Q.P.; **Sinnott, K.A.**; **Stanton, M.W. 1979**. An annotated list of the vascular plants of Sky Ranch, Alameda County, California. *The Wasmann Journal of Biology* **37**(34350): .

Skinner, M.W.; **Pavlick, B.M. 1994**. *Inventory of Rare and Endangered Vascular Plants of California*. California Native Plant Society Special Publication 1. ed. 5. Sacramento: California Native Plant Society.

Smith, C.F. 1952. *A Flora of Santa Barbara: An Annotated Catalogue of the Native and Naturalized Plants of Santa Barbara, California, and Vicinity*. Santa Barbara: Santa Barbara Botanic Garden.

Smith, C.F. 1976. *A Flora of the Santa Barbara Region, California*. Santa Barbara: Santa Barbara Museum of Natural History.

Smith, G.L. 1973. A flora of the Tahoe Basin and neighboring areas. *The Wasmann Journal of Biology* **31**: 1-231.

Smith, G.L.; **Wheeler, C.R. 1990-1991**. A flora of the vascular plants of Mendocino County, California. *The Wasmann Journal of Biology* **48/49**: 1-387.

Smith, J.P. 2001. California Floras: Literature on the Identification and Uses of California Vascular Plants. Humboldt State University Herbarium Miscellaneous Publication 1. ed. 14. Arcata: Humboldt State University Herbarium.

Stuart, J.D.; **Worley, T.**; **Buell, A.C. 1996**. Plant associations of Castle Crags State Park, Shasta County, California. *Madroño* **43**(2): 273-291.

Thomas, J.H. 1961. *Flora of the Santa Cruz Mountains, California*. Palo Alto: Stanford University Press.

Thorne, R.F.; **Prigge, B.A**; **Henrickson, J. 1981**. A flora of the higher ranges and the Kelso Dunes of the eastern Mojave Desert in California. *Aliso* **10**: 71-186.

Twisselman, E.C. 1956. A flora of the Temblor Range and the neighboring part of the San Joaquin Valley. *The Wasmann Journal of Biology* **14**: 161-300.

Twisselman, E.C. 1967. A flora of Kern County, California. *The Wasmann Journal of Biology* **25**(1-2): 1-395.

Vogl, R.J.; **Miller, B.C. 1968**. The vegetational composition of the south slope of Mt. Pinos, California. *Madroño* **19**: 225-234.

Waring, R.H. 1969. Forest plants of the eastern Siskiyous. *Northwest Science* **43**(34350): .

Weeden, N.F. 1996. *A Sierra Nevada Flora*. ed. 4. Berkeley: Wilderness Press.

Whittaker, R.H. 1960. Vegetation of the Siskiyou Mountains, Oregon and California. *Ecological Monographs* **30**(3): 279-338.

Wiggins, I.L. 1980. *Flora of Baja California*. Stanford: Stanford University Press.

York, D. 1997[1998]. A fire ecology study of a Sierra Nevada foothill basaltic mesa grassland. *Madroño* **44**(4): 374-383.

6.1.1.2 EcoRegional Classification

Anderson, M.; Bourgeron, P.; Bryer, M.T.; Crawford, R.; Engelking, L.; Faber-Langendoen, D.; Gallyoun, M.; Goodin, K.; Grossman, D.H.; Landaal, S.; Metzler, K.; Patterson, K.D.; Pyne, M.; Reid, M.; Sneddon, L.; Weakley, A.S. 1998. International Classification of Ecological Communities: Terrestrial Vegetation of the United States. Vol. II. The National Vegetation Classification System: List of Types. Arlington, VA: The Nature Conservancy.

Avers, P.E.; **Cleland, D.T.**; **McNab, W.H. 1994.** National Hierarchical Framework of Ecological Units. pp. 48-61. In L.H. Foley (ed.), Silviculture: From the Cradle of Forestry to Ecosystem Management. *USDA–Forest Service Southeastern Experiment Station* **GTR SE-88**.

Bailey, R.G. 1995. Description of the Ecoregions of the United States. ed. 2. *USDA–Forest Service Miscellaneous Publication* **1391/995** (with map supplement at 1:7,500,000). Washington, D.C.: U.S. Department of Agriculture, Forest Service.

Bailey, R.G. 1996. *Ecosystem Geography*. New York: Springer-Verlag.

CDFF. 1999. California Watersheds (CALWATER 2.2). Computer file. Sacramento: California Department of Forestry and Fire. http://frap.cdf.ca.gov/data.html

Cleland, D.T.; Avers, P.E.; McNab, W.H.; Jensen, M.E.; Bailey, R.G., King, T.; Russell, W.E. 1997. National Hierarchical Framework of Ecological Units. pp. 181-200. *In* Boyce, M. S.; Haney, A. (eds.) *Ecosystem Management Applications for Sustainable Forest and Wildlife Resources*. New Haven, CT: Yale University Press.

Conservation Committee of The Nature Conservancy. 1997. Conservation By Design: A Framework For Mission Success. Arlington, VA: The Nature Conservancy.

Davis, F. W.; **Stoms, D.**; **Hollander, M.A.D.**; **Thomas, K. A.**; **Stine, P.A.**; **Odion, D.**; **Borchert, M.I.**; **Thorne, J.H.**; **Gray, M.V.**; **Walker, R.E.**; **Warner**, **K.**; **Graae, J. 1998**. Gap Analysis of Mainland California. CD-ROM. University of California, Santa Barbara, CA.

Driscoll, R.S.; **Merkel, D.L.**; **Radloff, D.L.**; **Snyder, D.E.**; **Hagihara, J.S. 1984.** An ecological classification framework for the United States. *USDA–Forest Service Miscellaneous Publication* **1439**.

Franklin, J. 2003. Clustering versus regression trees for determining ecological land units in the Southern California mountains and foothills. *Forest Science* **49**(3): 354-368.

Grossman, D.H.; Faber-Langendoen, D.; Weakley, A.S.; Anderson, M.; Bourgeron, P.; Crawford, R.; Goodin, K.; Landaal, S.; Metzler, K.; Patterson, K.D.; Pyne, M.; Reid, M.; Sneddon, L. 1998. International Classification of Ecological Communities: Terrestrial Vegetation of the United States. Vol. I. The National Vegetation Classification System: Development, Status, and Applications. Arlington, VA: The Nature Conservancy.

Goudey, C.B.; Smith, D.W. (eds.) 1994. Ecological Units of California: Subsections. USDA Forest Service Pacific Southwest Region. Printed Map. Scale 1:1,000,000.

Holdridge, L.R. 1947. Determination of world plant formations from simple climatic data. *Science* **105**: 367-368.

Holdridge, L.R. 1967. *Life Zone Ecology*. San. Jose, Costa Rica: Tropical Science Center.

Hornbeck, D.; **Phillip, K.**; **Fuller, D.L. (design and cartography) 1983**. *California Patterns: A Geographical Atlas*. Palo Alto: Mayfield Publishing.

Küchler, A.W. 1964. Potential natural vegetation of the conterminous United States. *American Geographical Society Special Publication* **36**. Map Supplement 1:3,168,000.

McArthur, E.D.; **Ott, J.E. 1996**. *Potential natural vegetation in the 17 conterminous western United States*. In: Barrow, J.R.; McArthur, E.D.; Sosebee, R.E.; Tausch, R.J. (eds.), *Proceedings: Shrubland ecosystem dynamics in a changing environment, 23-25, 1995, Las Cruces, NM*. USDA Forest Service Intermountain Research Station. General Technical Report **INT-338**: 16-28.

McMahon, G.; Gregonis, S.M.; Waltman, S.W.; Omernik, J.M.; Thorson, T.D.; Freeouf, J.A.; Rorick, A.H.; Keys, J.E. 2001. Developing a spatial framework of common ecological regions of the conterminous United States. *Environmental Management* **28**(3): 293-316.

Miles, S.R.; **Goudey, C.B. 1997.** Ecological Subregions of California: Section and Subsection Descriptions. USDA Forest Service Pacific Southwest Region Technical Report R5-EM-TP-005

Raven, P.H.; **Axelrod, D.I. 1978**. Origin and relationships of the California Flora. *University of California Publications in Botany* **72**: 1-134.

Rivas-Martínez, S.; **Sánchez-Mata, D.**; **Costa, M. 1999.** North American Boreal and Western Temperate Forest Vegetation. Syntaxonomical synopsis of the potential natural plant communities of North America II. *Itinera Geobot.* **12**: 5-316.

Sawyer, J.O.; **Keeler-Wolf, T. 1995**. *A Manual of California Vegetation*. Sacramento: California Native Plant Society.

Trewartha, G.T.; **Horn, L.H. 1983**. *An Introduction to Climate*. ed. 5. New York: McGraw-Hill.

USDA, Natural Resources Conservation Service. 2002. Land Resource Regions and Major Land Resource Areas of the United States. USDA Agriculture Handbook 296 (revised).

USGS 1978. *Hydrologic Unit Map–State of California*. Reston, VA: United States Department of the Interior, Unites States Geological Survey.

Vogel, K.P.; Schmer, M.R.; Mitchell, R.B. 2005. Plant Adaptation Regions: ecological and climatic classification of plant materials. *Rangeland Ecology and Management* **58**: 315-319.

6.1.1.3 Climate

Brenzel, K.N. (ed.) 2001. *Sunset Western Garden Book*. ed. 8. Menlo Park, CA: Sunset Publishing.

James, J.W. 1966. A modified Koeppen classification of California's climates according to recent data. *California Geographer* **7**: 1-12 + map.

Kesseli, J.E. 1942. The climates of California according to the Koppen Classification. *Geographical Review* **32**(3): 476-480.

Kimball, M.H.; **Brooks, F.A. 1959**. Plantclimates of California. *California Agriculture* **13**(5): 7-12.

Köppen, W.; **Geiger, R. 1936**. *Handbuch der Klimatologie*. Vol. 1, Part C. Berlin: Gerbrüder Borntraeger.

Patton, C.P. 1962. A note on the classification of dry climates in the Koppen system. *California Geographer* **3**: 105-112.

Rivas-Martínez, S.; **Penas, A.**; **Luengo, M.A.**; **Rivas-Sáenz, S. 2004.** Worldwide Bioclimatic Classification System. Centro de Investigaciones Fitosociológicas, Madrid. www.globalbioclimatics.org.

Russell, R.J. 1926. Climates of California. *University of California Publications in Geography* **2**(4): 73-84.

Russell, R.J. 1931. Dry climates of the United States. I. Climatic map. *University of California Publications in Geography* **5**(1): 1-41.

UCCE (University of California Cooperative Extension). 1989. Generalized Plant Climate Map of California. [ca 1 : 1,500,000]. San Francisco: Pacific Gas & Electric Company.

Yahr, C.C. 1961. Climate fluctuations along the Pacific Coast. *California Geographer* **2**: 45-54.

6.1.1.4 Roadside Vegetation

Bickford, I.; **Curto, M.**; **Glazier, C.**; **MacMahon, J.A. 1998**. ROADVEG: Utah Department of Transportation Roadside Vegetation Inventory and Geographic Information System. *Transportation Research Record* **1650**: 13-18.

6.1.1.5 Revegetation

Hansen, D.J.; **McKell, C.M.**; **Clark, S.L.**; **Hobbs, L. 1991**. *Native Plant Establishment Techniques for Successful Roadside Revegetation*. Weber State University for the Utah Department of Transportation. Unpublished Report. 266 pp.

Plummer, A.P.; **Christensen, D.R.**; **Monson, S.B. 1968**. *Restoring Big-Game Range in Utah*. Utah Division of Fish and Game Publication 68-3. Ephraim, UT: Utah Division of Fish and Game.

6.1.1.6 Weeds

Bossard, C.C.; **Randall, J.M.**; **Hoshovsky, M.C. (eds.). 2000.** *Invasive Plants of California's Wildlands.* Berkeley: University of California Press.

Pyšek, P.; **Richardson, D.M.**; **Rejmánek, M.**; **Webster, G.L.**; **Williamson, M.**; **Kirschner, J. 2004.** Alien plants in checklists and floras: toward better communication between taxonomists and ecologists. *Taxon* **53**(1): 131-143.

6.1.1.7 Wetlands

Cowardin, L.M.; **Carter, V.**; **Golet, F.C.**; **LaRoe, E.T. 1979.** Classification of Wetlands and Deep Water Habitats of the United States. FWS\OBS 79-31. Washington, D.C.: U.S. Department of Interior, Fish and Wildlife Service.

US Fish and Wildlife Service (USFWS). 1996. National list of vascular plant species that occur in wetlands. Draft revision. Available at http://wetlands.fws.gov/bha.

6.1.2 Data Standards

National Institute of Standards and Technology (NIST). 1994. Guideline: Codes for Named Populated Places, Primary County Divisions, and Other Locational Entities of the United States, Puerto Rico, and the Outlying Areas. Federal Information Processing Standards Publication **55-3**. Washington, D.C.: U.S. Department of Commerce, National Institute of Standards and Technology.

6.1.3 Computer Software

ArcGIS Desktop™. 2002. Geographic information system software. Version 8.3. Redlands, CA: Environmental Systems Research Institute (ESRI®), Incorporated. Licensed to Cal Poly State University, San Luis Obispo.

Fabulous Force Database Designer 4. 2003. Version 4.0.5.6 Beta (freeware). Boston: Free Software Foundation, Inc.

Microsoft® Office Excel®. 2003. Spreadsheet software. Version 2003. Redmond, WA: Microsoft® Corporation. Licensed to Cal Poly State University, San Luis Obispo.

Microsoft® Office Access®. 2003. Database software. Version 2003. Redmond, WA: Microsoft® Corporation. Licensed to Cal Poly State University, San Luis Obispo.

TOPO!® 2002. California State Series 1:24000 USGS Maps and 30 meter Digital Elevation Models. San Francisco: National Geographic Maps.

TOPO!® for ArcGIS™. 2003. Multilayer Ed. San Francisco: National Geographic Maps.

Viescas, J.L. 2004. *Microsoft® Office Access® 2003.* Redmond, WA: Microsoft Press.

Viescas, J.L. 2005. *Building Microsoft® Access® Applications*. Redmond, WA: Microsoft Press.

6.1.4 VEMS Products

Curto, M.; **Hallock, B.**; **Rein, S.**; **Scharff, M. 2002.** A GIS to Select Plant Species for Erosion Control Along California Highways. Proceedings of the 33rd Annual Conference and Expo of the International Erosion Control Association, 25 February-1 March 2002, Orlando, FL.

Vegetation Establishment and Maintenance Study (VEMS). 2002. Caltrans District 5 Advisory Guide to Plant Species Selection for Erosion Control and Native Revegetation. CTSW-RT-01-079.

Vegetation Establishment and Maintenance Study VEMS. 2004. Seed and Plant Calculator and User Manual. Prototype for Caltrans District 5. ver. 2.0 Beta. Technical Report. Prepared for Caltrans by Cal Poly State University, Earth and Soil Sciences.

6.2 Glossary

Allaby, M. 1994. *The Concise Oxford Dictionary of Ecology*. New York: Oxford Press.

California Storm Water Quality Taskforce. 2001. Storm Water Sampling Guidance Document For Compliance with California State Water Resources Control Board Resolution No. 2001-046. Technical Report Draft as of 31 July. Sacramento, CA.

Caltrans. 2002. Caltrans Storm Water Quality Handbooks: Project Planning and Design Guide. Technical Report. Sacramento, CA.

Dines, N.T., and K.D. Brown. 2001. *Landscape Architect's Portable Handbook*. New York: McGraw Hill.

Parker, P. (ed.) 1997. *McGraw Hill Dictionary of Science*. New York: McGraw Hill.

6.3 Units and Conversions

American Society for Testing and Materials. 2002. Standard for Use of the International System of Units (SI): The Modern Metric System. ASTM SI 10-2002.

Bureau International des Poids et Mesures (BIPM). 1998. Le Système international d'unités (SI) [The International System of Units]. edition 7.

Bureau International des Poids et Mesures (BIPM). 2000. Le Système international d'unités (SI) [The International System of Units]. Supplement: Addenda and Corrigenda to edition 7 (1998).

Tapson, F. 2004. A Dictionary of Units. http://www.projects.ex.ac.uk/trol/dictunit/dictunit1.htm.

Taylor, B.N. (ed.) 1995. The International System of Units (SI). NIST Special Publication 811. Washington, D.C.: United States Department of Commerce, National Institute of Standards and Technology.

Taylor, B.N. (ed.) 1991. The International System of Units (SI). NIST Special Publication 330. Washington, D.C.: United States Department of Commerce, National Institute of Standards and Technology.

Young, R.A., and T.J. Glover. Measure for Measure. ed. 1. Littleton, CO.: Sequoia Publishing, Inc.

Appendix A
GLOSSARY

A.1 Abbreviations

ac	acre
^oC	degrees Celsius
cm	centimeter
cm/hr	centimeters per hour
CO_2	Carbon Dioxide
^oF	degrees Fahrenheit
ft	feet
ft^2	square feet
ft^3	cubic feet
g	gram
ha	hectares
in	inches
in/hr	inches per hour
hr(s)	hour(s)
^oK	degrees Kelvin
kg/ha	kilograms per hectare
kPa	kilo pascals (force)
kg/m^2	kilograms per square meter
km	kilometer
l	liter
lb	pound (US)
lb/ac	pounds per acre
m	meter
mg	milligram
mg/l	milligrams per liter
meq	milliequivalents
min	minute
mm	millimeter
m/s	meters per second
m^3	cubic meters
m^3/yr	cubic meters/year
N	Nitrogen (elemental)
N_2	Nitrogen (molecular) or Nitrogen gas
NH_3	Ammonia
NH_4^+	Ammonium ion
NO_3^-	Nitrate ion
O_2	Oxygen
pH	“power of Hydrogen” $-\log_{10} [H^+]$
ppm	parts per million
psi	pounds (force) per square inch
s	second
v:h	vertical : horizontal
yd^3	cubic yard
yr(s)	year(s)

>	greater than
≥	greater than or equal to
<	less than
≤	less than or equal to

A.2 Acronyms

ANOVA	Analysis of Variance
ASTM	American Society for Testing and Materials International
BFM	Bonded Fiber Matrix
BMP	Best Management Practice
Caltrans	California Department of Transportation
CEC	Cation Exchange Capacity (soil property)
CEQA	California Environmental Quality Act
CIMIS	California Irrigation Management Information System
CWA	Clean Water Act
DWR	California Department of Water Resources
EA	Expenditure Authorization
EC	Electrical Conductivity; Erosion Control (context-dependent)
EPA	U.S. Environmental Protection Agency
FHWA	Federal Highway Administration
GW	Groundwater
HSD	Honestly Significant Difference (statistical sense)
HSG	Hydrologic Soil Group
KP	Kilometer Post
MCL	Maximum Contaminant Level
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service (USDA)
NTU	Nephelometric Turbidity Unit
OC	Organic Content
PLS	Pure Live Seed
RECP	Rolled Erosion Control Products
RO	Runoff
RS	Rainfall Simulator
RSP	Rock Slope Protection
RWQCB	Regional Water Quality Control Board
SW	Storm Water
SWMP	Storm Water Management Plan
SWPPP	Storm Water Pollution Prevention Plan
SWQA	Storm Water Quality Assessment
SWRCB	California State Water Resources Control Board
TDS	Total Dissolved Solids or Sediment
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids
USDA	United States Department of Agriculture
USGS	United States Geological Survey
UV	Ultraviolet
VEMS	Vegetation Establishment and Maintenance Study
WQ	Water Quality

A.3 Terms

Analysis of Variance (ANOVA) — A suite of univariate statistical methods that test a null hypothesis that population means are equal by analysing group variances.

Best Management Practice (BMP) — A BMP is a measure that is implemented to protect water quality and reduce potential for pollution associated with storm water **runoff**. Any program, technology, process, siting criteria, operating method, or device that controls, prevents, removes, or reduces pollution. There are four categories of BMPs: Maintenance, Design Pollution Prevention, Construction Site, and Treatment

> **Maintenance BMPs** are water quality controls used to reduce pollutant discharges during highway maintenance activities and activities conducted at maintenance facilities. These BMPs are technology-based controls that attain MEP pollutant control. This category of BMPs includes litter pickup, toxics control, street sweeping, etc.
>
> **Design Pollution Prevention BMPs** are permanent water quality controls used to reduce pollutant discharges by preventing **erosion**. These BMPs are standard technology-based, non-treatment controls selected to reduce pollutant discharges to the **MEP** requirements. They are applicable to all projects. This category of BMPs includes preservation of existing vegetation; concentrated flow conveyance systems, such as ditches, berms, dikes, swales, overside drains, outlet protection/velocity dissipation devices; and slope/surface protection systems such as vegetated surfaces and hard surfaces.
>
> **Construction site BMPs** are temporary controls used to reduce pollutant discharges during construction. These controls are best conventional technology/best available technology **BCT/BAT** based BMPs that may include **soil stabilization**, sediment control, wind **erosion** control, tracking control, non-storm water management and waste management.
>
> **Treatment BMPs** are permanent water quality controls used to remove pollutants from storm water **runoff** prior to being discharged from Caltrans right-of-way. These controls are used to meet **MEP** requirements and are considered for projects discharging directly or indirectly to **receiving waters**. This category of BMPs includes: traction sand traps, infiltration basins, detention devices, biofiltration strips/swales, dry weather flow diversion, and **GSRDs**.

California Environmental Quality Act (CEQA) — The CEQA of 1970 requires public agencies to prevent significant, avoidable damage to the environment by regulating activities that may affect the quality of the environment. Public agencies accomplish this by requiring projects to consider the use of alternatives or mitigation measures. Regulations for the implementation of CEQA are found in the CEQA Guidelines and are available online by the California Resources Agency at http://ceres.ca.gov/ceqa.

Caltrans Permit — Caltrans Permit refers to the **NPDES** Statewide Storm Water Permit issued to Caltrans in 1999 (Order No. 99-06-DWQ) (CAS000003), to regulate storm water discharges from Caltrans facilities.

Categorical Exemption (CE) — A CE is a list of classes of projects that have been determined not to have a significant effect on the environment and which shall, therefore, be exempt from the provisions of **CEQA**. For a list of classes of projects and further information see the web site http://ceres.ca.gov/topic/env_law/ceqa/guidelines/art19.html

Clean Water Act (CWA) — The CWA, originally enacted by Congress in 1972, is a federal law that requires states to protect, restore, and maintain the quality of the waters of the United States, including lakes, rivers, aquifers and coastal areas. The CWA, as amended in 1987, is the enabling legislation for the **NPDES** permitting process.

Code of Federal Regulations (CFR) — The CFR is a document that codifies all rules of the executive departments and agencies of the federal government. It is divided into 50 volumes, known as titles. Title 40 of the CFR (referenced as 40 CFR) contains all environmental regulations. 40 CFR is available from bookstores operated by the Government Printing Office and online at: http://www.epa.gov/epahome/cfr40.htm.

Construction Site — The term "construction site" should apply to all areas both within the construction limits on state right-of-way and areas that are directly related to the construction activity, including but not limited to staging areas, storage yards, material borrow areas and storage areas, access roads, barges or platforms, etc., whether or not they reside within the Caltrans right-of-way.

Appendix A: GLOSSARY

Construction Site Best Management Practices Manual — The Construction Site Best Management Practices Manual provides instructions for the selection and implementation of Construction Site **BMPs**. Caltrans requires contractors to identify and utilize these BMPs in preparation of their **SWPPP** or **WPCP**.

Department of Water Resources (DWR) — The California DWR (http://wwwdwr.water.ca.gov/) is a State Government department created to manage the water resources of California in cooperation with other agencies in such a way as to benefit the State's people, and to protect, restore, and enhance the natural and human environments. The DWR is a source for hydrology data, **groundwater** information, water maps, etc.

Duff — As defined by Caltrans, duff consists of a mixture of existing decomposed, chopped, broken or chipped plant material, leaves, grasses, weeds, and other plant material no greater than 150 mm (5.9 in) in greatest dimension. When duff is to be excavated to a specified depth, duff may consist of plant material and soil. Rocks and plant material in excess of 150 mm (5.9 in) in greatest dimension shall be removed from the excavated duff.

This definition differs from longstanding terminology used by foresters where duff is considered to be the layer of partially and fully decomposed organic materials lying below the litter and immediately above the mineral soil. It corresponds to the fermentation (F) and humus (H) layers of the forest floor. When moss is present, the top of the duff is just below the green portion of the moss.

Electrical Conductivity (EC) — Measure of the ability of water to carry an electric current. This ability depends on the presence of ions, their concentration, valence, mobility and temperature. EC measurements can give an estimate of the variations in the dissolved mineral content of storm water in relation to receiving waters.

Erosion — Wearing away of land surfaces by water, wind, ice, or kinetics causing detachment of soil or rock.

Existing Vegetation — Existing vegetation is any plant material within the project limits that is present prior to the beginning of construction.

Geographic Information System (GIS) — GIS is a system of hardware and software used for storage, retrieval, mapping, and spatial analysis of geographic data.

Groundwater (GW) — GW is defined as the water that is naturally occurring under the earth's surface. It is situated below the surface of the land, irrespective of its source and transient status. Subterranean streams are flows of GW parallel to and adjoining stream waters, and usually determined to be integral parts of the visible streams. GW is considered a jurisdictional water of the State under the Porter-Cologne Water Quality Act (California Water Code, Division 7).

Highway Planting — Vegetation placed for aesthetic, safety, environmental mitigation, or erosion control purposes, including necessary irrigation systems, inert materials, mulches, and appurtenances. Highway planting provides for a level of planting that is compatible with the surrounding environment.

Holding Time — Holding time is specified by the analytical method and is the elapsed time between the time the sample is collected and the time the analysis must be initiated.

Metals (Total and Dissolved) — Metals, both total and dissolved, are commonly monitored constituents and, next to **TSS** and **nutrients**, are the most common constituents cited in the literature as being present in storm water **runoff.**

Trace quantities of many metals are necessary for biological growth and may naturally occur in runoff. Most metals, however, have numeric water quality standards because of their toxicity to aquatic organisms at high concentrations. Toxicity of some metals is inversely related to water hardness. The numeric water quality standards for cadmium, chromium, copper, lead, nickel, silver and zinc are hardness-dependent. Copper, lead and zinc are the metals most commonly found in highway runoff.

National Environmental Policy Act (NEPA) — The NEPA of 1969 establishes policies and procedures to bring environmental considerations into the planning process for federal projects. NEPA requires all federal agencies to identify and assess reasonable alternatives to proposed actions that will restore and enhance the quality of the human environment and avoid or minimize adverse environmental impacts. The NEPA process is an overall framework for the environmental evaluation of federal actions.

Natural Resources Conservation Service (NRCS) — As part of the USDA, the NRCS provides leadership in a partnership effort to help people conserve, maintain, and improve natural resources and the environment. Soil types and local soil survey data can be obtained from the NRCS soil maps. The soil type and soil survey data are used during the desktop screening of potential infiltration basin sites.

Nephelometric Turbidity Units (NTU) — Unit that measures water quality based on "cloudiness" using a **nephelometer** (Greek: *nephele*, cloud) that assesses turbidity directly by comparing the amount of light transmitted straight through a water sample with the amount scattered at an angle of 90° to one side; this **unitless ratio** determines the turbidity in NTU's. The instrument is calibrated using samples of a standard solution such as **formazin**, a synthetic polymer. Drinking water should not exhibit turbidity above 1 NTU, although values up to 5 NTU are usually considered safe. Outside the U.S., this unit is usually called the **FNU** (**F**ormazin **N**ephelometric **U**nit), specified in standard ISO 7027 by the International Organization for Standardization.

New Construction/Major Reconstruction — New construction and major reconstruction includes new routes, route alignments, route upgrades (i.e., from two-lane conventional highway to four-lane expressway or freeway), and right-of-way acquisitions for whole parcels or wide swaths. New construction activity does not include routine maintenance to maintain original line and grade, hydraulic capacity, or original purpose of the facility, nor does it include emergency construction activities required to protect public health and safety.

Nutrients — Nutrients are nutritive substances such as phosphorous and nitrogen whose excessive input into **receiving waters** can over-stimulate the growth of aquatic plants.

Algae and vascular plants can cause numerous deleterious effects. Algae and vascular aquatic plants produce oxygen during the day via photosynthesis and consume oxygen during the night via respiration. The pH of the water is linked to this phenomenon through the carbonate cycle: the pH rises during the day when carbon dioxide (CO_2) is consumed for the photosynthetic production of plant tissue and falls at night when CO_2 is released by respiration. Algal blooms due to inputs of nitrogen or phosphorus can cause wide fluctuations in this dissolved oxygen and pH cycle during a 24-hour period, which can cause fish kills and mass mortality of benthic organisms. In addition, excessive algal and vascular plant growth can accelerate eutrophication, interfere with navigation, and cause unsightly conditions with reduced water clarity, odors, and diminished habitat for fish and shellfish.

Other trace nutrients, such as iron, are also needed for plant growth. In general, however, phosphorus and nitrogen are the nutrients of importance in aquatic environments.

Phosphorus. Phosphorus is taken up by algae and vascular aquatic plants and, when available in excess of the plant's immediate needs for metabolism and reproduction, can be stored in the cells. With bacterial decomposition of plant materials, relatively labile pools of phosphorus are later released and recycled within the biotic community. The refractory portion (i.e., compounds relatively resistant to biodegradation) tends to sink to the bottom, where it degrades slowly over time.

Analytical tests for the minimum constituent list include TP, which is the sum of the dissolved and particulate orthophosphate, polyphosphate and organic phosphorus; and Total Ortho-P, which is the sum of the dissolved and particulate orthophosphate.

Nitrogen. Transformation of nitrogen compounds can occur through several key mechanisms: fixation, ammonification, synthesis, nitrification, and denitrification. Nitrogen fixation is the conversion of nitrogen gas into nitrogen compounds that can be assimilated by plants; biological fixation is the most common, but fixation can also occur by lightning and through industrial processes. Ammonification is the biochemical degradation of organic-N into NH_3 or NH_4^+ by heterotrophic bacteria under aerobic or anaerobic conditions. Synthesis is the biochemical mechanism in which NH_4^+-N or NO_3^--N is converted into plant protein (Organic-N); nitrogen fixation is also a unique form of synthesis that can be performed only by nitrogen-fixing bacteria. Nitrification is the biological oxidation of NH_4^+ to NO_3^- through a two-step autotrophic process by the bacteria *Nitrosomonas* and *Nitrobacter*; the two-step reactions are usually very rapid, and hence it is rare to find nitrite levels higher than 1.0 mg/l in water. The nitrate formed by nitrification is, in the nitrogen cycle, used by plants as a nitrogen source (synthesis) or reduced to N_2 gas through the process of denitrification; NO_3^- can be reduced, under anoxic conditions, to N_2 gas through heterotrophic biological denitrification.

Analytical tests for the minimum constituent list include NH_3/NH_4^+-N, NO_3^--N, and Total TKN. TKN is a measure of NH_3/NH_4^+-N plus organic-N; the concentration of organic-N is thus obtained by subtracting the concentration of NH_3/NH_4^+-N found in the sample from that of the TKN value.

Appendix A: GLOSSARY

pH — The pH scale is based on $-\log_{10}[H^+]$ in a sample and literally translates as the "power of Hydrogen" and expresses the intensity of an acid or base (alkaline) condition. The pH scale ranges from extreme acids of 1 to extreme bases of 14, with neutral being 7. Units are moles of hydrogen per liter. Extremes of pH can have deleterious effects on biological systems.

Planting Restoration — The renovation or rehabilitation of planting areas and irrigation systems to improve access and working conditions, incorporate "design for safety" features, reduce maintenance expenditures, reduce water consumption or utilize nonpotable water. Restoration is justified when capital costs can be recovered through maintenance savings within 12 years. Improvement of access and working conditions, incorporation of safety features, installation of Remote Irrigation Control System (RICS), and conversion to nonpotable water (see "Nonpotable Water" in Chapter 29, Section 2, Article 1 – General Policy) do not require a 12-year payback.

Regional Water Quality Control Board (RWQCB) — The RWQCB means any California RWQCB for a region as specified in Section 13200 of the California Water Code. There are nine RWQCBs that serve under the **SWRCB.** These nine RWQCBs are located in California and are responsible for enforcing water quality standards within their boundaries. A map of these boundaries is located in Section 2, Figure 2-1.

Replacement Planting — Planting to replace planting (installed by Caltrans or others) that is damaged or removed as a result of highway construction activity, including irrigation modification and/or replacement.

Revegetation — Planting of indigenous plants to replace natural vegetation that is damaged or removed as a result of highway construction projects or permits requirements. This work may include irrigation systems.

Runoff (RO) — Surface waters that exceed the soil's infiltration rate and depression storage. It includes that portion of precipitation that appears as flow in streams, and also includes drainage or flood discharges that leave an area as surface flow or as pipeline flow, having reached a channel or pipeline by either surface or subsurface routes.

Sediment — Solid particulate matter, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity, or ice and has come to rest on the earth's surface either above or below sea level.

Sedimentation/Siltation — The process of sediment/silt deposition.

Settleable Solids — The settleable solids (SS) tests measures the solid material that can be settled within a water column during a specified time frame. This typically is tested by placing a water sample into an Imhoff settling cone and allowing the solids to settle by gravity. Results are reported either as a volume (mL/L) or a weight (mg/L).

Silt — Soil particles between 0.05mm and 0.002mm in size. (For the purposes of its use here, it also includes clay, which is categorized by a particle size less than 0.002mm.)

Slope/Soil Stabilization — Soil stabilization is described as vegetation, such as grasses and wildflowers, and other materials, such as straw, fiber, stabilizing emulsion, protective blankets, etc. Soil stabilization is placed to stabilize areas disturbed by grading operations, to reduce loss of soil due to the action of water or wind, and to prevent water pollution.

Soil Amendment — Any material that is added to the soil to change its chemical properties, engineering properties, or erosion resistance that could become mobilized by storm water and would be not visible in the runoff. Soil amendments include lime, cementitious binders, chlorides, emulsions, polymers, soil stabilizers, and tackifiers applied as a stand-alone treatment (i.e., without mulch). Plant fibers (such as straw or hay), wood and recycled paper fibers (such as mulches and matrices), bark or wood chips, green waste or composted organic materials, and biodegradable or synthetic blanket fibers would not be included as soil amendments in this context because they would be visible in storm water runoff.

State Water Resources Control Board (SWRCB) — As delegated by the **EPA**, the SWRCB is a California agency that implements and enforces the **CWA** Section 401 (p) **NPDES** permit requirements, and is the issuer and administrator of the **Caltrans Permit**. The SWRCB's mission is to preserve, enhance and restore the quality of California's water resources, and ensure their proper allocation and efficient use for the benefit of present and future generations.

Statewide Storm Water Quality Practice Guidelines (Guidelines) — The Caltrans Guidelines describe each approved **BMP** included in the **SWMP** for Statewide application,. with instructions on implementing each approved storm water management practice or BMP.

Storm Water Management Plan (SWMP) — The SWMP is the Caltrans policy document that describes how Caltrans conducts its storm water management activities (i.e., procedures and practices). The SWMP provides descriptions of each of the major management program elements, discusses the processes used to evaluate and select appropriate **BMPs**, and presents key implementation responsibilities and schedules.

Storm Water Quality Assessment (SWQA) — The SWQA is a technical report prepared by the Caltrans Environmental Unit staff during the PA/ED process, for inclusion into the **CEQA/NEPA** documents. The SWQA provides input to the PE for completing the **SWDR**.

Suspended Sediment Concentration (SSC) — The suspended sediment concentration (SSC) test measures the concentration of suspended solid material in a water sample by measuring the dry weight of all of the solid material from a known volume of a collected water sample. Results are reported in mg/L. A high suspended solids level impacts the clarity of the water which may decrease the depth to which sunlight can penetrate the water and adversely impact aquatic plant growth. It also reduces the concentration of oxygen in the water, potentially affecting the ability of aquatic animals and plants to survive and flourish due to oxygen deprivation.

Total Dissolved Solids (TDS) — TDS refers to the sum of all cations or anions (sometimes measured in parts per million as calcium carbonate). TDS comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates) and small amounts of organic matter that are dissolved in water.

In fresh water the total dissolved solids concentration typically ranges from 20 to 1,000 mg/l; in seawater it ranges from 30,000 to 35,000 mg/l. High levels of dissolved solids concentrations can adversely affect drinking water quality.

Total Maximum Daily Load (TMDL) — TMDLs are pollutant load allocations for all point sources and nonpoint sources, and are intended to achieve a pollutant reduction goal along with a safety factor. TMDLs are developed in response to identification of **pollutants** as impairing a specific body of water identified in the 303(d) list.

Total Suspended Solids (TSS) — TSS is the weight of particles that are suspended in water. The total suspended solids test (TSS) test measures the concentration of suspended solids in water by measuring the dry weight of a solid material contained in a known volume of a sub-sample of a collected water sample. Results are reported in mg/L. A high suspended solids level impacts the clarity of the water which may decrease the depth to which sunlight can penetrate the water and adversely impact aquatic plant growth. It also reduces the concentration of oxygen in the water, potentially affecting the ability of aquatic animals and plants to survive and flourish due to oxygen deprivation. Suspended solids in a water sample include inorganic substances, such as soil particles and organic substances, such as algae, aquatic plant/animal waste, particles related to industrial/sewage waste, etc.

Turbidity — Cloudiness of water quantified by the degree to which light traveling through a water column is scattered by the suspended organic and inorganic particles it contains. The scattering of light increases with a greater suspended load. Turbidity is commonly measured in Nephelometric Turbidity Units (NTU), *q.v.*

United States Environmental Protection Agency (EPA) — The EPA (http://www.epa.gov/) provides leadership in the nation's environmental science, research, education and assessment efforts. The EPA works closely with other federal agencies, state and local governments, and Indian tribes to develop and enforce regulations under existing environmental laws. The EPA is responsible for researching and setting national standards for a variety of environmental programs and delegates to states and tribes responsible for issuing permits, and monitoring and enforcing compliance. The EPA issued regulations to control pollutants in storm water **runoff discharges**, such as the **CWA**. (The CWA and **NPDES** permit requirement.)

Vegetative Erosion Control — Vegetation (grasses and wildflowers, and other materials like straw, fiber, stabilizing emulsion, protective blankets, etc.) placed to stabilize areas disturbed by grading operations, to reduce loss of soil due to the action of water or wind, and to prevent water pollution.

Water Quality Volume (WQV) — The WQV is the volume of flows associated with the frequent storm events that must be treated. The WQV of treatment **BMPs** is based upon, where established, the sizing criteria from the **RWQCB** or local agency (whichever is more stringent). If no sizing criterion has been established, Caltrans will do one of the following: maximize detention volume determined by the 85th percentile **runoff** capture ratio or; use volume of annual runoff based on unit basin storage WQV to achieve 80 percent or more volume of treatment. For further detail, refer to Section 2.4.2.2.

A.4 *trans*PLANT

Database — A digital collection of records and files organized for a specific purpose (Viescas 2004). Data are stored as *attributes* (field\column\variable) of *tuples* (record\row\case) contained in *relations* (tables).

Division — An ecological unit in the ecoregion planning and analysis scale of the National Hierarchical Framework corresponding to subdivisions of a Domain that have the same regional climate (Cleland et al. 1997).

Domain — An ecological unit in the ecoregion planning and analysis scale of the National Hierarchical Framework corresponding to subcontinental divisions of broad climatic similarity that are affected by latitude and global atmospheric conditions (Cleland et al. 1997).

Dry — A classification of climate based on the Köppen System for regions where evaporation exceeds precipitation (Bailey 1995).

Ecoregion — A scale of planning and analysis in the National Hierarchical Framework that has broad applicability for modeling and sampling, strategic planning and assessment, and international planning. Ecoregions include Domain, Division, and Province ecological units (Cleland et al. 1997).

Foreign Key — A primary key from another “foreign” table included to link *relations* (tables); sometimes compound foreign keys are formed from two or more *attributes* (Viescas 2004).

Life Zones — A classification of macroclimatic conditions based on temperature and precipitation that has been widely applied in tropical environments to delineate zones dominated by vegetative communities of characteristic physiognomy and composition (Holdridge 1967)

Major Land Resource Area (MLRA) — A broad geographical area that has a distinct combination of climate, soil, vegetation, management needs, and kinds of crops that can be grown (USDA, NRCS 2002).

Primary Key — An *attribute* (field\column\variable) that uniquely identifies each *tuple* (record\row\case) of a *relation* (table); sometimes compound primary keys are formed from two or more *attributes* (Viescas 2004).

Province — An ecological unit in the ecoregion planning and analysis scale of the National Hierarchical Framework corresponding to subdivisions of a Division that conform to climatic subzones controlled mainly by continental weather patterns. (Cleland et al. 1997).

Regionalization — A mapping procedure in which a set of criteria are used to subdivide the earth’s surface into smaller, more homogeneous units that display spatial patterns related to ecosystem structure, composition, and function (Bailey 1996).

Scale — The degree of resolution at which ecological processes, structures, and changes across space and time are observed and measured (Bailey 1996).

Section — An ecological unit in the subregion planning and analysis scale of the National Hierarchical Framework corresponding to subdivisions of a Province having broad areas of similar geomorphic process, stratigraphy, geologic origin, drainage networks, topography, and regional climate. Such areas are often inferred by relating geologic maps to maps of potential natural vegetation polygons [e.g., Kuchler (1964)] (Cleland et al. 1997).

Subregion — A scale of planning and analysis in the National Hierarchical Framework that has applicability for strategic, multi-forest, statewide, and multi-agency analysis and assessment. Subregions include Section and Subsection ecological units (Cleland et al. 1997).

Subsection — An ecological unit in the subregion planning and analysis scale of the National Hierarchical Framework corresponding to subdivisions of a Section into areas with similar surficial geology, lithology, geomorphic process, soil groups, subregional climate, and potential natural communities (Cleland et al. 1997).

Appendix B
UNITS and CONVERSIONS

B.1 Basic SI Units

The International System of Units (SI) derives from the French *Le Systeme International d'Unites* that was formally adopted during October 1960 and has been officially recognised and adopted by nearly all countries. The System is based upon 7 principal units, 1 in each of 7 different categories (adapted from Tapson 2004).

Basic Unit	Unit Name	Definition
Length	**metre [m]**	The distance light travels, in a vacuum, in 1/299792458*th* of a second.
Mass	**kilogram [kg]**	The mass of an international prototype in the form of a platinum-iridium cylinder kept at Sevres in France. *It is now the only basic unit still defined in terms of a material object, and also the only one with a prefix [kilo] already in place.*
Time	**second [s]**	The length of time taken for 9192631770 periods of vibration of the caesium-133 atom to occur.
Temperature	**kelvin [K]**	It is 1/273**.**16*th* of the thermodynamic temperature of the triple point of water. *It is named after the Scottish mathematician and physicist William Thomson 1st Lord Kelvin (1824-1907).*
Electric Current	**ampere [A]**	That constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to 2 x 10-7 newton per metre of length. *It is named after the French physicist Andre Ampere (1775-1836).*
Matter	**mole [mol]**	The amount of substance that contains as many elementary units as there are atoms in 0**.**012 kg of carbon-12.
Light Intensity	**candela [cd]**	The luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 ´ 1012 hertz and that has a radiant intensity in that direction of 1/683 watt per steradian.

B.2 Derived SI Units

From the 7 basic SI units other units are derived. A few of the most common are listed here (adapted from Tapson 2004).

Derived Unit	Unit Name	Definition
Work	**joule [J]**	The joule is the SI unit of work or energy. One joule is the amount of work done when an applied force of 1 **newton** moves through a distance of 1 **metre** in the direction of the force. It is named after the English physicist James Prescott Joule (1818-89).
Power	**watt [W]**	The watt is used to measure power or the rate of doing work. One **watt** is a power of 1 **joule** per second. It is named after the Scottish engineer James Watt (1736-1819).
Force	**newton [N]**	The newton is the SI unit of force. One newton is the force required to give a mass of 1 kilogram an acceleration of 1 metre per second per second. It is named after the English mathematician and physicist Sir Isaac Newton (1642-1727).
Pressure	**pascal [Pa]**	The pascal is the SI unit of pressure. One pascal is the pressure generated by a force of 1 **newton** acting on an area of 1 square **metre**. It is a rather small unit as defined and is more often used as a **kilopascal** [**kPa**]. It is named after the French mathematician, *physicist and philosopher Blaise Pascal (1623-62).*
Period Frequency	**hertz [Hz]**	The hertz is the SI unit of the frequency of a periodic phenomenon. One hertz indicates that **1 cycle** of the phenomenon occurs **every second**. For most work much higher frequencies are needed such as the **kilohertz** [**kHz**] and **megahertz** [**MHz**]. It is named after the German physicist Heinrich Rudolph Hertz (1857-94).
Electrical Capacitance	**farad [F]**	The farad is the SI unit of the capacitance of an electrical system, that is, its capacity to store electricity. It is a rather large unit as defined and is more often used as a **microfarad**. *It is named after the English chemist and physicist Michael Faraday (1791-1867).*
Electrical Resistance	**ohm [Ω]**	The ohm is the SI unit of resistance of an electrical conductor. Its symbol, is the capital Greek letter 'omega'. It is named after the German physicist Georg Simon Ohm (1789-1854).
Electrical Potential	**volt [V]**	The volt is the SI unit of electric potential. One volt is the difference of potential between two points of an electical conductor when a current of 1 **ampere** flowing between those points dissipates a power of 1 **watt**. It is named after the Italian physicist Count Alessandro Giuseppe Anastasio Volta (1745-1827).

B.3 Common Conversion Factors

FROM	Operation		TO	FROM	Operation		TO
acres	**x 0.4047**	=	hectares	kilograms	**x 35.3**	=	ounces
acres	**/ 247**	=	sq. kilometres	kilograms	**x 2.2046**	=	pounds
acres	**x 4047**	=	sq. metres	kilograms	**/ 1000**	=	tonnes
acres	**/ 640**	=	sq. miles	kilograms	**/ 1016**	=	tons (UK/long)
barrels (oil)	**/ 6.29**	=	cu.metres	kilograms	**/ 907**	=	tons (US/short)
barrels (oil)	**x 34.97**	=	gallons (UK)	kilometres	**x 1000**	=	metres
barrels (oil)	**x 42**	=	gallons (US)	kilometres	**x 0.6214**	=	miles
barrels (oil)	**x 159**	=	litres	litres	**x 61.02**	=	cu.inches
centimetres	**/ 30.48**	=	feet	litres	**x 0.2200**	=	gallons (UK)
centimetres	**/ 2.54**	=	inches	litres	**x 0.2642**	=	gallons (US)
centimetres	**/ 100**	=	metres	litres	**x 1.760**	=	pints (UK)
centimetres	**x 10**	=	millimetres	litres	**x 2.113**	=	pints (US liquid)
cubic cm	**x 0.06102**	=	cubic inches	metres	**/ 0.9144**	=	yards
cubic cm	**/ 1000**	=	litres	metres	**x 100**	=	centimetres
cubic cm	**x 1**	=	millilitres	miles	**x 1.609**	=	kilometres
cubic feet	**x 1728**	=	cubic inches	millimetres	**/ 25.4**	=	inches
cubic feet	**x 0.0283**	=	cubic metres	ounces	**x 28.35**	=	grams
cubic feet	**/ 27**	=	cubic yards	pints (UK)	**x 0.5683**	=	litres
cubic feet	**x 6.229**	=	gallons (UK)	pints (UK)	**x 1.201**	=	pints (US liquid)
cubic feet	**x 7.481**	=	gallons (US)	pints (US liquid)	**x 0.4732**	=	litres
cubic feet	**x 28.32**	=	litres	pints (US liquid)	**x 0.8327**	=	pints (UK)
cubic inches	**x 16.39**	=	cubic cm	pounds	**x 0.4536**	=	kilograms
cubic inches	**x 0.01639**	=	litres	pounds	**x 16**	=	ounces
cubic metres	**x 35.31**	=	cubic feet	square cm	**x 0.1550**	=	sq. inches
feet	**x 30.48**	=	centimetres	square feet	**x 144**	=	sq. inches
feet	**x 0.3048**	=	metres	square feet	**x 0.0929**	=	sq. metres
feet	**/ 3**	=	yards	square inches	**x 6.4516**	=	square cm
fl.ounces (UK)	**x 0.961**	=	fl.ounces (US)	square inches	**/ 144**	=	square feet
fl.ounces (UK)	**x 28.41**	=	millilitres	square km	**x 247**	=	acres
fl.ounces (US)	**x 1.041**	=	fl.ounces (UK)	square km	**x 100**	=	hectares
fl.ounces (US)	**x 29.57**	=	millilitres	square km	**x 0.3861**	=	square miles
gallons	**x 8**	=	pints	square metres	**/ 4047**	=	acres
gallons (UK)	**x 0.1605**	=	cubic feet	square metres	**/ 10 000**	=	hectares
gallons (UK)	**x 1.2009**	=	gallons (US)	square metres	**x 10.76**	=	square feet
gallons (UK)	**x 4.54609**	=	litres	square metres	**x 1.196**	=	square yards
gallons (US)	**x 0.1337**	=	cubic feet	square miles	**x 640**	=	acres
gallons (US)	**x 0.8327**	=	gallons (UK)	square miles	**x 259**	=	hectares
gallons (US)	**x 3.785**	=	litres	square miles	**x 2.590**	=	square km
grams	**/ 1000**	=	kilograms	square yards	**/ 1.196**	=	square metres
grams	**/ 28.35**	=	ounces	tonnes	**x 1000**	=	kilograms
hectares	**x 2.471**	=	acres	tonnes	**x 0.9842**	=	tons (UK/long)
hectares	**/ 100**	=	square km	tonnes	**x 1.1023**	=	tons (US/short)
hectares	**x 10000**	=	square metres	tons (UK/long)	**x 1016**	=	kilograms
hectares	**/ 259**	=	square miles	tons (UK/long)	**x 1.016**	=	tonnes
hectares	**x 11 960**	=	square yards	tons (US/short)	**x 907.2**	=	kilograms
inches	**x 2.54**	=	centimetres	tons (US/short)	**x 0.9072**	=	tonnes
inches	**/ 12**	=	feet	yards	**x 0.9144**	=	metres

Appendix C

PRODUCTS TO DATE

C.1 Experiments (27 Products)

C.1.1 Technical Reports

California Department of Transportation (Caltrans). 2007. Runoff Water Quality Relative To Groundcover Treatments Under Simulated Rainfall. CTSW-RT-05-069.06.2

California Department of Transportation (Caltrans). 2006. RECMS Annual Report. CTSW-RT-06-167.01.1.

California Department of Transportation (Caltrans). 2005. Native Shrub Germination Relative to Compost Type, Application Method, and Layer Depth. CTSW-RT-05-069.06.2.

California Department of Transportation (Caltrans). 2005. Performance of Erosion Control Treatments on Reapplied Topsoil. CTSW-RT-04-069.06.1.

California Department of Transportation (Caltrans). 2004. Effectiveness of Planting Techniques for Minimizing Erosion. CTSW-RT-04-004.69.01.

California Department of Transportation (Caltrans). 2002. Evaluating Hydroseeding & Plug Planting Techniques For Erosion Control & Improved Water Quality. CTSW-RT-02-052.

California Department of Transportation (Caltrans). 2001. Vegetation Establishment for Erosion Control Under Simulated Rainfall. CTSW-RT-01-078.

C.1.2 Research Papers for Academic Degrees

Blanquies, J. 2002. Nozzles and nozzle spacing for the redesign of the Norton Ladder Type Rainfall Simulator. Cal Poly State University Senior Project 02-1490.

Castile, Danielle. 2005. Depth and moisture requirements for germination and seedling establishment of selected California native grass and shrub species. Cal Poly State University Senior Project 05-1058.

Furnare, L. 2002. Heavy metal transport into storm water runoff involving roadside factors. Cal Poly State University Senior Project 02-1157.

Dettman, K.A. 2003. An erosion control and forage production plan for the Cal Poly Equine Center. Master's Thesis. Cal Poly State University.

Mansager, S. 2003. Soil stabilization treatment and burial depth influences on the ecesis of several native California plant species. Cal Poly State University Senior Project 04-034.

Power, A. 2006. Establishment of Native California Graminoids for Use in Restoration. Master's Thesis. Cal Poly State University

Rhodes, N.M. 2004. Establishment of native plug plantings on tops and toes of a natural hillside. Cal Poly State University Senior Project 04-0428.

C.1.3 Conference Proceedings

Hallock, B., L. Corkins, S. Rein, M. Curto, and M. Scharff. 2007. Analysis of Compost Treatments to Establish Shrubs and Improve Water Quality. Proceedings of the 38th

Annual Conference and Expo of the International Erosion Control Association, 12-16 February 2007, Reno, NV.

Hallock, B., L. Corkins, S. Rein, M. Curto, and M. Scharff. 2007. Water Quality Relative to Slope Toe Strip Type and Length. Proceedings of the 38th Annual Conference and Expo of the International Erosion Control Association, 12-16 February 2007, Reno, NV.

Hallock, B., A. Power, S. Rein, and M. Scharff. 2006. Native Shrub Germination Relative to Compost Type, Application Method, and Layer Depth. Proceedings of the 37th Annual Conference and Expo of the International Erosion Control Association, 20-24 February 2006, Long Beach, CA.

Hallock, B., A. Power, S. Rein, and M. Scharff. 2005. Performance of Erosion Control Treatments on Reapplied Topsoil. Proceedings of the 36th Annual Conference and Expo of the International Erosion Control Association, 20-23 February 2005, Dallas, TX.

Hallock, B., K. Dettman, S. Rein, M. Curto, and M. Scharff. 2004. Effectiveness of native vegetation planting techniques to minimize erosion. Distinguished Paper. Proceedings of the 35th Annual Conference and Expo of the International Erosion Control Association, 16-20 February 2004, Philadelphia, PA.

Hallock, B., K. Dettman, S. Rein, M. Curto, and M. Scharff. 2003. Effectiveness of native vegetation planting techniques to minimize erosion. Proceedings of the American Water Resources Association Annual Conference, 2-5 November 2003, San Diego, CA.

Hallock, B., K. Dettman, S. Rein, M. Curto, and M. Scharff. 2003. Rainfall Simulation: Evaluating Hydroseeding & Plug Planting Techniques For Erosion Control & Improved Water Quality. Proceedings of the 34th Annual Conference and Expo of the International Erosion Control Association, 24-28 February 2003, Las Vegas, NV.

Hallock, B., M. Chiramonte, M. Curto, and M. Scharff. 2003. Effects of Erosion Control Treatments on Native Plant and Ryegrass Establishment. Proceedings of the 34th Annual Conference and Expo of the International Erosion Control Association, 24-28 February 2003, Las Vegas, NV.

Hallock, B., J. Blanquies, and M. Scharff. 2003. The Design And Construction Of A Rainfall Simulator. Proceedings of the 34th Annual Conference and Expo of the International Erosion Control Association, 24-28 February 2003, Las Vegas, NV.

Hallock, B., M. Curto, S. Rein, and M. Scharff. 2002. Vegetation Establishment For Erosion Control Under Simulated Rainfall. Proceedings of the 33rd Annual Conference and Expo of the International Erosion Control Association, 25 February-1 March 2002, Orlando, FL.

C.1.4 Magazine Articles

Grobe, K. 2006. Compost use for erosion control: performance in construction and roadway projects. *Erosion Control.* May/June.

Grobe, K. 2006. Compost use for erosion control in California. *Biocycle.* April. Vol. 47(4): 56.

Hallock, B., K. Dettman, S. Rein, M. Curto, and M. Scharff. 2004. Effectiveness of native vegetation planting techniques to minimize erosion. *Land and Water* 48(6): 26-30.

C.2 Database Application (10 Products)

C.2.1 Technical Reports

2002. Caltrans District 5 Advisory Guide to Plant Species Selection for Erosion Control & Native Revegetation. CTSW-RT-01-079.

C.2.2 Technical Documents

2005. transPLANT: A Caltrans Highway Planting Database and Specification Tool. Design. Prototype for Districts 4, 5, and 11, and Template for All Districts.

2004. Seed and Plant Calculator User Manual. Prototype for Caltrans District 5. ver. 2.0 (beta). Computer Application Manual.

C.2.3 Conference Presentations/Proceedings

Hallock, B., M. Curto, D. Brown, J. Broadbent, and M. Scharff. 2008. transPLANT: A Caltrans Highway Planting Database. Design/Build Status Brief March 2008. Caltrans Super Swat Statewide Stormwater Conference, 25 March 2008.

Curto, M., B. Hallock, and M. Scharff. 2005. A Database Application and Calculator for California Highway Revegetation Specifications. TRB Stormwater Management for Highways Symposium, 11-13 July 2005, Sanibel Island, FL.

Curto, M., B. Hallock, and M. Scharff. 2005. Caltrans Vegetation Erosion Control Research and Seed Selection Tool. California Stormwater Quality Association Conference, October, 2005.

Curto, M., B. Hallock, S. Rein, and M. Scharff. 2002. A GIS to Select Plant Species for Erosion Control Along California Highways. Proceedings of the 33rd Annual Conference and Expo of the International Erosion Control Association, 25 February-1 March 2002, Orlando, FL.

C.2.4 Training Workshops

2005. Statewide Webcast to all Caltrans Districts providing overview of transPLANT

2004. District 5: Training for Landscape Architect use of Seed and Plant Calculator.

2003. District 5: Training for Landscape Architect use of Seed and Plant Calculator.

C.3 Expert Assistance (27 Products)

C.3.1 Technical Reports

2007. Nutrient Augmentation Management for Highway Planting. CTSW-RT-07-XXX.XX.X.

2006. Scoping Review Of Some Potential Ecological Consequences From Compost Used For Revegetation of Native Plants Along California Highways.

2006. Seed Mixes for Bioswales. EA 116791, CA Highway 118, Ventura County, CA.

2006. Candidate Plants for Orange County I5 PM 3.9/4.3 and SR73 PM 12.5/15.6.

2006. Legume Seed Inoculation for Highway Planting in California. CTSW-RT-06-167.01.2.

2006. A Qualitative Assessment of Post-Construction Revegetation Success on Cuesta Grade, San Luis Obispo County, CA.

2006. US 101 Prunedale Improvement Project: Field assessment of past revegetation projects to provide recommendations for post-construction revegetation scheduled for 2008+.

2006. Review and recommendations for a Native Sod Strip Specification and species selection for State Route 46 Corridor Improvement Project post-construction revegetation scheduled for 2007+

2006. Advisory Regarding Identification and Provenance of Plant Materials Presently Sold in California.

2006. A Review of "Soil Resource Evaluation A Stepwise Process for Regeneration and Revegetation of Drastically Disturbed Soils. (CTSW-RT-05-073.20.1.)".

2006. Recommendations Regarding Erosion Control Along the Union Road Segment (SR46).

2005. Assessment of Potential Sites Along SR46 to Obtain or Stockpile Topsoil For Reapplication.

2005. Candidate Plants for Biofilters and Sod Strips. Draft.

2004. Proposal: Guidance and Specifications for the Use of Compost and Mulch for Erosion Control and Stormwater Treatment (LAP-01).

2003. Simi and Piru Burn Visit: Meeting Observations and Recommendations.

2003. Old and Grand Prix Burn Visit: Meeting Observations and Recommendations.

2003. Revisions to Sections 2 and 3 of the Caltrans Erosion Control Manual.

2004. District 5: Plant species list and recommendations for planned post-construction revegetation along CA Hwy 41 and CA Hwy 46.

2004. District 12: Plant species list and recommendations for biofilters.

2003. District 5: Plant species list and recommendations for Coastal Scrub Revegetation.

2003. District 2: Plant species list and recommendations for biofilters.

2002. District 12: Comments on Orange County Bioretention Filter Planting Plan.

C.3.2 Training Workshops

2006. Envisioning Ecologically-Based Roadside Vegetation Management for California. Central Region Landscape Architecture Off-Site Meeting, 25 May 2006, Santa Barbara, CA.

2006. Principles and Practices for Using Vegetation to Prevent Erosion. IECA 2006 Conference, 21 February 2006, Long Beach, CA.

2004. Erosion and Sediment Control for Construction Projects. Training Workshop sponsored by Central Coast Regional Water Quality Control Board and the Land Conservancy of San Luis Obispo County, 29 October 2004, San Luis Obispo, CA.

C.3.3 Technical Assistance

2004. Sacramento: Research Development Workshop Sponsored by the Caltrans Divisions of Design, Construction, Right-of-Way / Land Surveys.

2004. District 4 Landscape Architects. Recommendations regarding portable rainfall simulators.

Appendix D
PROJECT HISTORY

D.1 Need For Project

During 2000, Caltrans Storm Water, in cooperation with the Sacramento State University Office of Water Programs and the Earth and Soil Sciences Department of Cal Poly State University, San Luis Obispo, initiated a research program to statistically test for significant differences in water quality and vegetation establishment among existing soil stabilization specifications used by Caltrans to better reduce runoff and sediment transport in compliance with regulatory requirements. To date, results have been reported elsewhere for six primary experiments (Caltrans 2001a, 2002b, 2004, 2005) and two secondary experiments (Mansager 2003; Rhodes 2004).

In general, this project seeks to:

- Measure the effectiveness of a hydroseeded plant species in controlling runoff under varying rainfall regimes and hydroseed application methods;
- Identify and select plant species for hydroseeding that demonstrate initially fast growth and long-term erosion control under a variety of rainfall regimes;
- Characterize how various rainfall regimes affect seed germination and plant establishment;
- Characterize how various hydroseeding techniques affect seed germination and plant establishment;
- Compare the effects of plugs, flats (sod strips), and hydroseed planting techniques on minimizing erosion and improving water quality;
- Ascertain the effects of compost soil amendment on native vegetation cover, species composition, and weedy annual species suppression.

The following pages provide synopses of the experimental designs and results of experiments conducted to date involving modifications to existing soil stabilization specifications, as well as some promising innovative methods previously untested.

Design elements common to all experiments are listed or discussed in other appendices.

DESIGN ELEMENT	DETAILS
Terminology	**Appendix A**
Units And Conversions	**Appendix B**
Rainfall Simulators And Test Boxes	**Appendix E**
Runoff Collection And Analysis	**Appendix F**
Vegetation Sampling And Analysis	**Appendix G**

Because natural rainfall governed results to a large degree, **Chart D.1** shows the monthly average rainfall amounts from September 2000 through April 2005 and the 55 year monthly averages for comparison.

Appendix C provides a list of products and services generated by this project to date.

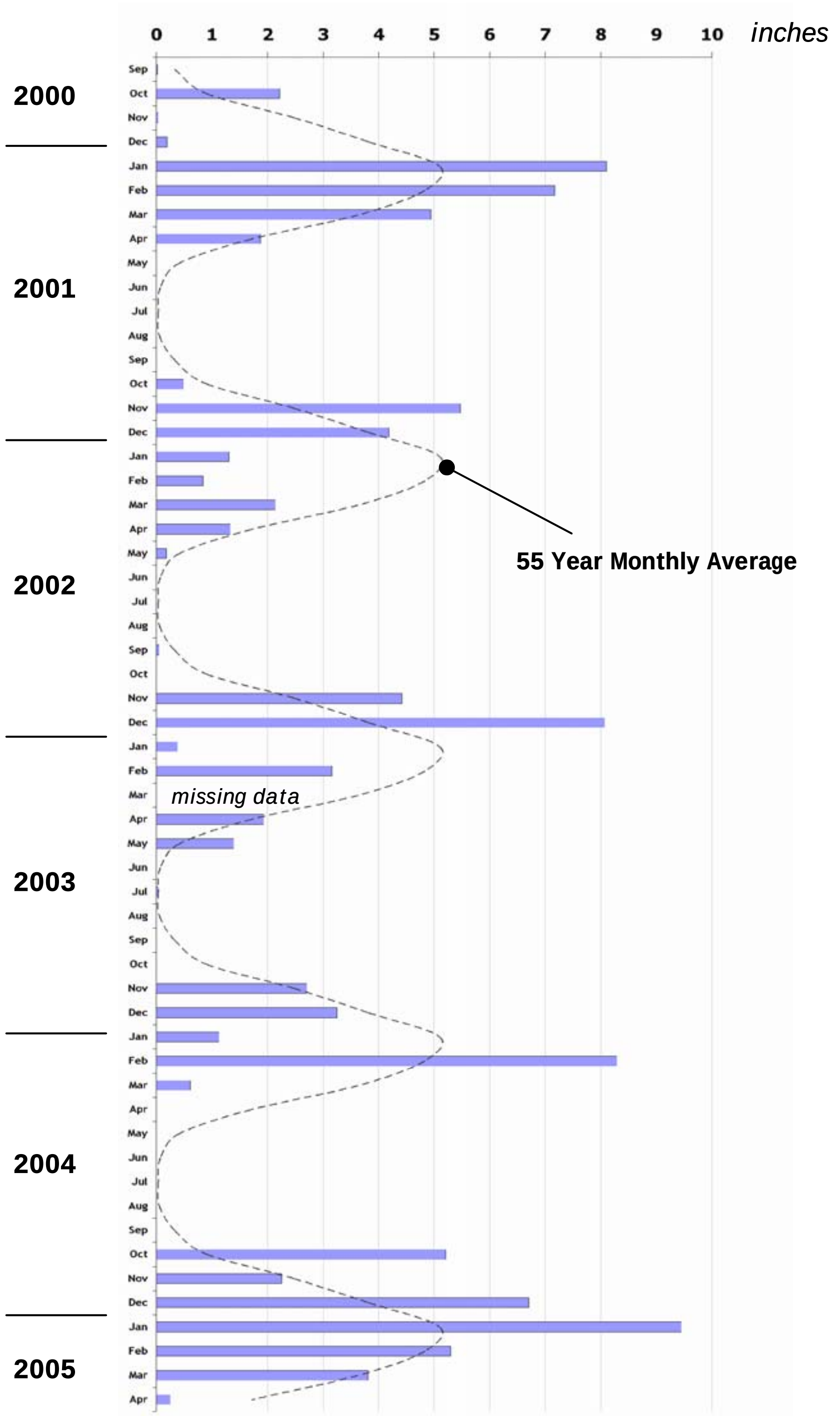


Chart D.1. Monthly Precipitation From September 2000 Through April 2005

D.2 Exploratory Modifications to Existing Soil Stabilization Methods.

RS1 Experiment November 2000 – June 2001

Performance of standard erosion control measures and of a District 5 native seed mix on reapplied topsoil under simulated rainfall.

California Department of Transportation (Caltrans). 2001. Vegetation Establishment For Erosion Control Under Simulated Rainfall. **CTSW-RT-01-078**.

D.2.1 Research Problem

Problems with germination and establishment by burial intolerant native species or races are common to hydroseeding applications throughout California. Such problems are related to present erosion control specifications (Soil Stabilization BMP SS-4) designed to apply burial tolerant species, typically cereal grains or naturalized alien grasses, beneath layers of fiber, bonded fiber matrix, straw, erosion control blankets, used with or without tackifiers. Most cereal grains, naturalized alien grasses, and some native species used in seed mixes, are capable of emerging through such layers to provide additional aerial plant cover for soil stabilization. However, many native species are intolerant of such burial as they require diurnal fluctuations in light, temperature, moisture, or combinations thereof, to break dormancy. Existing specifications need modification to improve germination and establishment by burial intolerant native species. RS1 was designed to be an initial exploratory experiment using modifications to typical District 5 hydroseeding specifications and applications.

D.2.2 RS1 Experimental Design

The RS1 experiment was designed to test:

- whether present specifications of crimped straw or tackifier are effective at minimizing erosion;
- whether germination and establishment by a District 5 native species mix is inhibited by existing standard specifications for rates of crimped straw or tackifier;
- whether adequate plant cover can be established by 60 days or by 150 days to mollify erosion during modal or extreme precipitation events, respectively.

Table D.1 provides a synopsis of the experimental design; **Table D.2** lists the experimental treatments; and **Table D.3** lists the native species of the District 5 seed mix applied to all boxes.

Table D.1. RS1 Experimental Design.

Test Boxes	**36**		
Treatments	**16** combinations of EC Treatment and Precipitation		
Replicates	**2** each		
Control	**4** (no EC treatment)		
Soil	Commercial “topsoil”; medium sandy loam		
Factor	**Level**	**Amount**	**Application**
Rainfall	High	840 mm (33 in)	Every 7–10 days
	Medium	560 mm (22 in)	Every 14–21 days
	Low	280 mm (11 in)	Every 21–28 days
	Natural	Natural [584mm (23 in)]	As seasonal rain fell
EC Treatment			
Straw	None	0	
	Straw	2240 kg/ha (2000 lb/ac)	Experiment Initiation
Tackifier(Psyllium)	None	0	
	Tackifier	168 kg/ha (150 lb/ac)	Experiment Initiation
Fertilizer (15:15:15)	None	0	
	Fertilizer	45 kg/ha (40 lb/ac)	Experiment Initiation
Seed Application			
Fiber	Fiber	897 kg/ha (800 lb/ac)	Experiment Initiation
Seed Mix	D5 natives	45 kg/ha (40 lb/ac)	Experiment Initiation
Response Variables	**Variable**	**Data Collection**	**Data Analysis**
	Total Runoff	see **Appx E**	see **Appx E**
	Total Sediment	see **Appx E**	see **Appx E**
	Sediment Concentration	see **Appx E**	see **Appx E**
	Plant Cover	see **Appx F.3**	see **Appx F.6.2**

Table D.2. RS1 Treatments.

Box	Trtmnt	EC Combination				PPT
2	1	Straw	~	~	D5 Mix	Low
30	1	Straw	~	~	D5 Mix	Low
11	2	Straw	~	~	D5 Mix	Medium
13	2	Straw	~	~	D5 Mix	Medium
17	3	Straw	~	~	D5 Mix	High
20	3	Straw	~	~	D5 Mix	High
22	4	Straw	~	~	D5 Mix	Natural
24	4	Straw	~	~	D5 Mix	Natural
1	5	~	~	Tackifier	D5 Mix	Low
28	5	~	~	Tackifier	D5 Mix	Low
4	6	~	~	Tackifier	D5 Mix	Medium
6	6	~	~	Tackifier	D5 Mix	Medium
9	7	~	~	Tackifier	D5 Mix	High
15	7	~	~	Tackifier	D5 Mix	High
19	8	~	~	Tackifier	D5 Mix	Natural
25	8	~	~	Tackifier	D5 Mix	Natural

Box	Trtmnt	EC Combination				PPT
10	9	Straw	Fertilizer	~	D5 Mix	Low
12	9	Straw	Fertilizer	~	D5 Mix	Low
8	10	Straw	Fertilizer	~	D5 Mix	Medium
31	10	Straw	Fertilizer	~	D5 Mix	Medium
3	11	Straw	Fertilizer	~	D5 Mix	High
29	11	Straw	Fertilizer	~	D5 Mix	High
21	12	Straw	Fertilizer	~	D5 Mix	Natural
26	12	Straw	Fertilizer	~	D5 Mix	Natural
23	13	~	Fertilizer	Tackifier	D5 Mix	Low
27	13	~	Fertilizer	Tackifier	D5 Mix	Low
16	14	~	Fertilizer	Tackifier	D5 Mix	Medium
18	14	~	Fertilizer	Tackifier	D5 Mix	Medium
7	15	~	Fertilizer	Tackifier	D5 Mix	High
14	15	~	Fertilizer	Tackifier	D5 Mix	High
5	16	~	Fertilizer	Tackifier	D5 Mix	Natural
32	16	~	Fertilizer	Tackifier	D5 Mix	Natural

Table D.3. RS1 D5 Native Seed Mix.

Scientific Name	Vernacular Name	%PLS	Rate PLS lb/ ac	Rate PLS kg/ ha
Shrub				
Artemisia californica	California Sagebrush	2.5	1.0	1.2
Baccharis pilularis	Coyote Bush	2.5	1.0	1.2
Eriogonum fasiculatum	California Buckwheat	12.5	5.0	5.6
Lotus scoparius	Deer Lotus	5.0	2.0	2.2
Salvia mellifera	Black Sage	2.5	1.0	1.2
Perennial Grass				
Bromus carinatus	California Brome	25.0	10.0	11.2
Elymus glaucus	Blue Wild Rye	12.5	5.0	5.6
Nassella lepida	Foothill Needlegrass	5.0	2.0	2.2
Nassella pulchra	Purple Needlegrass	5.0	2.0	2.2
Annual Grass				
Festuca microstachys	Small Fescue	2.5	1.0	1.2
Perennal Forb				
Achillea millefolium	Common Yarrow	2.5	1.0	1.2
Annual Forb				
Eschscholzia californica	California Poppy	5.0	2.0	2.2
Lupinus succulentus	Arroyo Lupine	5.0	2.0	2.2
Trifolium gracilentum	Pin-Point Clover	12.5	5.0	5.6
		100.0	**40.0**	**44.8**

D.2.3 Results Summary

Straw treatments decreased both Sediment and SSC overall for all treatments. As expected, HIGH rainfall treatments generated the most amount of sediment.

D.2.3.1 Suspended Sediment Concentration (SSC)

Statistically Significant Groupings

Highest Sediment Concentration	Group 1	Tackifier with Fertilizer under HIGH or NATURAL Straw with Fertilizer under LOW ALL LOW rainfall treatments (least vegetation)
	Group 2	ALL other treatment combinations
Lowest Sediment Concentration	Group 3	Straw with Fertilizer under HIGH or NATURAL

D.2.3.2 Vegetation

Rainfall consistency matters more in the production of plant cover than does seasonal total. The LOW treatments that received 280 mm (11 in) of seasonal rainfall at 1 inch every 3 weeks produced more cover than did the NATURAL treatment that received the annual average of 584 mm (23 in), but with a 6 week gap where no rain fell. Rainfall consistency produced more understory plants, thus greater protection from raindrop impact on soil surfaces. Fertilizer produced significantly more understory and more overstory, but alien grasses benefited most.

Statistically Significant Groupings

Most Overstory Cover	Group 1	ALL Fertilizer treatments under HIGH or MEDIUM ALL MEDIUM rainfall treatments
	Group 2	ALL other treatment combinations
Least Overstory Cover	Group 3	ALL LOW rainfall treatments
Most Understory Cover	Group 1	ALL Straw treatments under HIGH, MEDIUM, or LOW
	Group 2	ALL other treatment combinations
Least Understory Cover	Group 3	ALL LOW rainfall treatments ALL NATURAL rainfall treatments

Vegetation Composition

Over all 36 boxes, 45 species were observed: 10 were members of the seed mix, 35 were not Annual Ryegrass (*Lolium multiflorum*), a naturalized alien species present in the soil seedbank, constituted 64% absolute cover (plants + non-vegetated soil) and 70% relative cover (plants only) overall. Of the seeded species, grasses and forbs exhibited greater establishment than di d shrubs. California Sagebrush (*Artemisia californica*) was the only seeded shrub to emerge with any success at about 1.4% cover and 216 total seedlings counted, mostly under MEDIUM to HIGH rainfall treatments. No sagebrush seedlings were observed among any of the boxes that received NATURAL rainfall even though the total precipitation for the season was just above the 50-year average. **Table D.4** shows percent cover after 150 days for species in the seed mix.

Table D.4. Percent Cover Recorded For RS1 D5 Native Seed Mix After 150 Days.

				Percent Cover			
				Overstory		Understory	
Scientific Name	**Vernacular Name**	**%PLS/Mix**	**PLS/ft2**	**Absolute**	**Relative**	**Absolute**	**Relative**
Bromus carinatus	**California Brome**	25	24	**14.97**	**16.46**	**0.22**	**0.45**
Lupinus succulentus	Arroyo Lupine	5	1	**5.41**	**5.95**	**1.28**	**2.63**
Achillea millefolium	**White Yarrow**	2.5	63	**0.22**	**0.24**	**8.00**	**16.40**
Eschscholzia californica	California Poppy	5	13	**0.09**	**0.10**	**14.03**	**28.76**
Trifolium gracilentum	Pin-Point Clover	12.5	58	**0.06**	**0.07**	**2.00**	**4.10**
Festuca microstachys	Small Fescue	2.5	23	nd	nd	**4.41**	**9.03**
Artemisia californica	California Sagebrush	2.5	127	nd	nd	**0.66**	**1.35**
Baccharis pilularis	Coyote Bush	2.5	116	nd	nd	**0.09**	**0.19**
Nassella pulchra	Purple Needlegrass	2.5	5	nd	nd	**0.06**	**0.13**
Salvia mellifera	Black Sage	2.5	14	nd	nd	**0.03**	**0.06**
Elymus glaucus	Blue Wild Rye	12.5	15	nd	nd	nd	nd
Nassella lepida	Foothill Needlegrass	5	15	nd	nd	nd	nd
Eriogonum fasiculatum	California Buckwheat	12.5	52	nd	nd	nd	nd
Lotus scoparius	Deer Lotus	5	21	nd	nd	nd	nd

nd = non detectable; no hits recorded, but species may have been present in very low numbers

D.2.4 Conclusions

Considering combined effects on runoff, sediment concentration, and vegetation production, Crimped Straw performed best. The addition of Fertilizer generally produced more plant cover, but more of the cover produced was naturalized alien annual grass, not native species in the seed mix. **Table D.5** provides a ranked evaluation of the treatments follows. Bear in mind that these are qualitative assessments based on the statistical output.

Table D.5. Ranked Evaluation of RS1 EC Treatment Effects.

Performance Rank : 1 = Poor 2 = Fair 3 = Good

Sed Conc = Sediment Concentration in Runoff

			Runoff		Vegetation				
					Overstory		Understory		
EC Treatment	**Fertilizer**	**PPT**	Total	Sed Conc	Native	Non-Native	Native	Non-Native	Score
No Treatment	**No**	High	*1*	*1*	*1*	*2*	*1*	*1*	**7**
		Med	*1*	*1*	*1*	*2*	*1*	*1*	**7**
		Low	*1*	*1*	*1*	*1*	*1*	*1*	**6**
		Nat	*1*	*1*	*1*	*1*	*1*	*1*	**6**
Straw	**No**	High	***3***	***3***	***2***	***2***	***3***	***3***	**16**
		Med	***3***	***2***	***3***	***2***	***2***	***2***	**14**
		Low	*2*	*2*	*2*	*2*	*2*	*2*	**12**
		Nat	*3*	*3*	*2*	*2*	*1*	*1*	**12**
	Yes	High	*2*	*3*	*1*	*2*	*2*	*2*	**12**
		Med	***2***	***2***	***2***	***2***	***3***	***2***	**13**
		Low	*3*	*1*	*2*	*2*	*2*	*2*	**12**
		Nat	*3*	*3*	*1*	*2*	*1*	*1*	**11**
Tackifier	**No**	High	*2*	*2*	*1*	*2*	*2*	*2*	**11**
		Med	*2*	*2*	*2*	*2*	*2*	*1*	**11**
		Low	*2*	*2*	*2*	*2*	*1*	*1*	**10**
		Nat	*3*	*3*	*1*	*2*	*1*	*1*	**11**
	Yes	High	*1*	*1*	*1*	*3*	*1*	*1*	**8**
		Med	*2*	*2*	*1*	*3*	*2*	*1*	**11**
		Low	*1*	*1*	*1*	*3*	*1*	*1*	**8**
		Nat	*1*	*1*	*1*	*3*	*1*	*1*	**8**

D.3 Comparison of an Existing Seedbank with Native or Naturalized Rapid Cover Seed Mixes.

RS2 Experiment October 2001 – February 2002

Establishment from seed by native and non-native plants relative to standard soil stabilization treatments on reapplied topsoil under simulated rainfall.

California Department of Transportation (Caltrans). 2002. Evaluating Hydroseeding & Plug Planting Techniques For Erosion Control & Improved Water Quality. **CTSW-RT-02-052**.

D.3.1 Research Problem

Based on results from RS1 where Crimped Straw treatments provided the best compromise between soil stabilization and plant cover production, further exploration of standard Soil Stabilization BMPs resulted from the RS2 experiment.

D.3.2 RS2 Experimental Design

The RS2 experiment was designed to test:

- whether germination and establishment by an existing seedbank, by a District 5 native species mix, or by a rapid cover alien annual mix, is inhibited by existing standard specifications for rates of Crimped Straw, Gypsum, Bonded Fiber Matrix (BFM), or *Psyllium* Tackifier;
- whether plant cover produced by an existing seedbank provides adequate protection to soil surfaces during extremely intense precipitation events, thus negating need for additional seed
- whether adequate plant cover can be established by 45 days, or by 70 days, to mollify soil erosion during extreme precipitation events.

Table D.6 provides a synopsis of the experimental design; **Table D.7** lists the experimental treatments; **Table D.3** lists the native species of the District 5 seed mix; and **Table D.8** lists the alien annual species of the rapid cover seed mix.

Table D.6. RS2 Experimental Design.

Test Boxes	**32**		
Treatments	**15** combinations of EC Treatment and Simulated Precipitation		
Replicates	**2** each		
Control	**2** (no EC treatment)		
Soil	Commercial "topsoil"; medium sandy loam		
Factor	**Level**	**Amount**	**Application**
Rainfall	Natural	Natural [312mm (12.3 in)]	As seasonal rain fell
Simulated	100 yr storm	51 mm (2 in) per hr	@ 45 days only
	100 yr storm	51 mm (2 in) per hr	@ 45 days & 70 days
EC Treatment			
Straw	None	0	
	Straw	2240 kg/ha (2000 lb/ac)	Experiment Initiation
Jute	None	0	
	Jute	2.5 cm net	Experiment Initiation
Gypsum	None	0	
	Gypsum	4483 kg/ha (4000 lb/ac)	Experiment Initiation
BFM	None	0	
	BFM	4483 kg/ha (4000 lb/ac)	Experiment Initiation
Tackifier(Psyllium)	None	0	
	Tackifier	269 kg/ha (240 lb/ac)	Experiment Initiation
Seed Application			
Fiber	Fiber	1793 kg/ha (1600 lb/ac)	
Seed Mix	None	0	
	D5 natives	45 kg/ha (40 lb/ac)	Experiment Initiation
	EC mix (alien annuals)	45 kg/ha (40 lb/ac)	Experiment Initiation
Response Variables	**Variable**	**Data Collection**	**Data Analysis**
	Total Runoff	see **Appx E**	see **Appx E**
	Total Sediment	see **Appx E**	see **Appx E**
	Sediment Concentration	see **Appx E**	see **Appx E**
	Plant Cover	see **Appx F.3**	see **Appx F.6.2**

Table D.7. RS2 Treatments.

BOX	EC	SEED	Sim PPT
17	Straw	Existing	45
20	Straw	Existing	45 & 70
41	Straw	Existing+D5Natives	45
25	Straw	Existing+D5Natives	45 & 70
43	Straw	Existing+EC Mix	45
34	Straw	Existing+EC Mix	45 & 70
12	Jute	Existing	45
14	Jute	Existing	45 & 70
22	Jute	Existing+D5Natives	45
32	Jute	Existing+D5Natives	45 & 70
5	Jute	Existing+EC Mix	45
39	Jute	Existing+EC Mix	45 & 70
10	Gypsum	Existing	45
42	Gypsum	Existing	45 & 70
40	Gypsum	Existing+D5Natives	45
2	Gypsum	Existing+D5Natives	45 & 70
24	Gypsum	Existing+EC Mix	45
29	Gypsum	Existing+EC Mix	45 & 70

BOX	EC	SEED	Sim PPT
9	BFM	Existing	45
33	BFM	Existing	45 & 70
27	BFM	Existing+D5Natives	45
21	BFM	Existing+D5Natives	45 & 70
38	BFM	Existing+EC Mix	45
30	BFM	Existing+EC Mix	45 & 70
19	Tackifier	Existing	45
37	Tackifier	Existing	45 & 70
28	Tackifier	Existing+D5Natives	45
26	Tackifier	Existing+D5Natives	45 & 70
23	Tackifier	Existing+EC Mix	45
1	Tackifier	Existing+EC Mix	45 & 70

Table D.8. RS2 Rapid Cover Seed Mix of Alien Annual Grasses and Forbs.

Scientific Name	Vernacular Name	%PLS	Rate PLS lb/ ac	Rate PLS kg/ ha
Annual Grass				
Lolium multiflorum	Annual Ryegrass	95.0	28.0	31.3
Hordeum vulgare	Cereal Barley	99.0	4.0	4.5
Annual Legume Forb				
Trifolium hirtum	Rose Clover	50.0	4.0	4.5
Trifolium incarnatum	Crimson Clover	45.0	4.0	4.5
		100.0	**40.0**	**44.8**

D.3.3 Results Summary

The BFM Treatment had the best overall water quality with 438 g of total runoff, the lowest amount of sediment with 0.4 g and the lowest sediment concentration with 1,144 g/ml. The Jute Treatment and the Crimped Straw Treatment followed closely producing greater runoff, sediment, and sediment concentration. The Gypsum Treatment and the Tackifier Treatment produced greater than 60 times the total runoff, over 200 times the total sediment and over 4 times the sediment concentration of the Jute Treatment and the Crimped Straw Treatment. No Treatment produced the worst overall water quality including the most runoff at 965,360 g, the most sediment load at 14,406 g and the highest sediment concentration at 14,944 g/ml.

D.3.3.1 Suspended Sediment Concentration (SSC)

Statistically Significant Groupings

Highest Sediment Concentration	Group 1	No Treatment (nearly five times worse)
	Group 2	Tackifier Treatment with Existing Seed Bank Gypsum Treatment with Existing Seed Bank
	Group 3	Crimped Straw Treatment with D5 Native Mix Jute Treatment with D5 Native Mix
Lowest Sediment Concentration	Group 4	BFM Treatment with D5 Native Mix

D.3.3.2 Vegetation

At 45 days seedling cover was poor, thus vegetation had no significant affect on runoff. No statistically significant difference was detected between grass cover (p=.253) and forb cover (p=.060) across the five EC treatments. At 70 days, both the commercial Rapid Cover Mix and the D5 Native Seed Mix produced significantly greater cover over the Existing Seed Bank (p<.001). The Crimped Straw, BFM, Jute, and Tackifier Treatments all produced significantly (p<.001) more plant cover than the Gypsum Treatment or No Treatment. Shrubs were so scarce that they were eliminated from the analysis (only 19 shrubs occurred in 3000 data points) because no relationships between treatments and shrub cover could be estimated with any reliability. See **Table D.9** for percent cover values by vegetation class.

Table D.9. Percent Cover Recorded For RS2 After 45 and 70 Days.

	AFTER 45 DAYS		AFTER 70 DAYS	
Class	**Absolute %**	**Relative %**	**Absolute %**	**Relative %**
Grasses	6.30	53.80	20.50	38.80
All Forbs	5.40	46.20	31.80	60.10
Legume Forbs			*24.50*	*46.30*
Other Forbs			*7.30*	*13.70*
Shrubs			0.60	1.20
All Veg	**11.70**	**100.00**	**52.90**	**100.00**
No Veg	**88.30**		**47.10**	

Statistically Significant Groupings

Most Grass Cover	Group 1	Crimped Straw Treatment with Existing Seed Bank Crimped Straw Treatment with D5 Native Mix Tackifier Treatment with existing seed bank
	Group 2	Gypsum Treatment with Existing Seed Bank Jute Treatment with Existing Seed Bank
Least Grass Cover	Group 3	No Treatment with Existing Seed Bank BFM Treatment with Existing Seed Bank
Most Legume Cover	Group 1	BFM treatments with Rapid Cover Mix Jute Treatment with Rapid Cover Mix
	Group 2	Gypsum Treatment with Rapid Cover Mix Crimped Straw Treatment with Rapid Cover Mix
Least Legume Cover	Group 3	ALL No Treatment combinations

D.3.4 Conclusions

Considering combined effects on runoff, sediment concentration, and vegetation production, Crimped Straw performed best for grass from an Existing Seedbank or from the D5 Native Mix. BFM provided the best water quality overall, and best legume cover. However, BFM negatively affects grass cover from both native and naturalized species. **Table D.10** provides a ranked evaluation of the treatments follows. Bear in mind that these are qualitative assessments based on the statistical output.

Table D.10. Ranked Evaluation of RS2 EC Treatment Effects.

Performance Rank : 1 = Poor 2 = Fair 3 = Good

Sed Conc = Sediment Concentration in Runoff

		Runoff		Vegetation					
				Grasses			Legumes		
EC Treatment	Seed	Total	Sed Conc	Native	Non-Native	Score	Native	Non-Native	Score
No Treatment	Existing	1	1	1	1	4	1	1	10
	Rapid Cover	1	1	1	1	4	1	1	10
	D5 Natives	1	1	1	1	4	1	1	10
Crimped Straw	Existing	2	2	1	3	8	1	1	18
	Rapid Cover	2	2	1	2	7	2	2	18
	D5 Natives	3	3	1	3	10	1	1	22
Jute	Existing	2	2	1	2	7	1	1	16
	Rapid Cover	2	2	1	2	7	3	3	20
	D5 Natives	3	3	1	1	8	1	1	18
Gypsum	Existing	1	1	1	2	5	1	1	12
	Rapid Cover	1	1	1	2	5	2	2	14
	D5 Natives	1	1	1	1	4	1	1	10
BFM	Existing	3	3	1	1	8	2	2	20
	Rapid Cover	3	3	1	1	8	3	3	22
	D5 Natives	3	3	1	1	8	3	3	22
Tackifier (*Psyllium*)	Existing	1	1	1	3	6	1	1	14
	Rapid Cover	1	1	1	2	5	1	1	12
	D5 Natives	1	1	1	1	4	1	1	10

D.4 Establishment by California Brome From Seed or Live Plugs.

RS3 Experiment March 2002 – June 2002

Performance of standard erosion control measures and of California Brome from live plugs or from seed on reapplied topsoil under simulated rainfall.

California Department of Transportation (Caltrans). 2002. Evaluating Hydroseeding & Plug Planting Techniques For Erosion Control & Improved Water Quality. **CTSW-RT-02-052**.

D.4.1 Research Problem

Results from RS1 and RS2, as well as from other revegetation work in California, indicate that California Brome is one of the best native perennial grasses for establishment of rapid cover from seed. The RS3 experiment sought to evaluate whether accelerated establishment of California Brome through the use of live plugs versus seed offers significant short-term advantages to water quality of runoff from more the rapid development of desired vegetation cover.

D.4.2 RS3 Experimental Design

The RS3 experiment was designed:

- to compare hydroseeded versus plug-planted California Brome (*Bromus carinatus* H.& A. *sensu stricto*) in respective effectiveness at controlling sediment transport under intense simulated rainfall at 70 days;
- to test whether germination and establishment of California Brome from seed or plugs is positively or negatively affected by topical soil treatments using Jute netting, Bonded Fiber Matrix (BFM), Wood Fiber with *Psyllium* Tackifier, or soil imprinting to simulate a track-walk;
- to compare whether water quality of runoff is significantly better when California Brome is planted at 44/m^2 (4/ft^2) versus 22/m^2 (2/ft^2).

Table D.11 provides a synopsis of the experimental design; **Table D.12** lists the experimental treatments.

Table D.11. RS3 Experimental Design.

Test Boxes	**32**		
Treatments	**15** combinations of EC Treatment and Simulated Precipitation		
Replicates	**2** each		
Control	**2** (no EC treatment)		
Soil	Commercial "topsoil"; medium sandy loam		
Factor	**Level**	**Amount**	**Application**
Rainfall	Natural	Natural [93mm (3.65 in)]	As seasonal rain fell
Simulated	100 yr storm	51 mm (2 in) per hr	@ 45 days only
	100 yr storm	51 mm (2 in) per hr	@ 45 days & 70 days
EC Treatment			
Jute	None	0	
	Jute	2.5 cm net	Experiment Initiation
BFM	None	0	
	BFM	4483 kg/ha (4000 lb/ac)	Experiment Initiation
Fiber & Tackifier (Psyllium)	None	0	
	Fiber &	4483 kg/ha (4000 lb/ac)	Experiment Initiation
	Tackifier	160 kg/ha (143 lb/ac)	Experiment Initiation
Imprint	None		
	Imprint		Experiment Initiation
Brome Installation			
Seed	California Brome	520 PLS/m^2 (40 PLS/ft^2)	Experiment Initiation
	Fiber	1793 kg/ha (1600 lb/ac)	
Plugs	@ 22/m^2 (2/ft^2)		Experiment Initiation
	@ 44/m^2 (4/ft^2)		Experiment Initiation
Response Variables	**Variable**	**Data Collection**	**Data Analysis**
	Total Runoff	see **Appx E**	see **Appx E**
	Total Sediment	see **Appx E**	see **Appx E**
	Sediment Concentration	see **Appx E**	see **Appx E**
	Plant Cover	see **Appx F.3**	see **Appx F.6.2**

Table D.12. RS3 Treatments.

EC Treatment		Seed/Plug Treatment	
EC1	**Jute** (2.5 cm or 1 in mesh)	**S1**	**Seed** @ 520 PLS/m^2
		S2	**Plugs** @ 22/m^2 (2/ft^2)
		S3	**Plugs** @ 44/m^2 (4/ft^2)
EC2	**BFM** @ 4483 kg/ha (4000 lb/ac)	**S1**	**Seed** @ 520 PLS/m^2
		S2	**Plugs** @ 22/m^2 (2/ft^2)
		S3	**Plugs** @ 44/m^2 (4/ft^2)
EC3	**Fiber** @ 4483 kg/ha (4000 lb/ac) & **Tackifier** @ 160 kg/ha (143 lb/ac)	**S1**	**Seed** @ 520 PLS/m^2
		S2	**Plugs** @ 22/m^2 (2/ft^2)
		S3	**Plugs** @ 44/m^2 (4/ft^2)
EC4	**Imprint** to simulate track-walk	**S1**	**Seed** @ 520 PLS/m^2
		S2	**Plugs** @ 22/m^2 (2/ft^2)
		S3	**Plugs** @ 44/m^2 (4/ft^2)
EC5	**None**	**S1**	**Seed** @ 520 PLS/m^2
		S2	**Plugs** @ 22/m^2 (2/ft^2)
		S3	**Plugs** @ 44/m^2 (4/ft^2)
		S4	**No Seed / No Plugs**

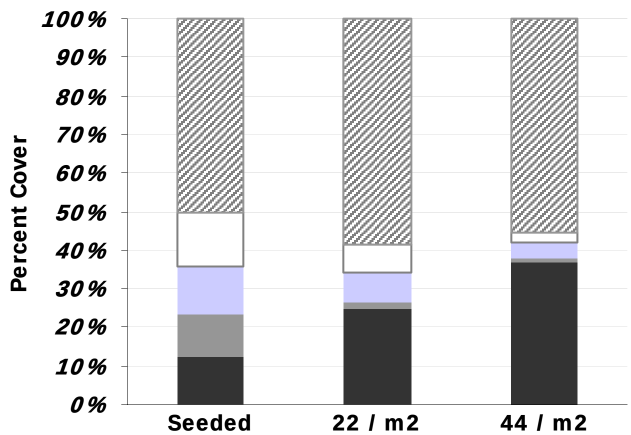
D.4.3 Results Summary

Hydroseeded California Brome treatments initially resulted in lesser sediment loads over plug planting owing to roughly twice the amount of weedy annual plant cover in the understory that arose from the existing soil seedbank and provided more surface protection. Although California Brome plugs at 44 / m^2 produced more California Brome cover than plugs at 22 / m^2, there was no statistically significant difference in sediment load, suggesting that planting at the greater density did not provide more protection to soil surfaces. See **Table D.13** for percent cover values by vegetation class.

Statistically Significant Groupings

Highest Sediment Concentration	Group 1	No Treatment
	Group 2	All other treatment combinations
Lowest Sediment Concentration	Group 3	Jute Treatment with CA Brome Seed BFM Treatment with CA Brome Seed

Table D.13. Percent Cover Recorded For RS3 After 70 Days.



	Seeded	22 / m2	44 / m2
No Veg	50.20	58.70	55.20
Other Forb	14.10	7.10	2.60
Legume Forb	12.20	7.70	4.20
Other Grass	10.60	1.60	0.90
California Brome	12.60	24.90	36.90

California Brome Installation

D.4.4 Conclusions

Considering combined effects on runoff, sediment concentration, and vegetation production, Hydroseeded California Brome Treatments performed better than either Plug Planted California Brome Treatment. Plug Planted California Brome Treatments produced two to three times more California Brome cover, but Hydroseeded California Brome Treatments produced more understory and other grass cover that combined to offer greater protection to soil surfaces. If a specific management goal is to establish the greatest California Brome cover with the fewest naturalized weeds as well, then establishment from plugs is much more effective than from seed. However, the physical act of plug planting does cause more initial soil surface disruption that causes increased sediment loads over hydroseeding during the first rains after installation. BFM provided the best water quality overall, and best legume cover. However, BFM negatively affects grass cover from both native and naturalized species.

Table D.14 provides a ranked evaluation of the treatments follows. Bear in mind that these are qualitative assessments based on the statistical output.

Table D.14. Ranked Evaluation of RS3 EC Treatment Effects.

Performance Rank : 1 = Poor 2 = Fair 3 = Good

Sed Conc = Sediment Concentration in Runoff

		Runoff		Vegetation				
				Grasses		Forbs		
EC Treatment	**Seed**	Total	Sed Conc	CA Brome	Non-Native	Legume	Other	Score
Jute	**Seed**	*3*	*3*	*1*	*3*	*3*	*2*	**15**
	Plugs 22 / m²	*2*	*2*	*2*	*1*	*2*	*1*	**10**
	Plugs 44 / m²	*2*	*2*	*3*	*1*	*2*	*2*	**12**
BFM	**Seed**	*3*	*3*	*2*	*1*	*3*	*2*	**14**
	Plugs 22 / m²	*2*	*2*	*3*	*1*	*2*	*2*	**12**
	Plugs 44 / m²	*2*	*2*	*3*	*1*	*2*	*2*	**12**
Fiber & Tackifier (*Psyllium*)	**Seed**	*3*	*3*	*2*	*3*	*3*	*3*	**17**
	Plugs 22 / m²	*2*	*2*	*2*	*2*	*2*	*3*	**13**
	Plugs 44 / m²	*2*	*2*	*2*	*2*	*2*	*2*	**12**
Imprint	**Seed**	*1*	*1*	*1*	*1*	*1*	*1*	**6**
	Plugs 22 / m²	*1*	*1*	*1*	*1*	*2*	*2*	**8**
	Plugs 44 / m²	*1*	*1*	*1*	*1*	*1*	*1*	**6**
No Treatment	**Seed**	*2*	*2*	*1*	*2*	*2*	*2*	**11**
	Plugs 22 / m²	*1*	*1*	*1*	*1*	*2*	*2*	**8**
	Plugs 44 / m²	*1*	*1*	*1*	*1*	*2*	*2*	**8**

D.5 Comparisons Among Seed, Live Plug, And Live Flat Treatments.

RS4 Experiment November 2002 – May 2003

Performance of standard erosion control measures and of native seed, live plugs, and live flats on reapplied topsoil under simulated rainfall.

California Department of Transportation (Caltrans). 2004. Effectiveness of Planting Techniques for Minimizing Erosion. **CTSW-RT-04-004.69.01**.

D.5.1 Research Problem

Expanding on results from RS1 and RS2 regarding native seed mixes, and from RS3 results using plugs of California Brome, the RS4 experiment was designed to maximize germination and establishment by a native seed mix, and to test whether flats container live plants grown from the same seed mix, or plugs of California Brome or Common Yarrow, provided significantly more slope protection if applied at the toe, or at the top and toe, of treatment boxes. To promote native seed germination over existing naturalized aliens in the soil seed bank, a thick layer [5.08 cm (2.0in)] was applied topically to both suppress germination by more aggressive aliens, and to promote germination by Common Yarrow and Small Fescue, two species shown in RS1 and RS2 to produce significantly more cover when seeded on top of, rather than beneath, a layer of wood fiber or bonded fiber matrix.

D.5.2 RS4 Experimental Design

The RS4 experiment was designed to test:

- whether a topical layer of compost 5.08 cm (2.0in) thick significantly suppresses germination by naturalized aliens in the soil seedbank;
- whether a topical layer of compost 5.08 cm (2.0in) thick significantly promotes germination by native species in an applied seed mix;
- whether water quality of runoff is significantly better when California Brome and Common Yarrow are planted from plugs at the toe, or at the top and toe, of treatment boxes.
- whether water quality of runoff is significantly better when California Brome and Common Yarrow are planted from flats at the toe, or at the top and toe, of treatment boxes.

Table D.15 provides a synopsis of the experimental design; **Table D.16** lists the experimental treatments; **Table D.17** lists the native species used in the seed mix; and **Figure D.18** shows the configuration of live plant treatments.

Table D.15. RS4 Experimental Design.

Test Boxes	**32**		
Treatments	**30** combinations of EC Treatment and Simulated Precipitation		
Replicates	**1** each		
Control	**2** (no EC treatment)		
Soil	Commercial "topsoil"; medium sandy loam		
Factor	**Level**	**Amount**	**Application**
Rainfall	Natural	Natural [93mm (3.65 in)]	As seasonal rain fell
Simulated	100 yr storm	51 mm (2 in) per hr	13 May 2003
EC Treatment			
Jute	None	0	
	Jute	2.5 cm net	Experiment Initiation
Compost	None	0	
	Compost	5.08 cm (2.0 in) Topical	Experiment Initiation
Seed			
Native Seed	None		
	Under Compost		Experiment Initiation
	Over Compost		Experiment Initiation
	Over Soil		Experiment Initiation
Live Plants	None		
	Plugs at Toe Only	20 / 0.125 m2 (1.35 ft2)	Experiment Initiation
	Plugs at Top & Toe	20 / 0.125 m2 (1.35 ft2)	Experiment Initiation
	Flats at Toe Only	2 @ 0.125 m2 (1.35 ft2)	Experiment Initiation
	Flats at Top & Toe	1 @ 0.125 m2 (1.35 ft2)	Experiment Initiation
Response Variables	**Variable**	**Data Collection**	**Data Analysis**
	Total Runoff	see **Appx E**	see **Appx E**
	Total Sediment	see **Appx E**	see **Appx E**
	Sediment Concentration	see **Appx E**	see **Appx E**
	Plant Cover	see **Appx F.3**	see **Appx F.6.2**

Table D.16. RS4 Treatments.

Physical Treatments			Vegetation Treatments				
			Seed			Live	
	Jute	Compost				Plugs	Flats
EC1	Yes	5.08 cm (2.0 in) Topical	S1	UNDER Compost	T1	Toe	—
					T2	Top & Toe	—
					T3	—	Toe
					T4	—	Top & Toe
					T5	—	—
			S2	OVER Compost	T1	Toe	—
					T2	Top & Toe	—
					T3	—	Toe
					T4	—	Top & Toe
					T5	—	—
EC2	Yes	NONE Added	S3	OVER Soil	T1	Toe	—
					T2	Top & Toe	—
					T3	—	Toe
					T4	—	Top & Toe
					T5	—	—
			S4	NONE Added	T1	Toe	—
					T2	Top & Toe	—
					T3	—	Toe
					T4	—	Top & Toe
					T5	—	—
EC3	No	NONE Added	S3	OVER Soil	T1	Toe	—
					T2	Top & Toe	—
					T3	—	Toe
					T4	—	Top & Toe
					T5	—	—
			S4	NONE Added	T1	Toe	—
					T2	Top & Toe	—
					T3	—	Toe
					T4	—	Top & Toe
					T5	—	—

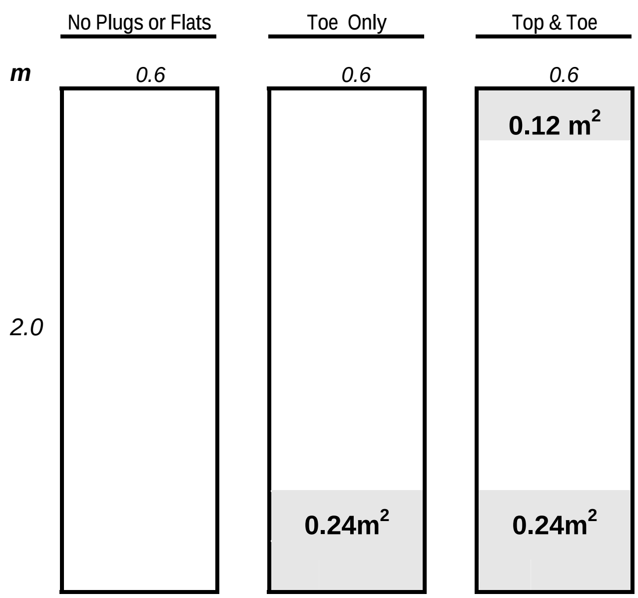
Table D.17. RS4 Native Seed Mix.

Duration	Lifeform	Scientific Name	Common Name	PLS	PLS/ft^2	lb PLS/ac	PLS/m^2	kg PLS/ha
Per	Gr	*Bromus carinatus* Hook. & Arn.	California Brome	95%	27	12.0	290	13.45
Per	Gr	*Festuca microstachys* Nuttall	Small Fescue	90%	54	3.0	581	3.35
Per	F	*Achillea millefolium* L.	Common Yarrow	69%	27	0.5	291	0.56
Ann	F_L	*Lupinus succulentus* Douglas ex Koch	Arroyo Lupine	83%	3	9.0	32	10.08
					111	**24.5**	**1194.0**	**27.4**

Ann = Annual
Per = Perennial

Gr = Grass
F = Forb
F_L = Legume Forb

Figure D.18. RS4 Configuration of Live Plant Treatments.



D.5.3 Results Summary

Results from this multifactorial experiment are complex, but expectedly follow trends observed in prior experiments. No Treatment resulted in extremely high sediment loads—over 1000 times worse than the best combination of Flats Top & Toe of a Seed Over Compost Treatment covered by Jute. The combination of Jute with Seed Over Compost resulted in significantly less runoff and significantly lower sediment concentrations. Adding Flats Top & Toe to Jute with Seed Over Compost resulted in nearly no sediment loss at all (0.2g) after simulation of a 50-year storm event. The relatively thick layer of compost did significantly reduce germination and cover produced by naturalized alien species, and did produce significantly more germination. See **Table D.19** for percent cover values by vegetation class.

Statistically Significant Groupings

			Physical		Vegetation		
		Combination	**Jute**	**Compost**	**Seed**	**Plugs**	**Flats**
Highest Sediment Concentration	**Group 1**	EC3 S4 T5	None	None	None	None	None
	Group 2	EC* S1 S2 S3 T5	All Combinations			None	None
	Group 3	EC* S* T1	All Combinations			Top	None
		EC* S* T2	All Combinations			Top & Toe	None
Lowest Sediment Concentration	**Group 4**	EC1 S2 T2	Yes	Yes	OVER	None	Top
		EC1 S2 T3	Yes	Yes	OVER	None	Top & Toe

Table D.19. Percent Cover Recorded For RS4 After 120 Days.

		T1	T2	T3	T4	T5	*avg*
EC1	S1	48%	65%	44%	65%	63%	*57%*
EC2	S2	64%	75%	68%	76%	63%	*69%*
EC2	S3	73%	84%	70%	69%	58%	*71%*
EC2	S4	66%	63%	57%	53%	47%	*57%*
EC3	S3	71%	83%	62%	92%	69%	*75%*
	avg	*64%*	*74%*	*60%*	*71%*	*60%*	

D.5.4 Conclusions

Considering combined effects on runoff, sediment concentration, and vegetation production, any erosion control treatment that uses Jute with Seed Over Compost should result in significantly more native cover, less runoff and significantly lower sediment concentrations. Addition of Flats at the toe of slopes should provide the best overall slope protection.

Table D.20 provides a ranked evaluation of the treatments follows. Bear in mind that these are qualitative assessments based on the statistical output.

Table D.20. Ranked Evaluation of RS4 EC Treatment Effects.

Performance Rank : 1 = Poor 2 = Fair 3 = Good

Sed Conc = Sediment Concentration in Runoff

Physical Treatments			Vegetation Treatments					Runoff		Vegetation				
			Seed		Live					Overstory		Understory		
	Jute	Compost				Plugs	Flats	Total	Sed Conc	Native	Non-Native	Native	Non-Native	Score
EC1	Yes	5.08 cm (2.0 in) Topical	S1	UNDER Compost	T1	Toe	—	2	2	2	2	2	1	11
					T2	Top & Toe	—	2	2	2	2	2	1	11
					T3	—	Toe	3	3	2	2	2	1	13
					T4	—	Top & Toe	3	3	2	2	2	1	13
					T5	—	—	2	2	2	2	2	1	11
			S2	OVER Compost	T1	Toe	—	2	2	3	2	3	1	13
					T2	Top & Toe	—	2	2	3	2	3	1	13
					T3	—	Toe	3	3	3	2	3	1	15
					T4	—	Top & Toe	3	3	3	2	3	1	15
					T5	—	—	2	2	2	2	3	1	12
EC2	Yes	NONE Added	S3	OVER Soil	T1	Toe	—	2	2	3	2	1	2	12
					T2	Top & Toe	—	2	2	3	2	1	2	12
					T3	—	Toe	2	2	3	2	1	2	12
					T4	—	Top & Toe	2	2	3	2	1	2	12
					T5	—	—	2	2	3	2	1	2	12
			S4	NONE Added	T1	Toe	—	2	2	3	2	1	2	12
					T2	Top & Toe	—	2	2	3	2	1	2	12
					T3	—	Toe	2	2	3	2	1	2	12
					T4	—	Top & Toe	2	2	3	2	1	2	12
					T5	—	—	1	1	3	2	1	2	10
EC3	No	NONE Added	S3	OVER Soil	T1	Toe	—	1	1	1	3	1	2	9
					T2	Top & Toe	—	1	1	1	3	1	2	9
					T3	—	Toe	2	2	1	3	1	2	11
					T4	—	Top & Toe	2	2	1	3	1	2	11
					T5	—	—	1	1	1	3	1	2	9
			S4	NONE Added	T1	Toe	—	1	1	1	2	1	1	7
					T2	Top & Toe	—	1	1	1	2	1	1	7
					T3	—	Toe	2	2	1	2	1	1	9
					T4	—	Top & Toe	2	2	1	2	1	1	9
					T5	—	—	1	1	1	2	1	1	7

D.6 Reapplied Topsoil and No Added Seed.

RS5 Experiment November 2003 - February 2004

Performance of standard erosion control measures on, and of seed existing in, reapplied topsoil under natural rainfall.

California Department of Transportation (Caltrans). 2005. Performance of Erosion Control Treatments on Reapplied Topsoil. **CTSW-RT-04-069.06.1-D1**.

D.6.1 Research Problem

As background data for projected revegetation during phases of the Route 46 Corridor Improvement Project scheduled to begin construction in summer 2007, this experiment sought to examine erosion control treatments in conjunction with reapplied topsoil to compare the effects of physical erosion control treatments (soil roughening, jute netting, jute netting over compost, straw crimped into compost, straw crimped into soil) on clay loam and fine sandy loam topsoils *with existing soil seedbanks*, and to ascertain how these treatments and vegetation from the seedbank affect runoff, sediment loss, and water quality during natural rainfall events.

D.6.2 RS5 Experimental Design

Twelve test boxes were filled with clay loam (S1), and twelve with fine sandy loam (S2). Six erosion control treatments were replicated twice for each soil type (see **D.21** for the design matrix, and **Table D.22** for treatment details). Boxes were randomly numbered and positioned to assure unbiased assignment of each treatment.

Table D.21. RS 5 Experimental Design.

Test Boxes	**24**			
Treatments	**12**			
Replicates	**2**			
Factor	**Soil Type**		**EC Treatment**	
Level	*1*	Clay Loam	*1*	None (Control)
	2	Fine Sandy Loam	*2*	Soil roughening
			3	Jute only
			4	Jute over Compost
			5	Crimped Straw
			6	Crimped Straw over Compost
Seed	Existing Soil Seed Bank (*no added seed*)			
Water Regime	Natural Rainfall			
Response Variables	Total Runoff Total Sediment Sediment Concentration Plant Cover			

Table D.22. RS 5 Treatments.

Label	Treatment	Method
EC1	None (Control)	None
EC2	Soil roughening	The edge of a soil tamp was pressed into the soil at 20.32- to 25.4-cm (8- to 10-in) intervals to simulate texturing the soil surface.
EC3	Jute only	Jute netting cut to box size, placed on soil surface, and fastened with jute hooks.
EC4	Jute over Compost	Hydropost®, a humified, fine, rich compost product was topically applied at recommended rate of 0.6 cm (0.25 in) (Caltrans 2003);
		Jute netting cut to box size, placed on soil surface, and fastened with jute hooks.
EC5	Crimped Straw	A rounded metal bar was used to press straw into the soil to simulate crimping.
EC6	Crimped Straw over Compost	Hydropost®, a humified, fine, rich compost product was topically applied at recommended rate of 0.6 cm (0.25 in) (Caltrans 2003);
		A rounded metal bar was used to press straw into the soil to simulate crimping.

D.6.3 Seed

The purpose of this experiment was to evaluate response by the seed existing in the soil samples. Thus, no additional seed was added to any treatment.

D.6.4 Rainfall Regime

Throughout the experiment, natural rainfall was permitted to fall on the boxes. In total, data for nine natural storms and one simulated storm were collected. Precipitation fell as rain because the average high temperature was 18.1C (64.5F) and the average low temperature was 5.4C (41.8F). Rainfall was collected from November to mid-February. The highest amount of rainfall, 50.8 mm (2.0 in), was collected 2 February 2004. Rainfall data are listed in **Table D.23**.

Table D.23. Natural Rainfall Data for the Duration of Experiment RS5.

			Rainfall	
Storm	Day	Year	mm	in
1	8-Nov	2003	2.0	0.08
2	12-Nov	2003	1.5	0.06
3	6-Dec	2003	5.6	0.22
3	7-Dec	2003	3.0	0.12
4	12-Dec	2003	3.4	0.13
4	13-Dec	2003	4.0	0.16
4	14-Dec	2003	5.0	0.20
5	19-Dec	2003	3.9	0.15
5	20-Dec	2003	3.0	0.12
6	24-Dec	2003	10.3	0.41
6	25-Dec	2003	12.3	0.48
6	26-Dec	2003	16.4	0.65
7	1-Jan	2004	15.2	0.60
7	2-Jan	2004	13.0	0.51
8	2-Feb	2004	50.8	2.00
9	18-Feb	2004	27.9	1.10
			177.3	**6.98**

D.6.5 Results Summary

D.6.5.1 Runoff Data Analyses

There appeared to be an effect of EC treatment on the amount of water in the runoff and that effect was different by soil type.

S1: Clay Loam Soil

EC4 had the highest total runoff, followed by EC2, EC3, EC5, EC1 and EC6, in order. EC4 had runoff significantly higher than all others. EC2 and EC3 could not be said to differ, but they were both significantly higher than EC5, EC1 and EC6. EC5, EC1 and EC6 could not be said to differ.

Statistically Significant Groupings

Most Runoff	Group 1	EC4 (Jute over Compost)
	Group 2	EC2 (Soil Roughening) EC3 (Jute)
Least Runoff	Group 3	EC5 (Crimped Straw) EC1 (Control) EC6 (Crimped Straw over Compost)

S2: Fine Sandy Loam Soil

EC2 had the highest total runoff, followed by EC1, EC4, EC3, EC5 and EC6, in order. EC3 and EC5 were not statistically different, but all other pairs were noticeably different.

Statistically Significant Groupings

Most Runoff	Group 1	EC2 (Soil Roughening) EC1 (Control) EC4 (Jute over Compost)
	Group 2	EC3 (Jute) EC5 (Crimped Straw)
Least Runoff	Group 3	EC6 (Crimped Straw over Compost)

D.6.5.2 Total Sediment Analyses

There was an effect of soil type and EC method on the sediment in the runoff. Furthermore, the effect of EC on sediment in the runoff exhibited the same pattern between soil types.

S1: Clay Loam Soil

EC1 and EC2 had the highest amounts of sediment, on average, and all other EC methods were significantly lower.

Statistically Significant Groupings

Most Sediment	Group 1	EC1 (Control) EC2 (Soil Roughening)
Least Sediment	Group 2	EC3 (Jute) EC4 (Jute over Compost) EC5 (Crimped Straw) EC6 (Crimped Straw over Compost)

S2: Fine Sandy Loam Soil

EC1 and EC2 had the highest amounts of sediment, on average, and all other EC methods were significantly lower.

Statistically Significant Groupings

Most Sediment	Group 1	EC1 (Control) EC2 (Soil Roughening)
Least Sediment	Group 2	EC3 (Jute) EC4 (Jute over Compost) EC5 (Crimped Straw) EC6 (Crimped Straw over Compost)

D.6.5.3 Sediment Concentration Analyses

There was an effect of EC on sediment concentration in the runoff, **but the effect did not differ by soil type**.

Statistically Significant Groupings

Highest Sediment Concentration	Group 1	EC1 (Control)
	Group 2	EC2 (Soil Roughening)
	Group 3	EC5 (Crimped Straw) EC3 (Jute) EC6 (Crimped Straw over Compost)
Lowest Sediment Concentration	Group 4	EC4 (Jute over Compost)

D.6.5.4 Vegetation Analyses

Grass Cover

There was an effect of EC on grass cover, and the effect of EC depended on the soil type.

S1: Clay Loam Soil

EC3 produced the greatest cover from grass. EC4, EC2 and EC6 could not be said to differ. EC5 and EC1, which had the lowest overall rates of grass cover. Certified weed-free *Hordeum vulgare* (cultivated barley) straw was used for EC5 (Crimped Straw) and EC6 (Crimped Straw over Compost). This grass was identified in the vegetation cover. Presumably, the straw contained viable seed and added to total grass cover.

Statistically Significant Groupings

Greatest Cover	Group 1	EC3 (Jute)
	Group 2	EC2 (Soil Roughening) EC4 (Jute over Compost) EC6 (Crimped Straw over Compost)
Least Cover	Group 3	EC5 (Crimped Straw) EC1 (Control)

S2: Fine Sandy Loam Soil

In summary, for fine sandy loam (S2), grass cover was lowest in EC4, which was significantly lower than all others except EC2. EC6 had the highest grass cover, but the grass cover in EC 6 was not significantly higher than EC1 EC3 and EC5.

Statistically Significant Groupings

Greatest Cover	Group 1	EC6 (Crimped Straw over Compost) EC1 (Control) EC3 (Jute) EC5 (Crimped Straw)
Least Cover	Group 2	EC2 (Soil Roughening) EC4 (Jute over Compost)

Legume Cover

There was an effect of EC on legume cover, and the effect of EC depended on the soil type.

S1: Clay Loam Soil

EC1 had the significantly highest rate of legume cover. No other significant differences were observed, but EC6 had a higher rate of legume cover than EC2 and EC3.

Statistically Significant Groupings

Greatest Cover	Group 1	EC1 (Control)
Least Cover	Group 2	EC6 (Crimped Straw over Compost) EC4 (Jute over Compost) EC5 (Crimped Straw) EC2 (Soil Roughening) EC3 (Jute)

S2: Fine Sandy Loam Soil

EC4 had the highest rate of legume cover. No other significant differences were observed.

Statistically Significant Groupings

Greatest Cover	Group 1	EC4 (Jute over Compost)
Least Cover	Group 2	EC2 (Soil Roughening) EC5 (Crimped Straw) EC6 (Crimped Straw over Compost) EC3 (Jute) EC1 (Control)

D.6.6 Conclusions

Considering combined effects on runoff, sediment concentration, and vegetation production, Jute over Compost seems to be the best EC treatment over both soil types. Jute Without Compost also performed well in plant cover production, but water quality is not as good as when Jute is used in conjunction with Compost. Of course, sources of compost vary and results may vary from those of this experiment. Although No Treatment boxes did produce seemingly ample plant cover of either grasses or legumes, sediment concentration was also very high. Soil Roughening also performed poorly overall, and even worse than No Treatment.

Table D.24 provides a ranked evaluation of the six treatments over both soil types follows. Bear in mind that these are qualitative assessments based on the statistical output. These ranking also reflect response trends in these data concordant with past experiments.

Table D.24. Ranked Evaluation of RS5 EC Treatment Effects on Each Soil Type.

Performance Rank : 1 = Poor 2 = Fair 3 = Good

Sed Conc = Sediment Concentration in Runoff

	CLAY LOAM					FINE SANDY LOAM					
	Runoff		Vegetation		*Sub*	Runoff		Vegetation		*Sub*	*Total*
	Total	Sed Conc	Grass	Legume	*Score*	Total	Sed Conc	Grass	Legume	*Score*	Score
No Treatment	***3***	*1*	*1*	***3***	**8**	*1*	*1*	***3***	*1*	**6**	**14**
Soil Roughening	*2*	*1*	*2*	*1*	**6**	*1*	*1*	*1*	*1*	**4**	**10**
Jute Only	*2*	*2*	***3***	*1*	**8**	*2*	*2*	***3***	*1*	**8**	**16**
Jute over Compost	*1*	***3***	*2*	*2*	**8**	*1*	***3***	*1*	***3***	**8**	**16**
Crimped Straw	***3***	*2*	*1*	*1*	**7**	*2*	*2*	***3***	*1*	**8**	**15**
Crimped Straw over Compost	***3***	*2*	*2*	*2*	**9**	***3***	*2*	***3***	*1*	**9**	**18**

	CLAY LOAM			FINE SANDY LOAM		
	Sed Conc	Plant Cover	*Score*	Sed Conc	Plant Cover	*Score*
No Treatment	*1*	*4*	**5**	*1*	*4*	**5**
Soil Roughening	*1*	*3*	**4**	*1*	*2*	**3**
Jute Only	*2*	*4*	**6**	*2*	*4*	**6**
Jute over Compost	***3***	***4***	**7**	***3***	***4***	**7**
Crimped Straw	*2*	*2*	**4**	*2*	*4*	**6**
Crimped Straw over Compost	*2*	*4*	**6**	*2*	*4*	**6**

D.7 Reapplied Topsoil and Added Seed.

RS6 Experiment February 2004 – August 2004

Performance of standard erosion control measures on, and of seed existing in and hydroapplied to, reapplied topsoil under natural and simulated rainfall.

California Department of Transportation (Caltrans). 2005. Performance of Erosion Control Treatments on Reapplied Topsoil. **CTSW-RT-04-069.06.1-D1**.

D.7.1 Research Problem

As background data for projected revegetation during phases of the Route 46 Corridor Improvement Project scheduled to begin construction in summer 2007, this experiment sought to ascertain how various rates of fiber and compost in a hydroseed mix affect germination of existing soil seedbanks and germination of added California native seed on clay loam and fine sandy loam topsoils, and how these factors affect runoff, sediment loss, water quality, and vegetation cover under simulated rainfall.

Twelve test boxes were filled with clay loam (S1), and twelve with fine sandy loam (S2). Six erosion control treatments were replicated twice for each soil type. **Table D.25** shows the design matrix; **Table D.26** lists treatment details; **Table D.27** provides fiber calculations; and **Table D.28** lists materials loaded per hydroseeder tankfull. Boxes were randomly numbered and positioned to assure unbiased assignment of each treatment.

Table D.25. RS 6 Experimental Design.

Test Boxes	24			
Treatments	12			
Replicates	2			
Factor	**Soil Type**		**EC Treatment**	
Level	*1*	Clay Loam	*1*	None (Control)
	2	Fine Sandy Loam	*2*	Seed in Low Fiber, No Compost
			3	Seed in Low Fiber and High Compost
			4	Seed in Low Fiber and Low Compost
			5	Seed over High Fiber and Low Compost
			6	Seed under High Fiber and Low Compost
Seed	Existing Soil Seed Bank			
	Hydroseeded Species			
	Achillea millefolium L.		Common Yarrow	
	Bromus carinatus Hook & Arn.		California Brome	
Water Regime	Natural Rainfall			
Response Variables	Total Runoff			
	Total Sediment			
	Sediment Concentration			
	Plant Cover			

Table D.26. RS 6 Treatments.

Label	Treatment	Method
EC1	None (Control)	None
EC2	Seed *in* 1680 kg/ha (1500 lb/ac) fiber, with no compost	Hydroseed
EC3	Seed *in* 1680 kg/ha (1500 lb/ac) fiber with 1680 kg/ha(1500 lb/ac) compost	Hydroseed
EC4	Seed *in* 1680 kg/ha (1500 lb/ac) fiber with 560 kg/ha (500 lb/ac) compost	Hydroseed
EC5	Seed *over* 3920 kg/ha fiber (3500 lb/ac) with 560 kg/ha (500 lb/ac)compost	Hydroseed
EC6	Seed *under* 3920 kg/ha (3500 lb/ac) fiber with 560 kg/ha (500 lb/ac) compost	Hydroseed

Table D.27. RS 6 Fiber Calculations.

	RATES			
	SI Measures		US Measures	
Fiber Calculations	Quantity	Units	Quantity	Units
Mass rate of fiber per area	3923.00	kg/ha	3500.00	lb/ac
Mass per bale	22.68	kg	50.00	lb
Volume per bale	0.06	m^3	2.00	ft^3
Mass per unit volume	400.46	kg/m^3	25.00	lb/ft^3
Mass per unit volume applied	100.12	kg/m^3	6.25	lb/ft^3
Volume per plot area	39.185	m^3/ha	560.00	ft^3/ac
Depth of topical layer	3.00	mm	0.125	in

Table D.28. RS 6 Materials Used Per Hydroseeder Tankfull.

	RATES			
	SI Measures		US Measures	
Materials Per Tankfull	Quantity	Units	Quantity	Units
Fiber	22.70	kg	50.00	lb
Compost	2.83	kg	6.25	lb
Water	432.60	L	114.00	gal

D.7.2 Seed

The purpose of this experiment was to evaluate response by two hydroseeded native plant species in potential competition with species from seed existing in the soil samples. Thus, additional seed was added to treatments EC2 through EC6. **Table D.29** shows the calculations used to scale a typical application rate of pure live seed to quantities proportional to the amount of water in the small tank (1500 L / 400 gal) of the hydroseeder used to apply these seeds.

Table D.29. RS 6 Calculations for Hydroseeded Species.

	BASE RATE PLS				SCALED RATE PLS PER TANKFULL			
	SI Measures		US Measures		SI Measures		US Measures	
Species	Qty	Units	Qty	Units	Qty	Units	Qty	Units
Bromus carinatus Hook & Arn. California Brome	33.6	kg/ha	30.0	lb/ac	0.194	kg	0.4300	lb
Achillea millefolium L Common Yarrow	0.907	kg/ha	2.0	lb/ac	0.013	kg	0.0286	lb

D.7.3 Rainfall Regime

Although consistent fall and winter storm events in RS5 alleviated the need for irrigation, RS6, received no rainfall during the late spring and summer months. Light irrigation was applied three times per day for two minutes to provide adequate soil moisture while preventing runoff from occurring. NOAA rated March and April 2004 temperatures as “much above normal”. The average high temperature was 26.9C (75F), reaching 39.5C (103F), and the average low temperature was 8.3C (47F). May and June temperatures were rated as “above normal”, with the average high temperature at 26.6C (79.8F) and the average lows at 10.0C (50F) (NOAA 2004). **Table D.30** provides the schedule of simulations performed during this experiment.

Table D.30. RS 6 Simulation Schedule.

Simulation Date	Box	Treatment	Simulation Date	Box	Treatment
5/18/2004	12	S1EC1	6/9/2004	20	S1EC3
5/18/2004	18	S2EC1	6/9/2004	21	S1EC4
5/19/2004	17	S1EC2	6/11/2004	23	S2EC1
5/19/2004	19	S2EC2	6/13/2004	22	S1EC6
5/20/2004	4	S1EC3	6/13/2004	9	S2EC6
5/20/2004	2	S2EC3	6/14/2004	10	S2EC3
5/25/2004	14	S1EC4	6/15/2004	16	S1EC2
5/25/2004	24	S2EC4	6/15/2004	8	S1EC5
5/26/2004	11	S1EC5	6/15/2004	7	S2EC4
5/26/2004	3	S2EC5	6/15/2004	15	S2EC5
5/27/2004	1	S1EC6	6/16/2004	6	S1EC1
5/27/2004	13	S2EC6	6/16/2004	5	S2EC2

D.7.4 Results Summary

D.7.4.1 Runoff Data Analyses

It appeared that only EC had an effect on log of total water in runoff. EC5 had log of total water 2.18 units below the average log of total water (p=.007). EC6 had a log of total water 1.56 below the average log of total water (p=.039).

Statistically Significant Groupings

			Seed	Fiber	Compost
Most Runoff	Group 1	EC1	*None*	*None*	*None*
		EC2	Mixed In	1680 kg/ha = 1500 lb/ac	*None*
		EC3	Mixed In	1680 kg/ha = 1500 lb/ac	1680 kg/ha = 1500 lb/ac
		EC4	Mixed In	1680 kg/ha = 1500 lb/ac	560 kg/ha = 500 lb/ac
	Group 2	EC6	Underseeded	3920 kg/ha = 3500 lb/ac	560 kg/ha = 500 lb/ac
Least Runoff	Group 3	EC5	Overseeded	3920 kg/ha = 3500 lb/ac	560 kg/ha = 500 lb/ac

D.7.4.2 Total Sediment Analyses

Only EC has an effect on total sediment. EC1 has log sediment levels 3.61 higher than the average sediment level (p<.001), EC5 has log sediment levels 2.64 lower than the average sediment level (p=.003) and EC6 has log sediment levels 2.03 lower than the average sediment level (p=.013).

Statistically Significant Groupings

			Seed	Fiber	Compost
Most Sediment	Group 1	EC1	*None*	*None*	*None*
		EC2	Mixed In	1680 kg/ha = 1500 lb/ac	*None*
		EC3	Mixed In	1680 kg/ha = 1500 lb/ac	1680 kg/ha = 1500 lb/ac
		EC4	Mixed In	1680 kg/ha = 1500 lb/ac	560 kg/ha = 500 lb/ac
	Group 2	EC6	Underseeded	3920 kg/ha = 3500 lb/ac	560 kg/ha = 500 lb/ac
Least Sediment	Group 3	EC5	Overseeded	3920 kg/ha = 3500 lb/ac	560 kg/ha = 500 lb/ac

D.7.4.3 Sediment Concentration Analyses

No significant interaction was noted between Soil and EC. EC1 differed from all other levels of EC treatment. On average, the log of sediment concentration was 2.16 units higher than the log of sediment concentrations for the other treatments, p<.001, but none of the other levels had significantly different log sediment concentrations.

Statistically Significant Groupings

			Seed	Fiber	Compost
Highest Sediment Concentration	Group 1	EC1	*None*	*None*	*None*
Lowest Sediment Concentration	Group 2	EC2	Mixed In	1680 kg/ha = 1500 lb/ac	*None*
		EC3	Mixed In	1680 kg/ha = 1500 lb/ac	1680 kg/ha = 1500 lb/ac
		EC4	Mixed In	1680 kg/ha = 1500 lb/ac	560 kg/ha = 500 lb/ac
		EC5	Overseeded	3920 kg/ha = 3500 lb/ac	560 kg/ha = 500 lb/ac
		EC6	Underseeded	3920 kg/ha = 3500 lb/ac	560 kg/ha = 500 lb/ac

D.7.4.4 pH Data Analyses

There were no significant effects of Soil or EC on pH of runoff.

D.7.4.5 Fiber Rate Analyses

The mean difference in runoff between fiber rates of 3920 kg/ha (3500 lb/ac) and of 1680 kg/ha (1500 lb/ac) was not significantly different.

D.7.4.6 Compost Rate Analyses

The mean difference in runoff between compost rates of 1680 kg/ha (1500 lb/ac) and of 560 kg/ha (500 lb/ac) was not significantly different.

D.7.4.7 Vegetation Analyses

Grass Cover

There was a statistically significant effect of EC, a statistically significant effect of soil type (S) and an interaction between EC method (EC) and soil type (S) that differs by soil type. Overall, S1 (Clay Loam) provided lower rates of grass cover than did S2 (Fine Sandy Loam). Percentage cover estimates by soil type for each treatment method were separately presented due to the interaction.

S1: Clay Loam Soil

EC1 and EC5 had the lowest percentage of grass cover. EC2 had grass cover lower than EC3 and EC6, but not significantly lower than EC4 which also was not significantly different from EC3 and EC6.

Statistically Significant Groupings

			Seed	Fiber	Compost
Most Cover	Group 1	EC3	Mixed In	1680 kg/ha = 1500 lb/ac	1680 kg/ha = 1500 lb/ac
		EC6	Underseeded	3920 kg/ha = 3500 lb/ac	560 kg/ha = 500 lb/ac
		EC4	Mixed In	1680 kg/ha = 1500 lb/ac	560 kg/ha = 500 lb/ac
		EC2	Mixed In	1680 kg/ha = 1500 lb/ac	*None*
Least Cover	Group 2	EC5	Overseeded	3920 kg/ha = 3500 lb/ac	560 kg/ha = 500 lb/ac
		EC1	*None*	*None*	*None*

S2: Fine Sandy Loam Soil

EC5 produced the highest grass cover. EC 1 had the lowest grass cover. All other EC methods (EC2, EC3, EC4 and EC6) produced cover rates that were not significantly different.

Statistically Significant Groupings

			Seed	Fiber	Compost
Most Cover	Group 1	EC5	Overseeded	3920 kg/ha = 3500 lb/ac	560 kg/ha = 500 lb/ac
Least Cover	Group 2	EC6	Underseeded	3920 kg/ha = 3500 lb/ac	560 kg/ha = 500 lb/ac
		EC4	Mixed In	1680 kg/ha = 1500 lb/ac	560 kg/ha = 500 lb/ac
		EC3	Mixed In	1680 kg/ha = 1500 lb/ac	1680 kg/ha = 1500 lb/ac
		EC2	Mixed In	1680 kg/ha = 1500 lb/ac	*None*
		EC1	*None*	*None*	*None*

Legume Cover

Soil type and EC each had a significant effect on percent cover, but there did not appear to be an interaction. S1 (Clay Loam) had a significantly higher percent cover at 47.6% than the 5.1% for S2 (Fine Sandy Loam), but the trend in the EC treatment by Soil interaction was the same. The legumes *Lupinus* spp. (Lupine) and *Lotus* spp. (Lotus) were California native species from the existing seedbank that germinated. *Lupinus* spp. was found on S1 (Clay Loam) only, and a small amount of *Lotus* spp. was found on the S2 (Fine Sandy Loam) only. A higher amount of legume cover overall was noted on the S1 (Clay Loam) compared to S2 (Fine Sandy Loam) ($p<0.001$). On S1 (Clay Loam), EC1 (Control) rated lowest in legume cover, followed by EC6.

Statistically Significant Groupings

			Seed	Fiber	Compost
Most Cover	Group 1	EC5	Overseeded	3920 kg/ha = 3500 lb/ac	560 kg/ha = 500 lb/ac
	Group 2	EC4	Mixed In	1680 kg/ha = 1500 lb/ac	560 kg/ha = 500 lb/ac
		EC2	Mixed In	1680 kg/ha = 1500 lb/ac	*None*
		EC3	Mixed In	1680 kg/ha = 1500 lb/ac	1680 kg/ha = 1500 lb/ac
Least Cover	Group 3	EC6	Underseeded	3920 kg/ha = 3500 lb/ac	560 kg/ha = 500 lb/ac
		EC1	*None*	*None*	*None*

Common Yarrow Cover

Soil type and EC both effected the percent cover due to Common Yarrow (*Achillea millefolium*). Furthermore, the interaction between soil type and EC method asserted that the effects of EC on Common Yarrow cover depended on the soil type. S1 (Clay Loam) had lower percent Common Yarrow cover than did S2 (Fine Sandy Loam). Relatively few Common Yarrow or California Brome (*Bromus carinatus*) seeds germinated. Lower overall Common Yarrow cover was found on S1 (Clay Loam) than on S2 (Fine Sandy Loam). Common Yarrow cover was highest on S1 (Clay Loam) with seed *in* 1680 kg/ha fiber with 1680 kg/ha compost and highest on S2 (Fine Sandy Loam) with seed *over* 3920 kg/ha fiber with 560 kg/ha compost.

On S1 (Clay Loam), there may have been more Common Yarrow germination on the lighter fiber and compost treatments due to lesser shading by other vegetation. Since Common Yarrow seeds are extremely small, seeding *under* 3920 kg/ha of fiber with 560 kg/ha of compost may have hindered germination by burying the seeds too deeply. Seeding *over* fiber seemed to encourage germination on S2 (Fine Sandy Loam). This effect was also noted in a previous experiment (Caltrans 2004). Common Yarrow presence is important because previous results (Caltrans 2004) indicate that the fine, mat-like foliage is an excellent sediment filter.

S1: Clay Loam Soil

EC3 produced more Common Yarrow cover than did other treatments. EC1, EC2, EC3, EC4, EC5, and EC6 did not differ significantly.

Statistically Significant Groupings

			Seed	Fiber	Compost
Most Cover	Group 1	EC3	Mixed In	1680 kg/ha = 1500 lb/ac	1680 kg/ha = 1500 lb/ac
Least Cover	Group 2	EC6	Underseeded	3920 kg/ha = 3500 lb/ac	560 kg/ha = 500 lb/ac
		EC2	Mixed In	1680 kg/ha = 1500 lb/ac	*None*
		EC4	Mixed In	1680 kg/ha = 1500 lb/ac	560 kg/ha = 500 lb/ac
		EC5	Overseeded	3920 kg/ha = 3500 lb/ac	560 kg/ha = 500 lb/ac
		EC1	*None*	*None*	*None*

S2: Fine Sandy Loam Soil

EC5 produced more Common Yarrow cover than did other treatments. EC1, EC2, EC3, EC4, and EC6 did not differ significantly.

Statistically Significant Groupings

			Seed	Fiber	Compost
Most Cover	Group 1	EC5	Overseeded	3920 kg/ha = 3500 lb/ac	560 kg/ha = 500 lb/ac
Least Cover	Group 2	EC4	Mixed In	1680 kg/ha = 1500 lb/ac	560 kg/ha = 500 lb/ac
		EC3	Mixed In	1680 kg/ha = 1500 lb/ac	1680 kg/ha = 1500 lb/ac
		EC2	Mixed In	1680 kg/ha = 1500 lb/ac	*None*
		EC1	*None*	*None*	*None*
		EC6	Underseeded	3920 kg/ha = 3500 lb/ac	560 kg/ha = 500 lb/ac

Other Forb Cover

There was not a statistically significant effect of EC on Other Forb cover. Averaging across treatment groups (where there was no difference) and quadrat (upper versus lower), the following average estimated rank for Other Forb cover (and associated percent Other Forb cover) for each soil type. S1 (Clay Loam) had lower rates of “Other Forb” cover than did S2 (Fine Sandy Loam), but no effect of EC treatment was found on “Other Forb” cover.

D.7.5 Conclusions

Considering combined effects on runoff, sediment concentration, and vegetation production, Seed *Over* 3920 Kg/Ha (3500 Lb/Ac) Fiber With 560 Kg/Ha (500 Lb/Ac) Compost seems to be the best EC treatment over both soil types, followed closely by Seed *Under* 3920 kg/ha (3500 lb/ac) Fiber With 560 kg/ha (500 lb/ac) Compost. Again, the predominant influence is likely the higher rate of Fiber and Compost rather than seed position, but seed position over or under a thicker layer of Fiber and Compost does matter to individual species germination and subsequent abundance in developing vegetation. No Treatment boxes again performed poorly, yielding high sediment concentrations and producing poor plant cover. The Seed *In* 1680 kg/ha (1500 lb/ac) Fiber with No Compost was only marginally better than No Treatment.

Table D.31 provides a ranked evaluation of the six treatments over both soil types follows. Bear in mind that these are qualitative assessments based on the statistical output. These ranking also reflect response trends in these data concordant with past experiments.

Table D.31. Ranked Evaluation of RS6 EC Treatment Effects on Each Soil Type.

Performance Rank : 1 = Poor 2 = Fair 3 = Good

Sed Conc = Sediment Concentration in Runoff

			CLAY LOAM					FINE SANDY LOAM					
			Runoff		Vegetation		*Sub*	Runoff		Vegetation		*Sub*	*Total*
Seed	**Fiber**	**Compost**	Total	Sed Conc	Grass	Legume	*Score*	Total	Sed Conc	Grass	Legume	*Score*	Score
None	*None*	*None*	*1*	*1*	*1*	*1*	***4***	*1*	*1*	*1*	*1*	***4***	***8***
Mixed In	1680 kg/ha 1500 lb/ac	*None*	*1*	*1*	*2*	*2*	***6***	*1*	*1*	*1*	*2*	***5***	***11***
Mixed In	1680 kg/ha 1500 lb/ac	1680 kg/ha 1500 lb/ac	*1*	*2*	***3***	*2*	***8***	*1*	*2*	*2*	*2*	***7***	***15***
Mixed In	1680 kg/ha 1500 lb/ac	560 kg/ha 500 lb/ac	*1*	*2*	*2*	*2*	***7***	*1*	*2*	*2*	*2*	***7***	***14***
Over seeded	3920 kg/ha 3500 lb/ac	560 kg/ha 500 lb/ac	***3***	***2***	*1*	*3*	***9***	***3***	***2***	*3*	*3*	***11***	***20***
Under seeded	3920 kg/ha 3500 lb/ac	560 kg/ha 500 lb/ac	*2*	***3***	***3***	*1*	***9***	*2*	***3***	*3*	*1*	***9***	***18***

			CLAY LOAM			FINE SANDY LOAM		
Seed	**Fiber**	**Compost**	Water Quality	Plant Cover	*Score*	Water Quality	Plant Cover	*Score*
None	*None*	*None*	*2*	*2*	***4***	*2*	*2*	***4***
Mixed In	1680 kg/ha 1500 lb/ac	*None*	*2*	*4*	***6***	*2*	*3*	***5***
Mixed In	1680 kg/ha 1500 lb/ac	1680 kg/ha 1500 lb/ac	*3*	*5*	***8***	*3*	*4*	***7***
Mixed In	1680 kg/ha 1500 lb/ac	560 kg/ha 500 lb/ac	*3*	*4*	***7***	*3*	*4*	***7***
Over seeded	**3920 kg/ha 3500 lb/ac**	**560 kg/ha 500 lb/ac**	*5*	*4*	***9***	*5*	*6*	***11***
Under seeded	3920 kg/ha 3500 lb/ac	560 kg/ha 500 lb/ac	*5*	*4*	***9***	*5*	*4*	***9***

D.8 Native Shrub Germination Relative to Compost Type, Application Method, and Layer Depth

RS7 Experiment November 2004 – March 2005

Performance of compost type, depth, and application method on water quality and growth success of California native shrub species under natural and simulated rainfall.

California Department of Transportation (Caltrans). 2005. Performance of Erosion Control Treatments on Reapplied Topsoil. **CTSW-RT-05-069.06.2**.

D.8.1 Research Problem

Where ecologically appropriate, shrubs, especially native species of a specific context landscape, are used for revegetation either as foundation plants of a shrubland system, or as deeply-rooting individuals that promote water infiltration and provide structural stability to slopes. However, germination, survivorship, and growth of native shrubs along highways and other disturbed sites are typically precarious and difficult to engineer during a short-term project timetable. Despite these difficulties, locally common pioneer shrub species, such as California Buckwheat, often do colonize these disturbed sites in time. Presently, we know little about the factors that promote establishment from seed by native shrub species in conjunction with typical erosion control practices, such as topical or incorporated compost applications.

The first experiment of this current research program showed that germination by five frequently specified California native shrub species was largely inhibited when seed was hydroapplied in and under the standard layers of fiber mulch of a Type D erosion control treatment. The goal of this experiment was to compare the effects of different compost treatments on water quality and the establishment of native shrubs. Principal questions included the following:

1. What affects do soil type, compost type, compost application method, and compost layer depth have on ***total runoff***, ***sediment***, and ***water quality***, and on ***plant establishment*** (specifically, germination rates, short-term survivorship, and aerial growth of some geographically widespread California native shrub species)?
2. Which combinations of compost types, compost application method, and compost layer depth provide the best "cost/benefit" compromise with regard to ***total runoff***, ***sediment***, and ***water quality***?
3. Which combinations of compost types, compost application method, and compost layer depth provide the best "cost/benefit" compromise with regard to shrub germination, short-term survivorship, and aerial growth?
4. Does relatively expensive commercial compost produce a better combined positive result than does a topical spread of inexpensive or free municipal compost? If so, how much better, and at what added initial or projected costs?

D.8.2 RS7 Experimental Design

Ten pressure-treated wood test boxes measuring 2.0 m (6.6 ft) x 0.6 m (2 ft) x 0.3 m (1 ft) were filled with Silty Clay (S1), and ten with Sandy Clay Loam (S2). Ten erosion control treatments were applied to each soil type with no replications. Boxes were randomly numbered and positioned to assure unbiased assignment of each treatment. **Table D.32** presents a synopsis of the experimental design. **Table D.33** lists the three types of compost used. **Table D.34** lists the ten treatments using compost.

Table D.32. RS7 Design Matrix.

Individuals	Factors			Response Variables
Test Boxes (n = 20)	**Soil Types (n= 2)**	**EC Treatments (n =10)**	**Vegetation Treatment (n = 1)**	
no replications	Silty Clay	NONE	*Baccharis pilularis*	Total Runoff
	Sandy Clay Loam	MNCPL-INC	*Eriogonum fasciculatum,*	Total Sediment
		MNCPL-TOP16	*Eriophyllum confertiflorum*	Sediment Concentration
		MNURE-INC	*Lotus scoparius*	Runoff pH
		MNURE-TOP16		Total Dissolved Salts
		CMRCL-INC		Shrub Cover
		CMRCL-TOP16		Weed Cover
		CMRCL+FBR-TOP2		
		CMRCL+FBR-TOP8		
		CMRCL+FBR-TOP16		

Table D.33. RS7 Compost Types.

Label	Source Type
MNCPL	A municipal yard-waste and biosolid mixture with large woody pieces, ranging from approximately 8 to 20 cm in length and less than 2cm in diameter.
MNURE	A manure-based, fine textured organic with no woody material.
CMRCL	A humified, fine-textured, commercial product typically specified by Caltrans consisting of chipped, shredded or ground vegetation less than one centimeter in diameter, and Class A exceptional quality biosolids. This product is typically sold in bags.

Table D.34. RS7 EC Treatments Using Compost.

Treatment		Compost		
	Label	Appl Method	Rate	Topical Layer Depth (mm)
EC1	**NONE**	None	None	**0**
EC2	**MNCPL-INC**	Incorporated	Admixture of upper 8 cm soil and compost (25% by volume).	**0**
EC3	**MNCPL-TOP16**	Topical	16mm topical application of compost by hand on soil surface.	**16**
EC4	**MNURE-INC**	Incorporated	Admixture of upper 8 cm soil and compost (25% by volume).	**0**
EC5	**MNURE-TOP16**	Topical	16mm topical application of compost by hand on soil surface.	**16**
EC6	**CMRCL-INC**	Incorporated	Admixture of upper 8 cm soil and compost (25% by volume).	**0**
EC7	**CMRCL-TOP16**	Topical	16mm topical application of compost by hand on soil surface.	**16**
EC8	**CMRCL+FBR-TOP2**	Topical	*Compost*: 3363 kg/ha (3000 lbs/ac) *Wood Fiber*:1121 kg/ha. (1000 lbs/ac) Hand applied to a depth of 2 mm.	**2**
EC9	**CMRCL+FBR-TOP8**	Topical	*Compost*: 3363 kg/ha (3000 lbs/ac) *Wood Fiber*:1121 kg/ha. (1000 lbs/ac) Hand applied to a depth of 8 mm.	**8**
EC10	**CMRCL+FBR-TOP16**	Topical	*Compost*: 3363 kg/ha (3000 lbs/ac) *Wood Fiber*:1121 kg/ha. (1000 lbs/ac) Hand applied to a depth of 16 mm.	**16**

D.8.3 Seed Mix

After compost treatments were applied, seed was applied to all boxes in a slurry containing wood fiber at a rate of 1680 kg/ha (1500 lb/ac). The seed mix consisted of four shrub species native to Coastal California. These shrubs are common pioneers on disturbed sites and are frequently specified for Caltrans projects. Seeding rates are listed in **Table D.35**.

Table D.35. RS7 California Native Shrub Species Seeding Rates.

Scientific Name	Common Name	PLS/m^2	kg PLS/ha	PLS/ft^2	lb PLS/ac
Baccharis pilularis	Coyote Brush	323	0.3	30	0.3
Eriogonum fasciculatum	California Buckwheat	323	3.3	30	2.9
Eriophyllum confertiflorum	Coastal Golden Yarrow	323	0.5	30	0.5
Lotus scoparius	Deer Weed	323	3.3	30	2.9

D.8.4 Rainfall Regime

Throughout the experiment (November 2004 to March 2005), natural rainfall was permitted to fall on the boxes. Eighteen storm events were collected (data listed in **Table D.36**). No simulated storm events were performed and no irrigation was applied.

Table D.36. Natural Rainfall Data for the Duration of Experiment RS7.

			Rainfall					Rainfall	
Storm	**Day**	**Year**	**cm**	**in**	**Storm**	**Day**	**Year**	**cm**	**in**
1	7-Dec	2004	3.21	1.15	10	15-Feb	2005	0.53	0.21
2	27-Dec	2004	0.81	0.32	11	18-Feb	2005	1.27	0.50
3	29-Dec	2004	5.89	2.32	12	20-Feb	2005	1.04	0.41
4	30-Dec	2004	0.41	0.16	13	21-Feb	2005	3.53	1.39
5	31-Dec	2004	2.64	1.04	14	22-Feb	2005	1.27	0.50
6	11-Jan	2005	0.25	0.10	15	27-Feb	2005	0.30	0.12
7	26-Jan	2005	0.81	0.32	16	20-Mar	2005	0.53	0.21
8	28-Jan	2005	2.03	0.80	17	22-Mar	2005	6.45	2.54
9	11-Feb	2005	0.91	0.36	18	23-Mar	2005	0.48	0.19

D.8.5 Results Summary

D.8.5.1 Runoff Data Analyses

There appeared to be an effect of EC on total amount of water runoff and that effect was different with each soil type. On average, when compost was Incorporated into soil, the total runoff was higher than when a Topical application of compost was used. There were no noticeable differences among any of the Topical Commericial+Fiber depths.

S1: Silty Clay Soil

For Incorporated applications on Clay soil, there were no noticeable differences in total runoff among EC2, EC4 and EC6. For Topical applications, EC3 had lower total runoff than EC5 or EC10. EC7 also had lower runoff than EC10.

Statistically Significant Groupings Based on Main Effects Plots

Most Runoff	Group 1	EC9 (CMRCL+FBR-TOP8) EC10 (CMRCL+FBR-TOP16)
	Group 2	EC1 (None) EC2 (MNCPL-INC) EC4 (MNURE-INC) EC5 (MNURE-TOP16) EC6 (CMRCL-INC) EC8 (CMRCL+FBR-TOP2)
Least Runoff	Group 3	EC3 (MNCPL-TOP16) EC7 (CMRCL-TOP16)

S2: Sandy Clay Loam Soil

For Incorporated applications on sandy soil, there were no noticeable differences in total runoff between EC2, EC4 and EC6. For Topical applications, EC7 had lower total runoff than EC5, EC10 and EC3 which did not differ significantly.

Statistically Significant Groupings based on Main Effects Plots

Most Runoff	Group 1	EC3 (MNCPL-TOP16)
	Group 2	EC1 (None) EC5 (MNURE-TOP16) EC6 (CMRCL-INC) EC8 (CMRCL+FBR-TOP2) EC9 (CMRCL+FBR-TOP8) EC10 (CMRCL+FBR-TOP16)
Least Runoff	Group 3	EC2 (MNCPL-INC) EC4 (MNURE-INC) EC7 (CMRCL-TOP16)

D.8.5.2 Total Sediment Analyses

There was an effect of EC method and soil type on amount of sediment in runoff water. On average, when compost was Incorporated into soil, the total sediment in the runoff was higher than when a Topical application of compost was used.

S1: Silty Clay Soil

For Clay soil with Incorporated application, there were no noticeable differences in total sediment between EC2, EC4 and EC6. There were no noticeable differences in total sediment among the types of compost when using a Topical application. For Topical Commercial+Fiber treatments, EC8 had significantly lower total sediment than EC10.

Statistically Significant Groupings based on Main Effects Plots

Most Sediment	Group 1	EC1 (None)
	Group 2	EC2 (MNCPL-INC) EC4 (MNURE-INC) EC6 (CMRCL-INC)
Least Sediment	Group 3	EC3 (MNCPL-TOP16) EC5 (MNURE-TOP16) EC7 (CMRCL-TOP16) EC8 (CMRCL+FBR-TOP2) EC9 (CMRCL+FBR-TOP8) EC10 (CMRCL+FBR-TOP16)

S2: Sandy Clay Loam Soil

For Incorporated applications on Sandy soil, EC2 and EC4 had significantly lower sediment in the runoff than did EC6. For Topical applications, EC3 had more sediment in the runoff than did EC5, EC10 and EC7. For the Topical Commercial+Fiber treatments, EC8 had significantly higher sediment than did EC10 and EC9.

Statistically Significant Groupings based on Main Effects Plots

Most Sediment	Group 1	EC1 (None) EC6 (CMRCL-INC)
	Group 2	EC2 (MNCPL-INC) EC3 (MNCPL-TOP16) EC4 (MNURE-INC) EC8 (CMRCL+FBR-TOP2)
Least Sediment	Group 3	EC5 (MNURE-TOP16) EC5 (CMRCL-TOP16) EC9 (CMRCL+FBR-TOP8) EC10 (CMRCL+FBR-TOP16)

D.8.5.3 Sediment Concentration Analyses

On average, when compost was Incorporated into soil, the sediment concentration in the runoff was higher than when a Topical application of compost was used.

S1: Silty Clay Soil

For Incorporated application on Clay soil, there were no noticeable differences in sediment concentration between EC2, EC4 and EC6. For Topical applications, EC10 had a significantly lower concentration of sediment in the runoff than do EC5, EC7 and EC3 which were not significantly different. Topical treatments of Commercial+Fiber resulted in EC8 having significantly higher sediment concentration than did EC10 and EC9 which were not significantly different.

Statistically Significant Groupings based on Main Effects Plots

Highest Sediment Concentration	Group 1	EC1 (None)
	Group 2	EC2 (MNCPL-INC) EC3 (MNCPL-TOP16) EC4 (MNURE-INC) EC6 (CMRCL-INC)
	Group 3	EC5 (MNURE-TOP16) EC7 (CMRCL-TOP16) EC8 (CMRCL+FBR-TOP2)
Lowest Sediment Concentration	Group 4	EC9 (CMRCL+FBR-TOP8) EC10 (CMRCL+FBR-TOP16)

S2: Sandy Clay Loam Soil

For Sandy soil with Incorporated applications, there were no noticeable differences in sediment concentration among EC2, EC4 and EC6. Topical applications yieled EC5 and EC10 having a significantly lower concentration of sediment in the runoff than did EC3 and EC7. For Topical Commercial+Fiber treatments, EC8 had significantly higher sediment concentration than did EC10 and EC9 which were not significantly different.

Statistically Significant Groupings based on Main Effects Plots

Highest Sediment Concentration	Group 1	EC1 (None) EC6 (CMRCL-INC)
	Group 2	EC2 (MNCPL-INC) EC4 (MNURE-INC)
	Group 3	EC2 (MNCPL-TOP16) EC5 (CMRCL-TOP16) EC8 (CMRCL+FBR-TOP2)
Lowest Sediment Concentration	Group 4	EC5 (MNURE-TOP16) EC9 (CMRCL+FBR-TOP8) EC10 (CMRCL+FBR-TOP16)

D.8.5.4 pH Data Analyses

On average, when compost was Incorporated into soil, the pH of the runoff was higher than when a Topical application of compost was used. There were no significant differences in pH across the three depths of Topical Commericial+Fiber.

S1: Silty Clay Soil

For Clay soil with Incorporated applications, there were no noticeable differences in pH among EC2, EC4 and EC6. For Topical applications, there were no significant differences in pH of the runoff across the four different types of Topical compost.

Statistically Significant Groupings based on Main Effects Plots

Highest pH	Group 1	EC1 (None)
	Group 2	EC2 (MNCPL-INC) EC6 (CMRCL-INC)
	Group 3	EC4 (MNURE-INC) EC5 (MNURE-TOP16) EC8 (CMRCL+FBR-TOP2)
Lowest pH	Group 4	EC3 (MNCPL-TOP16) EC7 (CMRCL-TOP16) EC9 (CMRCL+FBR-TOP8) EC10 (CMRCL+FBR-TOP16)

S2: Sandy Clay Loam Soil

For Incorporated applications on Sandy soil, there were no noticeable differences in pH among EC2, EC4 and EC6. For Topical applications, EC3 had a significantly lower pH than did EC5. No other statistically significant differences were observed.

Statistically Significant Groupings based on Main Effects Plots

Most Basic pH	Group 1	EC1 (None)
	Group 2	EC2 (MNCPL-INC) EC4 (MNURE-INC) EC6 (CMRCL-INC)
	Group 3	EC5 (MNURE-TOP16) EC7 (CMRCL-TOP16) EC8 (CMRCL+FBR-TOP2) EC9 (CMRCL+FBR-TOP8) EC10 (CMRCL+FBR-TOP16)
Least Basic pH	Group 4	EC2 (MNCPL-TOP16)

D.8.5.5 Total Dissolved Salts Data Analyses

On average, when compost is Incorporated into soil, the TDS of the runoff is lower than when a Topical application of compost is used.

S1: Silty Clay Soil

For Incorporated applications on Clay soil, there were no noticeable differences in TDS between EC2, EC4 and EC6. For Topical applications, TDS were significantly lower for EC10 than for EC7, EC3 and EC5 which were not significantly different. EC10 and EC9, while not significantly different from each other, did have a significantly lower log(TDS) than did EC8 for the Topical Commercial+Fiber treatments.

Statistically Significant Groupings based on Main Effects Plots

Highest Total Dissolved Salts	Group 1	EC3 (MNCPL-TOP16) EC5 (MNURE-TOP16)
	Group 2	EC1 (None) EC2 (MNCPL-INC) EC4 (MNURE-INC) EC6 (CMRCL-INC) EC7 (CMRCL-TOP16) EC8 (CMRCL+FBR-TOP2)
Lowest Total Dissolved Salts	Group 3	EC9 (CMRCL+FBR-TOP8) EC10 (CMRCL+FBR-TOP16)

S2: Sandy Clay Loam Soil

For Sandy soil with Incorporated applications, there were no noticeable differences in TDS between EC2, EC4 and EC6. TDS was significantly lower for EC10 than for EC5, and no other significant differences were observed for Topical Treatments. Topical treatments of Commercial+Fiber yielded no significant differences.

Statistically Significant Groupings based on Main Effects Plots

Highest Total Dissolved Salts	Group 1	EC3 (MNCPL-TOP16) EC5 (MNURE-TOP16)
	Group 2	EC4 (MNURE-INC) EC7 (CMRCL-TOP16) EC8 (CMRCL+FBR-TOP2)
	Group 3	EC10 (CMRCL+FBR-TOP16) EC6 (CMRCL-INC) EC9 (CMRCL+FBR-TOP8)
Lowest Total Dissolved Salts	Group 4	EC1 (None) EC2 (MNCPL-INC)

D.8.5.6 Turbidity Data Analyses

On average, when compost was Incorporated into soil, the NTU of the runoff was higher than when a Topical application of compost was used.

S1: Silty Clay Soil

For Incorporated applications in Clay soil, there were no noticeable differences in NTU between EC2, EC4 and EC6. Topical applications gave a log(NTU) significantly lower for EC10 than for EC7, EC3 and EC5. Furthermore, EC7 had a significantly lower log(NTU) than did EC3 for Topical applications. For Topical treatments of Commercial+Fiber, EC10 and EC9, while not significantly different from each other did have a significantly lower log(NTU) than did EC8.

Statistically Significant Groupings based on Main Effects Plots

Highest Turbidity	Group 1	EC1 (None) EC2 (MNCPL-INC) EC4 (MNURE-INC) EC6 (CMRCL-INC)
	Group 2	EC3 (MNCPL-TOP16) EC5 (CMRCL-TOP16) EC5 (MNURE-TOP16) EC8 (CMRCL+FBR-TOP2)
Lowest Turbidity	Group 3	EC9 (CMRCL+FBR-TOP8) EC10 (CMRCL+FBR-TOP16)

S2: Sandy Clay Loam Soil

For Incorporated applications in Sandy soil, there were no noticeable differences in NTU between EC2, EC4 and EC6. Topical applications gave a log(NTU) significantly lower for EC10 than for EC7, EC3 and EC5. Furthermore, EC7 had a significantly lower log(NTU) than did EC3 for Topical applications. For Topical treatments of Commercial+Fiber, EC10 and EC9, while not significantly different from each other did have a significantly lower log(NTU) than did EC8.

Statistically Significant Groupings based on Main Effects Plots

Highest Turbidity	Group 1	EC4 (MNURE-INC) EC6 (CMRCL-INC)
	Group 2	EC1 (None) EC2 (MNCPL-INC)
	Group 3	EC2 (MNCPL-TOP16) EC5 (CMRCL-TOP16) EC5 (MNURE-TOP16) EC8 (CMRCL+FBR-TOP2)
Lowest Turbidity	Group 4	EC9 (CMRCL+FBR-TOP8) EC10 (CMRCL+FBR-TOP16)

D.8.5.7 Vegetation Analyses

D.8.5.7.1 Shrub Cover

When compost was Incorporated into the soil, the percent shrub cover was not significantly different than when Topical compost was used.

S1: Silty Clay Soil

Shrub Cover At 60 Days Following Experiment Initiation

With Incorporated soil, EC2 had significantly lower shrub cover than with EC6. For Topical applications EC7 had significantly higher shrub coverage than do EC3, EC5 and EC10, none of which differ significantly from each other. EC10 had significantly lower shrub coverage than EC9 for Topical Commercial+Fiber treatments.

Statistically Significant Groupings based on Main Effects Plots

Most Cover	Group 1	EC6 (CMRCL-INC) EC7 (CMRCL-TOP16) EC8 (CMRCL+FBR-TOP2) EC9 (CMRCL+FBR-TOP8)
	Group 2	EC1 (None) EC10 (CMRCL+FBR-TOP16) EC2 (MNCPL-INC) EC3 (MNCPL-TOP16) EC4 (MNURE-INC)
Least Cover	Group 3	EC5 (MNURE-TOP16)

Shrub Cover At 90 Days Following Experiment Initiation

With Incorporated soil, EC2 had significantly lower shrub cover than both EC4 and EC6. For Topical applications, EC7 had significantly higher shrub coverage than do EC3, EC5 and EC10, none of which differed significantly from each other. EC10 and EC8 had significantly lower shrub coverage than EC9 for Topical treatments of Commercial+Fiber.

Statistically Significant Groupings based on Main Effects Plots

Most Cover	Group 1	EC6 (CMRCL-INC) EC7 (CMRCL-TOP16)
	Group 2	EC3 (MNCPL-TOP16) EC4 (MNURE-INC) EC9 (CMRCL+FBR-TOP8)
Least Cover	Group 3	EC1 (None) EC2 (MNCPL-INC) EC5 (MNURE-TOP16) EC8 (CMRCL+FBR-TOP2) EC10 (CMRCL+FBR-TOP16)

S2: Sandy Clay Loam Soil

Shrub Cover At 60 Days Following Experiment Initiation

With Incorporated soil, there was no significant difference in shrub coverage across EC2, EC4 and EC6. EC5 and EC7 have significantly higher shrub coverage than did EC10. For Topical applications, EC3 did not differ significantly from any of the other EC treatments. With Topical Commercial+Fiber treatments EC10 had significantly lower shrub coverage than EC8.

Statistically Significant Groupings based on Main Effects Plots

Most Cover	Group 1	EC4 (MNURE-INC) EC5 (MNURE-TOP16) EC6 (CMRCL-INC) EC7 (CMRCL-TOP16) EC8 (CMRCL+FBR-TOP2)
	Group 2	EC1 (None) EC2 (MNCPL-INC) EC3 (MNCPL-TOP16)
Least Cover	Group 3	EC9 (CMRCL+FBR-TOP8) EC10 (CMRCL+FBR-TOP16)

At 90 Days Following Experiment Initiation

With Incorporated soil, EC2 had significantly lower shrub cover than both EC4 and EC6. Furthermore, EC4 had significantly lower shrub cover than EC6. For Topical applications, EC10 and EC3 had significantly lower shrub coverage than did EC5 and EC7. There was not a significant difference across the three Topical Commericial+Fiber depths.

Statistically Significant Groupings based on Main Effects Plots

Most Cover	Group 1	EC6 (CMRCL-INC) EC7 (CMRCL-TOP16)
	Group 2	EC3 (MNCPL-TOP16) EC4 (MNURE-INC) EC9 (CMRCL+FBR-TOP8)
Least Cover	Group 3	EC1 (None) EC2 (MNCPL-INC) EC5 (MNURE-TOP16) EC8 (CMRCL+FBR-TOP2) EC10 (CMRCL+FBR-TOP16)

D.8.5.7.2 Weed Cover

When compost was Incorporated into the soil, the percent weed cover was significantly higher than when Topical compost was used.

S1: Silty Clay Soil

Weed Cover At 60 Days Following Experiment Initiation

With compost Incorporated into the soil, the weed cover did not differ significantly across the three compost types. Using Topical compost only, the weed cover did not vary significantly across the compost types. For Topical Commercial+Fiber treatments, EC9 had significantly lower weed cover than EC8.

Statistically Significant Groupings based on Main Effects Plots

Most Cover	Group 1	EC6 (CMRCL-INC) EC8 (CMRCL+FBR-TOP2)
	Group 2	EC1 (None) EC2 (MNCPL-INC) EC4 (MNURE-INC) EC5 (MNURE-TOP16) EC7 (CMRCL-TOP16) EC10 (CMRCL+FBR-TOP16)
Least Cover	Group 3	EC3 (MNCPL-TOP16) EC9 (CMRCL+FBR-TOP8)

Weed Cover At 90 Days Following Experiment Initiation

With compost Incorporated into the soil, the weed cover was significantly lower for EC6 than for EC2 and EC4 which did not differ significantly. Using Topical compost only, the weed cover was significantly lower for EC7 than EC3, EC5 and EC10 which were not noticeably different. For Topical Commercial+Fiber treatments EC9 had significantly lower weed cover than EC8 and EC10 which were not significantly different.

Statistically Significant Groupings based on Main Effects Plots

Most Cover	Group 1	EC1 (None)
	Group 2	EC2 (MNCPL-INC) EC3 (MNCPL-TOP16) EC4 (MNURE-INC) EC5 (MNURE-TOP16) EC8 (CMRCL+FBR-TOP2) EC10 (CMRCL+FBR-TOP16)
Least Cover	Group 3	EC6 (CMRCL-INC) EC7 (CMRCL-TOP16) EC9 (CMRCL+FBR-TOP8)

S2: Sandy Clay Loam Soil

Weed Cover At 60 Days Following Experiment Initiation

With compost Incorporated into the soil, the weed cover was significantly lower for EC4 and EC6 than for EC2. Using Topical compost only, the weed cover was significantly lower for EC10, EC5 and EC7 than for EC3. There were no significant differences across the three Topical Commericial+Fiber depths.

Statistically Significant Groupings based on Main Effects Plots

Most Cover	Group 1	EC2 (MNCPL-INC)
	Group 2	EC1 (None) EC3 (MNCPL-TOP16) EC4 (MNURE-INC) EC6 (CMRCL-INC)
Least Cover	Group 3	EC5 (MNURE-TOP16) EC7 (CMRCL-TOP16) EC8 (CMRCL+FBR-TOP2) EC9 (CMRCL+FBR-TOP8) EC10 (CMRCL+FBR-TOP16)

Weed Cover At 90 Days Following Experiment Initiation

With compost Incorporated into the soil, the weed cover was significantly lower for EC6 than for EC2 and EC4. EC4 had significantly lower weed cover than EC2. Using Topical compost only, the weed cover is significantly lower for EC5 and EC7 than EC10 and EC3. For Topical Commercial+Fiber treatments, EC8 and EC9 had significantly lower weed cover than EC10.

Statistically Significant Groupings based on Main Effects Plots (see Appendix G)

Most Cover	Group 1	EC2 (MNCPL-INC) EC3 (MNCPL-TOP16)
	Group 2	EC1 (None) EC4 (MNURE-INC) EC7 (CMRCL-TOP16) EC8 (CMRCL+FBR-TOP2) EC9 (CMRCL+FBR-TOP8) EC10 (CMRCL+FBR-TOP16)
Least Cover	Group 3	EC5 (MNURE-TOP16) EC6 (CMRCL-INC)

D.8.6 Conclusions

Based on summed rankings derived from statistical analyses of the eight response variables (Total Runoff, Total Sediment, Sediment Concentration, Runoff pH, Total Dissolved Salts, Turbidity, Shrub Cover, and Weed Suppression), the following patterns are evident.

D.8.6.1 Compost Type

Commercial Compost (fine-textured biosolids and plant materials) **alone or mixed** with the type of fine-textured wood fiber typically applied as a hydromulch **performed better overall** than did immature Manure Compost or immature Municipal Compost that included more coarse woody pieces. As expected, the fine-textured, more mature Commercial material provided a better seed bed for the shrub seeds.

D.8.6.2 Compost Application Method

Topical applications of Compost or Compost+Fiber performed better than Incorporated applications regardless of Compost source type (Commercial, Manure, or Municipal). The increased sediment concentration of Incorporated Compost treatments is perhaps due to a difference in compaction. Topical treatments were applied over soil compacted to 90% (calculated from bulk density); Incorporated treatments were compacted as well after the soil–compost admixture was reapplied to the test box, but the admixture is distinctly different than soil alone. Soil fines were likely released more readily from the admixture.

D.8.6.3 Topical Compost Layer Depth

Performance of Topical Compost Layer Depths (16mm, 8mm, or 2mm) depended on both Compost Type and Soil Type. CMRCL+FBR-TOP8 (EC9) and CMRCL-TOP16 (EC7) performed the best on both soils. CMRCL+FBR-TOP16 (EC10) exhibited the same data trends as CMRCL+FBR-TOP8 (EC9), but with lesser shrub germination and lesser weed suppression. These counter intuitive results showing better performance from the 8mm layer than from the 16mm layer need further replication to ascertain whether the results obtained in this experiment are repeatable. The results are similar enough to suggest that a layer between 8 and 16 mm deep of fine-textured Commercial Compost alone or of Commercial Compost mixed with Wood Fiber provides superior sediment reduction, ample shrub seed germination, and superior weed suppression. The 16 mm deep layer of Manure Compost performed reasonably well on both soils also. The 16 mm deep layer of Municipal Compost performed reasonably well on the Silty Clay Soil, but produced poor shrub germination with higher weed cover on the Sandy Clay Loam. This may be due to the unequal distribution of weed seed in the test soil. Test box soil seed reserves were not individually tested for this experiment. **Table D.37** and **Chart D.2** present an overall ranked evaluation of EC Treatment Effects on both Soil Types.

Table D.37. RS7 Overall Ranked Evaluation of EC Treatment Effects on Both Soil Types.

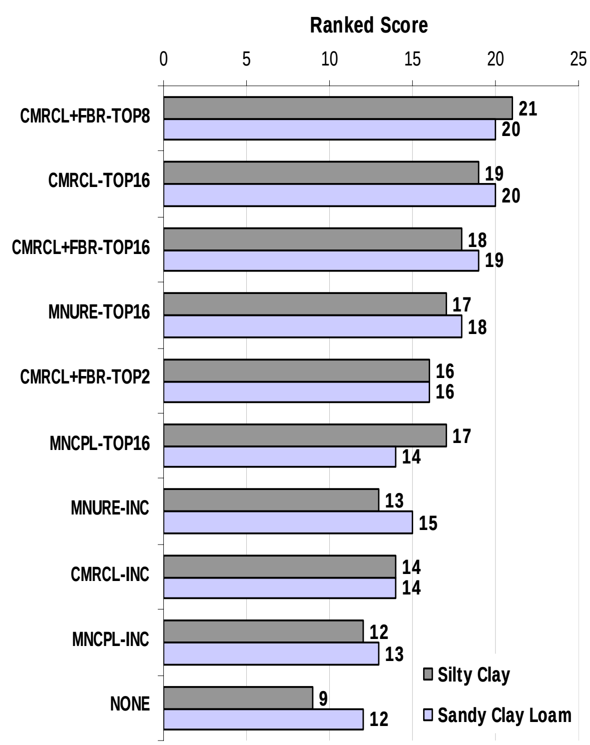
Performance Ranking: **3** = Good; **2** = Fair; **1** = Poor

Treatment		Soil Type: Silty Clay									Soil Type: Sandy Clay Loam									
Trt	Label	Total Runoff	Total Sediment	Sediment Conc	Runoff pH	Dissolved Salts	Turbidity	Shrub Cover	Weed Suppression	*Subtotal*	Total Runoff	Total Sediment	Sediment Conc	Runoff pH	Dissolved Salts	Turbidity	Shrub Cover	Weed Suppression	*Subtotal*	*TOTAL*
EC9	**CMRCL+FBR-TOP8**	1	3	3	3	3	3	2	3	21	2	3	3	2	2	3	2	3	20	*41*
EC7	**CMRCL-TOP16**	3	3	2	2	2	2	2	3	19	3	3	2	2	2	2	3	3	20	*39*
EC10	**CMRCL+FBR-TOP16**	1	3	3	2	3	3	1	2	18	2	3	3	2	3	3	1	2	19	*37*
EC5	**MNURE-TOP16**	2	3	2	2	2	2	1	3	17	2	3	3	2	1	2	2	3	18	*35*
EC8	**CMRCL+FBR-TOP2**	2	3	2	2	2	2	1	2	16	2	2	2	2	2	2	1	3	16	*32*
EC3	**MNCPL-TOP16**	3	3	2	2	2	2	1	2	17	1	2	3	3	1	2	1	1	14	*31*
EC4	**MNURE-INC**	2	2	2	2	1	1	1	2	13	3	2	2	1	1	1	2	3	15	*28*
EC6	**CMRCL-INC**	2	2	2	2	1	1	2	2	14	2	1	1	1	2	1	3	3	14	*28*
EC2	**MNCPL-INC**	2	2	2	1	1	1	1	2	12	3	2	2	1	2	1	1	1	13	*25*
EC1	**NONE**	2	1	1	1	1	1	1	1	9	2	1	1	1	3	1	1	2	12	*21*

Chart D.2. Overall Ranked Evaluation of EC Treatment Effects on Both Soil Types for RS7.

KEY

Treatment		Compost		
Trt	Label	Type	Appl Method	Depth(mm)
EC1	**NONE**	None	None	**0**
EC2	**MNCPL-INC**	Municipal	Incorporated	**0**
EC3	**MNCPL-TOP16**	Municipal	Topical	**16**
EC4	**MNURE-INC**	Manure	Incorporated	**0**
EC5	**MNURE-TOP16**	Manure	Topical	**16**
EC6	**CMRCL-INC**	Commercial	Incorporated	**0**
EC7	**CMRCL-TOP16**	Commercial	Topical	**16**
EC8	**CMRCL+FBR-TOP2**	Commercial	Topical	**2**
EC9	**CMRCL+FBR-TOP8**	Commercial	Topical	**8**
EC10	**CMRCL+FBR-TOP16**	Commercial	Topical	**16**



D.9 Runoff Water Quality Relative to Groundcover Treatments Under Simulated Rainfall

RS8 Experiment June 2006 – May 2007

Performance of ground cover vegetation strips and jute netting on reapplied topsoil under simulated rainfall.

California Department of Transportation (Caltrans). 2005. Performance of Erosion Control Treatments on Reapplied Topsoil. **CTSW-RT-07-167-01-4**.

D.9.1 Research Problem

In primarily urban settings, Caltrans has "landscaped" significant roadside areas with ground cover vegetation, most notably with South African "Iceplant", *Carpobrotus* spp., but also with cultivars of *Acacia, Baccharis, Hedera. Lampranthus, Lantana, Myoporum, Rosmarinus*, and others. These plant materials vary in both life form and architecture that together determine density and size of shoots. These factors collectively form the vegetation cover on the soil surface where it is most effective at filtering runoff. Although the growth rate and spatial spread of all ground cover cultivars depends on local site conditions during establishment, primarily water availability, production of > 70% cover on the soil surface also depends on the cultivar used as some produce more aerially arching or sinuous shoots than others.

The principal objective of this controlled experiment was to examine some fundamental questions surrounding use of ornamental ground cover vegetation to reduce runoff and sediment transport from roadsides:

1) Does runoff filtration effectiveness vary with length (parallel with slope face) of toe strip proportional to total slope length?

2) Would a slope toe strip of ground cover vegetation in conjunction with jute netting on the upper slopes be as effective at reducing sediment transport as 70 % or greater vegetation cover over an entire slope?

3) Is jute netting as effective as ground cover vegetation as a runoff water treatment in compliance with regulatory requirements?

4) Does runoff filtration effectiveness vary among the common cultivars used by Caltrans?

5) Is the existing ground cover vegetation used on landscaped roadsides functioning effectively as a runoff water treatment in compliance with regulatory requirements?

D.9.2 RS8 Experimental Design

During 2000, Caltrans Storm Water, in cooperation with the Sacramento State University Office of Water Programs and the Earth and Soil Sciences Department of Cal Poly State University, San Luis Obispo, initiated a research program to statistically test for significant differences in water quality and vegetation establishment among existing soil stabilization specifications used by Caltrans to better reduce runoff and sediment transport in compliance with regulatory requirements.

This report presents the design and results of the eighth primary experiment completed by this research program designed to provide data from controlled rainfall simulators to compare with field data gathered for the biostrip study.

To examine effectiveness of vegetation over an entire box, or of vegetation as toe-strips in combination with jute netting over the top slope, nine combinations were made with a consistent proportion of 20% toe slope vegetation and 80% top slope jute netting.

Table D.38. RS8 Design Matrix.

Toe	**Top**
20%	80%
Bottom 16 in	Upper 64 in
Bare Soil	Bare Soil
Jute Netting	Jute Netting
Hottentot Fig	Jute Netting
Hottentot Fig	Hottentot Fig
English Ivy	Jute Netting
English Ivy	English Ivy
Creeping Myoporum	Jute Netting
Creeping Myoporum	Creeping Myoporum
Rosemary	Jute Netting
Rosemary	Rosemary

D.9.3 Groundcover Plant Materials

At the direction of the Caltrans Landscape Architecture Program (email 2005.09.08 from D. Cadd), plant materials listed in **Table D.39** were selected as experimental subjects.

Table D.39. RS8 Groundcover Plant Materials.

Code	Scientific Name	Vernacular Name	Cultivar	Lifeform
V-**Ce**	*Carpobrotus edulis* (L.) N.E.Br.	**Hottentot Fig, Iceplant**	*Unspecified*	Leaf Succulent
V-**Hh**	*Hedera helix* L.	**English Ivy**	*Unspecified*	Shrub
V-**Lm**	*Lantana montevidensis* (Spreng.) Briq.	**Trailing Lantana**	*Unspecified*	Shrub
V-**Ls**	*Lampranthus spectabilis* (Haw.) N.E.Br.	**Trailing Iceplant**	*Unspecified*	Leaf Succulent
V-**Mp**	*Myoporum parvifolium* R.Br.	**Creeping Myoporum, Creeping Boobialla**	**Pink Dwarf**	Shrub
V-**Ro**	*Rosmarinus officinalis* L.	**Rosemary, Romero**	**Prostratus**	Shrub

D.9.4 Rainfall Regime

Simulated storm events were performed on paired replicates simultaneously to reduce between-box variation. Irrigation to maintain plant materials was applied as needed, but not to the point of runoff. Throughout the experiment test boxes were covered with a plastic tarp during natural rainfall events to exclude uncontrolled precipitation. Natural rainfall from June 2006 through May 2007 was about 40% of the fifty-eight year average for Cal Poly with all months below average. Thus boxes did not remain covered for excessive durations and ample sunlight was available. Moderate temperatures conducive to plant growth were experienced over the experiment duration. Some leaf discoloration or damage was observed following freezing events.

D.9.5 Results Summary

D.9.5.1 Total Runoff

There was a significant difference in the runoff levels between bare soil and all treatments, jute or vegetation. There was not a significant difference between the 16 inch or 80 inch vegetation treatments, nor of ground cover vegetation cultivar.

Runoff varied greatly between the Bare Soil boxes and those with erosion control treatments (jute, 16in vegetation, 80in vegetation). Bare yielded the greatest quantity of runoff at nearly 28.62 quarts. Jute and 16in vegetation exhibited nearly identical 92% reductions in runoff to about 2.23 quarts. 80in vegetation yielded 98.6% reduction over bare soil with only 0.403 quarts of runoff.

D.9.5.2 Total Sediment

There was a significant difference in the total sediment levels between bare soil and all treatments, jute or vegetation. There was not a significant difference between the 16 inch or 80 inch vegetation treatments, nor of ground cover vegetation cultivar.

Total Sediment followed the same trend exhibited by Runoff. Bare soil yielded the greatest quantity of runoff at nearly 1,873.93 lbs. Jute, 16in vegetation, and 80in vegetation exhibited nearly identical 99% or greater reductions in runoff from 8.93 lbs for jute netting to 13.77 lbs for 16in vegetation, to 5.23 lbs for 80in vegetation.

D.9.5.3 Sediment Concentration

There was a significant difference in the total sediment levels between bare soil and all other treatments, jute or vegetation. There was not a significant difference between the 16 inch or 80 inch vegetation treatments, nor of ground cover vegetation cultivar.

D.9.5.4 Turbidity

There was a significant difference in turbidity levels between bare soil and all other treatments, jute or vegetation. There was not a significant difference between the 16 inch or 80 inch vegetation treatments, **but there was a significant difference of ground cover vegetation.**

D.9.5.5 Total Dissolved Solids

There were no significant differences in any treatment factors.

D.9.5.6 Electrical Conductivity

There were no significant differences in any treatment factors.

D.9.5.7 pH

There was a significant difference in mean pH levels between bare soil and all other treatments, jute or vegetation. Within the vegetation treatments, there are differences between ground cover vegetation cultivar, and the effect of ground cover vegetation depends on toe length. Bare soil had the most-basic average pH at 8.3, whereas jute alone was the most-acidic with average pH of 6.2. Ground cover vegetation plus jute or vegetation alone had neutral average pH values of 7.0.

D.9.6 Conclusions

D.9.6.1 Ground Cover Strip Length

Owing to the relatively short two-meter slope run available in the soil test boxes, length of ground cover strip alone, whether 10%, 20%, or 100% of total box length, was not significant. This is not certain to hold true for longer slope runs on actual roadsides with varying soil types. As expected, statistical significance was seen with all physical or ground cover vegetation treatments versus bare soil.

D.9.6.2 Ground Cover Vegetation Toe Strip with Jute Netting Top

The boxes with a 20% vegetative toe slopes and 80% jute netting averaged a **92% reduction in total runoff**. These boxes exhibited 2.23 quarts of average runoff as opposed to 28.62 quarts produced by bare soil. Total Runoff averaged over all 100% vegetation boxes exhibited a **98.6% reduction in runoff**, about 0.403 quarts-- again compared to 28.62 quarts gathered from bare soil tests.

Total Sediment followed the same trend as Total Runoff. Averaged either over all boxes with 20% vegetation toe strips with 80% jute netting, or all 100% ground cover vegetation, the tests exhibited a **99.5% reduction in sediment.** Total sediment dropped to about 11.02 lbs from an average of nearly 1,873.93 lbs produced by bare soil.

D.9.6.3 Jute Netting Compared to Ground Cover Vegetation

Boxes with 100% jute netting over bare soil performed equivalently to boxes with 20% or 100% ground cover vegetation. Total Runoff and Total Sediment followed the same trend as boxes with 20% ground cover vegetation toe strips and 80% Jute netting upslope. Hence, most of the reductions from Bare Soil result from the application of Jute netting. **Over a short slope run Jute netting provides nearly the same soil surface protection as ground cover vegetation offers.**

D.9.6.4 Comparison among Cultivars Used by Caltrans

All of the ground cover vegetation cultivars tested at 20% cover with 80% Jute netting upslope, or with 100% ground cover vegetation, performed very effectively at reducing Total Runoff and Total Sediment by 90% or greater over Bare Soil. No consistently significant differences were seen among the cultivars tested. Plant architecture seems to determine how effective ground cover vegetation is at filtering runoff and sediment. Plants with prostrate branches and many leaves at the soil surface provide greater filtration than plants with arching branches that leave areas of soil uncovered and vulnerable to overland flow.

D.9.6.5 Existing Ground Cover Vegetation as Runoff Water Treatment in Compliance with Regulatory Requirements

Because this experiment employed test boxes under simulated rainfall, no direct conclusions, inferences, suppositions, deductions, or assumptions can be made regarding the effectiveness as storm water treatment of ground cover vegetation existing along California roadsides. However, results from these simulated rainfall trials indicate that the cultivars tested may be performing storm water treatment as intended. This implication is important owing to the amount of California roadside area that is presently covered by these same cultivars.

Appendix E
RAINFALL SIMULATORS and TEST BOXES

E.1. Rainfall Simulation

The primary purpose of a rainfall simulator is to imitate natural rainfall patterns accurately and precisely. Rainfall is complex, with interactions among properties (drop size, drop velocity, etc.), and with large climatic variation based on topography, marine influences, and water vapor temperature.

Properly simulating rainfall requires several criteria:

1) Drop size distribution near to natural rainfall (Bubenzer 1979a);
2) Drop impact velocity near natural rainfall of terminal velocity (Gunn and Kinzer 1949; Laws 1941);
3) Uniform rainfall intensity and random drop size distribution (Laws and Parsons 1943);
4) Uniform rainfall application over the entire test plot;
5) Vertical angle of impact;
6) Reproducible storm patterns of significant duration and intensity (Meyer and Harmon 1979; Moore et. al. 1983).

Drop size distribution, impact velocity and reproducible storm patterns must be met to simulate the kinetic energy of rainfall. Kinetic energy ($KE = mass \cdot Velocity^2/2$) is a single measure of the rainfall used to correlate natural storms and simulator settings. Drop size distribution depends on many storm characteristics, especially rainfall intensity. Drop size distribution varies with intensity from less than 1 mm to about 7 mm. Most design standards are based on a 2.25 mm median drop size arrived at through empirical studies by Laws and Parson (1943).

To date, most studies of natural rainfall characteristics have outside California (e.g., Washington, Illinois, Washington DC, or locations in the southeast). Proximity to marine influence together with orographic lifting over the mountains of California contributes to variation in rainfall characteristics (McCool 1979). Parameters can be approximated using the studies from other regions, but an accurate simulation of California rainfall is difficult without adequate research studies of California conditions.

Drop velocity is important in designing a rainfall simulator. Drops from natural rainfall are at terminal velocity when they hit the soil surface (Meyer and McCune 1958). Therefore, a rainfall simulator must create drops of adequate size and velocity to simulate the same condition. A direct relationship exists between drop diameter and fall distance (Laws 1941). A reproducible storm pattern is easy to simulate when a simulator can be adjusted to the desired intensities and duration.

E.1.1. Types of Rainfall Simulators

Simulators can be separated into two large groups: drop-forming simulators and pressurized nozzle simulators (Thomas and El Swaify 1989). Drop-forming simulators are impractical for field use since they require such a huge distance (10 meters) to reach terminal velocity (Grierson and Oades 1977). The drop-forming simulators do not produce a distribution of drops unless a variety of drop-forming sized tubes are used. Another negative of the drop forming simulator is their limited application to small plots (Bubenzer 1979b). Several points of raindrop production must be closely packed to create an intense enough downpour of rain. Drop forming simulators use small pieces of yarn, glass capillary tubes, hypodermic needles, polyethylene tubing, or metal tubing to form drops (Bubenzer 1979b). Pressurized nozzle simulators are suited for a variety of uses. They can be used in the field and their intensities can be varied more than the drop forming type (Grierson and Oades 1977). Since drops exiting the nozzles have an initial velocity greater than zero due to the pressure driving them out, a shorter fall distance is required to reach terminal velocity. Nozzle intensities vary with orifice diameter, the hydraulic pressure on the nozzle, the spacing of the nozzle and nozzle movement (Meyer 1979). Pressurized nozzle simulators can produce variable storm intensities. A continuous spray from a nozzle creates an unnaturally intense storm. Thus, some method of starting or stopping the spray is needed. Tested solutions include: a rotating disc, a rotating boom, a solenoid-controlled simulator (Miller, 1987) or an elaborate sprinkler system (Sumner et al. 1996). The simplest to use is a rotating or oscillating boom (Bubenzer 1979b). The most popular nozzle is the Veejet 80100 nozzle run at 41 kPa (6psi). It was chosen because it most closely resembles the drop size distribution of erosive storm patterns in the Midwest (Bubenzer 1979a). Accurate testing of nozzles must be done to ensure adequate spray coverage and uniformity in the plot. Since computers are now relatively inexpensive, a simulator can be driven by specialized software controlling the intensity and duration of the storm.

E.1.2. Rainfall Simulators Selected For These Experiments

Two Norton Ladder-type variable sweep rainfall simulators were purchased for use in this study (see Photo 3.9 and 3.10). These pressurized nozzle type simulators were developed at the USDA Erosion Research Center at Purdue University and manufactured by Advanced Design and Machine, Clarks Hill, IN. Each simulator consists of a boom oscillating side-to-side by way of a cam (see Photo 3.11). A small motor drives the cam at one end of each simulator. Intensity of rainfall is determined by how many times the nozzles of the boom sweep past the box opening in a given amount of time. The boxes are configured to regulate spray pattern and return non-effective rainfall to the water supply system. Rainfall is simulated by industrial spray nozzles with an optimum pressure range of 35 to 2068 kPa (5 to 300 psi) set at 41 kPa (6 psi) for rainfall simulation purposes. At 41 kPa (6 psi), the drop size should be about 2.25 mm (0.09 in) in diameter, corresponding to the average drop size of erosive storms in the Midwestern United States. Drop size along the Pacific Coast is frequently smaller, but actual measurement data are lacking in the literature. Most nozzles tend to produce irregular spray when used at its capacity limits due to machining differences. Thus, any differences between nozzles are amplified by the weak pressure used, leading to reduced uniformity.

E.1.3. Designed Simulated Storms

Rainfall simulators used in this experimental program are computer controlled to produce “bell shaped” storm patterns simulating the intensity variation inherent in typical winter storm events where smaller drops fall with lighter intensity as storms begin and end. Larger drops falling with increased intensity often occur sometime in between. Two designed storms were written for the simulations of the erosion test boxes. One storm delivers of one inch of rain in two hours; the other delivers two inches of rain in three hours. The frequency and intensity pattern, simulating the west coast hydrograph model, delivers 15 minutes of low intensity rainfall (rising limb), followed by an hour of high intensity rainfall (peak), and again 15 minutes of low intensity rainfall (falling limb), totaling 3.81 cm (1.5 in) in 1.5 hrs (see **Chart E.1)**.

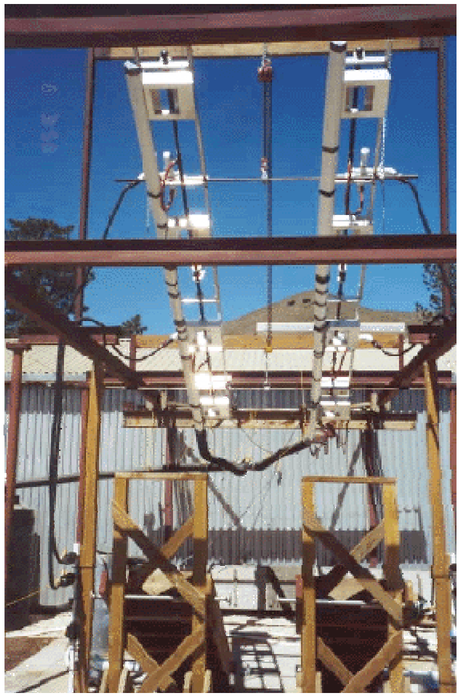


Photo E.1. Rainfall Simulator 1.

Photo E.2. Rainfall Simulator 2.

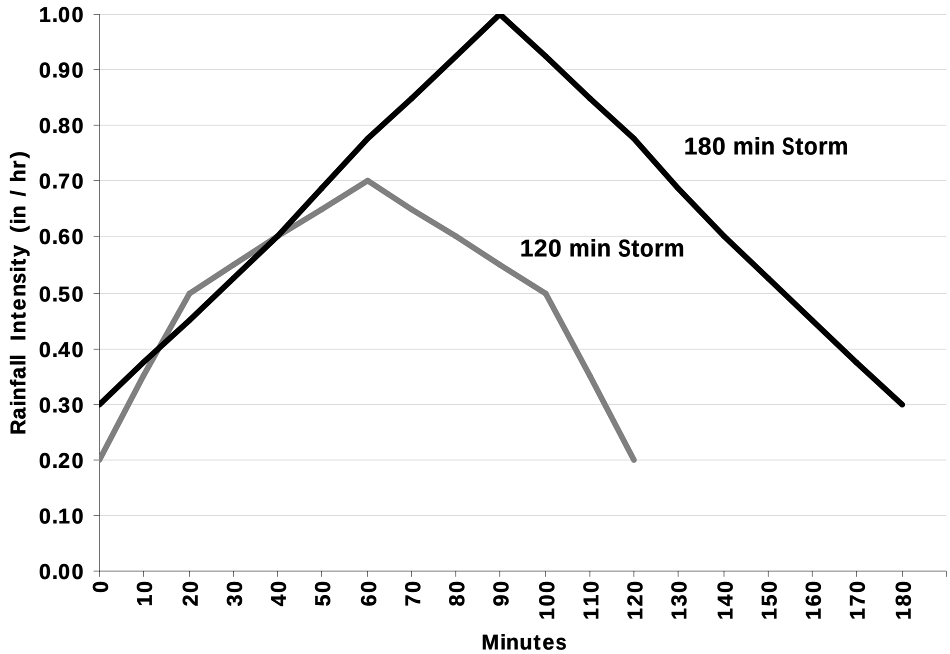


Chart E.1. Simulated Storm Event Patterns

E.2. Test Box Design

Two criteria were used to determine the size of the erosion test boxes. First, box dimensions must relate to boxes used in experiments found in the soil erosion literature. Second, size, shape, and weight must be appropriate for easy handling by two people using a simple one-ton chain hoist. Pearce et al. (1998) utilized field micro-plots of 0.6 m (2 ft) by 2.0 m (6.6 ft) alongside standard plots of 3.0 m (9.9 ft) by 10 m (32.9 ft). A box having the same dimensions as the micro-plots and with a soil depth of 20 cm (7.8 in) weighs less than one ton when saturated and is easily moved by two people using a hoist.

During early 2000, a prototype erosion test box measuring 2.0m L x 0.6m W x 0.3m was designed and built. The design called for the use of standard pressure-treated lumber for outdoor applications. The lumber is treated with chromated copper arsenate and is considered safe to humans when proper safety guidelines are followed. Boxes constructed for the project differ slightly from the prototype. An extra pressure-treated cross-member was placed at the base of the box to support the soil load and to allow the steel mesh at the base of the box to remain more rigid under load. When necessary additional steel pipe supports are inserted through and mounted to the side rails to provide additional stability as boxes age and wood integrity diminishes. Boxes were assembled using a drill press, mitre box saw, and a variable speed hand drill. To facilitate runoff collection, one end of each box was cut to a height of 20 cm (7.8 inches) to coincide with the height of the added soil (see **Photo E-3**).

In addition to the erosion test boxes, support stands were specially designed. The supports are constructed of pressure treated lumber, and 2.5 cm OD, schedule 40, galvanized steel pipe to support the boxes at a 2:1 slope. These supports were used during rainfall simulations, and for positioning boxes throughout the experiment. Each box had a designated space under the box transport system. The erosion test boxes were aligned five to six boxes per row with a total of five rows (see **Photo E-4**).

Photo E.3. Test Box.

Photo E.4. Test Box Rows.

E.3. Runoff Collection Systems

E.3.1. Simulator Runoff

A length of vinyl gutter is used to collect runoff from the base of each erosion test box and channel it into a basin where it was collected. A rectangular piece of synthetic pond liner is cut and riveted to the vinyl gutter (see **Photo E-5**). This prevents simulated rainfall from entering the erosion collection system. The collection system is secured to the box with screws (see **Photo E-6**). The basin consists of a 7.6 L (8 qt) plastic container, trimmed to accept the curve of the gutter (see **Photo E-7**).

Photo E.5. Liner.

Photo E.6.Collection

Photo E.7. Collection 2.

E.3.2. Natural Storm Runoff

For experiments including natural precipitation collection in the design, rainfall is allowed to flow along the surface of the boxes and runoff is collected in plastic containers at the base. Synthetic pond liner is attached to the bottom of the boxes above the runoff opening to prevent rain from directly entering the collection containers (see **Photo E-8**). After each storm, the samples are collected and analyzed.

Photo E.8. Collection Containers.

E.3. Test Box Arrangement

Test boxes are positioned in rows on a concrete slab 21.3 m (70 ft) long by 10.6 m (35 ft) wide. Boxes are oriented such that soil surfaces faces about 165 south for adequate sun exposure. Rainfall simulators are positioned at the north end of this concrete slab.

E.4. Rainfall Simulator Operation

Each rainfall simulation follows the same protocol to ensure both repeatability and worker safety among simulation events. Prior to a simulation, two erosion test boxes are moved into place beneath the simulators. The I-beam of a one-ton hoist is positioned directly over the box to be moved. Three heavy-duty nylon straps, each with a capacity in excess of the weight of a saturated erosion test box, are used to cradle the box. The hoist lifts the box at the union of the straps. To position boxes for simulation, two box supports are utilized. Although the design of the box transport system allows each box to be moved by one person, this operation is best performed by two people for safety reasons. Workers are required to wear a properly fitting hard hat, gloves, and approved footwear.

After the boxes are set in place, the runoff collection systems are installed. Prior to a rainfall simulation event, the hoses supplying the deionized water to the simulators are attached from the manifold to each simulator. To start the flow of deionized water, the valve at the base of the water storage tank is opened prior to turning on the Jacuzzi pump. This ensures a long life for the pump. Using a ladder, fine-tune adjustments are made using the C-clamps on the supply hoses to ensure 6 psi at the nozzles.

A laptop computer is used to run rainfall simulation software. After each rainfall simulation, the two boxes are moved back to their respective locations within the box transport system using the same procedures used to move them into place.

E.5. Rainfall Simulator Quality Assurance/ Quality Control

Experimental repeatability of rainfall simulation is achieved by creating uniform rainfall across each test box during every simulation event. Lateral uniformity is achieved by selection of a nozzle with proper drop size distribution, and by spacing such nozzles in series with adequate spacing to allow sufficient overlap. When this laterally-uniform boom is swept back and forth across an area, the spray will be uniform. Properly designing and testing the boxes used for cutting off the spray is critical for creating uniform rainfall.

E.5.1. Drop-Size Tests

Proper drop size is critical for simulation of rainfall. The drop size distribution was tested using Eigel and Moore’s (1983) oil method. This entails mixing 1 part STP oil treatment and 1 part Swan brand mineral oil. Drops with ranges from 0.5mm - 7 mm (0.02 in to 0.28 in) are caught in a petri dish of oil and held there for enough time to count and measure them (see **Photo E-9**).

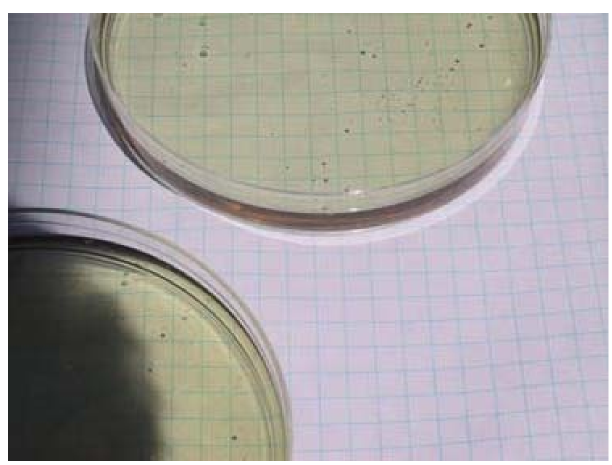


Photo E.9. Drop-Size Test Dishes.

This approach was much simpler and easier to perform than methods that use flour and time-lapse photography. The found drop size distribution is that of natural rainfall.
Drop size ranges from less than 1 mm to about 7 mm (0.04 in to 0.28 in) in diameter. The average drop size is 1.71 mm (0.067 in). The average drop size is smaller than the standard of 2.25 mm (0.089 in) used on previous simulators but, agrees with the literature for drop size for lower intensity storms [less than 50 mm, (2 in) per hour]. The drops were assumed to be at terminal velocity due to their size and the height of the boom. No tests were performed to find drop velocity or energy due to several previously conducted studies in the literature.

E.5.2. Lateral Uniformity Tests

In order to be sure the Norton rainfall simulators were consistently applying the proper amount of rainfall for a given storm event, uniformity is routinely tested about once each month. These tests are performed using two empty erosion test boxes each filled with 48 six-inch cans. After assuring the support stands and erosion test boxes filled with cans are properly placed, a typical two-hour storm is run.

Collected water amounts are measured in milliliters. Average values are calculated and the amount each value deviated from the average is added and used to determine the coefficient of uniformity for each simulator. Typical results from a two hour, one inch storm test are presented below. The mean for Simulator 1 was 428 ml. The mean for Simulator 2 was 452 ml. Coefficient of uniformity measured for simulator 1 was 93.9%, while uniformity for simulator 2 was 93.6%.

Table E.1. Typical Data From Lateral Uniformity Tests.

Avg	Simulator 1			
435	407	444	438	450
469	447	478	475	477
471	440	478	488	478
470	439	475	475	490
433	409	413	474	435
396	383	394	380	425
413	397	407	438	409
405	393	412	400	415
423	401	426	431	435
421	407	420	433	425
398	376	397	415	405
403	378	404	410	419
428	**406**	**429**	**438**	**439**

Uniformity 93.9 %

Avg	Simulator 2			
439	390	441	460	466
481	427	484	500	511
499	441	501	530	525
501	461	511	530	502
446	417	435	495	437
444	432	455	420	470
455	430	440	480	470
425	395	423	438	445
431	388	420	455	460
436	415	430	450	447
417	385	407	440	435
445	420	450	445	463
452	**417**	**450**	**470**	**469**

Uniformity 93.6 %

E.6. Rainfall Simulation References

Bubenzer, G. D. 1979. Rainfall characteristics important for simulation. Pages 22-34 in Proceedings of the Rainfall Simulator Workshop, Tucson Arizona, March 7-9, 1979. U.S. Department of Agriculture Science and Education Administration Agricultural Reviews and Manuals. ARM-W-10/July 1979. (a)

Bubenzer, G. D.. 1979. Inventory of rainfall simulators. Pages 120-130 In Proceedings of the Rainfall Simulator Workshop, Tucson Arizona, March 7-9, 1979. U.S. Department of Agriculture Science and Education Administration Agricultural Reviews and Manuals. ARM-W-10/July 1979. (b)

Eigel, J. D., and I. D. Moore. 1983. A simplified technique for measuring raindrop size and distribution. *Transactions of the ASAE*: 1079-1084

Grierson, I. T., J. M. Oades. 1977. A rainfall simulator for field studies of run-off and soil erosion. *Agricultural Engineering Res*. **22**: 37-44

Gunn, R., and G. D. Kinzer, 1949. The terminal velocity of fall for water droplets. *Journal Of Meteorology* **6**: 243-248.

Hallock, B., J. Blanquies, and M. Scharff. 2003. The Design And Construction Of A Rainfall Simulator. Proceedings of the 34th Annual Conference and Expo of the International Erosion Control Association, 24-28 February 2003, Las Vegas, NV.

Laws, J. O., 1941. Measurements of fall velocity of water drops and raindrops. *Transactions of American Geophysics Union* **22**: 709-721.

Laws, J. O., and D. A. Parsons, 1943. The relationship of raindrop-size to intensity. *Transactions of American Geophysics Union* **24**: 452-459

McCool, D. K. 1979. Regional differences if rainfall characteristics and their influence on rainfall simulator design. Pages 17-22 In Proceedings of the Rainfall Simulator Workshop, Tucson Arizona, March 7-9, 1979. U.S. Department of Agriculture Science and Education Administration Agricultural Reviews and Manuals. ARM-W-10/July 1979.

Meyer, L D.. 1979. Methods for attaining desired rainfall characteristics in rainfall simulators. Pages 35-44 In Proceedings of the Rainfall Simulator Workshop, Tucson Arizona, March 7-9, 1979. U.S. Department of Agriculture Science and Education Administration Agricultural Reviews and Manuals. ARM-W-10/July 1979.

Meyer, L. D. and D. L. McCune. 1958. Rainfall simulator for runoff plots. *Agricultural Engineering* **10**: 644-648

Meyer, L. D. and W. C. Harmon. 1979. Multiple-intensity rainfall simulator for erosion research on row sideslopes. *Transactions of the American Society of Agricultural Engineers* **22**: 100-103.

Miller, W. P. 1987. A solenoid-operated, variable intensity rainfall simulator. *Soil Science Society of America Journal* **51**: 832-834.

Moore, I.D., M.C. Hirschi, and B.J. Barfield. 1983. Kentucky rainfall simulator. *Transactions of the American Society of Agricultural Engineers* **23**: 1085-1089.

Pearce, R.A., G.W. Frasier, M.J. Trlica, W.C. Leininger, J.D. Stednick, and J.L. Smith. 1998. Sediment filtration in a montane riparian zone under simulated rainfall. *Journal of Range Management* **51**: 309-314.

Sumner, H. R., R. D. Wauchope, C. C. Truman, C. C. Dowler, and J. E. Hook. 1996. Rainfall simulator and plot design for mesoplot runoff studies. *Transactions of the American Society of Agricultural Engineers* **39**: 125-130.

Thomas, N. P. and S. A. El Swaify. 1989. Construction and calibration of a rainfall Simulator. *Journal of Agricultural Engineering Research* **43**: 1-9.

Appendix F
RUNOFF SAMPLING and ANALYSES

F.1 Runoff Collection

Runoff contained in collection basins is carefully poured into 18.9 liter (5 gallon) or 4 liter runoff collection containers as required to accommodate the volume. Each container is labeled with unique container number, date of simulation, erosion test box #, simulator #, and total volume of deionized water used to rinse any sediment remaining in the collection gutter or basins. After collection of each runoff sample, samples receive 10-20 ml 1 M AlCl3, a common water treatment flocculant used to precipitate as much colloidal sediment as possible. **Photo F.1** shows runoff collected after a simulated storm ran for one hour on boxes containing California Brome seeded over jute netting as an erosion control method.

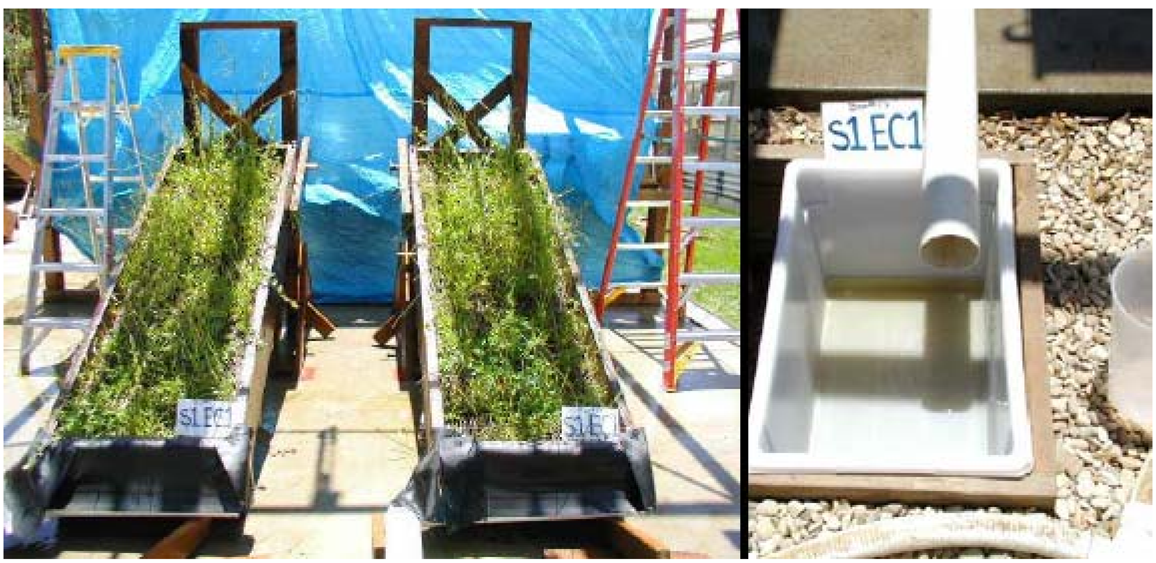


Photo F.1. Runoff Collected From One-Hour Storm on Boxes with California Brome.

F.2 Water Quality Analyses

F.2.1 pH / TDS / Turbidity Sampling

For each collected sample, pH, and total dissolved salts (electrical conductivity) were measured with a handheld pH/EC/TDS/Temperature meter, and turbidity as NTU (Nephelometric Turbidity Unit) was measured using a Hach 2100P Turbidimeter.

F.2.2 Total Suspended Sediment

The two most common methods of measuring suspended sediment in water are Suspended Sediment Concentration (SSC) analysis (ASTM D3977-97) and Total Suspended Solids (TSS) analysis (EPA Method 160. 2). Section **F.4** below provides synopses for these standards. One major difference between these two methods is that SSC utilizes an entire sample for sediment analysis, whereas TSS utilizes a small portion (aliquot) of the original sample. Because TSS uses a smaller sample, it is often the preferred method due to time and money savings over SSC. Although TSS has been widely utilized as a replacement for SSC, there are fundamental problems associated with it. These problems lead to the production of data that are negatively biased from 25 to 34 percent when compared to SSC data from samples taken at the same time and same location as TSS samples (Gray and Glysson, 2000). The major problem with TSS is the inability to reliably extract an aliquot of suspended sediment from a water sample. Particles in suspension vary in size and settling time; therefore, it is inherently difficult to shake or suspend all sample particles evenly throughout the sample and then to pull an aliquot before any significant settling has occurred. This is especially true for sand-size particles in a sample (due to their high settling rate). Use of different methods of aliquot extraction and the individual techniques of laboratory personnel compound the difficulties associated with accurate TSS analysis. In order to avoid the problems associated with TSS and in order to obtain the most accurate measure of sediment concentration possible, a modified version of ASTM D3977-97 is used for water quality analyses conducted for this experiment series because of the relatively small box size (0. 6 m by 2. 0 m) used as compared with the standard plot size of 3. 0 m by 10 m for most simulated rainfall studies. Additionally, the rather small sizes of entire samples (~0. 5 L to 3. 5 L) lend themselves to analysis in their entirety.

F.2.2.1 Test Method A: Modified Evaporation

This method is utilized when most of the solid material in the liquid had settled down from suspension. Two measurements are obtained: final filter weight and final evaporation weight. The summation of these two measurements yielded the total sediment weight. This sediment weight is divided by total water volume (determined by the weight of water) to yield Suspended Sediment Concentration (SSC) for given sample. Supernatant water (clear, overlying water, which contains mainly fine sediment) is slowly filtered through a vacuum-filtration manifold. The supernatant water is decanted onto oven dried, pre-weighed Whatman 934AH filter paper. Filters are then oven dried for a minimum of eight hours at a temperature of 115 degrees Celsius. After oven drying, filters are placed into a desiccator. A desiccator prevented airborne moisture from collecting in the sediment specimens while the filters are cooling. After filters are at room temperature, an analytical balance is used to obtain the final filter weight. Once the supernatant water is filtered, the remaining water-sediment mixture is flushed from the storage container into a pre-weighed Nalgene evaporation beaker. The additional water amount used to flush the water-sediment mixture did not affect final calculations for any data analysis. Multiple evaporation beakers are required for most samples. Evaporation beakers are then oven dried at a temperature of 115 degrees Celsius until all water is evaporated. Since most of the evaporation beakers are over 2 liters in volume and too large for the desiccator, a desiccator is not used for the evaporation beakers. After the evaporation beakers are brought to room temperature, a digital balance is used to obtain the final evaporation weight of sediment.

F.2.2.2 Test Method B: Evaporation

This method is utilized when most of the solid material in the liquid has not settled from suspension. An entire sample is poured into a pre-weighed Nalgene evaporation beaker. Multiple evaporation beakers are needed for most samples. Evaporation beakers are then oven dried at a temperature of 115 degrees Celsius until all water is evaporated. Since most of the evaporation beakers are over 2 liters in volume and too large for the desiccator, a desiccator is not used for the evaporation beakers. After evaporation beakers are at room temperature, a digital balance is used to obtain the final evaporation weight.

F.2.2.3 Example Data and Example Calculations

Total Runoff

From the combined mass of all collection containers with respective runoff, the combined mass of all runoff containers used is subtracted to yield the mass of total runoff.

Sum Of Collection_Mass_Total_g — Sum Of Collection_Container_Mass_g = Runoff_Total_g

Box_ID	Collection_Event_ID	Collection_Container_ID	Collection_Mass_Total_g	Container_Mass_g	RunOff_Total_g
1	1	64	1711.7	200.9	1510.8
1	1	5	2476.3	197.3	2279.0
			4188.0	**398.2**	**3789.8**
1	2	234	9551.0	1067.2	8483.8
			9551.0	**1067.2**	**8483.8**
1	3	74	2354.0	199.8	2154.2
1	3	56	2437.9	199.4	2238.5
1	3	231	15751.0	1001.5	14749.5
			20542.9	**1400.7**	**19142.2**

Final formatted data.

Box_ID	Collection_Event_ID	Collection_Mass_Total_g	Container_Mass_g	RunOff_Total_g
1	1	**4188.0**	**398.2**	**3789.8**
1	2	**9551.0**	**1067.2**	**8483.8**
1	3	**20542.9**	**1400.7**	**19142.2**

Total Sediment

From the combined mass of all evaporation containers with respective runoff, the combined mass of all evaporation containers used is subtracted to yield the mass of total sediment.

Sum Of Evaporation_Mass_Total_g — Sum Of Evaporation_Container_Mass_g = Sediment_Total_g

Calculations and data format are similar to those for Total Runoff.

Suspended Sediment Concentration

Suspended Sediment Concentration is calculated as follows:

$$\text{Suspended Sediment Concentration} = \frac{\text{Sediment\_Total\_g}}{\text{Runoff\_Total\_g}}$$

Water Quality Data

To both facilitate and control data input to analyses, a small custom relational database is used that consists of a frontend forms and queries in Microsoft® Access®, and backend data tables in Microsoft® Excel®. Data can be entered either directly into Excel tables, or through the Access forms. The rationale for this design is that some project workers are more comfortable using Excel, but data queries are easier and faster using Access. Through a command button, a query is run to both calculate and format data for export to Excel for basic statistical analysis and charting, and further into dedicated statistical software.

Table F.1 lists the data tables, **Figure F.1** shows the relationships, and **Figure F.2** shows the Access interface. **Figure F.3** shows an example row/record/tuple of formatted data.

Table F.1. Data Tables of Custom Relational Database.

Date Table	Data Stored
tblCollectionEvents	Date, source, and amount of each rainfall event (may span > 1 day)
tblCollectionMass	Data for each unique collection of runoff water + sediment
tblEvaporationMass	Data for each unique evaporated sample
tblContainers	Unique ID and mass of each empty collection or evaporation container

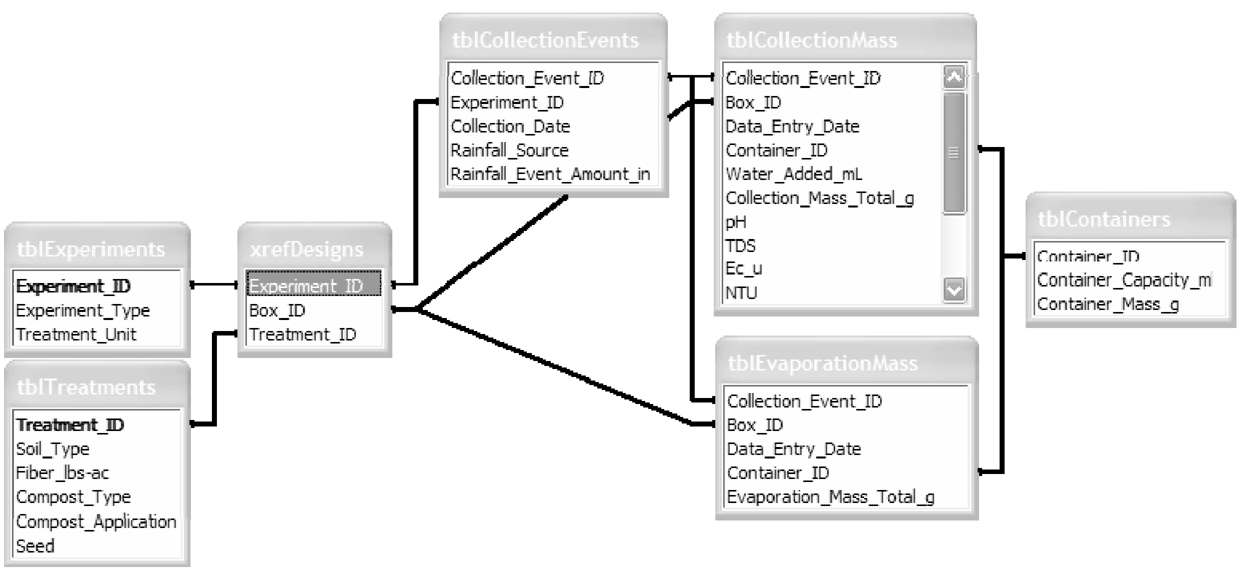


Figure F.1. Relationships of Custom Relational Database.

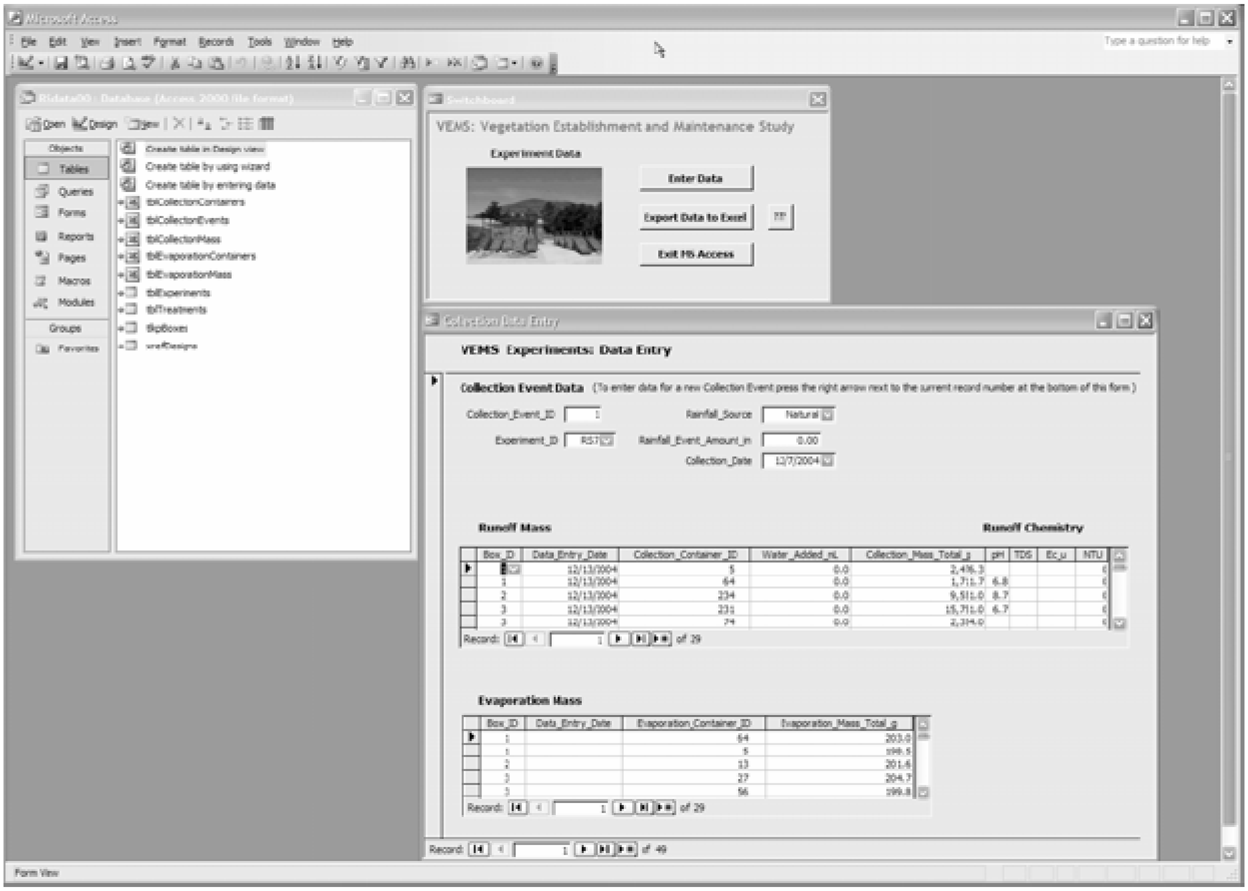


Figure F.2. Interface of Custom Relational Database.

Experiment_ID	Treatment_ID	Collection_Event_ID	Rainfall_Source	Rainfall_Event_Amount_in
RS7	2	1	Natural	1.54

Box_ID	Runoff_Total_g	Sediment_Total_g	pH	TDS_ppm	Ec_u	NTU
2	11245	232	7.9	58.4	29.1	602

Figure F.3. Example Record from Custom Relational Database.

F.3 Standards

F.3.1 EPA Method 160. 2

TOTAL SUSPENDED SOLIDS (TSS)
Gravimetric, Dried at 103°-105°C

Follow the procedure outlined in EPA method 160. 2 for the analysis of samples for TSS. Weigh solid residue to a constant weight, defined as two consecutive weight measurements differing by less than 0. 5 mg, or less than 4%, whichever is smaller.

Data Calculations and Reporting Units:
Calculate the sample results according to Section 8 of EPA Method 160. 2. Report sample results in concentration units of milligram per liter (mg/L) as total suspended solids. Report TSS concentrations that are less than 100 mg/L to 2 significant figures, and TSS concentrations that are greater than or equal to 100 mg/L to 3 significant figures.

For rounding results, adhere to the following rules:

a) If the number following those to be retained is less than 5, round down;

b) If the number following those to be retained is greater than 5, round up; or

c) If the number following the last digit to be retained is equal to 5, round down if the digit is even, or round up if the digit is odd.

All records of analysis and calculations must be legible and sufficient to recalculate all sample concentrations and QC results. Include an example calculation in the data package.

Table F.2. Summary of Sample Requirements for Total Suspended Solids (TSS).

Analytical Parameter	Contract Required Detection Limit (CRDL)	Technical and Contract Holding Times	Preservation
Total Suspended Solids (TSS)	10 mg/L	Technical: 7 days from collection; Contract: 5 days from receipt at laboratory	Cool to 4°C ±2°C

Use sample aliquots of 100 mL. If the weight of captured residue is less than 1. 0 mg, increase the sample volume (up to 200 mL) to provide at least 1. 0 mg of residue and repeat the analysis.

Table F.3. Summary of Internal Quality Control Procedures for EPA 160. 2.

QC Element	Frequency	Acceptance	Corrective Action
Analytical Balance Check: ***Weights of 100 mg, 1 g, and 100 g***	Daily	Difference < 0. 5 mg	1. Identify and document problem 2. Verify before sample analysis
Method Blank (MB)	One per Batch or SDG (1 per 20 samples minimum)	< CRDL	1. If lowest sample concentration is more than 10X the blank conc. , no action 2. If samples are non-detected, no action 3. If detected sample concentrations are less than 10X blank conc. , all associated samples must be prepared again with another method blank and reanalyzed
Duplicate Sample (DUP)	One per batch or SDG (1 per 20 samples minimum)	RPD <20% for samples >5X CRDL; ± CRDL for samples <5X CRDL	1. Flag associated data with an "*"
One set (two concentration levels) mineral reference samples	One set per batch or SDG (1 set per 20 samples minimum)	± 15% from expected concentration	1. Terminate analysis 2. Identify, document, and correct the problem 3. Reanalyze all associated samples

CRDL = Contract Required Detection Limit

SDG = Sample Delivery Group - each case of field samples received; or each 20 field samples within a case; or each 14 calendar day period during which field samples in a case are received.

Appendix G
VEGETATION SAMPLING and ANALYSES

G.1 Basic Variables

The primary measures of vegetation are: ***density***, the number of rooted individuals of a species, lifeform, or structural class per unit area; ***frequency***, the number of times that a species occurs over a series of sampling units; ***cover***, a two-dimensional perpendicular projection down onto the ground surface of the three-dimensional aerial vegetation above; and ***biomass***, the quantity of herbaceous or woody tissue produced by individuals of a species, lifeform, or structural class per unit area per unit time (Bonham 1989; Interagency Technical Team 1996; Kent and Coker 1992; Mueller-Dombois and Ellenberg 1974). Biomass measures require destructive sampling, intensive labor, and extensive time; thus are not typically performed because such measurements would likely not repay their costs nor provide additional information beyond cover estimates. A synopsis of the typically assessed vegetation attributes of density, frequency, and cover, is presented in **Table G.1.** The discussion that follows focuses primarily on estimates of aerial plant cover because cover is the most important vegetation attribute relative to any reduction of soil erosion owing to the ability for aerial plant parts to intercept a raindrop before it strikes the soil surface. Aerial plant cover percentages are typically used by regulatory agencies to determine adequate soil surface protection and compliance with environmental regulations.

Table G.1. Definitions of the Basic Vegetation Variables Typically Measured.

	Density	**Frequency**	**Cover (aerial)**
Definition	Number of rooted individuals per unit area	Number of times that a species occurs over a series of sampling units	Amount of ground surface "covered" by the perpendicular projection downward of aerial plant parts
Data required	Counts of the number of rooted individuals or aerial stems of each species	Recorded presence of each species	A quantitative or qualitative measure (ranked percentage) of the live aerial "cover" contributed by each species and by non-living ground litter
Attribute Calculation	Sum *n* rooted individuals/ total sampled area	Sum *n* occurrences/total sampled area	Sum *n* individual cover values/Sum *n* samples
Attribute Expression	Average # rooted individuals/ unit area	Average # occurrences/unit area	Average cover value/unit area

G.2 Cover

Over the last several decades, vegetation cover has been evaluated using various methods based upon the three fundamental models of one- or two-dimensional spatial phenomena: points, lines, or areas (see Mueller-Dombois and Ellenberg 1974; Bonham 1989; or Interagency Technical Team 1996 for thorough reviews). Points, lines (transects), or areas (polygons) are used either alone or in combination with varying success at estimating canopy cover of one or more vegetation strata across both organismal and geographic scales.
Even though vegetation is three-dimensional, methods employing volumetric measures are rarely used owing to both added complexity and added sampling time necessary to measure volume. Addition of time as a fourth dimension is also too infrequent, as the majority of vegetation sampling is effectively a temporal "snapshot" of a dynamic assemblage exhibiting both seasonal changes and longer term responses to climate, disturbance, interspecific interactions, and intraspecific demographic fluxes.

Cover is the most logical and time-efficient measure in that the interception of raindrops by aerial plant parts is fundamental in retarding water-driven soil erosion processes. Although plant density can provide important information about how many individuals of a given species in a seed mix germinated and established, obtaining plant counts are extremely labor intensive and time consuming, especially in a multi-species mix. Although ***cover*** is the most frequently employed vegetation measure, the term "cover" includes a multitude of possible measurement techniques, and connotes different meanings to different people (Bonham 1989). Therefore, an explicit discussion of the exact method(s) used to measure plant cover for any research project is imperative.

Valid estimates of plant cover are difficult owing to some complex and interacting factors:

- Plants are spatially three-dimensional, stratified, and interwoven;
- Plants are variable over space and time;
- Plant sizes and shapes influence the spatial dispersion of "hits" (i.e. the spacing of observation points must not be too closely or widely spaced for the vegetation).

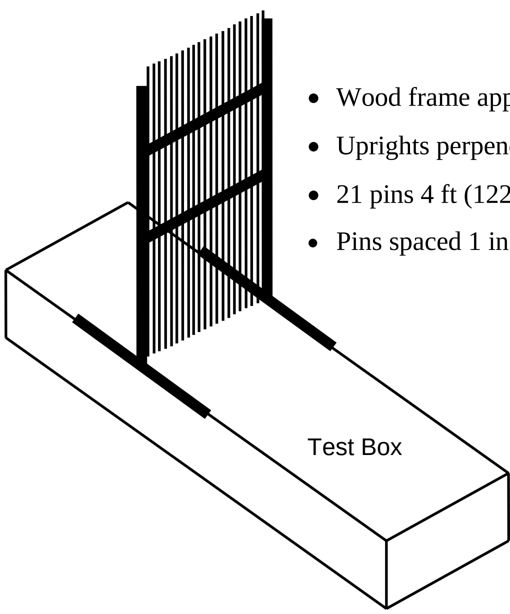
G.2.1 Point Cover Estimates

The oldest, most objective, and most repeatable measure of plant cover is by *point intercept* whereby a theoretically infinitely small point projected from above down onto vegetation surfaces contacts individual plant structures, soil surface litter, rock, or bare soil. Each contact is termed a "hit" for each category scored. Rules must be established beforehand regarding exactly what constitutes a "hit" for each purpose-dependent investigation. For example, for studies of long-term plant cover "hits" upon inflorescences may not be counted owing to their ephemeral presence. However, other studies, such as this one, may choose to count "hits" upon inflorescences because such plant organs do intercept raindrops when present during the season of precipitation.

G.2.2 Pin Frame Method

Although the best point method for cover measurements is through an optical sighting device (a tube with lenses and cross-hairs analogous to a short-range telescope) mounted on a frame and directed along an axis perpendicular to the ground surface, the observer must sight through the device from directly above or to the side. Because the test boxes in these experiments are inclined at a 2:1 H:V (=50% = 26.6°∠) or greater slope, and not readily movable to a position flat on the ground, an optical sighting device is not used. Instead, a pin-frame, the next-best traditional method for measuring cover over small areas, is used for cover analyses.

A custom pin-frame was designed and constructed for these experiments using wood and stainless steel rods as pins. The frame is designed such that the uprights are perpendicular to the actual ground surface, not to the soil in the box, because the vegetation in the boxes is growing perpendicular to the actual ground surface owing to phototropism. The frame contains 21 independently operated pins in a single row, each approximately 122 cm (4 ft) long and spaced 25.4 mm (1 in) apart (see **Figure G.1**). This length accommodates increasing plant height as plants grow through the season. Pin spacing reflects the finely textured, mostly grassy, nature of the vegetation growing in the soil test boxes, and the need to include as many potential sample points as possible in a randomized sampling scheme.



- Wood frame approximately 4 ft (122 cm) tall by 2 ft (61 cm) wide of 3/2 square stock
- Uprights perpendicular to the actual ground surface, not to the soil in the box
- 21 pins 4 ft (122cm) long of 5/32in (4 mm) diameter stainless-steel
- Pins spaced 1 in (25.4 mm) apart in a single row

Figure G.1. Details of the Custom Pin Frame Designed to Sample Plant Cover

The 21-pin design of the pin frame allows for two different sampling schemes. A standard method where 20 pin positions are sampled consecutively with the remaining pin position used to randomly select a starting position at pin 0 or 1. A second method randomly selects a subset of pins from the 21 positions possible. For this experiment series the latter method is used for cover estimates because it reduces the affect of spatial autocorrelation on the data set. Spatial autocorrelation is an important and complex issue in statistical analyses of spatial phenomena and too large of a topic for in-depth discussion here. In brief, the issue simplifies to this: spatial autocorrelation among observed values occurs where the value of a measured variable at one spatial location positively or negatively influences the value of that same variable at adjacent or nearby locations (Cliff and Ord 1973; Fortin et al. 1989; Legendre 1993).

G.2.3 Line-Point Method

For this modified line-point method a 600mm (24 in) length of 20mm (0.8 in) square wood stock is notched along the length of each angled face at 25mm (0.98 in) intervals. Along each face 10 positions are selected using random numbers to render four different point position arrays. The ends of the stock are affixed and allowed to rotate on uprights so that the bar is held approximately 25mm (0.98 in) above, and parallel to, the soil surface. A computer spreadsheet is used to assign randomly generated numbers to each of the 21 possible sample point positions, to sort the 21 positions, and to select the first 10 unique positions for each transect. Positions selected for the five transects in the upper half are used for lower half transects of the same box. The design renders 100 observations per box.

G.2.4 Point Cover Sampling Design

An outline of the sampling method devised to obtain plant cover estimates for the test boxes is as follows.

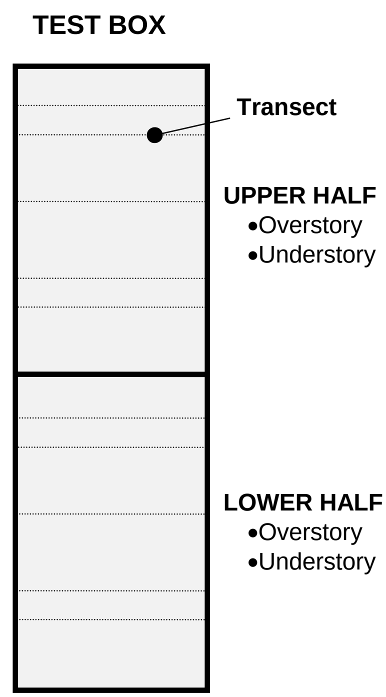
2 divisions per box

For sampling purposes, each test box is conceptually divided into an upper and a lower half to assess whether differences in plant cover exist between the two halves because of greater gravity water flow and retention in the lower end of each inclined box.

5 transects per box division (randomly spaced)

Positions are marked every decimeter along the rails of each box. This renders nine possible transect positions in each half of every box. A computer spreadsheet is used to assign randomly generated numbers to each of the nine possible positions, to sort the nine positions, and to select the first five unique positions for each box. Positions selected for the upper half are used for the lower half of the same box.

10 sample points per transect (randomly selected)



For Pin Frame Method Only

2 vegetation layers (overstory / understory) per transect

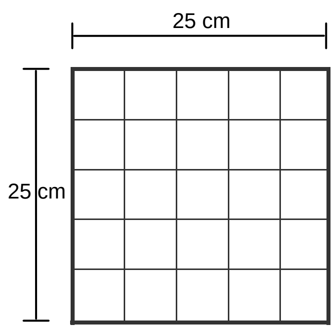
Vegetation within the test boxes is usually visibly stratified into two layers: an *overstory* consisting of mostly taller grasses, and an *understory* of shorter annuals, of first-year shoots of perennial forbs, or of shrub seedlings. To separate the treatment responses of these shorter plants from the faster growing and taller plants, "hits" are recorded in the overstory and understory separately. As each pin is pushed down into the vegetation, a single contact "hit" is recorded for any part of any plant in the overstory. The same pin is then pushed further down until a single contact "hit" is made with any part of a different plant occupying the lowest vegetation layer.

G.3 Area Cover Estimates

A long-standing method of estimating aerial plant cover within area plots uses portable squares or rectangles of wood, wire, or pipe, dubbed quadrats, to temporarily enclose a vegetation sample while an observer estimates canopy cover from above by class (forb, grass, litter, bare ground), or by species expressed ranked percentage ranges (Daubenmire 1959; Mueller-Dombois and Ellenberg 1974). Quadrat size and shape must be scaled appropriately for the vegetation at the time that observations are made to be accurate, precise, and statistically valid. This subject of quadrat size, shape, and placement has engendered much debate in the ecological literature with discussion much too lengthy for review here.

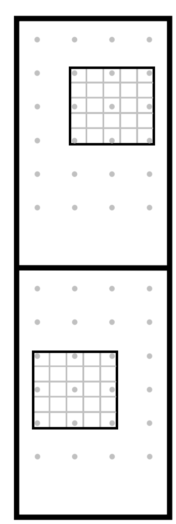
G.3.1 Quadrat Proportions and Cover Class

For this experiment series, a 25 cm x 25 cm square wire quadrat divided into twenty-five 5 cm x 5 cm squares is used as the basic sampling unit. Cover is estimated by cover class within each square and then averaged to obtain an estimate for the whole quadrat. The original six cover ranks devised by Daubenmire are expanded to seven by splitting the 0% – 5 % class into two ranks, < 1 % and 1 – 5% to ensure better resolution of species at very low cover values during the initial stages of revegetation. Midpoint values of these cover class ranks are then used to calculate absolute and relative percentages. Cover classes typically assessed are legume shrub seedlings, non-legume shrub seedlings, legume forbs, non-legume forbs, grasses, litter, and bare ground. Classes may vary with each experimental design, and may estimate cover for species rather than live cover classes.



Class	% CoverRange	Midpoint
1	<=1	0.5
2	1 to 5	2.5
3	5 to 25	15.0
4	25 to 50	37.5
5	50 to 75	62.5
6	75 to 95	85.0
7	95 to 100	97.5

TEST BOX



G.3.2 Quadrat Proportions and Cover Class

An outline of the sampling method devised to obtain plant cover estimates for the test boxes is as follows.

2 divisions per box

For sampling purposes, each test box is conceptually divided into an upper and a lower half to assess whether differences in plant cover exist between the two halves because of greater gravity water flow and retention in the lower end of each inclined box.

2 quadrats per box division (randomly placed)

Within each box half, 24 anchor positions spaced one decimeter apart are possible locations for placement of the top-right or top-left corner of the quadrat. A computer spreadsheet is used to randomly assign a quadrat to an anchor position.

G.4 Plant Identification

Species identification, taxonomy and nomenclature follow the most recent comprehensive flora for California, *The Jepson Manual: Higher Plants of California* (Hickman 1993) and subsequent updates available over the internet. Other pertinent floristic references (e.g., Hitchcock 1951; Munz 1974; Munz and Keck 1959) are consulted, as needed.

G.5 Analytical Methods

G.5.1 Descriptive Statistics

From point or quadrat data, the sample size, mean, min, max, standard deviation, variance, range, sum, standard error of the mean, kurtosis and skewness with their standard errors, and frequencies are calculated for cover, and, when sampled, for counts of individual species or lifeforms within quadrats.

G.5.2 Analyses of Point Cover Data

Proportion cover can be analyzed using three methods: logistic regression, a weighted analysis of variance (ANOVA) and ANOVA on arcsine root transformed data. Although the conceptual model of how treatments and other factors affect each of these response variables is the same with each of these three methods, different sets of assumptions must be satisfied for each method before the results can be trusted. If all three methods produce largely similar estimates of cover, and of treatment effects, then this can be viewed as confirmation of the conceptual model. While proportion cover estimates are informative and perhaps the easiest method for comparison between treatments (light versus heavy rainfall, etc.) they do not allow for formal conclusions. Thus, formal statistical tests appropriate to each method are used to overtly test null hypotheses. What follows is an attempt to provide a brief description of each of these methods, but the fine points of using each method for estimation or testing should are best described in any of the standard reference books (e.g., Agresti 1996; Montgomery 1991). The conceptual model relating various experimental factors to the observed proportion cover in the context of each method is described by logistic regression and ANOVA.

G.5.2.1 Logistic Regression

Percent cover is measured in each box-half by determining cover or no cover for each of 50 points. If the presence or absence of plant matter at each sampled location is considered as the response variable of interest, then logistic regression is a method by which the presence of plant matter at any point in the box is modeled as a function of treatment and other factors. For example, for any location with a fixed rainfall regime, fertilizer level, treatment (straw versus tackifier) and box-half (upper versus lower) a probability exists that there is live plant cover at that location, i.e. the probability of cover at a location in the l^{th} box division with the i^{th} rainfall level, j^{th} level of fertilizer, k^{th} level of treatment (straw or tackifier) is π_{ijkl} which is modeled as:

$$\begin{aligned}\text{logit}(\pi_{kjkl}) = \log(\pi_{kjkl}/(1-\pi_{kjkl})) \quad &= \quad \mu + \alpha_i + \beta_j + \gamma_k + \delta_l + \\ &\alpha\beta_{ij} + \alpha\gamma_{ik} + \alpha\delta_{il} + \beta\gamma_{jk} + \beta\delta_{jl} + \gamma\delta_{kl}\end{aligned}$$

where

α_i	Effect of rainfall level *i*
β_j	Effect of fertilizer level *j*
γ_k	Effect of treatment level *k*
δ_l	Effect of Box-division *l*
$\alpha\beta_{ij}$	Interaction between rainfall level *i* and fertilizer level *j*
$\alpha\gamma_{ik}$	Interaction between rainfall level *i* and treatment level *k*
$\alpha\delta_{il}$	Interaction between rainfall level *i* and box-division level *l*
$\beta\gamma_{jk}$	Interaction between fertilizer level *j* and treatment level *k*
$\beta\delta_{jl}$	Interaction between fertilizer level *j* and box-division *l*
$\gamma\delta_{kl}$	Interaction between treatment level *k* and box-division *l*

Note that an interaction, e.g., between rainfall level and box-division, would imply that the effect of rainfall level on proportion cover differs between the two box-divisions. Thus, logistic regression attempts to model the proportion of “successes” (e.g., percent cover) as a function of these other factors.

G.5.2.2 Analysis of Variance (ANOVA)

Next is the same model described in the ANOVA context. Two ANOVA methods for analyzing these proportion cover data are used. The first method is to model the proportion cover directly with a weighted ANOVA and the second approach is to use a transformation of the proportion cover data, which is then modeled with a straightforward ANOVA.

For the weighted ANOVA, the following model was used to describe the relationship between experimental factors and proportion cover:

$$\begin{aligned} y_{kjklm} = {} & \mu + \alpha_i + \beta_j + \gamma_k + \delta_l + \\ & \alpha\beta_{ij} + \alpha\gamma_{ik} + \alpha\delta_{il} + \beta\gamma_{jk} + \beta\delta_{jl} + \gamma\delta_{kl} + \\ & \varepsilon_{ijklm} \end{aligned}$$

where y_{ijklm} is the proportion cover for the l^{th} box division of the m^{th} box with the i^{th} rainfall level, j^{th} level of fertilizer, k^{th} level of treatment (straw or tackifier) and the main effects and interactions are exactly analogous to the terms defined in the discussion of the model in the previous paragraph. According to these models, percent cover is affected by the rainfall level, fertilizer, treatment (straw versus tackifier) and box division. The two-way interaction terms allow for the affect of fertilizer on percent cover to depend on the rainfall level (etc). The ε_{ijklm} terms are assumed to be normally distributed and independent of each other. Due to the fact that the response variable plant cover is proportion data, the variance of the ε_{ijklm} terms is assumed to equal $p_{ijkl}(1 - p_{ijkl})$ where $p_{kjkl} = \mu + \alpha_i + \beta_j + \gamma_k + \delta_l + \alpha\beta_{ij} + \alpha\gamma_{ik} + \alpha\delta_{il} + \beta\gamma_{jk} + \beta\delta_{jl} + \gamma\delta_{kl}$ is the theoretical proportion cover.

G.5.2.3 Weighted Analysis of Variance (ANOVA)

A weighted ANOVA is performed when the analysis weights depend on estimated sample variances based on the nature of how data were collected. Thus, if the sample proportion of cover in any box-half is estimated to be $\hat{p}$, the analysis weights for that box-half would be proportional to $\frac{1}{\hat{p}(1-\hat{p})}$.

However, because in some cases 100% of the sampled points show vegetation cover , two successes and two failures are added to such data for the purpose of estimating sample weights, as suggested by Agresti and Coull (1998). Thus the sample weights for a box-half are proportional to $\frac{1}{\tilde{p}(1-\tilde{p})}$ where $\tilde{p}$ equals the number of sample points with vegetation plus two over the number of sampled points plus four. [Note: other ways to consider for sensitivity analysis would be byes or shrinkage estimated weights or weights that are based on the fitted estimated values (starting with no weighs) in the previous iteration and iterate until stable.]

Another approach could be to transform the response variable so that we have approximate normality of the disturbance terms. One common transformation is the arcsine root transform. The model remains:

$$\begin{aligned} y_{kjklm} \quad = \quad & \mu + \alpha_i + \beta_j + \gamma_k + \delta_l + \\ & \alpha\beta_{ij} + \alpha\gamma_{ik} + \alpha\delta_{il} + \beta\gamma_{jk} + \beta\delta_{jl} + \gamma\delta_{kl} + \\ & \varepsilon_{ijklm} \end{aligned}$$

but y_{ijklm} is the arcsine of the square root of proportion cover for the l^{th} box division of the m^{th} box with the i^{th} rainfall level, j^{th} level of fertilizer, k^{th} level of treatment (straw or tackifier) and the main effects and interactions are exactly analogous to the terms defined in the discussion of this model above. The ε_{ijklm} terms are assumed to be independent of each other, normally distributed and with constant variance.

A benefit of the weighted ANOVA over the arcsine root transformed response data ANOVA is that the interpretation of the parameter estimates is natural (i.e., parameter estimates may be thought of as the estimated difference in proportion cover between, say, high rainfall level and natural rainfall, all other things being held equal). A drawback of the weighted ANOVA is that there is no guarantee that the estimated proportion cover will fall in the zero to one range. Two benefits of the arcsine root transformation are that the estimated proportion cover will always be in the zero to one range and that post-hoc comparisons of treatments are straightforward. A drawback of the arcsine root transformation is that the parameter estimates do not have a natural interpretation.

Among the three methods, logistic regression should be thought of as most appropriate for estimating the effects of each factor on the proportion cover. However, arcsine root ANOVA is used for making comparisons across the various treatments within each rainfall regime. For the post-hoc comparisons Bonferroni based methods are used because they are conservative and thus are unlikely to announces difference among treatments if, in fact, no difference exists.

G.5.3 Analyses of Quadrat Cover Data

There are three reasonable methods for analyzing cover based on ranked estimates, such as the Daubenmire Method:

1. **Ordinal logistic regression** where the **chance** that a quadrat would receive any particular rank value is a function of explanatory variables. A benefit of this method is that it is reasonable with rank data. The drawback is that with such an analysis, only the effect of treatment conditions on the chance of cover for the cover rank categories (zero to 1%, 1% to 5%, 5% to 25%, etc.) could be determined;

2. **ANOVA using the midpoints of the each rank class** as the response variable (i.e., a rank of 1 corresponds to a midpoint of 0.5%, a rank of 2 corresponded to a midpoint of 2.5%, a rank of 3 corresponds to a midpoint of 15%, etc.). A benefit of this method is that it provides a direct estimate of the effects of treatment variables on percent cover. The drawback is that the ANOVA assumption of equality of variance is not satisfied. The only solution is to use a transformation of the midpoints. In fact, the best transformation appears to be something akin to using the original ranks themselves;

3. ANOVA **using the rank data** as the response variable. The benefit of this method is that there are no problems with the ANOVA assumptions. The drawback is that there is no direct estimate of the effects of treatment on percent cover. However, this can be finessed.

Because there are only ranks to work with, a method of transforming from an average of ranks back to percentage is necessary to estimate percentages. **Chart G.1** shows the relationship between ranks and percentages. If the original percentage cover for a location is 32%, it receives a rank of 4. In fact, any cover percentage in the range from 25% to 50% receives a rank of 4. Traditionally one might use midpoints for analysis, i.e. treat any observation with a rank of 4 as if it were 37.5% cover.

The relationship between rank and midpoint is approximately logistic. Because $\log\left(\frac{\text{midpoint}}{100\% - \text{midpoint}}\right) \approx -6.38 + 1.41 \times \text{rank}$, estimated ranks associated with particular treatment conditions are converted back to percentages via:

$$\text{estimated percentage} = \frac{e^{-6.38+1.41\times\text{rank}}}{1+e^{-6.38+1.41\times\text{rank}}} \times 100\% .$$

As an example, if for a particular set of treatment conditions, an average rank is 3.32, the estimated percentage is:

$$\text{estimated percentage} = \frac{e^{-6.38+1.41\times 3.32}}{1+e^{-6.38+1.41\times 3.32}} \times 100\% = 15.5\% .$$

The solid line in **Chart F.1** shows this relationship. ANOVA is used on the ranks themselves, then, as necessary, ANOVA results are transformed back to a percentage scale.

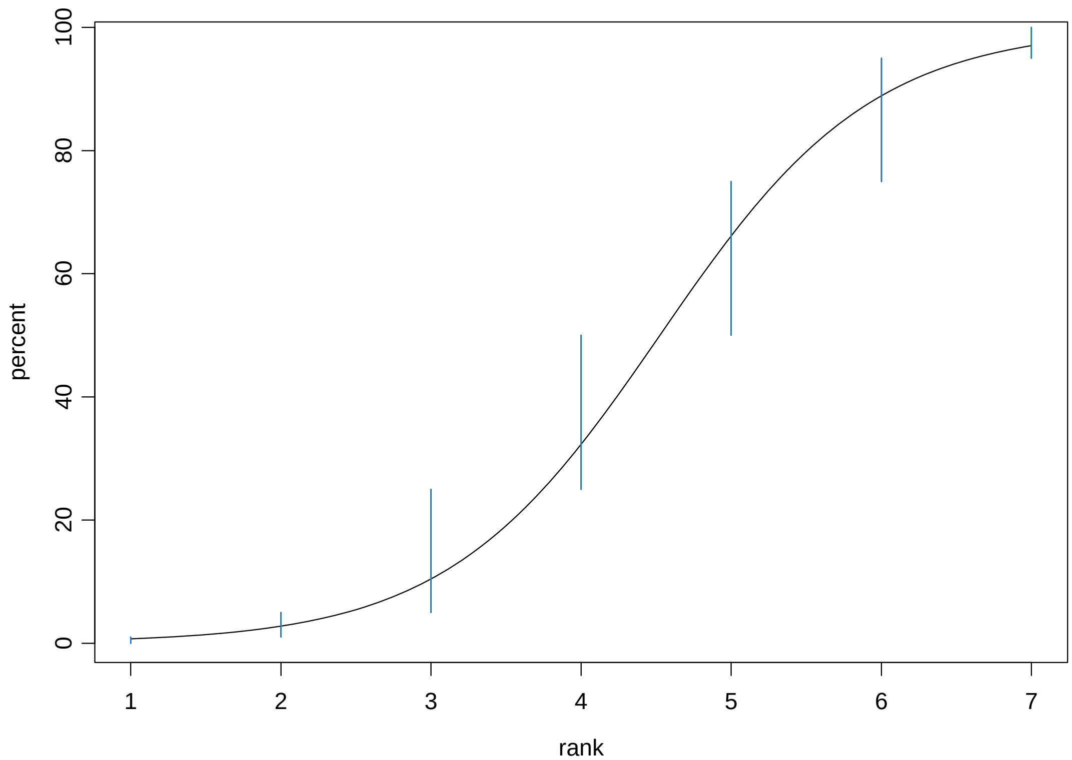


Chart G.1. Relationship Between Cover Ranks and Percentages.

G.6 Vegetation Sampling References

Agresti, A. 1996. *An Introduction to Categorical Data Analysis*. New York: John Wiley & Sons.

Agresti, A, and B.A. Coull. 1998. Approximate is better than "exact" for interval estimation of binomial proportions. *The American Statistician* **52**:119-126.

Bonham, C.D. 1989. *Measurements for Terrestrial Vegetation*. New York: John Wiley & Sons.

Cliff, A.D., and J.K. Ord. 1973. *Spatial Autocorrelation*. London: Pion.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. *Northwest Science* **33**: 43-64.

Fortin, M.-J., P. Drapeau, and P. Legendre. 1989. Spatial autocorrelation and sampling design in plant ecology. *Vegetatio* **83**: 209-222

Hickman, J.C. (ed.). 1993. *The Jepson Manual: Higher Plants of California*. Berkeley: University of California Press.

Hitchcock, A.S. 1951. Manual of the Grasses of the United States. ed. 2, revised by A. Chase. United States Department of Agriculture Miscellaneous Publication 200.

Interagency Technical Team. 1996. Sampling Vegetation Attributes. Bureau of Land Management National Applied Resource Sciences Center. USDI-BLM/RS/ST-96/002+1730

Kent, M., and P. Coker. 1992. *Vegetation Description and Analysis: A Practical Approach*. London: CRC Press.

Legendre, P. 1993. Spatial autocorrelation: trouble or new paradigm? *Ecology* **74**: 1659-1673.

Montgomery, D.C. 1991. *Design and Analysis of Experiments.* edition 3. New York: John Wiley & Sons.

Mueller-Dombois, D., and H. Ellenberg. 1974. *Aims and Methods of Vegetation Ecology*. New York: John Wiley & Sons.

Munz, P.A. 1974. A Flora of Southern California. Berkeley: Univeristy of Califrornia Press.

Munz, P.A., and D.D. Keck. 1959. A California Flora. Berkeley: Univeristy of Califrornia Press.

APPENDIX H

EXPERT ASSISTANCE

APPENDIX H.1

AN ECOREGIONAL APPROACH TO POST-FIRE EROSION CONTROL ALONG CALIFORNIA HIGHWAYS

Roadside Erosion Control and Management Reviews

An Ecoregional Approach to Post-Fire Erosion Control Along California Highways

Relevant to:

Standard Specifications 2006

SECTION 20: EROSION CONTROL AND HIGHWAY PLANTING

State of California
Department of Transportation
Division of Design
Landscape Architecture Program

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Erosion Control	Revegetation	Ecoregions
Rehabilitation	Hydroseeding	Ecounits
	Ecological Consequences	

SUMMARY

Summary to come …

CONTENTS

Section 1

INTRODUCTION

1.1 Erosion Potential Following Wildfire

Numerous legal mandates and policies direct the management of erosion-related water quality within California and guide post-fire remedial actions undertaken to mitigate the potential for subsequent erosion. Following wildfires it is a common occurrence for there to be a pulse of erosion due to the removal of vegetation, surface cover, and the structural support provided by root systems (Sugihara et Barbour 2006). Erosion and overland flow of water from burned watersheds are initially expressed during the first rainy seasons after fire resulting in flooding, debris flows, and sedimentation (Thode et al. 2006). Surface erosion occurs where surface litter and duff are removed by fire, allowing raindrop impact and overland flow to cause displacement of soil. Large erosional events such as landslides and debris torrents may then be initiated where slopes are steep and root strength of vegetation has been reduced by fire (Thode et al. 2006).

Erosion control along California's highway roadsides is commonly provided by vegetational cover. Thus, when highway roadsides sustain wildfire impacts the primary erosion control mechanism may be rendered ineffective until sufficient plant re-growth occurs.

Erosion potential varies considerably throughout the state depending on precipitation, intensity of rain events, topography, soil type, and the nature of the vegetation cover. To achieve post-fire emergency erosion control under such a broad range of conditions, an array of treatments has been devised. All post-fire intervention treatments bring with them some concerns about unintended ecological consequences. Where vegetation serves as the primary method of erosion control, decisions regarding post-fire roadside management should be informed by these potential consequences as they can alter short- and long-term erosion control effectiveness. The goal of this review is to provide a targeted synopsis of the current published information available on this topic. The bulk of the information has been extracted from the most recent and comprehensive volume on California's fire ecology to date, *Fire in California's Ecosystems* (Sugihara et al. 2006a). This is a thorough endeavor including contributions by academics, private-sector professionals, and those in resource agencies charged with natural resource management including the US Forest Service, US Geological Survey, National Park Service, and California Department of Fish and Game.

Although the subject coverage offered by the entire volume is extensive, this review is limited to those issues most applicable to highway roadside situations. Evaluation and presentation of the material has been organized within a construct of context dependence, specifically: 1) adjacent land use type and 2) ecological bioregions. The organizing principle of context is considered functional herein because it serves the needs of Caltrans to make management decisions within their organizational structure of 12 Districts, each of which may have distinct combinations of both adjacent land ownership with proscribed resource management directives (land use interface) and ecological site conditions (Bioregions).

1.2 Why Context Matters

1.2.1 Adjacent Land Use

Ecological concerns vary with respect to the type of land use occurring adjacent to highway roadsides. For this review, land use distinctions have been simplified into the basic categories of **urban**, **suburban** or **exurban** (agriculture and wildland). Level of concern about the ecological consequences of emergency roadside erosion control treatments varies with adjacent land use, reflecting the influence of 1) degree of natural landscape integrity in the adjacent land; and 2) land management policy directives of properties contiguous with Caltrans rights-of-way.

1.2.2 Ecological Bioregions

Each California Bioregion, as defined by Sugihara et al. 2006a, exhibits characteristic fire regimes, a complex set of attributes describing the predominant pattern of fire occurrence. Each Bioregion has unique ecosystem components, such as plant community composition, that affect the vegetational response to fire. Fire has a differential effect on plant species mortality and regeneration. Plant response to fire is one component to consider in post-fire erosion control treatment. Because general patterns link ecological bioregions to plant fire response trends, the bioregional context can be useful as one tool by which to evaluate post-fire erosion control treatments.

1.2.3 Plant Responses to Fire

Many plant species exhibit characteristics that enable them to survive fire. Fires enhance reproduction in some species whereas others are negatively affected, proliferating only during fire-free periods. Classification systems that categorize such fire-related responses have been developed for the purpose of characterizing and predicting the post-fire effects of individual plant species or entire plant communities (Fites-Kaufman et al. 2006).

Table 1.1 delineates a current plant fire-response classification system for the California flora. Fire responses are divided into two broad categories based on whether the plant is or is not stimulated by fire. Fire-stimulated plants are further divided into those which are fire-dependent or fire-enhanced categories. Plants not stimulated by fire are considered to be either fire-neutral or fire-inhibited.

For Caltrans, the utility of this classification system lies in its applicability to roadside vegetation after a fire. With their goals of 1) maximizing the soil surface cover with foliage, and 2) stabilizing the substrate with plant roots, it is advantageous to be able to predict which species will likely survive a fire or what options to consider when individuals are killed. For example, a roadside populated by plants that are top-killed and resprout soon after the fire, often has some foliar recovery prior to the first post-fire rain event, thus, affording a measure of soil protection during the first rain event. In contrast, a roadside populated by species that succumb to fire and do not resprout would present bare soil at the onset of seasonal rain; vegetational recovery occurs only after rain-induced seed germination and seedling establishment.

Table 1.1. Plant Fire Response Classification for California Flora

Adapted from Fites-Kaufman et al 2006 (Table 6.2, p. 104); modified from Bond and van Wilgen 1996

RESPONSE CATEGORY	RECOVERY STRATEGY		
	SPROUTERS	NON-SPROUTERS	
FIRE-STIMULATED			
Fire-Dependent	flowering only or almost entirely after fire	fire-stimulated flowering, seed release, germination	seed release from heat
	e.g. Mariposa Lily, Death Camas	*e.g.* Golden-Eyes	*e.g.* Knobcone Pine, Bishop Pine, Bigpod Ceanothus
Fire-Enhanced	species increase after fire, but some establishment during fire-free intervals also	seed release, seedling establishment enhanced	seed germination enhanced
	e.g. Black Oak, Aspen	*e.g.* Ponderosa Pine	*e.g.* Tobacco Brush, Mountain White Thorn
NOT FIRE-STIMULATED			
Fire-Neutral	sprouting recruitment same following fire as in fire-free interval; continuous sprouters	seed germination same following fire as in fire-free interval; seed producers survive fire	long-distance seed dispersal
	e.g. Scrub Oak, Bigleaf Maple, Cottonwood, Sedges	*e.g.* Douglas-Fir, Sugar Pine	*e.g.* Fireweed, Thistle
Fire-Inhibited	sprouting recruitment less following fire than in fire-free interval	seed germination less following fire than in fire-free interval	mature and seedling individuals killed by fire; post-fire recruitment low
		e.g. mature Firs	*e.g.* Sitka Spruce, Santa Lucia Fir; Fir seedlings

1.3 Bioregional Review

General patterns emerge between fire response characteristics of species within plant assemblages and bioregions of California. Although, the response of particular plant species are more predictable when assessed within a bioregional context, bear in mind that bioregions and fire regimes are very broad classifications that incorporate a large degree of variation. The effect of fire on a plant results from the interaction among the physical properties of a particular fire event, the characteristics of a species and the individual plant, and post-fire weather conditions (Fites-Kaufman et al. 2006). Concerns for Caltrans center on the following:

1) How will post-fire response by roadside vegetation affect potential for erosion?

2) Will resprout be adequate to mitigate erosion concerns?

3) If resprout is unlikely to mitigate erosion potential, then what unintended ecological consequences might ensue from erosion control intervention options? Are any options more ecosensitive?

Section 2

LANDUSE INTERFACE

Ecological concerns vary with respect to the category of land use occurring adjacent to the highway roadside. For the purpose of this review, land use distinctions are simplified into basic categories of 1) urban/suburban, and 2) exurban (agriculture and wildland). Of primary concern is the degree of natural landscape integrity that exists in the land contiguous with the roadside right-of-way. Unintended ecological consequences in the land adjacent to the roadside right-of-way caused by emergency erosion control response treatments generally are of lesser concern where the adjacent natural landscape integrity is no longer extant; a roadside planting within the horticulturally landscaped urban area generates a different measure of ecological concern than one adjacent to a native conservation or preservation zone.

Urban/suburban land use areas generally constitute highly altered landscapes with an absence or low occurrence of continuity with wild landscapes or self-sustaining native plant communities. The roadsides are often landscaped with horticultural specimens. Disjunction from any self-sustaining native plant communities reduces the likelihood of ecological impacts, except where there are designated conservation areas embedded within an otherwise urban/suburban zone. In some locations, horticultural specimens of native species are used in roadside plantings, but these are not necessarily considered the equivalent of a self-sustaining ecosystem. Yet even in these situations, it could be beneficial to understand a species response to fire in guiding post-fire erosion control and revegetation (sensu landscaping) decisions.

In areas of exurban land use roadsides may be contiguous with self-sustaining native plant communities of high internal integrity or with a landscape that may have been completely altered. Agriculture can include a highly altered condition associated with crop cultivation, or a less conspicuously modified open rangeland. Throughout agricultural areas there is concern for any action that would foster the introduction or increase of weeds. Wildlands, by definition, have greater integrity to the natural landscape; self-sustaining native plant communities occur in close proximity to the roadside. It is within these environments that concern should be greatest regarding post-fire response treatments that have the potential to disrupt natural ecosystem processes.

Section 3

POST-FIRE REMEDIAL TREATMENTS

Most post-fire remedial treatments have focused on controlling sediment and runoff while restoring vegetative cover. While many natural plant communities recover well from fire without further intervention, remedial actions are often undertaken to accelerate recovery. **Table 3.1** summarizes post-fire remedial treatments with regard to their purpose, benefits, and concerns. Ecological concerns are addressed in greater detail in the next section of this review.

Table 3.1. Post-Fire Rehabilitation Treatments

From Thode et al. 2006a, Table 20.1

	Purpose	Benefits	Concerns	Literature
		Hillslope Treatments		
Non-native grass seeding	Rapidly increase vegetation cover, reduce hillslope erosion, or prevent undesirable non- native species establishment	Can accelerate development of cover from vegetation; application is relatively inexpensive if non-native species are used, so can be applied to large areas	May take several growing seasons for effective cover to become established; abundant grass can create early reburn hazard; seeded species may compete with native vegetation (may not increase total cover); grazing too early can affect the plant community that will develop	Noble 1965, Orr 1970, Dyrness 1976, Tiedemann and Klock 1976, Ratliff and McDonald 1987, Robichaud et al. 2000
Native grass seeding	Same as above	Accelerate development of vegetation cover. May be less aggressive competition with natural regeneration than non-native species. Natural part of ecosystem.	Same as above; generally more expensive than non-native seed. May not be available in large quantities when needed; concerns about genetic contamination if non- local genotypes are used-often unknown is how local is 'local'?" "	Griffith 1998, Richards et al. 1998
Mulch	Provide ground cover, protect the soil surface, and promote water infiltration	Effective cover can be provided in short term, prior to precipitation.	Application expensive, especially away from roads; mulch may contain seed of non-native species; unknown effects on vegetation recovery.	Bautista et al. 1996, Edwards et al. 1995
Contour-felled logs and straw wattles	Provide breaks in slope, slowing runoff and promoting infiltration; also act to trap sediment	Utilizes materials available on site, provides some cover. Rilling and gullying are reduced if successfully applied.	Difficult to achieve contact between ground surface and logs	McCammon and Hughes 1980, Miles et al. 1989
Contour trenching or raking	Breaks through the soil, water repellent soil layer, and promotes infiltration	Reduced soil erosion and runoff	Difficult to economically treat enough area to achieve watershed scale benefits	DeByle 1970a, b, Costales and Costales 1984

Table 3.1. Post-Fire Rehabilitation Treatments (contd.)

	Purpose	Benefits	Concerns	Literature
Channel Treatments				
Straw bale check dams and gabions	Replace channel structure removed by fire. Check store sediment and slow water.	Sediment storage, improved channel stability, reduced channel erosion	Very hard to provide design that mimics natural system; straw bales may fail in high flows	Collins and]ohn- ston 1995, Goldman et al. 1986
Channel hardening	Uses logs or rocks to keep channels from eroding during high flow	Improved channel stability, reduced channel erosion	Expensive for broad- scale application. May not mimic natural structure or morphology and may conflict with long-term recovery	Miles et al. 1989
Debris basins	Store large amounts of sediment	Catch sediment and wood that would otherwise damage downstream improvements	Unnatural intrusion into channel system; difficult to size adequately to protect from largest (most damaging) events	Robichaud et al. 2000
Removal of large woody debris	Prevents damage to downstream culverts or structures during peak post-fire flows	Provides protection to in-channel and flood plain improvements	Large wood provides in-channel structure and habitat post-fire	Robichaud et al. 2000
Road and Trail Treatments				
Water bars on trails	Divert water from trail, preventing it from eroding into a channel	Prevents concentrated flow (rills and gullies); cheap and effective	Site disturbance to soil if improperly constructed	Furniss et al. 1998
Rolling dips on roads	Reduce connection of road surfaces with channel system	Avoids concentrated surface flow; reduces road ditch and surface erosion	None if properly designed and maintained, though dips may not be compatible with large vehicle traffic	Furniss et al. 1998
Culvert upgrades	Improve passage of water, wood, and sediment	Reduces risk of crossing failure, improves connectivity	Short-term impacts during construction; may be expensive	Furniss et al. 1998

Section 4

ECOLOGICAL CONCERNS

4.1 Ecological Consequences

Commonly utilized treatments, seeding and mulching, carry with them some potential ecological consequences that are presented here in more detail. Some are not listed in **Table 3.1**.

4.1.1 Ecologically Inappropriate Native Species Substitutions

Where native revegetation through seeding is specified there can be additional complications. When a seed vendor has an inadequate supply of any specified taxon, a substitution is generally permitted. These substitutions may not be ecologically appropriate to the site. Substitutions should require advance approval by the landscape architect of record in consultation with a District or Regional Biologist, if necessary.

4.1.2 Seeding Invasive Alien Plants

The use of alien plants adjacent to wildland areas is addressed in **Box 4.1**. Seeding invasive alien plants presents a complex problem that is difficult to manage with the potential for long-lasting effects.

The use of invasive species adjacent to agricultural areas can be equivalent to the introduction of weeds with the potential to migrate into the agricultural area and impact the intended crop. The invasive potential of some plants may be increased where supplemental irrigation fosters a suitable environment.

4.1.3 Mulch

Mulch, used as a method of physical erosion control, may include jute netting with a compost blanket, crimped straw, hydro-applied fiber, and BFM (bonded fiber matrix). The effects on vegetation recovery vary with each type of mulch used and the quantity used, i.e., depth of application.

Wohlgemuth et al. (2006), Fites-Kaufman et al. (2006), and Thode et al. (2006) have addressed this issue indirectly:

- Fires change the physical and chemical factors of the plant environment; fires alter availability of nutrients, water, light, soil surface substrate and chemistry, post-fire insolation and soil temperature effects, and a shift in the composition of the microbial community.
- These changes can differentially affect sprouting, growth, colonization, and germination and establishment of plant species.
- Application of a mulch layer would modify many of the typical post-fire physical changes, especially light and insolation effects such as soil temperature.

- Such changes can suppress seed germination and seedling success for the majority of fire-adapted species that require high-level light cues.
- In addition to perhaps modifying successional trajectories, it is likely that vegetational recovery from a dormant seed bank will be suppressed.
- Seeding on top of a mulch layer results in more successful recruitment [see Caltrans 2005a, 2005b], but the species composition would likely differ from the naturally occurring seed bank, especially in the case of a fire-enhanced, fire-dependent, or fire-follower flora.

Box 4.1

THE SEEDING CONTROVERSY

From Thode et al. 2006

The most common practice for post-fire emergency watershed rehabilitation is broadcast grass seeding, usually from aircraft (Robichaud et al. 2000). Hillslope erosion is inversely related to vegetative cover, and rapid vegetation establishment is regarded as the most cost-efficient way to keep soil on hillslopes and out of channels and downstream areas (Noble 1965, Rice et al. 1965, Miles et al. 1989). Grasses are particularly desirable for this purpose because their quick growth along with extensive, fibrous root systems increase water infiltration and hold soil in place. Grass seeding after fire for range improvement began decades ago, with the intent to gain useful outputs (e.g., livestock production) from land that would not yield harvestable timber for decades (Christ 1934, McClure 1956). Seed mixes were developed regionally based on germination and establishment success. Most mixes contain annual grasses to provide quick cover and short-lived perennials to establish longer-term protection, with legumes sometimes included for their ability to add nitrogen to the soil (Klock et al. 1975, Ratliff and McDonald 1987). Fast-growing alien species have typically been used. They are inexpensive and readily available in large quantities when an emergency arises (Barro and Conard 1987, Agee 1993).

Post-fire grass seeding has generated considerable controversy (Conrad 1979, Barra and Conard 1987, Robichaud et al. 2000, Beyers 2004, Keeley et al. 2006). Critics point to evidence that seeded grasses suppress native herbaceous plant establishment, out-compete tree and shrub seedlings, create flashy fuel conditions conducive to an early reburn of the site, and do not demonstratively reduce erosion in many cases (e.g., Schultz et al. 1955, Keeley et al. 1981, Griffin 1982, Gautier 1983, Zedler et al. 1983, Nadkarni and Odion 1986, Taskey et al. 1989, Conard et al. 1991, Conard et al. 1995, Beyers et al. 1998, Wohlgemuth et al. 1998). Persistent seeded species may delay recovery of native flora and potentially alter local plant diversity. Defenders argue that even small reductions in hillslope erosion due to grass seeding are justified by the method's relatively low cost and wide applicability (Rice et al. 1965, Miles et al. 1989); no other rehabilitation treatment can be applied relatively cheaply to thousands of acres after a large fire (Robichaud et al. 2000). The dilemma between short-term suppression of forest regeneration and long-term soil productivity maintenance is well recognized (Ruby 1989, Van de Water 1998).

In California, much of the concern over the impacts of grass seeding focused on the use of annual ryegrass *(Lolium multiflorum)* in chaparral ecosystems (Barra and Conard 1987). This fast-growing alien species typically persists for less than five years on chaparral sites. However, a specialized native annual flora exists that takes advantage of the light, space, and soil nutrients available immediately after fire in chaparral ("fire followers") (Sweeney 1956, Keeley et al. 1981). In addition, some dominant shrub species, particularly in the genera *Arctostaphylos* and *Ceanothus,* regenerate after fire only from seed that germinates during the first growing season after the fire (Sampson 1944, Keeley 1991). Both groups of plants can be negatively affected by competition from seeded grass. Many studies have shown reduced cover of native chaparral species on ryegrass-seeded plots, but most found no increase in total vegetation cover due to seeding (reviewed in Beyers et al. 1998, Beyers 2004). Very few studies (published or unpublished) have demonstrated that seeding reduced erosion on chaparral sites in the first or second year after a fire (see Robichaud et a!. 2000). Instead, Wohlgemuth et al. (1998) found erosion reduction attributable to seeded ryegrass occurred only after sediment movement had dropped to pre-fire rates or lower. As a result of these studies, the use of broadcast grass seeding after fire in California chaparral has declined considerably (Robichaud et al. 2000).

High-intensity fires that consume all aboveground vegetation, with the consequent soil effects, are well within the range of natural variation for chaparral ecosystems and thus not of particular concern from the standpoint of soil productivity. This is not true in most conifer forest types, where low-severity fires that seldom killed mature trees are thought to have been typical of pre-European fire regimes. Especially on sites with good soils and high tree-growing capability, seeding is often prescribed after crown fires to help hold soil in place and maintain site productivity. As in chaparral, however, seeded grasses can compete with tree seedlings and native shrubs. Several species commonly used for post-fire seeding, because of their rapid growth and wide adaptability (Klock et al. 1975), have been found to be strongly competitive with conifer seedlings. For example, the aliens orchardgrass *(Dactylis glomerata),* perennial ryegrass *(Lolium perenne),* and timothy *(Phleum pratense)* reduced growth of ponderosa pine *(Pinus ponderosa)* seedlings in experimental plots (Baron 1962). Low pine seedling densities were found on aerially seeded sites with annual ryegrass cover greater than 40% (Griffin 1982, Conard et al. 1991). These species can persist for several years after fire, affording extended soil protection but also increasing the competitive impact on tree regeneration. Grasses can provide some benefit to tree seedlings if they displace shrubs that would otherwise compete with the trees for soil moisture and nutrients (McDonald 1986, Amaranthus et al. 1993). In general, however, burned area rehabilitation assessment teams must take into consideration the cost of suppressing seeded grasses during reforestation efforts as part of their cost-benefit analysis when developing watershed treatment prescriptions (Griffith 1998). As with chaparral, there has been a decrease in the amount of seeding performed on forested areas in recent years as the impacts and effectiveness have been debated (Robichaud et al. 2000).

Most land management agencies now have direction to use native species wherever possible for revegetation projects, including emergency watershed rehabilitation. However, seed of locally adapted native grasses is seldom available in sufficient quantity to use after large fires, and costs are high compared to aliens such as annual ryegrass (Robichaud et al. 2000). Many rehabilitation assessment teams now prescribe non-reproducing annuals, such as cereal grains or sterile hybrids, which could provide quick cover and then die out to let native vegetation reoccupy the site. Few studies have been conducted on the effectiveness or ecosystem impacts of these grasses; preliminary information suggests that cereals largely die out after one year unless disturbed by grazers or salvage logging operations (Robichaud et al. 2000). If establishment success of cereals is high, first-year cover of native herbaceous species and tree seedling density can be reduced (Keeley 2004), just as with annual ryegrass. The cost of sterile hybrids, such as proprietary Regreen (a wheat-wheatgrass hybrid), can be very high compared to ordinary cereals, and they are generally prescribed only for highly sensitive areas such as wilderness (Beyers *in press).*

Burned-area assessment teams must weigh the likelihood of successful establishment and erosion reduction by seeded grasses against the economic and potential ecological costs of treatment when making the decision to seed or not after fire. Public pressure to do *something* to burned slopes, especially in the wildland-urban interface, can be intense. Seeding is probably most appropriate in high-value timberlands where fire intensity has been outside the range of natural variation, increasing the probability that soil seed banks have been damaged and excessive erosion will occur, and where tree seedlings can be planted if natural regeneration fails due to grass competition (Beyers 2004). Where protection of private property and public infrastructure from sediment movement after fire is essential, more reliable and immediately effective treatments such as straw mulch are more appropriate. *-JLB*

Section 5

RECOMMENDATIONS

Preparing for fire events in fire-prone regions of the state will expedite and improve post-fire decisions and erosion control implementation. Because adequate preparation should entail a fully-developed statewide program of roadside inventory and assessment, it would likely require multiple years to plan and complete. Until such a program can be realized, a consistent approach to post-fire erosion control action can be undertaken.

5.1 *Ad-hoc* Post-Fire Emergency Actions

Implement where no pre-fire vegetation data exist, e.g., inventory of roadside vegetation and prediction regarding the fire response of that vegetation.

5.1.1 Ascertain Adjacent Land-Use and Degree of Natural Landscape Integrity

The potential for adjacent ecological consequences of erosion control techniques needs to be addressed for differing landuse categories.

Urban/Suburban **Without** ***Conservation/Preservation Designations:***

Potential: **Limited**

Urban/Suburban **With** ***Conservation/Preservation Designations:***

Potential: **Identifiable**

Example- if seeding, species selection and propagule origin may be critical, so secured, uncontaminated mulch may offer an ecologically appropriate alternative.

Agriculture:

Potential: **Identifiable**

Example- seeding or mulching may introduce propagules of weed species or species considered dangerous to livestock, so appropriate species selection and certified pure seed should be considered; mulching with seed free material may be safer.

Wildlands:

Potential: **Identifiable**

Example- if seeding, species selection and propagule origin for seeding may be critical, so secured, uncontaminated mulch may offer an ecologically appropriate alternative.

5.1.2 Assess Probable Fire-Response of Burned Roadside Vegetation

This requires identifying roadside vegetation after a fire event, an often difficult, if not impossible, task. If identified, it is possible to evaluate the response and recovery of many species or vegetation assemblages.

If a plant is impacted but survives a fire, it may resprout, bringing into question the need for seeding. Regardless of whether a plant is killed or survives a fire it is necessary to assess if there is a fire-dependent or fire-enhanced recruitment response (e.g. a seed bank of fire followers). In these situations it is necessary to consider if seeding or mulching will negatively impact the fire-enhanced flora. If seeding is appropriate, should local taxa and propagules be used? Will exotic taxa be likely to escape off the roadside and spread into contiguous land?

5.2 Post-Fire Erosion Control Treatment Preparedness Plans

We suggest a comprehensive statewide preparedness plan implemented through a programmatic approach. To effect consistency, it is proposed that Regional and District input be coordinated with Environmental Planners (Natural Sciences) possessing expertise in botany and vegetation ecology.

The plans would require an *a priori* inventory of both roadside vegetation and adjacent land use within the framework of a geographical information system (GIS). This should be combined with existing data that provide the fire-response of plant species and vegetation assemblages within a bioregional context and fire regime. Data could also be provided identifying locations where factors such as fire-enhanced recruitment or other successional trajectories must be taken into consideration. Where managed wildlands occur, data providing a specific agency natural resource directives could be integrated, facilitating enactment of Memoranda of Understanding regarding post-fire erosion control treatments.

In the absence of detailed roadside vegetation inventory data, the bioregional ecounit lists in **Section 6** provide general patterns of observed plant species response to fire within each ecounit.

Section 6

BIOREGIONS

Understanding how vegetation responds to fire should inform decisions regarding post-fire erosion control measures. Many plant species commonly occur across multiple plant *assemblages/communities*. Because particular plant assemblages exhibit distinct fire regime attributes, individuals of a single species may vary in their response to fire among Bioregions.

6.1 The Bioregional Classification System and Caltrans Districts

Patterns of biological diversity within the California landscape have been classified under different schemes by various workers. The system used by Sugihara et al. (2006) is based on past work by Bailey (1995) and McMahon et al. (2001). (**Table 6.1**) lists the Bioregions and subordinate Sections within California.

We have provided a representation of the geographic overlap of the 12 Caltrans Districts with the Bioregional Classification System (**Table 6.2**; **Figure 6.1**) and, in the presentation of subsequent information, we have indicated which Bioregions pertain to each District.

Table 6.1. California's Ecological Bioregions and Sections.

Bioregions from Sugihara et al. 2006, Table 1.1; Sections from Bailey 1995; Miles and Goudey 1997.

BIOREGION	SECTIONS
NORTH COAST	Northern California Coast Northern California Coast Ranges
KLAMATH MOUNTAINS	Klamath Mountains
SOUTHERN CASCADES	Southern Cascades
NORTHEASTERN PLATEAUS	Northwestern Basin and Range Modoc Plateau
SIERRA NEVADA	Sierra Nevada Foothills Sierra Nevada
CENTRAL VALLEY	Northern California Interior Coast Ranges Great Valley
CENTRAL COAST	Central California Coast
SOUTH COAST	Southern California Coast Southern California Mountains and Valleys
SOUTHEASTERN DESERT	Mono Southeastern Great Basin Mojave Desert Sonoran Desert Colorado Desert

Table 6.2. Bioregions, Sections, and MLRAs By Caltrans District

Bioregions from Sugihara et al. 2006, Table 1.1; Sections from Bailey 1995; Miles and Goudey 1997; Land Resource Regions (LRR) and Areas (MLRA) from USDA 2006.

DISTRICT	BIOREGION	SECTION	SECTION NAME	LRR	MLRA	ACRES	HECTARES	PERCENT
1	North Coast	263A	Northern California Coast	A	4	2834268	1146992	**46.94%**
	North Coast	M261B	Northern California Coast Ranges	A	5	2360980	955459	**39.10%**
	Klamath Mountains	M261A	Klamath Mountains	A	5	819669	331709	**13.58%**
	Central Valley	M261C	Northern California Interior Coast Ranges	C	15	22953	9289	0.38%
						6037870	**2443449**	
2	North Coast	263A	Northern California Coast	A	4	861	348	< 1.00%
	North Coast	M261B	Northern California Coast Ranges	A	5	767135	310450	4.30%
	Klamath Mountains	M261A	Klamath Mountains	A	5	4749991	1922261	**26.65%**
	Southern Cascades	M261D	Southern Cascades	D	21	4036613	1633566	**22.65%**
	Southern Cascades	M261F	Sierra Nevada Foothills	C	18	551166	223050	3.09%
	Northeastern Plateau	342B	Northwestern Basin and Range	D	23	1277937	517165	7.17%
	Northeastern Plateau	M261G	Modoc Plateau	D	21	3592342	1453775	**20.15%**
	Sierra Nevada	M261E	Sierra Nevada	D	21	1612790	652675	9.05%
	Central Valley	262A	Great Valley	C	17	238988	96715	1.34%
	Central Valley	M261C	Northern California Interior Coast Ranges	C	15	936404	378951	5.25%
	Southeastern Deserts	341D	Mono	D	26	60762	24589	0.34%
						17824989	**7213546**	
3	North Coast	M261B	Northern California Coast Ranges	A	5	348087	140867	4.30%
	Southern Cascades	M261D	Southern Cascades	D	21	102467	41467	1.26%
	Southern Cascades	M261F	Sierra Nevada Foothills	C	18	117724	47642	1.45%
	Sierra Nevada	M261E	Sierra Nevada	D	21	2993769	1211540	**36.95%**
	Sierra Nevada	M261F	Sierra Nevada Foothills	C	18	823517	333267	**10.16%**
	Central Valley	262A	Great Valley	C	17	2851074	1153793	**35.19%**
	Central Valley	M261C	Northern California Interior Coast Ranges	C	15	770575	311842	9.51%
	Southeastern Deserts	341D	Mono	D	26	10328	4180	0.13%
						8017542	**3278575**	
4	North Coast	263A	Northern California Coast	A	4	1402768	567682	**30.91%**
	North Coast	M261B	Northern California Coast Ranges	A	5	359993	145685	7.93%
	Central Valley	262A	Great Valley	C	17	529962	214469	**11.68%**
	Central Valley	M261C	Northern California Interior Coast Ranges	C	15	121989	49368	2.69%
	Central Coast	261A	Central California Coast	A	4	1378280	557772	**30.37%**
	Central Coast	M262A	Central California Coast Ranges	C	15	744613	301335	**16.41%**
						4537606	**1836311**	
5	Central Valley	262A	Great Valley	C	17	2819	1141	0.04%
	Central Coast	261A	Central California Coast	A	4	2019709	817350	**28.64%**
	Central Coast	M262A	Central California Coast Ranges	C	15	3882954	1571382	**55.06%**
	South Coast	261B	Southern California Coast	C	19	797799	322859	**11.31%**
	South Coast	M261E	Sierra Nevada	D	21	11334	4587	0.16%
	South Coast	M262B	Southern California Mountains and Valleys	C	20	337125	136430	4.78%
						7051740	**2853749**	
6	Sierra Nevada	M261E	Sierra Nevada	D	21	4442041	1797637	**30.76%**
	Sierra Nevada	M261F	Sierra Nevada Foothills	C	18	1850287	748788	**12.81%**
	Central Valley	262A	Great Valley	C	17	5869931	2375486	**40.65%**
	Central Coast	M262A	Central California Coast Ranges	C	15	934929	378354	6.47%
	South Coast	M261E	Sierra Nevada	D	21	58427	23645	0.40%
	South Coast	M262B	Southern California Mountains and Valleys	C	20	12689	5135	0.09%
	Southeastern Deserts	322A	Mojave Desert	D	30	1271669	514628	8.81%
						14439973	**5843673**	

Table 3.1. (cont'd).

DISTRICT	BIOREGION	SECTION	SECTION NAME	LRR	MLRA	ACRES	HECTARES	*PERCENT*
7	Sierra Nevada	M261E	Sierra Nevada	D	21	23	9	*< 1.00%*
	Sierra Nevada	M261F	Sierra Nevada Foothills	C	18	6654	2693	*0.18%*
	Central Coast	M262A	Central California Coast Ranges	C	15	6942	2809	*0.19%*
	South Coast	261B	Southern California Coast	C	19	1420102	574697	***38.38%***
	South Coast	M261E	Sierra Nevada	D	21	101440	41051	*2.74%*
	South Coast	M262B	Southern California Mountains and Valleys	C	20	1528464	618550	***41.31%***
	Southeastern Deserts	322A	Mojave Desert	D	30	636510	257588	***17.20%***
						3700136	**1497398**	
8	South Coast	261B	Southern California Coast	C	19	2537	1027	*0.01%*
	South Coast	M261E	Sierra Nevada	D	21	60994	24683	*0.35%*
	South Coast	M262B	Southern California Mountains and Valleys	C	20	2826090	1143683	***16.11%***
	Southeastern Deserts	322A	Mojave Desert	D	30	11279987	4564867	***64.31%***
	Southeastern Deserts	322B	Sonoran Desert	D	30	2536428	1026460	***14.46%***
	Southeastern Deserts	322C	Colorado Desert	D	31	489900	198256	*2.79%*
	Southeastern Deserts	341F	Southeastern Great Basin	D	29	304427	123198	*1.74%*
						17500364	**7098144**	
9	Sierra Nevada	M261E	Sierra Nevada	D	22	939224	380092	***10.99%***
	Southeastern Deserts	322A	Mojave Desert	D	30	3109202	1258255	***36.37%***
	Southeastern Deserts	341D	Mono	D	26	1917246	775885	***22.43%***
	Southeastern Deserts	341F	Southeastern Great Basin	D	29	2583333	1045442	***30.22%***
						8549005	**3459673**	
10	Sierra Nevada	M261E	Sierra Nevada	D	21	2676941	1083324	***37.91%***
	Sierra Nevada	M261F	Sierra Nevada Foothills	C	18	1115718	451517	***15.80%***
	Central Valley	262A	Great Valley	C	17	2658818	1075990	***37.66%***
	Central Coast	M262A	Central California Coast Ranges	C	15	571640	231335	*8.10%*
	Southeastern Deserts	341D	Mono	D	26	37384	15129	*0.53%*
						7060502	**2857295**	
11	South Coast	261B	Southern California Coast	C	19	694113	280899	***12.45%***
	South Coast	M262B	Southern California Mountains and Valleys	C	20	1840149	744685	***33.01%***
	Southeastern Deserts	322B	Sonoran Desert	D	30	641340	259542	***11.50%***
	Southeastern Deserts	322C	Colorado Desert	D	31	2218719	897887	***39.80%***
						5394321	**2255994**	
12	South Coast	261B	Southern California Coast	C	19	441019	178475	***86.36%***
	South Coast	M262B	Southern California Mountains and Valleys	C	20	69642	28183	***13.64%***
						510661	**206658**	

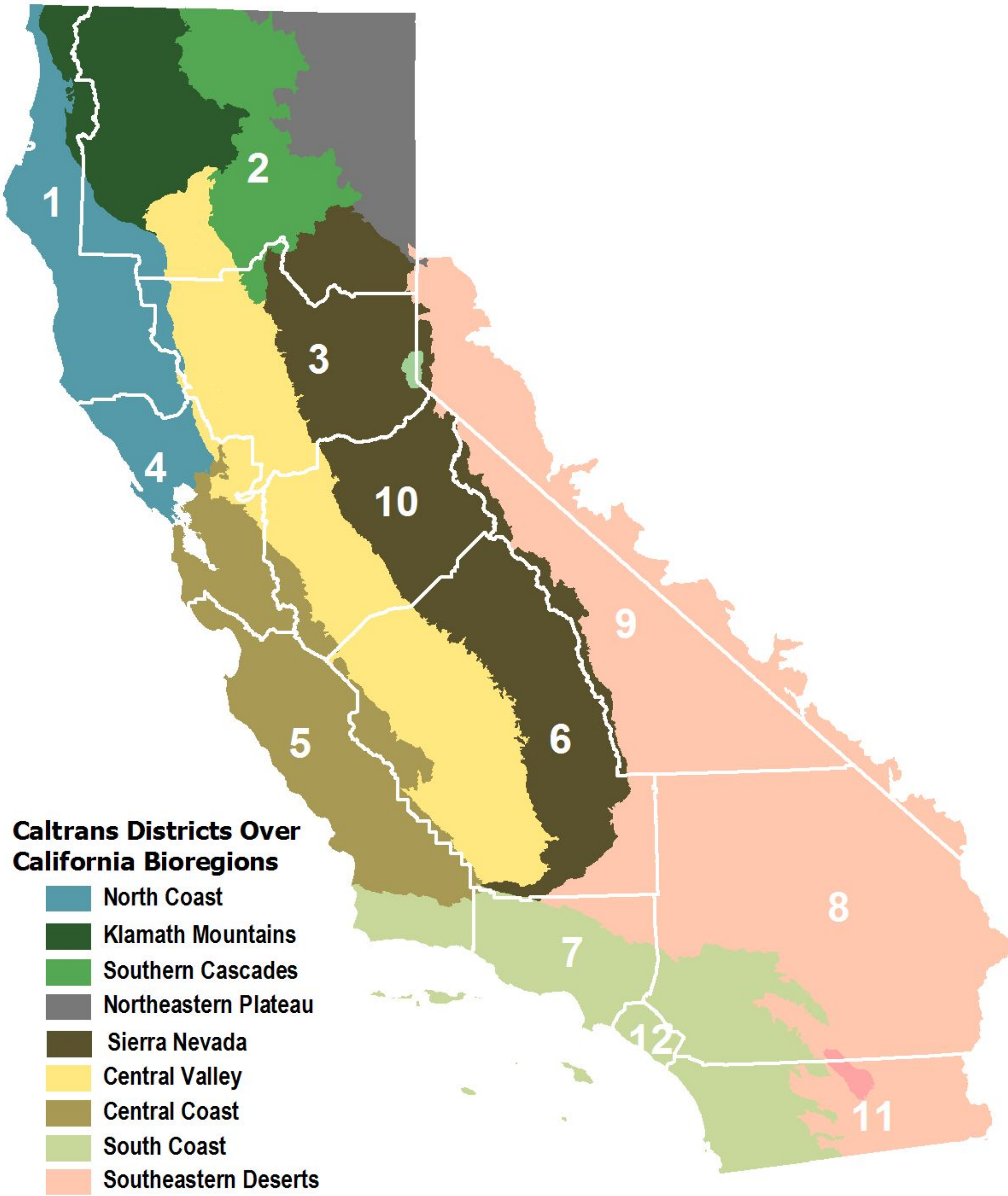

Figure 6.1. Bioregions and Caltrans Districts

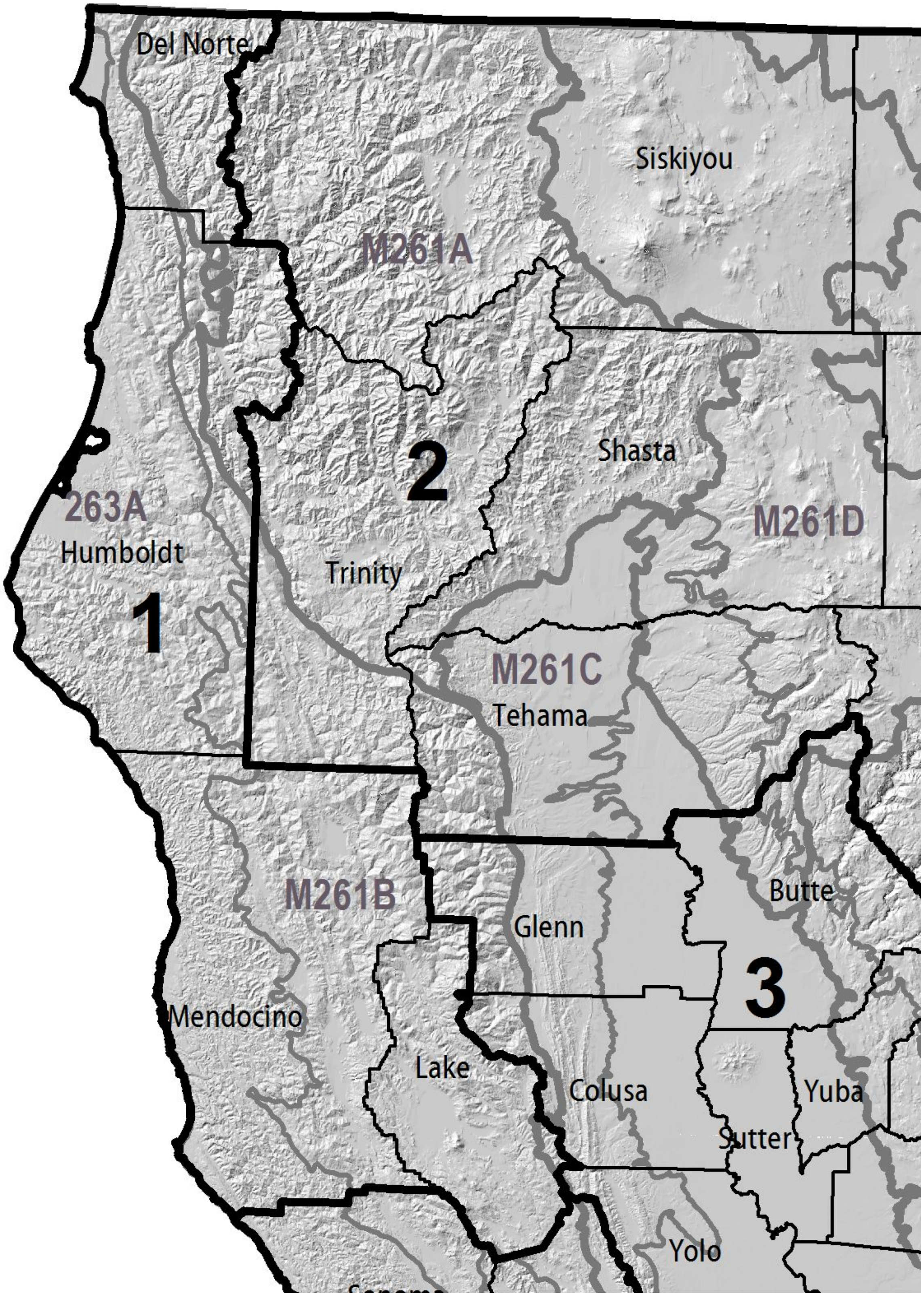

Figure 6.2. Caltrans District 1

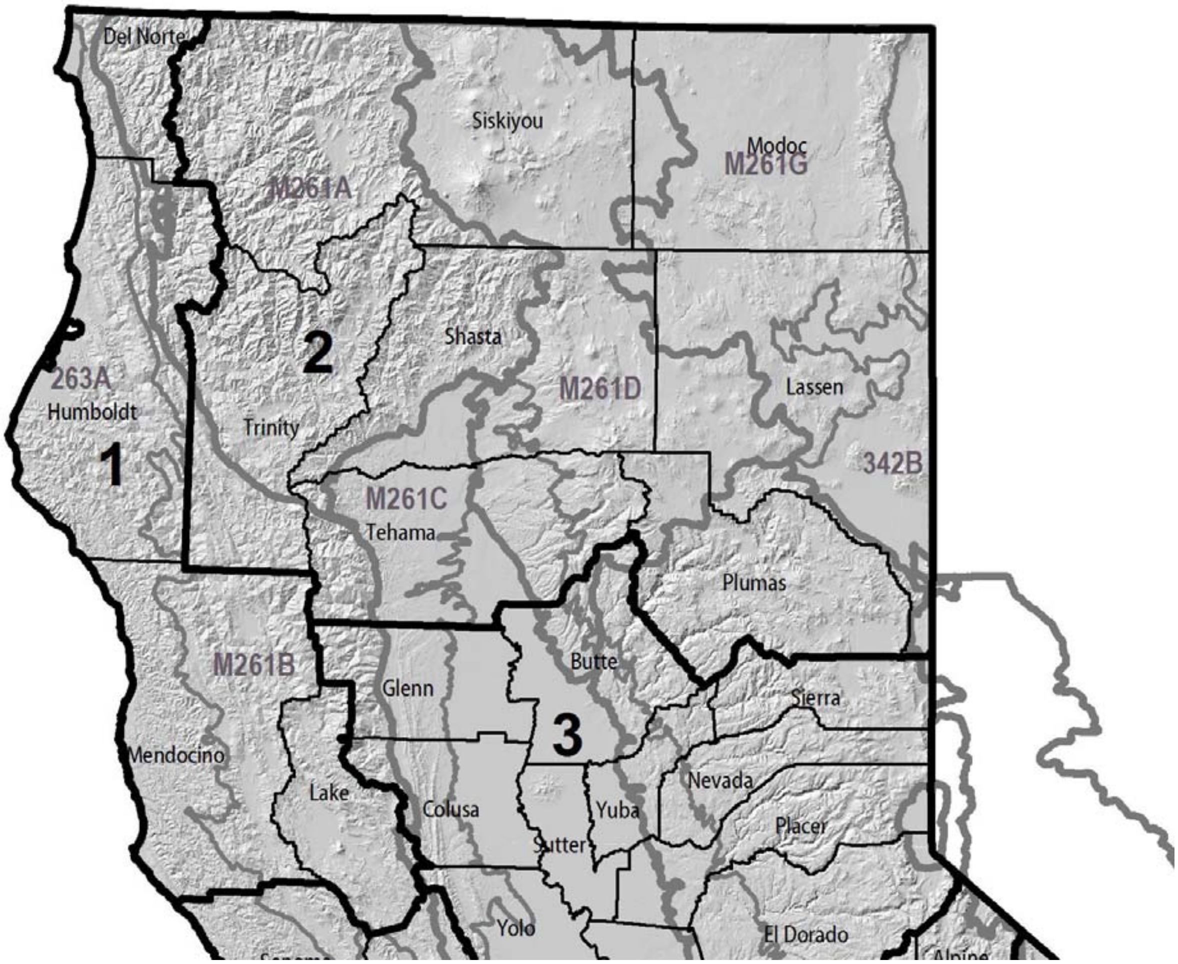

Figure 6.3. Caltrans District 2

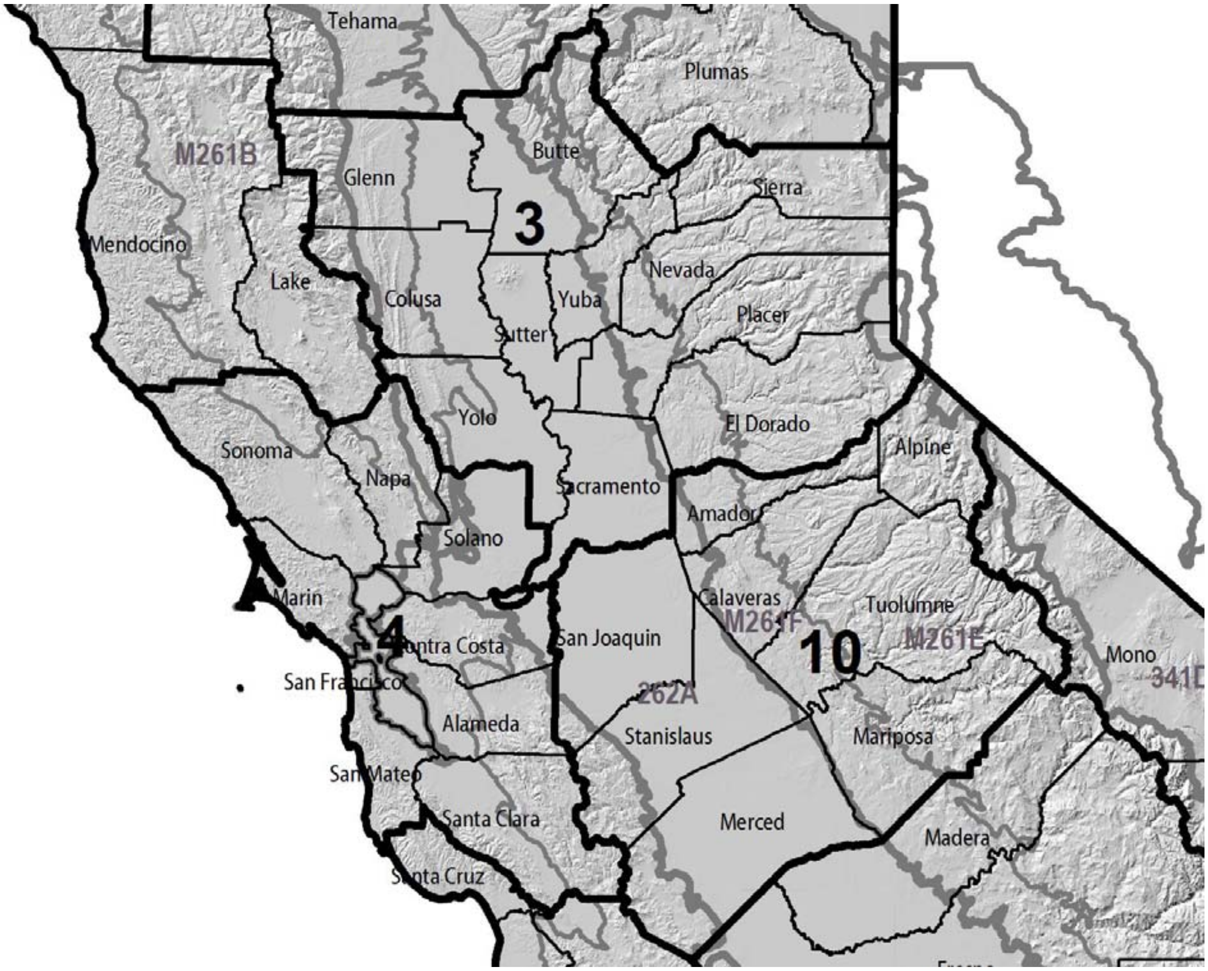

Figure 6.4. Caltrans District 3

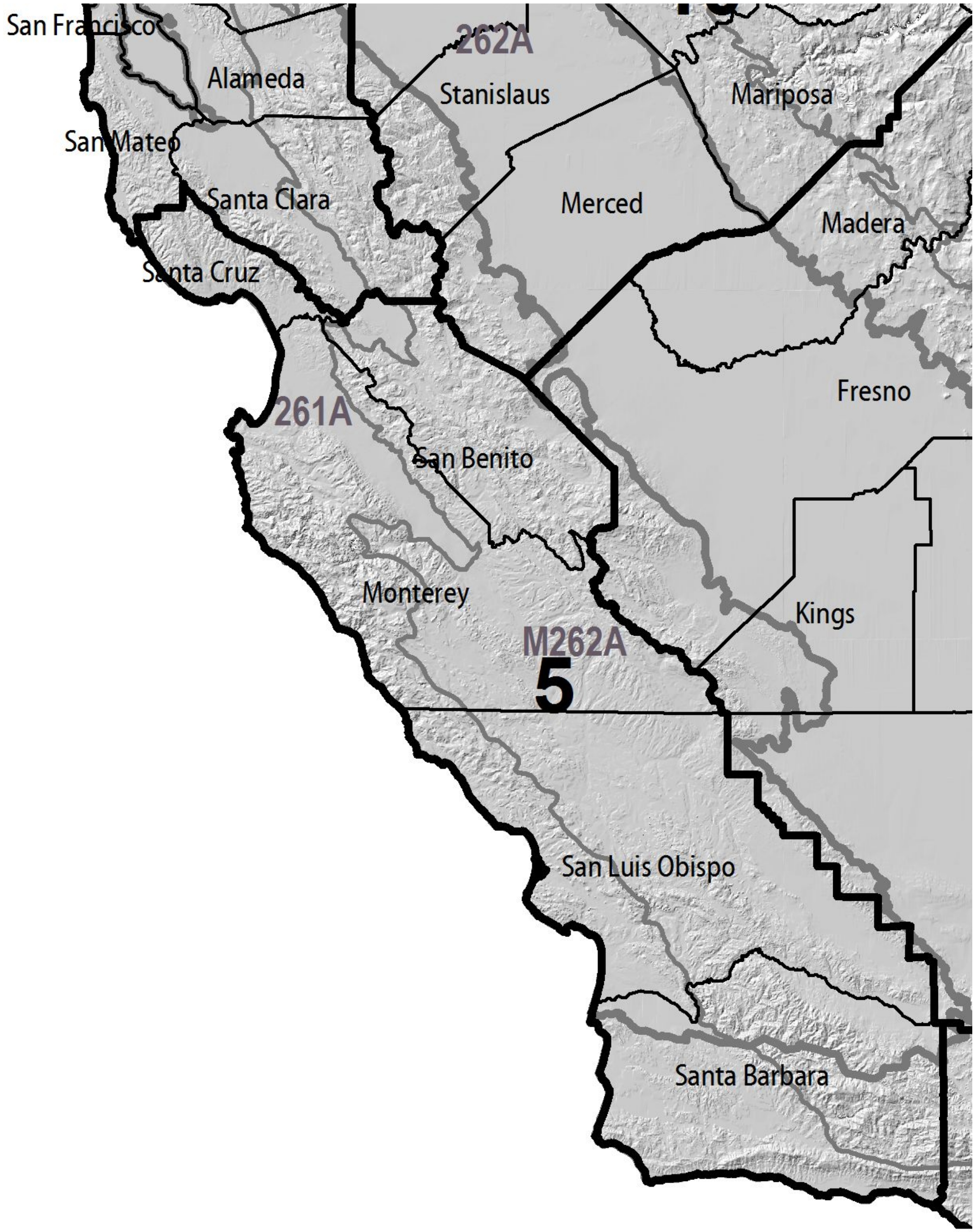

Figure 6.5. Caltrans District 5

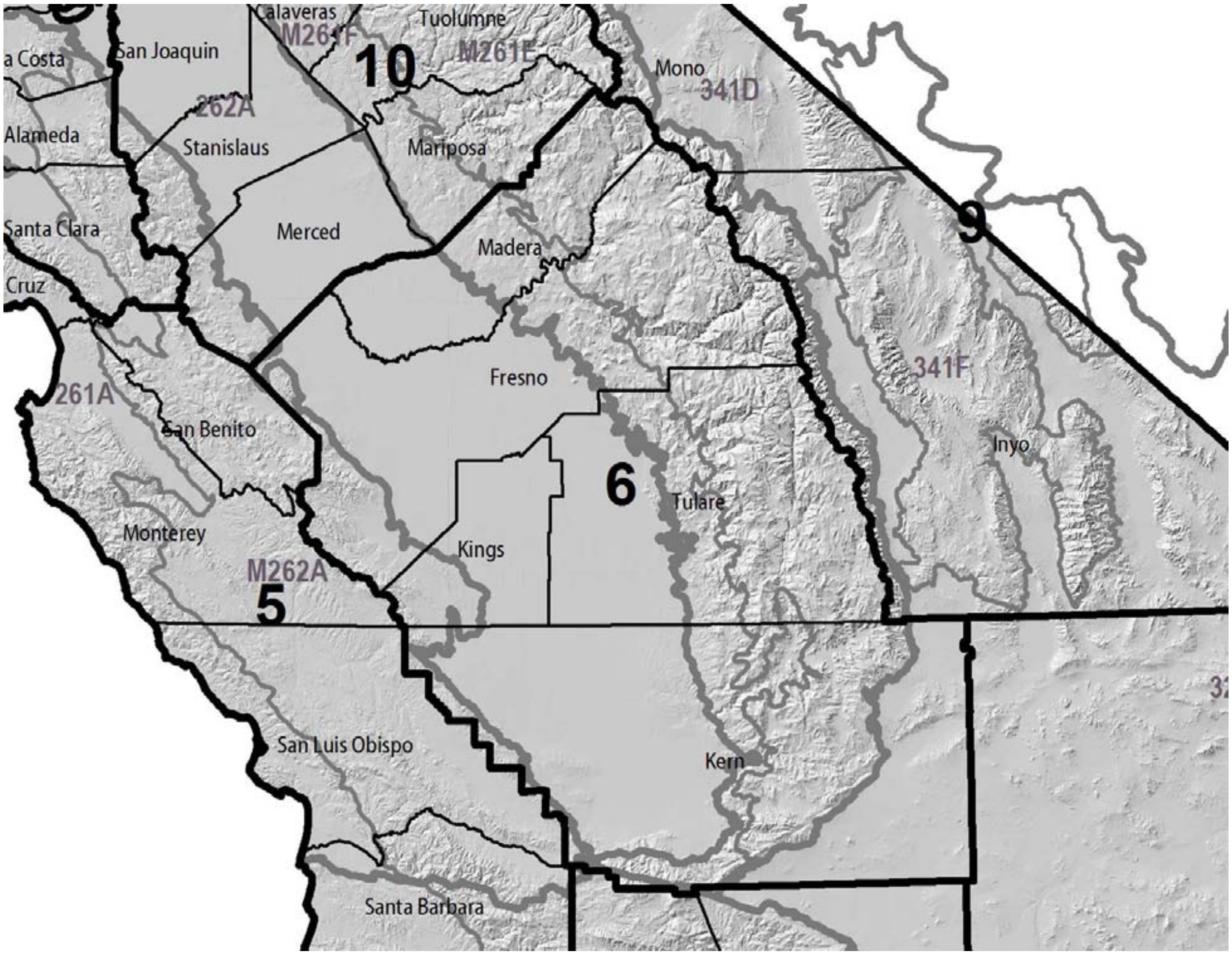

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Figure 6.6. Caltrans District 6

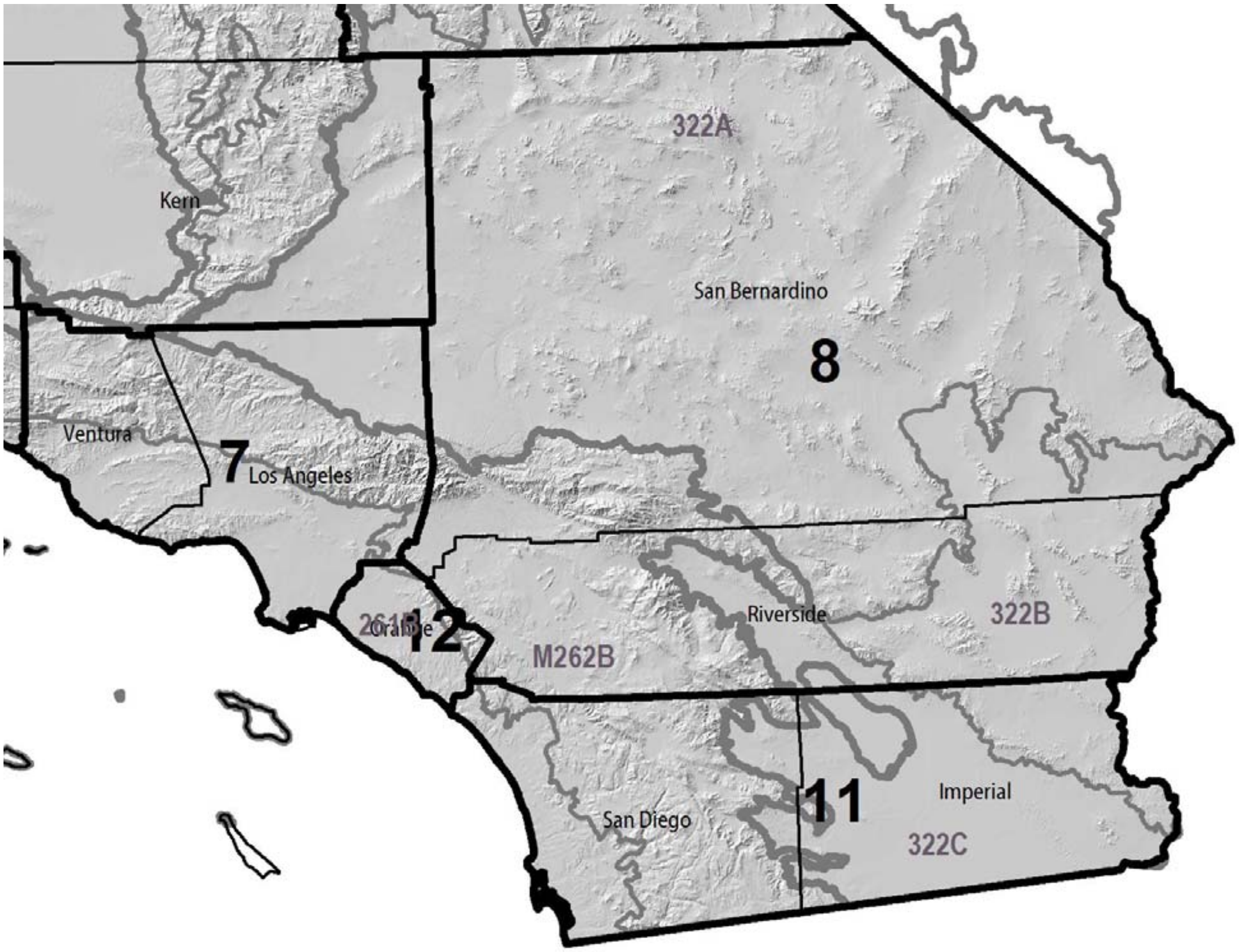

Figure 6.7. Caltrans Districts 7, 8, 11, 12

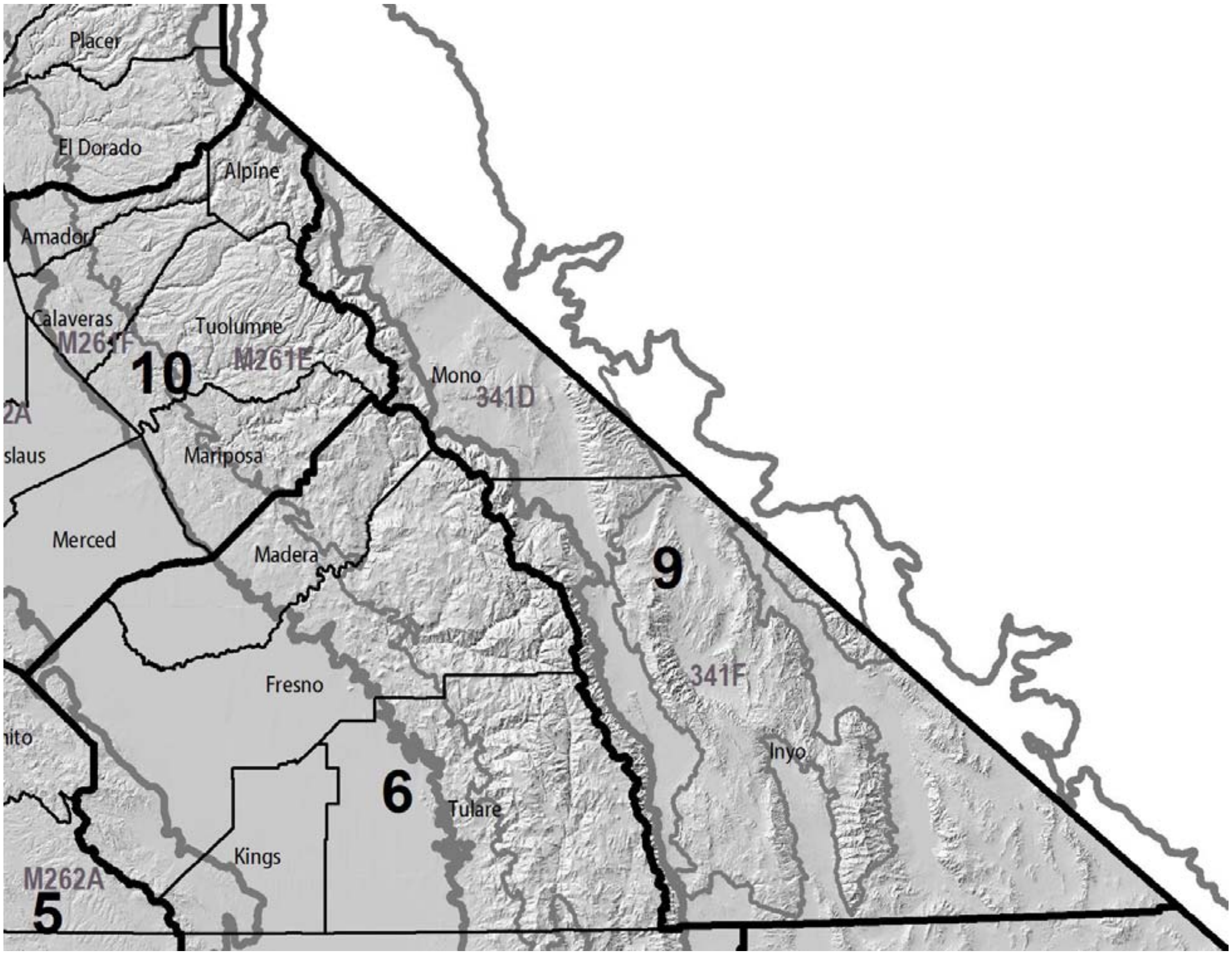

Figure 6.8. Caltrans District 9

BIOREGION > **North Coast**

USFS Section 263A > **Northern California Coast**

LRR A MLRA 4 > **California Coastal Redwood Belt**

In general, low elevation conifer forests dominate along the coast and in the northern part of the bioregion. Woodlands and montane forests increasingly dominate to the south and east. Grasslands and shrublands are interspersed.

263A.1 North Coastal Scrub and Grassland Ecological Zone

This zone contains many fire-neutral facultative sprouters that can aggressively recolonize a burn site by means of vegetative sprout or seed including Salal *(Gaultheria shallon)*, Evergreen Huckleberry *(Vaccinium ovatum)*, Coyotebrush *(Baccharis pilularis)*, Thimbleberry *(Rubus parviflorus)*, Salmonberry *(Rubus spectabilis)*, and California Blackberry *(Rubus spp.)*. Native perennial grasses including California Oatgrass *(Danthonia californica)*, Idaho Fescue *(Festuca idahoensis)*, Purple Needlegrass *(Nassella pulchra)*, Foothill Needlegrass *(Nassella lepida)*, and Tufted Hairgrass *(Deschampsia cespitosa)* usually survive low- to moderate-intensity fire but are top-killed and then resprout.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Baccharis pilularis	Coyotebrush	Top-Killed	Sprouter	Enhanced Recruitment
Danthonia californica	California Oatgrass	Top-Killed	Sprouter	Enhanced Recruitment
Deschampsia cespitosa ssp. holciformis	Tufted Hairgrass	Top-Killed	Sprouter	Enhanced Recruitment
Festuca idahoensis	Idaho Fescue	Top-Killed	Sprouter	Enhanced Recruitment
Festuca rubra	Red Fescue	Top-Killed	Sprouter	Enhanced Recruitment
Gaultheria shallon	Salal	Top-Killed	Sprouter	Neutral
Nassella pulchra	Purple Needlegrass	Top-Killed	Sprouter	Enhanced Recruitment
Rubus parviflorus	Thimbleberry	Top-Killed	Sprouter	Enhanced Recruitment
Rubus spectabilis	Salmonberry	Top-Killed	Sprouter	Enhanced Recruitment
Rubus spp.	Blackberry	Top-Killed	Sprouter	Enhanced Recruitment
Vaccinium ovatum	California Huckleberry	Top-Killed	Sprouter	Neutral

263A.2 North Coastal Pine Forest Ecological Zone

This zone contains isolated stands of conifers that are obligate seeders; regeneration is dependent on a seed bank, either crown-stored in cones that are variously serotinous, Bolander Pine *(Pinus contorta bolanderi)* and Pygmy Cypress *(Cupressus goveniana pygmaea)*, or soil-stored from non-serotinous cones, Beach Pine *(Pinus contorta contorta)* and Bishop Pine *(Pinus muricata)*. Seed germination and seedling establishment benefits from bare mineral soil present following fire.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Cupressus goveniana ssp. pygmaea	Pygmy Cypress	Killed	Dead	Enhanced Recruitment
Cupressus goveniana ssp. pygmaea	Pygmy Cypress	Survive	Non-Sprouter	Enhanced Recruitment
Cupressus goveniana ssp. pygmaea	Pygmy Cypress	Killed	Dead	Enhanced Recruitment
Pinus contorta ssp. bolanderi	Bolander Pine	Killed	Dead	Enhanced Recruitment
Pinus contorta ssp. bolanderi	Bolander Pine	Survive	Non-Sprouter	Enhanced Recruitment
Pinus contorta ssp. bolanderi	Bolander Pine	Killed	Dead	Enhanced Recruitment
Pinus contorta ssp. contorta	Beach Pine	Killed	Dead	Enhanced Recruitment
Pinus contorta ssp. contorta	Beach Pine	Survive	Non-Sprouter	Enhanced Recruitment
Pinus contorta ssp. contorta	Beach Pine	Killed	Dead	Neutral
Pinus muricata	Bishop Pine	Killed	Dead	Enhanced Release
Pinus muricata	Bishop Pine	Survive	Non-Sprouter	Enhanced Release
Pinus muricata	Bishop Pine	Killed	Dead	Enhanced Recruitment

263A.3 Sitka Spruce Forest Ecological Zone

This zone contains several common tree species that are obligate seeders that do not regenerate well post-fire, with a preference for organic seedbeds in shade or partial shade: Sitka Spruce *(Picea sitchensis)*, Western Hemlock *(Tsuga heterophylla)*, Port Orford-Cedar *(Chamaecyparis lawsoniana)*, Grand Fir *(Abies grandis)*, Western Redcedar *(Thuja plicata)*. Both Red Alder *(Alnus rubra)* and Douglas-Fir *(Pseudotsuga menziesii)* regenerate well post-fire; Red Alder is a facultative sprouter whereas Douglas-Fir is a fire-enhanced obligate seeder.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Cupressus goveniana ssp. pygmaea	Pygmy Cypress	Killed	Dead	Enhanced Recruitment
Cupressus goveniana ssp. pygmaea	Pygmy Cypress	Survive	Non-Sprouter	Enhanced Recruitment
Cupressus goveniana ssp. pygmaea	Pygmy Cypress	Killed	Dead	Enhanced Recruitment
Pinus contorta ssp. bolanderi	Bolander Pine	Killed	Dead	Enhanced Recruitment
Pinus contorta ssp. bolanderi	Bolander Pine	Survive	Non-Sprouter	Enhanced Recruitment
Pinus contorta ssp. bolanderi	Bolander Pine	Killed	Dead	Enhanced Recruitment
Pinus contorta ssp. contorta	Beach Pine	Killed	Dead	Enhanced Recruitment
Pinus contorta ssp. contorta	Beach Pine	Survive	Non-Sprouter	Enhanced Recruitment
Pinus contorta ssp. contorta	Beach Pine	Killed	Dead	Neutral
Pinus muricata	Bishop Pine	Killed	Dead	Enhanced Release
Pinus muricata	Bishop Pine	Survive	Non-Sprouter	Enhanced Release
Pinus muricata	Bishop Pine	Killed	Dead	Enhanced Recruitment

263A.4 Redwood Forest Ecological Zone

In this zone Redwood *(Sequoia sempervirens)* dominates as a fire-enhanced facultative sprouter; seedling establishment is problematic in the absence of fire or other disturbance that provides increased sunlight and an exposed mineral soil.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Sequoia sempervirens	Coastal Redwood	Survive	Sprouter	Enhanced Recruitment

263A.5 Douglas-Fir Tanoak Forest Ecological Zone

This zone comprises a variety of conifers and hardwood trees. Several hardwoods can resprout post-fire including Tanoak *(Lithocarpus densiflora)*, Pacific Madrone *(Arbutus menziesii)*, Oregon White Oak *(Quercus garryana)*, California Black Oak *(Quercus kelloggii)*, Golden Chinquapin *(Chrysolepis chrysophylla)*, Bigleaf Maple *(Acer macrophyllum)*, California Bay *(Umbellularia californica)*, and Canyon Live Oak *(Quercus chrysolepis)*.

The conifers Ponderosa Pine *(Pinus ponderosa)*, White Fir *(Abies concolor)*, Sugar Pine *(Pinus lambertiana)*, Incense Cedar *(Calocedrus decurrens)* and Douglas-Fir *(Pseudotsuga menziesii)* are obligate seeders. Douglas Fir reproduction is enhanced after low intensity fire when mineral soil is exposed.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Acer macrophyllum	Bigleaf Maple	Top-Killed	Sprouter	Neutral
Arbutus menziesii	Pacific Madrone	Top-Killed	Sprouter	Enhanced Recruitment
Chrysolepis chrysophylla	Golden Chinquapin	Top-Killed	Sprouter	Neutral
Lithocarpus densiflorus	Tanoak	Top-Killed	Sprouter	Neutral
Pseudotsuga menziesii var. menziesii	Douglas-fir	Survive	Non-Sprouter	Enhanced Recruitment
Quercus chrysolepis	Canyon Live Oak	Top-Killed	Sprouter	Neutral
Quercus garryana	Oregon White Oak	Top-Killed	Sprouter	Enhanced Recruitment
Quercus kelloggii	California Black Oak	Top-Killed	Sprouter	Enhanced Recruitment
Umbellularia californica	California Bay	Top-Killed	Sprouter	Neutral

263A.6 Oregon White Oak Woodland Ecological Zone

The hardwoods Oregon White Oak *(Quercus garryana)*, California Black Oak *(Quercus kelloggii)*, and Blue Oak *(Quercus douglasi)* are frequently top-killed by fire and can vigorously resprout, more so in youth. Seedling establishment is enhanced by the removal of litter.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Acer macrophyllum	Bigleaf Maple	Top-Killed	Sprouter	Neutral
Arbutus menziesii	Pacific Madrone	Top-Killed	Sprouter	Enhanced Recruitment
Chrysolepis chrysophylla	Golden Chinquapin	Top-Killed	Sprouter	Neutral
Lithocarpus densiflorus	Tanoak	Top-Killed	Sprouter	Neutral
Pseudotsuga menziesii var. menziesii	Douglas-fir	Survive	Non-Sprouter	Enhanced Recruitment
Quercus chrysolepis	Canyon Live Oak	Top-Killed	Sprouter	Neutral
Quercus garryana	Oregon White Oak	Top-Killed	Sprouter	Enhanced Recruitment
Quercus kelloggii	California Black Oak	Top-Killed	Sprouter	Enhanced Recruitment
Umbellularia californica	California Bay	Top-Killed	Sprouter	Neutral

BIOREGION > **Klamath Mountains**

USFS Section M261A > **Klamath Mountains**

LRR A MLRA 5 > **Siskiyou-Trinity Area**

The Klamath Mountains are an area of exceptional floristic diversity and complexity in vegetative patterns. Vegetation and species diversity generally increases with distance from the coast and species diversity is highest in woodlands with a highly developed herb stratum. Ecological zones presented herein represent broad elevational changes and by no means reflects the complex heterogeneity of the region's vegetation.

M261A.1 Lower-Montane Ecological Zone

This zone is dominated by shrublands and woodlands with a high diversity of species including many that resprout including Chamise *(Adenostoma fasciculatum)*, Greenleaf Manzanita *(Arctostaphylos patula)*, Canyon Live Oak *(Quercus chrysolepis)*, California Black Oak *(Quercus kelloggii)*, Brewer Oak *(Quercus garryana breweri)*, Birch-Leaf Mountain-Mahogany *(Cercocarpus betuloides)*, Holly-Leaf Redberry *(Rhamnus ilicifolia)*, California Buckeye *(Aesculus californica)*, California Bay *(Umbellularia californica)*, Brewer Oak *(Quercus garryana breweri)*, Deerbrush *(Ceanothus integerrimus)*, Poison Oak *(Toxicodendron diversilobum)*, Snowdrop Bush *(Styrax officinalis)*, Foothill Ash *(Fraxinus dipetala)*, and Redbud *(Cercis occidentalis)*. Plants that do not resprout, regenerating only from a seedbank include Buck Brush *(Ceanothus cuneatus)*, Whiteleaf Manzanita *(Arctostaphylos viscida)*, Douglas-Fir *(Pseudotsuga menziesii)*, Ponderosa Pine *(Pinus ponderosa)*, Jeffrey Pine *(Pinus jeffreyi)*, and Sugar Pine *(Pinus lambertiana)*.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Adenostoma fasciculatum	Chamise	Top-Killed	Sprouter	Enhanced Recruitment
Aesculus californica	California Buckeye	Top-Killed	Sprouter	Neutral
Alnus rhombifolia	White Alder	Top-Killed	Sprouter	Neutral
Arctostaphylos patula	Greenleaf Manzanita	Top-Killed	Sprouter	Enhanced Recruitment
Arctostaphylos viscida	Whiteleaf Manzanita	Killed	Dead	Enhanced Recruitment
Ceanothus cuneatus var. cuneatus	Buck Brush	Killed	Dead	Enhanced Recruitment
Ceanothus integerrimus	Deer Brush	Top-Killed	Sprouter	Enhanced Recruitment
Ceanothus lemmonii	Lemmon's Ceanothus	Top-Killed	Sprouter	Neutral
Ceanothus prostratus	Mahala Mat	Top-Killed	Sprouter	Enhanced Recruitment
Cercis occidentalis	Redbud	Top-Killed	Sprouter	Unknown
Cercocarpus betuloides var. betuloides	Birch-leaf Mountain-mahogany	Top-Killed	Sprouter	Neutral
Fraxinus dipetala	Foothill Ash	Top-Killed	Sprouter	Neutral
Fraxinus latifolia	Oregon Ash	Top-Killed	Sprouter	Neutral
Lithocarpus densiflorus	Tanoak	Top-Killed	Sprouter	Neutral
Lithocarpus densiflorus var. echinoides	Shrub Tanoak	Top-Killed	Sprouter	Neutral
Philadelphus lewisii	Wild Mock Orange	Top-Killed	Sprouter	Neutral
Pinus attenuata	Knobcone Pine	Killed	Dead	Enhanced Release
Pinus jeffreyi	Jeffrey Pine	Killed	Dead	Enhanced Recruitment
Pinus jeffreyi	Jeffrey Pine	Survive	Non-Sprouter	Enhanced Recruitment
Pinus lambertiana	Sugar Pine	Killed	Dead	Neutral
Pinus lambertiana	Sugar Pine	Survive	Non-Sprouter	Neutral

M261A.1 Lower-Montane Ecological Zone (cont'd)

Pinus ponderosa	Ponderosa Pine	Killed	Dead	Enhanced Recruitment
Pinus ponderosa	Ponderosa Pine	Survive	Non-Sprouter	Enhanced Recruitment
Pinus sabiniana	Foothill Pine	Killed	Dead	Enhanced Release
Pinus sabiniana	Foothill Pine	Survive	Non-Sprouter	Enhanced Release
Populus fremontii	Fremont Cottonwood	Top-Killed	Sprouter	Neutral
Pseudotsuga menziesii var. menziesii	Douglas-fir	Killed	Dead	Enhanced Recruitment
Pseudotsuga menziesii var. menziesii	Douglas-fir	Survive	Non-Sprouter	Enhanced Recruitment
Quercus chrysolepis	Canyon Live Oak	Top-Killed	Sprouter	Neutral
Quercus garryana var. breweri	Brewer Oak	Top-Killed	Sprouter	Neutral
Quercus kelloggii	California Black Oak	Top-Killed	Sprouter	Enhanced Recruitment
Rhamnus ilicifolia	Holly-leaf Redberry	Top-Killed	Sprouter	Neutral
Styrax officinalis	Snowdrop Bush	Top-Killed	Sprouter	Neutral
Toxicodendron diversilobum	Poison Oak	Top-Killed	Sprouter	Neutral
Umbellularia californica	California Bay	Top-Killed	Sprouter	Neutral

M261A.2 Mid- to Upper-Montane Ecological Zone

All dominant shrubs sprout vigorously if top-killed. Those with improved post-fire seed germination include Tobacco Brush *(Ceanothus velutinus)*, Greenleaf Manzanita *(Arctostaphylos patula)*, and Mahala Mat *(Ceanothus prostratus)*. Those without a seeding response include Bush Chinquapin *(Chrysolepis sempervirens)*, Shrub Tanoak *(Lithocarpus densiflorus echinoides)*, Huckleberry Oak *(Quercus vaccinifolia)*, California Buckeye *(Aesculus californica)*, Wild Mock Orange *(Philadelphus lewisii)*, Vine Maple *(Acer circinatum)*, and Mountain Maple *(Acer glabrum)*. Hardwood trees that are top-killed and resprout after fire include Bigleaf Maple *(Acer macrophyllum)*, Tanoak *(Lithocarpus densiflorus)*, Canyon Live Oak *(Quercus chrysolepis)*, California Black Oak *(Quercus kelloggii)*, Blue Oak *(Quercus douglasii)*, Pacific Madrone *(Arbutus menziesii)*, and Golden Chinquapin *(Chrysolepis chrysophylla)*. In addition, Oregon White Oak *(Quercus garryana)* has improved seedling recruitment. Curl-Leaf Mountain-Mahogany *(Cercocarpus ledifolius)* is often killed by fire with no change in seedling recruitment. None of the conifers in this zone resprout. Incense Cedar *(Calocedrus decurrens)*, Sugar Pine *(Pinus lambertiana)*, Western White Pine *(Pinus monticola)*, and Western Juniper *(Juniperus occidentalis)* may survive low intensity fire or succumb to one of high intensity without an enhanced seedling recruitment. Douglas-Fir *(Pseudotsuga menziesii)*, Ponderosa Pine *(Pinus ponderosa)* and Jeffreyi Pine *(Pinus jeffreyi)* benefit from enhanced seedling establishment after fire.

BIOREGION >

Klamath Mountains

USFS Section M261A > **Klamath Mountains**

LRR A MLRA 5 > **Siskiyou-Trinity Area**

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Abies magnifica var. magnifica	California Red Fir	Survive	Non-Sprouter	Neutral
Abies magnifica var. magnifica	California Red Fir	Killed	Dead	Neutral
Acer circinatum	Vine Maple	Top-Killed	Sprouter	Neutral
Acer glabrum	Mountain Maple	Top-Killed	Sprouter	Neutral
Acer macrophyllum	Bigleaf Maple	Top-Killed	Sprouter	Neutral
Aesculus californica	California Buckeye	Top-Killed	Sprouter	Neutral
Alnus rhombifolia	White Alder	Top-Killed	Sprouter	Neutral
Arbutus menziesii	Pacific Madrone	Top-Killed	Sprouter	Neutral
Arctostaphylos patula	Greenleaf Manzanita	Top-Killed	Sprouter	Enhanced Recruitment
Betula occidentalis	Water Birch	Top-Killed	Sprouter	Neutral
Calocedrus decurrens	Incense-cedar	Survive	Non-Sprouter	Neutral
Calocedrus decurrens	Incense-cedar	Killed	Dead	Neutral
Ceanothus prostratus	Mahala Mat	Top-Killed	Sprouter	Enhanced Recruitment
Ceanothus velutinus var. velutinus	Tobacco Brush	Top-Killed	Sprouter	Enhanced Recruitment
Cercocarpus ledifolius	Curl-leaf Mountain-mahogany	Killed	Dead	Neutral
Chamaecypatis lawsoniana	Port Orford-cedar	Survive	Non-Sprouter	Neutral
Chamaecypatis lawsoniana	Port Orford-cedar	Killed	Dead	Neutral
Chrysolepis chrysophylla	Golden Chinquapin	Top-Killed	Sprouter	Neutral
Chrysolepis sempervirens	Bush Chinquapin	Top-Killed	Sprouter	Neutral
Cornus nuttallii	Mountain Dogwood	Top-Killed	Sprouter	Neutral
Fraxinus latifolia	Oregon Ash	Top-Killed	Sprouter	Neutral
Juniperus occidentalis ssp. occidentalis	Western Juniper	Survive	Non-Sprouter	Neutral
Juniperus occidentalis ssp. occidentalis	Western Juniper	Killed	Dead	Neutral
Lithocarpus densiflorus	Tanoak	Top-Killed	Sprouter	Neutral
Lithocarpus densiflorus var. echinoides	Shrub Tanoak	Top-Killed	Sprouter	Neutral
Philadelphus lewisii	Wild Mock Orange	Top-Killed	Sprouter	Neutral
Picea breweriana	Brewer Spruce	Killed	Dead	Neutral
Pinus attenuata	Knobcone Pine	Killed	Dead	Enhanced Release
Pinus contorta var. murrayana	Lodgepole Pine	Killed	Dead	Neutral
Pinus jeffreyi	Jeffrey Pine	Survive	Non-Sprouter	Enhanced Recruitment
Pinus jeffreyi	Jeffrey Pine	Killed	Dead	Enhanced Recruitment
Pinus lambertiana	Sugar Pine	Survive	Non-Sprouter	Neutral
Pinus lambertiana	Sugar Pine	Killed	Dead	Neutral
Pinus monticola	Western White Pine	Survive	Non-Sprouter	Neutral
Pinus monticola	Western White Pine	Killed	Dead	Neutral
Pinus ponderosa	Ponderosa Pine	Survive	Non-Sprouter	Enhanced Recruitment
Pinus ponderosa	Ponderosa Pine	Killed	Dead	Enhanced Recruitment
Pinus sabiniana	Foothill Pine	Survive	Non-Sprouter	Enhanced Release
Pinus sabiniana	Foothill Pine	Killed	Dead	Enhanced Release
Pseudotsuga menziesii var. menziesii	Douglas-fir	Survive	Non-Sprouter	Enhanced Recruitment
Pseudotsuga menziesii var. menziesii	Douglas-fir	Killed	Dead	Enhanced Recruitment
Quercus chrysolepis	Canyon Live Oak	Top-Killed	Sprouter	Neutral
Quercus douglasii	California Blue Oak	Top-Killed	Sprouter	Neutral
Quercus garryana	Oregon White Oak	Top-Killed	Sprouter	Enhanced Recruitment
Quercus kelloggii	California Black Oak	Top-Killed	Sprouter	Neutral
Quercus vaccinifolia	Huckleberry Oak	Top-Killed	Sprouter	Neutral
Tsuga mertensiana	Mountain Hemlock	Survive	Non-Sprouter	Neutral
Tsuga mertensiana	Mountain Hemlock	Killed	Dead	Neutral

M261A.3 Subalpine Ecological Zone

Most trees at this elevation succomb to fire including Mountain Hemlock *(Tsuga mertensiana)*, Shasta Red Fir *(Abies magnifica shastensis)*, Whitebark Pine *(Pinus albicaulis)*, Foxtail Pine *(Pinus balfouriana)*, and Lodgepole Pine *(Pinus contorta murrayana)*and Curl-leaf Mountain-Mahogany. None sprout and none benefit from improved recruitment following fire.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Abies magnifica var. magnifica	California Red Fir	Survive	Non-Sprouter	Neutral
Abies magnifica var. magnifica	California Red Fir	Killed	Dead	Neutral
Cercocarpus ledifolius	Curl-leaf Mountain-mahogany	Killed	Dead	Neutral
Pinus albicaulis	Whitebark Pine	Survive	Non-Sprouter	Neutral
Pinus albicaulis	Whitebark Pine	Killed	Dead	Neutral
Pinus balfouriana spp. balfouriana	Foxtail Pine	Survive	Non-Sprouter	Neutral
Pinus balfouriana spp. balfouriana	Foxtail Pine	Killed	Dead	Neutral
Pinus contorta var. murrayana	Lodgepole Pine	Killed	Dead	Neutral
Pinus jeffreyi	Jeffrey Pine	Survive	Non-Sprouter	Neutral
Pinus jeffreyi	Jeffrey Pine	Killed	Dead	Neutral
Pinus monticola	Western White Pine	Survive	Non-Sprouter	Neutral
Pinus monticola	Western White Pine	Killed	Dead	Neutral
Tsuga mertensiana	Mountain Hemlock	Survive	Non-Sprouter	Neutral
Tsuga mertensiana	Mountain Hemlock	Killed	Dead	Neutral

BIOREGION > **Southern Cascades**

USFS Section M261D > **Southern Cascades**

LRR D MLRA 21 > **Klamath and Shasta Valleys and Basins**

South of the latitude of Mt. Shasta, vegetational composition and species dominance in the lower and mid-montane zones is similar to that in the northern Sierra Nevada, but the upper montane and subalpine zones are more similar to the Klamath Mountains and northern Cascades. When compared to the Sierra Nevada, vegetational composition in the Cascades is more strongly controlled by local topography and substrate and less so by elevation. Open woodlands, shrublands, and areas of sparse vegetation occur over wide areas on harsh sites. North of Mt. Shasta, in the rainshadow of the Klamath Mountains, the vegetation of the west side of the Cascades resembles vegetation more characteristic of the drier east side east side. Lower elevations on both sides are dominated by grasslands, shrublands, and woodlands.

M261D.1 Mid-Montane Westside Ecological Zone

Most information on fire ecology available for this zone concerns woody plants in conifer-dominated landscapes. When mature, the more common conifer species, Ponderosa Pine *(Pinus ponderosa)*, Douglas-Fir *(Pseudotsuga menziesii)*, Incense Cedar *(Calocedrus decurrens)*, Sugar Pine *(Pinus lambertiana)*, Jeffrey Pine *(Pinus jeffeyi)*, White Fir *(Abies concolor)*, survive low to moderate intensity fires. All of the common deciduous hardwoods, California Black Oak *(Quercus kelloggii)*, Big-Leaf Maple *(Acer macrophyllum)*, Mountain Dogwood *(Cornus nuttallii)*, Canyon Live Oak *(Quercus chrysolepis)* survive low to moderately intense fires by vigorously resprouting if top-killed. With few exceptions, the more common shrubs, Greenleaf Manzanita *(Arctostaphylos patula)*, Deer Brush *(Ceanothus integerrimus)*, Tobacco Brush *(Ceanothus velutinus)* reproduce from seed as well as sprout vigorously if top-killed. In contrast, Whiteleaf Manzanita *(Arctostaphylos viscida)* is killed by even low intensity fires, relying entirely on germination from a dormant seed bank to re-establish.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Abies concolor	White Fir	Killed	Dead	Neutral
Abies concolor	White Fir	Survive	Non-Sprouter	Neutral
Acer circinatum	Vine Maple	Top-Killed	Sprouter	Neutral
Acer glabrum	Mountain Maple	Top-Killed	Sprouter	Neutral
Acer macrophyllum	Bigleaf Maple	Top-Killed	Sprouter	Neutral
Alnus rhombifolia	White Alder	Top-Killed	Sprouter	Neutral
Arctostaphylos patula	Greenleaf Manzanita	Top-Killed	Sprouter	Enhanced Recruitment
Calocedrus decurrens	Incense-cedar	Survive	Non-Sprouter	Neutral
Calocedrus decurrens	Incense-cedar	Killed	Dead	Neutral
Ceanothus cuneatus var. cuneatus	Buck Brush	Killed	Dead	Enhanced Recruitment
Ceanothus integerrimus	Deer Brush	Top-Killed	Sprouter	Enhanced Recruitment
Ceanothus lemmonii	Lemmon's Ceanothus	Top-Killed	Sprouter	Neutral
Ceanothus prostratus	Mahala Mat	Top-Killed	Sprouter	Enhanced Recruitment
Ceanothus velutinus var. velutinus	Tobacco Brush	Top-Killed	Sprouter	Enhanced Recruitment
Cercocarpus betuloides var. betuloides	Birch-leaf Mountain-mahogany	Top-Killed	Sprouter	Neutral
Cercocarpus ledifolius	Curl-leaf Mountain-mahogany	Killed	Dead	Enhanced Recruitment
Chrysolepis sempervirens	Bush Chinquapin	Top-Killed	Sprouter	Neutral
Cornus nuttallii	Mountain Dogwood	Top-Killed	Sprouter	Neutral
Cupressus bakeri	Modoc Cypress	Killed	Dead	Enhanced Release
Fraxinus latifolia	Oregon Ash	Top-Killed	Sprouter	Neutral
Juniperus occidentalis ssp. occidentalis	Western Juniper	Killed	Dead	Neutral
Juniperus occidentalis ssp. occidentalis	Western Juniper	Survive	Non-Sprouter	Neutral
Lithocarpus densiflorus var. echinoides	Shrub Tanoak	Top-Killed	Sprouter	Neutral
Pinus attenuata	Knobcone Pine	Killed	Dead	Enhanced Release
Pinus jeffreyi	Jeffrey Pine	Survive	Non-Sprouter	Enhanced Recruitment
Pinus jeffreyi	Jeffrey Pine	Killed	Dead	Enhanced Recruitment
Pinus lambertiana	Sugar Pine	Killed	Dead	Neutral
Pinus lambertiana	Sugar Pine	Survive	Non-Sprouter	Neutral
Pinus ponderosa	Ponderosa Pine	Survive	Non-Sprouter	Enhanced Recruitment
Pinus ponderosa	Ponderosa Pine	Killed	Dead	Enhanced Recruitment
Populus tremuloides	Quaking Aspen	Top-Killed	Sprouter	Neutral
Pseudotsuga menziesii var. menziesii	Douglas-fir	Survive	Non-Sprouter	Enhanced Recruitment
Pseudotsuga menziesii var. menziesii	Douglas-fir	Killed	Dead	Enhanced Recruitment
Quercus chrysolepis	Canyon Live Oak	Top-Killed	Sprouter	Neutral
Quercus garryana	Oregon White Oak	Top-Killed	Sprouter	Enhanced Recruitment
Quercus kelloggii	California Black Oak	Top-Killed	Sprouter	Neutral
Taxus brevifolia	Pacific Yew	Killed	Dead	Neutral

M261D.2 Low- to Mid-Montane Eastside Ecological Zone

When mature most of the common conifer species, Jeffrey Pine *(pinus jeffreyi)*, Ponderosa Pine *(Pinus ponderosa)*, Incense Cedar *(Calocedrus decurrens)*, White Fir *(Abies concolor)*, survive low to moderate intensity fires. Western Juniper *(Juniperus occidentalis)* is less resistant. Three conifers that occur in small, widely scattered groves, Knobcone Pine *(Pinus attenuata)*, MacNab Cypress *(Cupresus macnabiana)*, and Modoc Cypress *(Cupressus bakeri)*, all have serotinous cones, requiring occasional crown fires to effect regeneration from seed. Most common hardwoods, Oregon White Oak *(Quercus garryana)*, Quaking Aspen *(Populus tremuloides)*, California Black Oak *(Quercus kelloggii)* resprout vigorously if top-killed. However, the shrubs Curl-Leaf Mountain-Mahogany *(Cercocarpus ledifolius)* and Buck Brush *(Ceanothus cuneatus)* are easily killed and must re-establish exclusively from seed; germination of Buck Brush is stimulated by fire. Prevalent understory shrubs, Mahala Mat *(Ceanothus prostratus)*, Mountain Misery *(Chamaebatia foliolosa)* are stimulated to sprout if top-killed. Seed germination of Mahala Mat is also stimulated by fire.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Ceanothus cuneatus var. cuneatus	Buck Brush	Killed	Dead	Enhanced Recruitment
Ceanothus prostratus	Mahala Mat	Top-Killed	Sprouter	Enhanced Recruitment
Cercocarpus ledifolius	Curl-leaf Mountain-mahogany	Killed	Dead	Enhanced Recruitment
Chamaebatia foliolosa	Mountain Misery	Top-Killed	Sprouter	Neutral
Chrysothamnus nauseosus	Rubber Rabbitbrush	Top-Killed	Sprouter	Neutral
Juniperus occidentalis ssp. occidentalis	Western Juniper	Killed	Dead	Neutral
Juniperus occidentalis ssp. occidentalis	Western Juniper	Survive	Non-Sprouter	Neutral
Pinus ponderosa	Ponderosa Pine	Killed	Dead	Neutral
Pinus ponderosa	Ponderosa Pine	Survive	Non-Sprouter	Neutral
Pinus sabiniana	Foothill Pine	Killed	Dead	Enhanced Release
Pinus sabiniana	Foothill Pine	Survive	Non-Sprouter	Enhanced Release
Purshia tridentata	Antelope Bitterbrush	Top-Killed	Sprouter	Neutral
Quercus garryana	Oregon White Oak	Top-Killed	Sprouter	Enhanced Recruitment
Quercus kelloggii	California Black Oak	Top-Killed	Sprouter	Neutral

BIOREGION > **Southern Cascades**

USFS Section M261D > **Southern Cascades**

LRR D MLRA 21 > **Klamath and Shasta Valleys and Basins**

M261D.3 Upper-Montane Ecological Zone

When mature, the common conifers, Jeffrey Pine *(Pinus jeffreyi)*, Ponderosa Pine *(Pinus ponderosa)*, White Fir *(Abies concolor)*, Red Fir *(Abies magnifica)*, and Western White Pine *(Pinus monticola)*, all exhibit some degree of resistance to low intensity fires. Lodgepole Pine *(Pinus contorta murrayana)* is not resistant to fire. Hardwood trees, Quaking Aspen *(Populus tremuloides)*, Willows *(Salix spp.)*, and Black Cottonwood *(Populus balsamifera trichocarpa)*, will sprout if top-killed. Nearly all dominant woody species, Bush Chinquapin *(Chrysolepis sempervirens)*, Huckleberry Oak *(Quercus vaccinifolia)*, Bitter Cherry *(Prunus emarginata)*, Rubber Rabbitbrush *(Chrysothamnus nauseosus)*, Tobacco Brush *(Ceanothus cuneatus)*, Greenleaf Manzanita *(Arctostaphylos patula)* sprout following fires if top-killed. Some also germinate from a dormant seed bank include Bush Chinqapin *(Chrysolepis sempervirens)*, *(Tobacco Brush (Ceanothus cuneatus)*, Greenleaf Manzanita *(Arctostaphylos patula)*, Mountain Whitethorn *(Ceanothus cordulatus)*, Deer Brush *(Ceanothus integerrimus)*, and Pinemat Manzanita *(Arctostaphylos nevadensis)*. Big Sagebrush *(Artemisia tridentata)* is killed by fire without a respout response nor seedling recruitment.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Abies concolor	White Fir	Killed	Dead	Neutral
Abies concolor	White Fir	Survive	Non-Sprouter	Neutral
Abies magnifica var. magnifica	California Red Fir	Killed	Dead	Neutral
Abies magnifica var. magnifica	California Red Fir	Survive	Non-Sprouter	Neutral
Arctostaphylos nevadensis	Pinemat Manzanita	Top-Killed	Dead	Enhanced Recruitment
Arctostaphylos patula	Greenleaf Manzanita	Top-Killed	Sprouter	Enhanced Recruitment
Artemisia tridentata	Big Sagebrush	Killed	Dead	Neutral
Ceanothus cordulatus	Mountain Whitethorn	Top-Killed	Sprouter	Enhanced Recruitment
Ceanothus integerrimus	Deer Brush	Top-Killed	Sprouter	Enhanced Recruitment
Ceanothus velutinus var. velutinus	Tobacco Brush	Top-Killed	Sprouter	Enhanced Recruitment
Chrysolepis sempervirens	Bush Chinquapin	Top-Killed	Sprouter	Enhanced Recruitment
Chrysothamnus nauseosus	Rubber Rabbitbrush	Top-Killed	Sprouter	Neutral
Pinus contorta var. murrayana	Lodgepole Pine	Killed	Dead	Neutral
Pinus jeffreyi	Jeffrey Pine	Killed	Dead	Neutral
Pinus jeffreyi	Jeffrey Pine	Survive	Non-Sprouter	Neutral
Pinus monticola	Western White Pine	Killed	Dead	Neutral
Pinus monticola	Western White Pine	Survive	Non-Sprouter	Neutral
Pinus ponderosa	Ponderosa Pine	Killed	Dead	Neutral
Pinus ponderosa	Ponderosa Pine	Survive	Non-Sprouter	Neutral
Populus balsamifera ssp. trichocarpa	Black Cottonwood	Top-Killed	Sprouter	Neutral
Populus tremuloides	Quaking Aspen	Top-Killed	Sprouter	Neutral
Prunus emarginata	Bitter Cherry	Top-Killed	Sprouter	Neutral
Quercus vaccinifolia	Huckleberry Oak	Top-Killed	Sprouter	Neutral
Salix spp.	Willow	Top-Killed	Sprouter	Neutral

BIOREGION > **Southern Cascades**

USFS Section M261F > **Sierra Nevada Foothills**

LRR C MLRA 18 > **Sierra Nevada Foothills**

M261F.1 Southwestern Foothills Ecological Zone

Most of the shrubs and hardwood trees in the foothills sprout following fire. These include Scrub Oak *(Quercus berberidifolia)*, Interior Live Oak *(Quercus wislizenii)*, Birch-leaf Mountain-Mahogany *(Cercocarpus betuloides)*, Yerba Santa *(Eriodictyon californicum)*, Bearbrush *(Garrya fremontii)*, Flannelbush *(Fremontodendron californicum)*, California Buckeye *(Aesculus californica)*, Poison Oak *(Toxicodendron diversilobum)*, and California Bay *(Umbellularia californica)*. Plant regeneration from the soil seedbank includes Buck Brush *(Ceanothus cuneatus)*, Whiteleaf Manzanita *(Arctostaphylos viscida)*, and Common Manzanita *(Arctostaphylos manzanita)*. When top-killed, California Black Oak *(Quercus kelloggii)* sprouts vigorously and Foothill Pine *(Pinus sabiniana)* is semi-serotinous, promoting seedling recruitment post-fire. Ponderosa Pine may survive low intensity fires while succombing to those of high intensity; it neither sprouts nor gains a recruitment advantage here. California Nutmeg *(Torreya californica)* can support resprout, but gains no seed recruitment advantage in the post-fire environment.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Acer macrophyllum	Bigleaf Maple	Top-Killed	Sprouter	Neutral
Aesculus californica	California Buckeye	Top-Killed	Sprouter	Neutral
Arctostaphylos manzanita	Common Manzanita	Killed	Dead	Enhanced Recruitment
Arctostaphylos viscida	Whiteleaf Manzanita	Killed	Dead	Enhanced Recruitment
Calocedrus decurrens	Incense-cedar	Killed	Dead	Neutral
Calocedrus decurrens	Incense-cedar	Survive	Non-Sprouter	Neutral
Ceanothus cuneatus var. cuneatus	Buck Brush	Killed	Dead	Enhanced Recruitment
Ceanothus lemmonii	Lemmon's Ceanothus	Top-Killed	Sprouter	Neutral
Cercocarpus betuloides var. betuloides	Birch-leaf Mountain-mahogany	Top-Killed	Sprouter	Neutral
Cornus nuttallii	Mountain Dogwood	Top-Killed	Sprouter	Neutral
Eriodictyon californicum	Yerba Santa	Top-Killed	Sprouter	Neutral
Fraxinus dipetala	Foothill Ash	Top-Killed	Sprouter	Neutral
Fremontodendron californicum	Flannelbush	Top-Killed	Sprouter	Neutral
Garrya fremontii	Bearbrush	Top-Killed	Sprouter	Neutral
Heteromeles arbutifolia	Toyon, Chaparral Holly	Top-Killed	Sprouter	Neutral
Juniperus califomica	California Juniper	Killed	Dead	Neutral
Juniperus califomica	California Juniper	Survive	Non-Sprouter	Neutral
Pinus ponderosa	Ponderosa Pine	Killed	Dead	Neutral
Pinus ponderosa	Ponderosa Pine	Survive	Non-Sprouter	Neutral
Pinus sabiniana	Foothill Pine	Survive	Non-Sprouter	Enhanced Release
Pinus sabiniana	Foothill Pine	Killed	Dead	Enhanced Release
Populus fremontii	Fremont Cottonwood	Top-Killed	Sprouter	Neutral
Quercus berberidifolia	Scrub Oak	Top-Killed	Sprouter	Neutral
Quercus chrysolepis	Canyon Live Oak	Top-Killed	Sprouter	Neutral
Quercus douglasii	California Blue Oak	Top-Killed	Sprouter	Neutral
Quercus kelloggii	California Black Oak	Top-Killed	Sprouter	Neutral
Quercus lobata	Valley Oak	Top-Killed	Sprouter	Neutral
Quercus wislizenii	Interior Live Oak	Top-Killed	Sprouter	Neutral
Torreya californica	California Nutmeg	Survive	Sprouter	Neutral
Torreya californica	California Nutmeg	Top-Killed	Sprouter	Neutral
Torreya californica	California Nutmeg	Killed	Dead	Neutral
Toxicodendron diversilobum	Poison Oak	Top-Killed	Sprouter	Neutral
Umbellularia californica	California Bay	Top-Killed	Sprouter	Neutral

BIOREGION > **Northeastern Plateaus**

USFS Section 342B > **Northwestern Basin and Range**

LRR D MLRA 23 > **Malheur High Plateau**

Northeastern California landscape is a mixture of vast arid basins and uplands, and forested mountain ranges interspersed with both fresh water and alkaline wetlands. The topography is extremely abrupt and elevations can change quickly. Several vegetation zones occur in the Northeastern Plateaus Bioregion. The general sequence, from low to high elevation, include: sagebrush steppe, lower montane, mid-montane, upper montane, and subalpine.

342B.1 Sagebrush and Salt Deserts Ecological Zone

Numerous sagebrush taxa *(Artemisia spp.)* characterize this zone, accompanied by other shrubs, Junipers *(Juniperus occidentalis)*, Antelope Bitterbrush *(Purshia tridentata)*, Curl-Leaf Mountain-Mahogany *(Cercocarpus ledifolius)*, Rabbbitbrush *(Ericameria bloomeri)*, Horsebrush *(Tetradymia spp.)*, and an herbaceous component that includes both natives and non-natives. Pluvial valley bottoms are occupied by Greasewood *(Sarcobatus vermiculatus)*, Saltbush *(Atriplex spp.)*, Hop-Sage *(Grayia spinosa)*, and Winterfat *(Kraschennikovia lanata)*.

Shrubs across the region are composed of a mix of fire-tolerant and fire-intolerant species. Most species of sagebrush are easily killed by fire with re-establishment dependent upon an unburned seedbank. Two species, Silver Sagebrush *(Artemisia cana)* and Snowfield Sagebrush *(Artemisia spiciformis)*, can resprout if top-killed. Antelope Bitterbrush has a variable response to fire, but is a weak sprouter; the majority of shrub establishment occurs from soil seedbanks. Both Rubber Rabbitbush *(Chrysothamnus nauseosus)* and Yellow Rabbitbrush *(Chrysothamnus viscidiflorus)* and Horsebrush are capable of sprouting and more rapidly recovering immediately following fire than Big Sagebrush. Curl-leaf Mountain-Mahogany is a weak sprouter that is highly susceptible to fire; re-establishment is dependent on seedling establishment from a nearby seed source.

The bunchgrass component, Columbia Needlegrass *(Achnatherum occidentalis)*, Idaho Fescue *(Festuca idahoensis,)* Bluebunch Wheatgrass *(Pseudoroegneria spicata)*, Squirreltail *(Elymus elymoides)*, can recover rapidly in the more mesic sagebrush communities. In more arid areas recovery is slower. Perennial forb species which resprout from below ground from a caudex, corm, bulb, rhizome, or rootstock, usually exhibit rapid recovery following fire. Forbs that are suffrutescent or mat forming can be severely damaged by fire or suffer mortality. As with bunchgrasses, the forb response is slower in more arid environments.

In sites maintaining good condition, the largest increases in vegetation during the first several years following fires are often composed of native annuals, if sufficient moisture is available. However, annual response typically lasts only two to five growing seasons following a fire event. In heavily disturbed or warmer sites, the native annual response is replaced by introduced annuals and biennials, which dominate the site.

BIOREGION > **Northeastern Plateaus**

USFS Section 342B > **Northwestern Basin and Range**

LRR D MLRA 23 > **Malheur High Plateau**

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Achillea millifolium	Yarrow	Top-Killed	Sprouter	Neutral
Achnatherum lemmonii	Columbia Needlegrass	Top-Killed	Sprouter	Neutral
Achnatherum thurberianum	Thurber Needlegrass	Top-Killed	Sprouter	Neutral
Agoseris spp.	Agoseris	Top-Killed	Sprouter	Neutral
Allium spp.	Onion/garlic	Top-Killed	Sprouter	Neutral
Antennaria spp.	Pussy-toes	Killed	Dead	Neutral
Arenaria spp.	Sandwort	Killed	Dead	Neutral
Artemisia arbuscula	Low Sagebrush	Killed	Dead	Neutral
Artemisia nova	Black Sagebrush	Killed	Dead	Neutral
Artemisia tridentata	Big Sagebrush	Killed	Dead	Neutral
Aster spp.	Aster	Top-Killed	Sprouter	Neutral
Astragalus purshii	Woollypod Milkvetch	Top-Killed	Sprouter	Unknown
Astragalus spp.	Milkvetch	Top-Killed	Sprouter	Unknown
Atriplex canescens	Fourwing Saltbush	Killed	Dead	Neutral
Balsamorhiza spp.	Balsam-root	Top-Killed	Sprouter	Neutral
Castilleja spp.	Indian Paintbrush, Owl's -Clover	Top-Killed	Sprouter	Neutral
Cercocarpus ledifolius	Curl-leaf Mountain-mahogany	Top-Killed	Sprouter	Neutral
Cercocarpus ledifolius	Curl-leaf Mountain-mahogany	Killed	Dead	Neutral
Chrysothamnus nauseosus	Rubber Rabbitbrush	Top-Killed	Sprouter	Neutral
Chrysothamnus nauseosus	Rubber Rabbitbrush	Killed	Dead	Neutral
Chysothamnus viscidiflorus	Yellow Rabbitbrush	Top-Killed	Sprouter	Neutral
Crepis spp.	Hawksbeard	Top-Killed	Sprouter	Neutral
Elymus elymoides	Squirreltail	Top-Killed	Sprouter	Neutral
Erigeron spp.	Fleabane Daisy	Top-Killed	Sprouter	Neutral
Eriogonum douglasii	Douglas' Buckwheat	Killed	Dead	Neutral
Eriogonum heracleoides	Parsnipflower Buckwheat	Killed	Dead	Neutral
Eriogonum microthecum	Slender Buckwheat	Killed	Dead	Neutral
Eriogonum umbellatum	Sulfur Flower	Killed	Dead	Neutral
Festuca idahoensis	Idaho Fescue	Top-Killed	Sprouter	Neutral
Geranium spp.	Cranesbill, Geranium	Top-Killed	Sprouter	Neutral
Geum spp.	Avens	Top-Killed	Sprouter	Neutral
Grayia spinosa	Spiny Hopsage	Killed	Dead	Neutral
Lactuca serriola	Prickly Lettuce	Top-Killed	Sprouter	Neutral
Lomatium spp.	Lomatium	Top-Killed	Sprouter	Neutral
Lupinus spp.	Lupine	Top-Killed	Sprouter	Unknown
Mertensia spp.	Bluebells, Lungwort	Top-Killed	Sprouter	Neutral
Phlox gracilis	Slender Phlox	Top-Killed	Sprouter	Neutral
Phlox hoodii	Spiny Phlox	Killed	Dead	Neutral
Potentilla spp.	Cinquefoil	Top-Killed	Sprouter	Neutral
Pseudoroegneria spicata	Bluebunch Wheatgrass	Top-Killed	Sprouter	Neutral
Purshia tridentata	Antelope Bitterbrush	Killed	Dead	Neutral
Purshia tridentata	Antelope Bitterbrush	Top-Killed	Sprouter	Neutral
Ribes cereum	Wax Currant	Top-Killed	Sprouter	Neutral
Ribes velutinum	Desert Gooseberry	Top-Killed	Sprouter	Neutral
Rosa woodsii ssp. ultramontana	Interior Rose	Top-Killed	Sprouter	Neutral
Sarcobatus vermiculatus	Greasewood	Top-Killed	Sprouter	Neutral
Senecio intergerrimus	Lambstongue Ragwort	Top-Killed	Sprouter	Neutral
Solidago spp.	Goldenrod	Top-Killed	Sprouter	Neutral
Svmphoricarpos oreophilus	Mountain Snowberry	Top-Killed	Sprouter	Neutral
Taraxacum spp.	Dandelion	Top-Killed	Sprouter	Neutral
Tetradymia canescens	Cotton-thorn, Horsebrush	Top-Killed	Sprouter	Neutral
Tragopogon dubius	Goat's Beard	Top-Killed	Sprouter	Neutral
Ttifolium macrocephalum	Largehead Clover	Top-Killed	Sprouter	Neutral
Zigadenus paniculatus	Foothill Death Camas	Top-Killed	Sprouter	Neutral

Relative Response of Common Shrubs in the Sagebrush Biome and Salt Deserts to Fire

TOLERANT TO FIRE	MODERATELY TOLERANT TO FIRE	INTOLERANT TO FIRE
Yellow Rabbitbrush ***(s)***	Rubber Rabbitbrush ***(s)***	Low Sagebrush
Wax Currant ***(s)***		Big Sagebrush
Desert Gooseberry ***(s)***		Fourwing Saltbrush
Wood Rose ***(s)***		Curl-leaf Mountain Mahogany
Greasewood ***(s)***		Hop-Sage
Mountain Snowberry ***(s)***		Antelope Bitterbrush ***(ws)***
Horsebrush ***(s)***		

s =sprouter; ***ws***= weak sprouter; Derived from Blaisdell 1953, Wright et al. 1979.

Relative Response of Common Perennial Forbs in the Sagebrush Biome to Fire

NONE TO SLIGHT	MODERATE TO SEVERE
Agoseris *(Agoseris spp.)*	Douglas' Buckwheat *(Eriogonum douglasii)*
Aster *(Aster spp.)*	Matted Buckwheat *(Eriogonum caespitosum)*
Avens *(Geum macrophyllum)*	Parsnipflower Buckwheat *(Eriogonum heracleoides)*
Balsam-Root *(Balsamorhiza spp.)*	Pussy-toes *(Antennaria spp.)*
Bluebells *(Mertensia spp.)*	Sandwort *(Arenaria spp.)*
Cinquefoil *(Potentilla spp.)*	Slender Buckheat *(Eriogonum microthecum)*
Common Yarrow *(Achillea millefolium)*	Spiny Phlox *(Phlox hoodii)*
Dandelion *(Taraxacum spp.)*	Sulfur Flower *(Eriogonum umbellatum)*
Fleabane Daisy *(Erigeron spp.)*	
Foothill Death Camas *(Zigadenus paniculatus)*	
Geranium *(Geranium spp.)*	
Goat's Beard *(Tragopogon spp.)*	
Goldenrod *(Solidago spp.)*	
Hawksbeard *(Crepis spp.)*	
Indian Paintbrush *(Castilleja spp.)*	
Lambstongue Ragwort *(Senecio integerrimus)*	
Largehead Clover *(Trifolium macrocephalum)*	
Lomatium *(Lomatium spp.)*	
Lupine *(Lupinus spp.)*	
Milkvetch *(Astragalus spp.)*	
Onion *(Allium spp.)*	
Prickly Lettuce *(Lactuca serriola)*	
Slender Phlox *(Phlox gracilis)*	
Woollypod Milkvetch *(Astraglus purshii)*	

Derived from Blaisdell 1953; Pechanec et al. 1954; Lyon and Stickney 1976; Klebenow and Beall 1977; Wright et al. 1979; Volland and Dell 1981; Bradley et al. 1992.

M261G.1 Lower-Montane Ecological Zone

This zone is wetter and cooler than the sagebrush steppe. Common trees and shrubs include Ponderosa Pine *(Pinus ponderosa)*, Jeffrey Pine *(Pinus jeffreyi)*, Western Juniper *(Juniperus occidentalis)*, Incense-Cedar *(Calocedrus decurrens)*, California Black Oak *(Quercus kelloggii)*, Antelope Bitterbrush *(Purshia tridentata)*, Mountain Big Sagebrush *(Artemisia tridentata vaseyana)*, Low Sagebrush *(Artemisia arbuscula)*, Greenleaf Manzanita *(Arctostaphylos patula)*, Curl-Leaf Mountain-Mahogany *(Cercocarpus ledifolius)*, Utah Service-Berry *(Amelanchier utahensis)*, and Western Choke-Cherry *(Prunus virginiana)*.

Ponderosa Pine, Jeffrey Pine, and Incense-Cedar are resistant to low intensity fires; their seeds can germinate and grow on bare exposed mineral soil after a fire. California Black Oak resprouts when top-killed.

Utah Service-Berry is generally considered to be fire tolerant, although it may be slightly injured by fire. When top-killed it resprouts; it is also a prolific seed producer. Bitter Cherry *(Prunus emarginata)* and Modoc Plum *(Prunus subcordata)* will resprout when top-killed

Western Choke-cherry, Greenleaf Manzanita, and Mahala Mat *(Ceanothus prostratus)* resprouts when top-killed. Fire also improves recruitment of these species.

The herbaceous perennial understory, Wooly Mule's Ears *(Wyethia mollis)*, Arrowleaf Balsam-Root *(Balsamorhiza)*, Lambs Tongue Ragwort *(Senecio integerrimus)*, Tailcup Lupine *(Lupinus caudatus)*, Nevada Wild Pea *(Lathyrus lanszwertii)*, Nineleaf Biscuitroot *(Lomatium triternatum)*, Brown's Peony *(Paeonia brownii)*, Sticky Cinquefoil *(Potentilla glandulosa)*, Indian Paintbrush *(Castilleja spp.)*, Fireweed *(Epilobium angustifolium)*, Idaho Fescue *(Festuca idahoensis)*, Squirreltail *(Elymus elymoides)*, Ross' Sedge *(Carex rossii)*, Canby Bluebgrass *(Poa secunda secunda)*, is typically top-killed and resprouts.

BIOREGION > **Northeastern Plateaus**

USFS Section M261G > **Modoc Plateau**

LRR D MLRA 21 > **Klamath and Shasta Valleys and Basins**

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Amelanchier utahensis	Utah Service-berry	Top-Killed	Sprouter	Neutral
Arctostaphylos patula	Greenleaf Manzanita	Top-Killed	Sprouter	Enhanced Recruitment
Artemisia tridentata ssp. vaseyana	Mountain Big Sagebrush	Killed	Dead	Neutral
Balsamorhiza spp.	Balsam-root	Top-Killed	Sprouter	Neutral
Calocedrus decurrens	Incense-cedar	Survive	Non-Sprouter	Neutral
Calocedrus decurrens	Incense-cedar	Killed	Dead	Neutral
Carex rossii	Ross' Sedge	Top-Killed	Sprouter	Neutral
Castilleja spp.	Indian Paintbrush, Owl's -Clover	Top-Killed	Sprouter	Neutral
Ceanothus prostratus	Mahala Mat	Top-Killed	Sprouter	Enhanced Recruitment
Elymus elymoides	Squirreltail	Top-Killed	Sprouter	Neutral
Festuca idahoensis	Idaho Fescue	Top-Killed	Sprouter	Neutral
Juniperus occidentalis ssp. occidentalis	Western Juniper	Survive	Non-Sprouter	Enhanced Recruitment
Juniperus occidentalis ssp. occidentalis	Western Juniper	Killed	Dead	Enhanced Recruitment
Lathryus lanszwertii	Wild Pea, Nevada Pea	Top-Killed	Sprouter	Neutral
Lomatium spp.	Lomatium	Top-Killed	Sprouter	Neutral
Lupinus spp.	Lupine	Top-Killed	Sprouter	Neutral
Paeonia brownii	Brown's Peony	Top-Killed	Sprouter	Neutral
Pinus jeffreyi	Jeffrey Pine	Survive	Non-Sprouter	Enhanced Recruitment
Pinus jeffreyi	Jeffrey Pine	Killed	Dead	Enhanced Recruitment
Pinus ponderosa	Ponderosa Pine	Survive	Non-Sprouter	Enhanced Recruitment
Pinus ponderosa	Ponderosa Pine	Killed	Dead	Enhanced Recruitment
Poa secunda ssp. secunda	Sandberg/Canby/Pine/One-Sided	Top-Killed	Sprouter	Neutral
Prunus emarginata	Bitter Cherry	Top-Killed	Sprouter	Neutral
Prunus subcordata	Modoc Plum	Top-Killed	Sprouter	Neutral
Prunus virginiana var. demissa	Western Choke-cherry	Top-Killed	Sprouter	Enhanced Recruitment
Purshia tridentata	Antelope Bitterbrush	Killed	Dead	Neutral
Purshia tridentata	Antelope Bitterbrush	Top-Killed	Sprouter	Neutral
Quercus kelloggii	California Black Oak	Top-Killed	Sprouter	Neutral
Senecio intergerrimus	Lambstongue Ragwort	Top-Killed	Sprouter	Neutral
Wyethia mollis	Woolly Mule's Ears	Top-Killed	Sprouter	Neutral

M261G.2 Mid-Montane Ecological Zone

White Fir *(Abies concolor)* occurs mixed with Ponderosa Pine *(Pinus ponderosa)*, Jeffrey Pine *(Pinus jeffreyi)*, Incense-Cedar *(Calocedrus decurrens)*. Other trees and shrubs include Western Juniper *(Juniperus occidentalis)*, Quaking Aspen *(Populus tremuloides)*, California Black Oak *(Quercus kelloggii)*, Antelope Bitterbrush *(Purshia tridentata)*, Mountain Big Sagebrush *(Artemisia tridentata vaseyana)*, Low Sagebrush *(Artemisia arbuscula)*, Bitter Cherry *(Prunus emarginata)*, Western Choke Cherry *(Prunus virginiana)*, Modoc Plum *(Prunus subcordata)*, Utah Service-Berry *(Amelanchier utahensis)*, Roundleaf Snowberry *(Symphoricarpos rotundifolius)*, Greenleaf Manzanita *(Arctostaphylos patula)*, and Tobacco Brush *(Ceanothus velutinus)*.

Ponderosa Pine, Jeffrey Pine, Incense-Cedar, and White Fir all have some tolerance for low intensity fire as adults. When killed they neither resprout nor are stimulated in seed response, however, the ashy mineral soil left by a fire does benefit some seedling recruitment for Ponderosa and Jeffrey Pine. Following fire, Greenleaf Manzanita, Tobacco Brush, and Mahala Mat *(Ceanothus prostratus)* resprout prolifically and their soil seedbanks are stimulated. When top-killed, Bitter Cherry, Western Choke-Cherry, Modoc Plum, and Creeping Barberry *(Berberis repens)* respond by resprouting. Mountain Snowberry resprouts after low intensity fires but is often killed by high intensity fires. Generally the herbaceous perennial understory, Heartleaf Arnica *(Arnica cordifolia)*, Tuber Starwort *(Pseudostellaria jamesii)*, Hawkweeds *(Hieracium spp.)*, Lupines *(Lupinus spp.)*, Nevada Wild Pea *(Lathyrus lanszwertii)*, Sweet Cicely *(Osmorhiza spp.)*, Squirreltail *(Elymus elymoides)*, Ross' Sedge *(Carex rossii)*, Wheeler's Bluegrass *(Poa wheeleri)*, Canby Bluegrass *(Poa secunda secunda)*, Needlegrasses *(Nassella spp.)*, Orcutt Brome *(Bromus orcuttianus)*, resprouts in response to fire, but has no enhanced seeding response.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Abies concolor	White Fir	Survive	Non-Sprouter	Neutral
Abies concolor	White Fir	Killed	Dead	Neutral
Arctostaphylos patula	Greenleaf Manzanita	Top-Killed	Sprouter	Enhanced Recruitment
Arnica cordifolia	Heartleaf Arnica	Top-Killed	Sprouter	Neutral
Artemisia tridentata ssp. vaseyana	Mountain Big Sagebrush	Killed	Dead	Neutral
Berberis repens	Creeping Barberry	Top-Killed	Sprouter	Neutral
Bromus orcuttianus	Orcutt Brome	Top-Killed	Sprouter	Neutral
Calocedrus decurrens	Incense-cedar	Survive	Non-Sprouter	Neutral
Calocedrus decurrens	Incense-cedar	Killed	Dead	Neutral
Ceanothus prostratus	Mahala Mat	Top-Killed	Sprouter	Enhanced Recruitment
Ceanothus velutinus var. velutinus	Tobacco Brush	Top-Killed	Sprouter	Enhanced Recruitment
Elymus elymoides	Squirreltail	Top-Killed	Sprouter	Neutral
Hieracium spp.	Hawkweed	Top-Killed	Sprouter	Neutral
Lathryus lanszwertii	Wild Pea, Nevada Pea	Top-Killed	Sprouter	Neutral
Lupinus spp.	Lupine	Top-Killed	Sprouter	Neutral
Osmorhiza spp.	Sweet Cicely	Top-Killed	Sprouter	Neutral
Pinus jeffreyi	Jeffrey Pine	Survive	Non-Sprouter	Enhanced Recruitment
Pinus jeffreyi	Jeffrey Pine	Killed	Dead	Enhanced Recruitment
Pinus ponderosa	Ponderosa Pine	Survive	Non-Sprouter	Enhanced Recruitment
Pinus ponderosa	Ponderosa Pine	Killed	Dead	Enhanced Recruitment
Poa secunda ssp. secunda	Sandberg/Canby/Pine/One-Sided	Top-Killed	Sprouter	Neutral
Poa wheeleri	Wheeler's Bluegrass	Top-Killed	Sprouter	Neutral
Prunus emarginata	Bitter Cherry	Top-Killed	Sprouter	Neutral
Prunus subcordata	Modoc Plum	Top-Killed	Sprouter	Neutral
Prunus virginiana var. demissa	Western Choke-cherry	Top-Killed	Sprouter	Neutral
Svmphoricarpos oreophilus	Mountain Snowberry	Top-Killed	Sprouter	Neutral

M261F.1 Foothill Shrub and Woodland Ecological Zone

The vegetation is a mix of chaparral and live oak woodland with scattered Foothill *(Pinus sabiniana)* or Ponderosa Pines *(Pinus ponderosa)*. Chamise *(Adenostoma fasciculatum)*, Manzanita *(Arctostaphylos spp.)*, and California-Lilac *(Ceanothus spp.)* dominate the chaparral. Interior Live Oaks *(Quercus wislizenii)* or Canyon Live Oaks *(Quercus chrysolepis)* are extensive on steep slopes of large canyons. Tall deciduous shrubs or forests dominate riparian areas with dense vertical layering and a cooler microclimate.

Chaparral includes many sprouting species but few that require heat for seed germination. The two live oaks are vigorous sprouters. The most prevalent conifers, such as Ponderosa Pine, are fire resistant or have serotinous cones, such as Foothill Pine and Knobcone Pine *(Pinus attenuata)*. Establishment, survival, and abundance of many species are enhanced by fire. Numerous chaparral shrubs sprout following fire. These include Chamise, Flannelbush *(Fremontodendron californicum)*, Poison Oak *(Toxicodendron diversilobum)*, Coyote Brush *(Baccharis pilularis)*, Birch-Leaf Mountain-Mahogany *(Cercocarpus betuloides)*, Redshank *(Adenostoma sparsifolium)*, Yerba Santa *(Eriodictyon californicum)*, California Coffeeberry *(Rhamnus californica)*, and Christmas Berry *(Heteromeles arbutifolia)*. Non-sprouting shrubs can be dominant as well, with seeds that are heat resistant and have fire-enhanced germination, such as Whiteleaf Manzanita *(Arctostaphylos viscida)*, Mariposa Manzanita *(Arctostaphylos viscida mariposa)*, Chaparral Whitethorn *(Ceanothus leucodermis)*, and Buck Brush *(Ceanothus cuneatus)*. Numerous geophytes, or bulb-bearing plants, Soap Plant *(Chlorogalum pomeridianum)*, Death Camas *(Zigadenus spp.)*, Mariposa Lilies *(Calochortus spp.)*, show an increased flowering and growth response following fire. Annual plants respond to fire by seeding prolifically.

Interior and Canyon Live Oaks both resprout following fire. Foothill Pines have cones that are opened by heat and seedlings survive well on mineral soil. Native perennial bunchgrasses and the associated forbs resprout well post-fire.

BIOREGION > **Sierra Nevada**

USFS Section M261F > **Sierra Nevada Foothills**

LRR C MLRA 18 > **Sierra Nevada Foothills**

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Adenostoma fasciculatum	Chamise	Top-Killed	Sprouter	Enhanced Recruitment
Adenostoma sparsifolium	Redshank	Top-Killed	Sprouter	Neutral
Arctostaphylos viscida	Whiteleaf Manzanita	Killed	Dead	Enhanced Recruitment
Arctostaphylos viscida ssp. mariposa	Mariposa Manzanita	Killed	Dead	Enhanced Recruitment
Baccharis pilularis	Coyotebrush	Top-Killed	Sprouter	Neutral
Brodiaea spp.	Brodiaea	Top-Killed	Sprouter	Enhanced Recruitment
Ceanothus cuneatus var. cuneatus	Buck Brush	Killed	Dead	Enhanced Recruitment
Ceanothus leucoderrnis	Chaparral Whitethorn	Killed	Dead	Enhanced Recruitment
Cercis occidentalis	Redbud	Top-Killed	Sprouter	Enhanced Recruitment
Cercocarpus betuloides var. betuloides	Birch-leaf Mountain-Mahogany	Top-Killed	Sprouter	Neutral
Chlorogalum pomeridianum	Soap Plant	Top-Killed	Sprouter	Enhanced Recruitment
Eriodictyon californicum	Yerba Santa	Top-Killed	Sprouter	Neutral
Fremontodendron californicum	Flannelbush	Top-Killed	Sprouter	Neutral
Heteromeles arbutifolia	Toyon, Chaparral Holly	Top-Killed	Sprouter	Neutral
Muhlenbergia rigens	Deergrass	Top-Killed	Sprouter	Enhanced Recruitment
Pinus attenuata	Knobcone Pine	Killed	Dead	Enhanced Release
Pinus attenuata	Knobcone Pine	Survive	Non-Sprouter	Enhanced Release
Pinus ponderosa	Ponderosa Pine	Killed	Dead	Neutral
Pinus ponderosa	Ponderosa Pine	Survive	Non-Sprouter	Neutral
Pinus sabiniana	Foothill Pine	Killed	Dead	Enhanced Release
Pinus sabiniana	Foothill Pine	Survive	Non-Sprouter	Enhanced Release
Quercus chrysolepis	Canyon Live Oak	Top-Killed	Sprouter	Neutral
Quercus douglasii	California Blue Oak	Top-Killed	Sprouter	Neutral
Quercus wislizenii	Interior Live Oak	Top-Killed	Sprouter	Neutral
Rhamnus californica	California Coffeeberry	Top-Killed	Sprouter	Neutral
Toxicodendron diversilobum	Poison Oak	Top-Killed	Sprouter	Neutral
Zigadenus paniculatus	Foothill Death Camas	Top-Killed	Sprouter	Enhanced Recruitment

BIOREGION > **Sierra Nevada**

USFS Section M261E > **Sierra Nevada**

LRR D MLRA 22 > **Sierra Nevada Range**

M261E.1 Lower Montane Ecological Zone

Within the Lower Montane zone, California Black Oak *(Quercus kelloggii)* and Ponderosa Pine *(Pinus ponderosa)* dominate large areas, particularly in the southern Sierra Nevada. Intermixed are patches of chaparral and Canyon Live Oak *(Quercus chrysolepis)*. Manzanita *(Arctostaphylos spp.)*and California Lilac *(Ceanothus spp.)* species dominate chaparral, whereas Canyon Live Oak is extensive on steep slopes. With increasing elevation, the proportion of White Fir *(Abies concolor)* or Douglas-Fir *(Pseudotsuga menziesii)* increases. Incense-Cedar *(Calocedrus decurrens)* and Sugar Pine *(Pinus lambertiana)* are found throughout. White Alder *(Alnus rhombifolia)*, Gray Alder *(Alnus incana)*, or Black Cottonwood *(Populus balsamifera trichocarpa)* dominate larger streams or wetter sites. Bigleaf Maple *(Acer macrophyllum)* and Mountain Dogwood *(Cornus nuttallii)* occur along smaller or intermittent streams.

The majority of the species in this zone have characteristics that resist fire ; they often have favorable responses to fire. Sprouting hardwood trees, shrubs, vines, herbs, and grasses are mostly fire enhanced. All conifers show improved establishment with mineral soil. Giant Sequoias *(Sequoiadendron giganteum)* have serotinous cones producing increased seedling density after fire. Young Giant Sequoias can also resprout. Pacific Yew *(Taxus brevifolia)* and California Nutmeg *(Torreya californica)* are uncommon and restricted to wet, riparian areas. The montane hardwoods, including Tanoak *(Lithocarpus densiflorus)*, Pacific Madrone *(Arbutus menziesii)*, California Black Oak *(Quercus kelloggii)*, Canyon Live Oak *(Quercus chrysolepis)*, California Bay *(Umbellularia californica)*, Mountain Dogwood *(Cornus nuttallii)*, Bigleaf Maple *(Acer macrophyllum)*, White Alder *(Alnus incana)*, and Black Cottonwood *(Populus balsamifera trichocarpa)*, all sprout following fire. Many shrubs have fire enhanced regeneration both with sprouting and heat-stimulated germination. Sprouters include Mountain Misery *(Chamaebatia foliolosa)*, Deer Brush *(Ceanothus integerrimus)*, Greenleaf Manzanita *(Arctostaphylos patula)*, Bush Chinquapin *(Chrysolepis sempervirens)*, Mountain Whitethorn *(Ceanothus cordulatus)*, and riparian shrubs Hazelnut *(Corylus cornuta)*, Thimbleberry *(Rubus parviflorus)*, and Gray Alder *(Alnus rhombifolia)*. Some shrubs, particularly California-Lilac, have heat-stimulated seed germination; species include Deer Brush *(Ceanothus integerrimus)*, Mountain Whitethorn *(Ceanothus cordulatus)*. Following fire, numerous herbaceous perennials resprout, including Pacific Starflower *(Trientalis latifolia)*, Trail Plant *(Adenocaulon bicolor)*, Western Blue Flag *(Iris missouriensis)*, Bolander's Bedstraw *(Galium bolanderi)*, Bear-Grass *(Xerophyllum tenax)*, Sanicles *(Sanicula spp.)*, Many-Stemmed Sedge *(Carex multicaulis)*, Ross; Sedge *(Carex rossii)*, Needlegrasses *(Nassella spp.)*, Oniongrass *(Melica bulbosa)*, Penstemons *(Penstemon spp.)* and Mariposa Lilies *(Calochortus spp.)*.

BIOREGION > **Sierra Nevada**

USFS Section M261E > **Sierra Nevada**

LRR D MLRA 22 > **Sierra Nevada Range**

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Abies concolor	White Fir	Survive	Non-Sprouter	Neutral
Abies concolor	White Fir	Killed	Dead	Neutral
Acer macrophyllum	Bigleaf Maple	Top-Killed	Sprouter	Neutral
Achnatherum spp.	Needlegrass	Top-Killed	Sprouter	Neutral
Adenocaulon bicolor	Trail Plant	Top-Killed	Sprouter	Neutral
Alnus incana	Gray Alder	Top-Killed	Sprouter	Neutral
Alnus rhombifolia	White Alder	Top-Killed	Sprouter	Neutral
Arbutus menziesii	Pacific Madrone	Top-Killed	Sprouter	Neutral
Arctostaphylos patula	Greenleaf Manzanita	Top-Killed	Sprouter	Neutral
Arctostaphylos viscida	Whiteleaf Manzanita	Killed	Dead	Enhanced Recruitment
Calocedrus decurrens	Incense-cedar	Survive	Non-Sprouter	Neutral
Calocedrus decurrens	Incense-cedar	Killed	Dead	Neutral
Carex multicaulis	Many-stemmed Sedge	Top-Killed	Sprouter	Neutral
Carex rossii	Ross' Sedge	Top-Killed	Sprouter	Neutral
Ceanothus cordulatus	Mountain Whitethorn	Top-Killed	Sprouter	Enhanced Recruitment
Ceanothus integerrimus	Deer Brush	Top-Killed	Sprouter	Enhanced Recruitment
Chamaebatia foliolosa	Mountain Misery	Top-Killed	Sprouter	Neutral
Chrysolepis sempervirens	Bush Chinquapin	Top-Killed	Sprouter	Neutral
Cornus nuttallii	Mountain Dogwood	Top-Killed	Sprouter	Neutral
Corylus comuta	Hazelnut	Top-Killed	Sprouter	Neutral
Cytisus scoparius	Scotch Broom	Top-Killed	Sprouter	Enhanced Recruitment
Galium bolanderi	Bolander's Bedstraw	Top-Killed	Sprouter	Neutral
Iris missouriensis	Western Blue Flag	Top-Killed	Sprouter	Neutral
Lithocarpus densiflorus	Tanoak	Top-Killed	Sprouter	Neutral
Melica bulbosa	Oniongrass	Top-Killed	Sprouter	Neutral
Penstemon spp.	Penstemon	Top-Killed	Sprouter	Neutral
Pinus lambertiana	Sugar Pine	Survive	Non-Sprouter	Neutral
Pinus lambertiana	Sugar Pine	Killed	Dead	Neutral
Pinus ponderosa	Ponderosa Pine	Survive	Non-Sprouter	Neutral
Pinus ponderosa	Ponderosa Pine	Killed	Dead	Neutral
Populus balsamifera ssp. trichocarpa	Black Cottonwood	Top-Killed	Sprouter	Neutral
Pseudotsuga menziesii var. menziesii	Douglas-fir	Survive	Non-Sprouter	Neutral
Pseudotsuga menziesii var. menziesii	Douglas-fir	Killed	Dead	Neutral
Quercus chrysolepis	Canyon Live Oak	Top-Killed	Sprouter	Neutral
Quercus kelloggii	California Black Oak	Top-Killed	Sprouter	Neutral
Ribes roezlii	Sierra Gooseberry	Top-Killed	Sprouter	Neutral
Rubus parviflorus	Thimbleberry	Top-Killed	Sprouter	Neutral
Salix spp.	Willow	Top-Killed	Sprouter	Neutral
Sanicula spp.	Sanicles	Top-Killed	Sprouter	Neutral
Sequoiadendron giganteum	Giant Sequoia	Survive	Non-Sprouter	Enhanced Release
Sequoiadendron giganteum	Giant Sequoia	Killed	Dead	Enhanced Release
Taxus brevifolia	Pacific Yew	Killed	Dead	Neutral
Toxicodendron diversilobum	Poison Oak	Top-Killed	Sprouter	Neutral
Trientalis latifolia	Pacific Starflower	Top-Killed	Sprouter	Neutral

M261E.2 Upper Montane Forest Ecological Zone

The vegetation of this zone is characterized by the presence of California Red Fir *(Abies magnifica magnifica)*, Western White Pine, *(Pinus monticola)* Jeffrey Pine *(Pinus jeffreyi)*, Quaking Aspen *(Populus tremuloides)*, Western Juniper *(Juniperus occidentalis)*, stands of montane chaparral, and an understory of herbaceous perennials. The conifers often survive low intensity fires but succomb to those of higher intensity; after fire, none sprout nor result in enhaned recruitment. Hardwoods and shrubs typically resprout after fire. Bush Chinquapin *(Chrysolepis sempervirens)*, Mountain Whitethorn *(Ceanothus cordulatus)*, and Huckleberry Oak *(Quercus vaccinifolia)* form extensive stands in the open and beneath conifers. They are all sprouters that can be top-killed by fire. Mountain Whitethorn is also a prolific seeder after fire. Pinemat Manzanita *(Arctostaphylos nevadensis)* and Greenleaf Manzanita *(Arctostaphylos patula)* are usually found in the understory; these non-sprouting Manzanitas are killed by intense heat and re-establish only by seed. Quaking Aspen is a vigorous fire-stimulated sprouter. The herbaceous understory comprises Woolly Mule's Ears *(Wyethia mollis)*, Corn Lily *(Veratrum californicum, Western Needlegrass (Achnatherum occidentalis)*, and Tufted Hairgrass *(Deschamsia cespitosa holciformis)*.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Abies concolor	White Fir	Survive	Non-Sprouter	Neutral
Abies concolor	White Fir	Killed	Dead	Neutral
Abies magnifica var. magnifica	California Red Fir	Survive	Non-Sprouter	Neutral
Abies magnifica var. magnifica	California Red Fir	Killed	Dead	Neutral
Achnatherum occidentalis	Western Needlegrass	Top-Killed	Sprouter	Neutral
Arctostaphylos nevadensis	Pinemat Manzanita	Killed	Dead	Enhanced Recruitment
Arctostaphylos viscida	Whiteleaf Manzanita	Killed	Dead	Enhanced Recruitment
Ceanothus cordulatus	Mountain Whitethorn	Top-Killed	Sprouter	Enhanced Recruitment
Chrysolepis sempervirens	Bush Chinquapin	Top-Killed	Sprouter	Enhanced Recruitment
Deschampsia cespitosa ssp. holciformis	Tufted Hairgrass	Top-Killed	Sprouter	Neutral
Juniperus occidentalis ssp. australis	Sierra Juniper	Survive	Non-Sprouter	Neutral
Juniperus occidentalis ssp. australis	Sierra Juniper	Killed	Dead	Neutral
Pinus jeffreyi	Jeffrey Pine	Survive	Non-Sprouter	Neutral
Pinus jeffreyi	Jeffrey Pine	Killed	Dead	Neutral
Pinus monticola	Western White Pine	Survive	Non-Sprouter	Neutral
Pinus monticola	Western White Pine	Killed	Dead	Neutral
Pinus ponderosa	Ponderosa Pine	Survive	Non-Sprouter	Neutral
Pinus ponderosa	Ponderosa Pine	Killed	Dead	Neutral
Populus tremuloides	Quaking Aspen	Top-Killed	Sprouter	Neutral
Quercus vaccinifolia	Huckleberry Oak	Top-Killed	Sprouter	Enhanced Recruitment
Veratrum californicum	Corn Lily	Top-Killed	Sprouter	Neutral
Wyethia mollis	Woolly Mule's Ears	Top-Killed	Sprouter	Neutral

M261E.3 Subalpine Forest Ecological Zone

Extensive stands of subalpine forest occur on the west side of the Sierra Nevada and a thin band exists on the east side of the range. The vegetation of the subalpine forest is dominated by Lodgepole Pine *(Pinus contorta murrayana)*. Approaching tree line, Lodgepole Pine is replaced by Mountain Hemlock *(Tsuga mertensiana)* and Whitebark Pine *(Pinus albicaulis)*. On the east side of the range, Limber Pine *(Pinus flexilis)* occurs with Whitebark Pine. Foxtail Pine *(Pinus balfouriana balfouriana)* is found at tree line. Extensive meadows of Shorthair Sedge *(Carex filifolia erostrata)* and Brewer's Reedgrass *(Calamagrostis breweri)* are mixed within the forest.

None of the conifers sprout in response to fire, but Lodgepole Pine has somewhat serotinous cones that experience enhanced seed release. Sedges and Reedgrasses re-establish from seeds and rhizomes.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Calamagrostis breweri	Brewer's Reedgrass	Top-Killed	Sprouter	Neutral
Carex spp.	Sedge	Top-Killed	Sprouter	Neutral
Pinus albicaulis	Whitebark Pine	Survive	Non-Sprouter	Neutral
Pinus albicaulis	Whitebark Pine	Killed	Dead	Neutral
Pinus balfouriana spp. balfouriana	Foxtail Pine	Survive	Non-Sprouter	Neutral
Pinus balfouriana spp. balfouriana	Foxtail Pine	Killed	Dead	Neutral
Pinus contorta var. murrayana	Lodgepole Pine	Killed	Dead	Enhanced Release
Pinus flexilis	Limber Pine	Survive	Non-Sprouter	Neutral
Pinus flexilis	Limber Pine	Killed	Dead	Neutral
Tsuga mertensiana	Mountain Hemlock	Survive	Non-Sprouter	Neutral
Tsuga mertensiana	Mountain Hemlock	Killed	Dead	Neutral

M261E.4 Eastside Forest and Woodland Ecological Zone

The vegetation of the eastside of the Sierra Nevada is often transitional from montane to Great Basin species in a coarse mosaic of open woodlands or forests and shrublands or grasslands. Conifers include Jeffrey Pine *(Pinus jeffreyi)*, Ponderosa Pine *(Pinus ponderosa)*, White Fir *(Abies concolor)*, and some Douglas-Fir *(Pseudotsuga menziesii)* and Pinyon Pine. Hardwoods include Aspen *(Populus tremuloides)* and California Black Oak *(Quercus kelloggii)*. Shrublands can be extensive and variable, ranging from composed mostly of Great Basin taxa including Sagebrush *(Artemisia spp.)* and Bitterbrush *(Purshia spp.)* to chaparral comprised of Tobacco Brush *(Ceanothus velutinus)*, Greenleaf Manzanita *(Arctostaphylos patula)*, Bearbrush *(Garrya fremontii)*, Bush Chinquapin *(Chrysolepis sempervirens)*, and Curl-Leaf Mountain-Mahogany *(Cercocarpus ledifolius)*. Riparian and wetland areas occur throughout the zone and include Quaking Aspen *(Populus tremuloides)*, Black Cottonwood *(Populus balsamifera tricocarpa)*, and Willows *(Salix spp.)*.

Species in this zone tend to be mixture of those with fire-resistant or fire-enhanced characteristics and those that are fire-inhibited. Where conifers occur in sparse vegetation, they often survive fire; when significantly damaged, none are capable of resprout. Hardwoods resprout when top-killed. Shrub species vary from those that have enhanced sprouting or seed germination following fire to those that have little fire resistance. Greenleaf Manzanita, Bearbrush, Bush Chinquapin, and Tobacco Brush all sprout from basal burls following fire. Tobacco Brush also has enhanced germination from fire. Sagebrush and Bitterbrush are killed by fire, without resprout here.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Abies concolor	White Fir	Survive	Non-Sprouter	Neutral
Abies concolor	White Fir	Killed	Dead	Neutral
Abies magnifica var. magnifica	California Red Fir	Survive	Non-Sprouter	Neutral
Abies magnifica var. magnifica	California Red Fir	Killed	Dead	Neutral
Arctostaphylos patula	Greenleaf Manzanita	Top-Killed	Sprouter	Neutral
Artemisia tridentata	Big Sagebrush	Killed	Dead	Neutral
Carex spp.	Sedge	Top-Killed	Sprouter	Neutral
Ceanothus velutinus var. velutinus	Tobacco Brush	Top-Killed	Sprouter	Enhanced Recruitment
Cercocarpus ledifolius	Curl-leaf Mountain-mahogany	Top-Killed	Sprouter	Neutral
Chrysolepis sempervirens	Bush Chinquapin	Top-Killed	Sprouter	Enhanced Recruitment
Garrya fremontii	Bearbrush	Top-Killed	Sprouter	Neutral
Pinus jeffreyi	Jeffrey Pine	Survive	Non-Sprouter	Neutral
Pinus jeffreyi	Jeffrey Pine	Killed	Dead	Neutral
Pinus monophylla	Singleleaf Pinyon Pine	Killed	Dead	Neutral
Pinus ponderosa	Ponderosa Pine	Survive	Non-Sprouter	Neutral
Pinus ponderosa	Ponderosa Pine	Killed	Dead	Neutral
Populus balsamifera ssp. trichocarpa	Black Cottonwood	Top-Killed	Sprouter	Neutral
Populus tremuloides	Quaking Aspen	Top-Killed	Sprouter	Neutral
Purshia tridentata	Antelope Bitterbrush	Top-Killed	Sprouter	Enhanced Recruitment
Purshia tridentata	Antelope Bitterbrush	Killed	Dead	Enhanced Recruitment
Quercus kelloggii	California Black Oak	Top-Killed	Sprouter	Neutral
Quercus vaccinifolia	Huckleberry Oak	Top-Killed	Sprouter	Neutral
Salix spp.	Willow	Top-Killed	Sprouter	Neutral
Svmphoricarpos oreophilus	Mountain Snowberry	Top-Killed	Sprouter	Neutral
Wyethia mollis	Woolly Mule's Ears	Top-Killed	Sprouter	Neutral

BIOREGION > **Central Valley**

USFS Section M261C > Northern California Interior Coast Ranges

LRR C MLRA 15 > Central California Coast Range

M261C.1 Foothill Woodland Ecological Zone

This bioregion has a long history of significant alteration that has resulted in land conversion throughout. It is the most highly altered bioregion in the contemporary landscape, largely devoid of intact natural vegetational assemblages. Lands fall into two categories: intensively used areas with total land conversion or a few scant protected remnants.

The valley is encircled by Foothill Woodlands characterized by the presence of either Blue Oak *(Quercus douglasii)* or Foothill Pine *(Pinus sabiniana)*. Valley Oaks *(Quercus lobata)* and Coast Live Oak *(Quercus agrifolia)* occur where soils are deep and well-developed. California Juniper *(Juniperus californica)* may also be present. Shrubs include California Buckeye *(Aesculus californica)*, Interior Live Oak *(Quercus wislizeni)*, Buck Brush *(Ceanothus cuneatus)*, Whiteleaf Manzanita *(Arctostaphylos viscida)*, California Coffeeberry *(Rhamnus californica)*, Redbud *(Cercis occidentalis)*, Birch-Leaf Mountain-Mahogany *(Cercocarpus betuloides)*, and Poison Oak *(Toxicodendron diversilobum)*. The herbaceous matrix, comprising grasses and forbs, has been dramatically altered by a non-native plant invasion. In some areas as much as 95% of the herbaceous understory biomass is made up of non-native species. Remnant native grasses include Squirreltail *(Elymus elymoides)*, Blue Wildrye *(Elymus glaucus)*, California Melic *(Melica californica)*, and Purple Needlegrass *(Nassella pulchra)* with a rich collection of forbs, Parry's Larkspur *(Delphinium parryi)*, Dotseed Plantain *(Plantago erecta)*, Johnny Jump-Up *(Viola pedunculata)*, and Popcornflower *(Plagiobothrys nothofulvus)*.

Predicting the response of Blue Oak to fire events is difficult. Mature trees may, but do not always, survive and resprout; seedlings usually resprout. When mature, the other oaks in this zone suffer little mortality from low to moderate intensity fires. High intensity fires, however, can result in severe damage and mortality. Birch-Leaf Mountain-Mahogany is usually top-killed and capable of resprout. Native herbaceous perennials usually survive to resprout and flower vigorously.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Allium spp.	Onion/garlic	Top-Killed	Sprouter	Neutral
Cercocarpus spp.	Mountain-mahogany	Top-Killed	Sprouter	Neutral
Delphinium spp.	Larkspur	Top-Killed	Sprouter	Enhanced Recruitment
Pinus sabiniana	Foothill Pine	Killed	Dead	Enhanced Release
Quercus douglasii	California Blue Oak	Top-Killed	Sprouter	Neutral
Quercus lobata	Valley Oak	Top-Killed	Sprouter	Neutral
Quercus wislizenii	Interior Live Oak	Top-Killed	Sprouter	Neutral

BIOREGION > **Central Valley**

USFS Section 262A > **Great Valley**

LRR C MLRA 17 > **Sacramento and San Joaquin Valleys**

262A.1 Valley Grassland Ecological Zone

Grasslands of the Central Valley are currently characterized by a large group of non-native annual plants. Still, scattered throughout the sea of introduced plants, are relatively intact islands of native plant diversity. There are remnant pockets of native perennial grasses, Needlegrasses *(Nassella ssp.)* Blue Wildrye *(Elymus glaucus)* Creeping Wildrye *(Leymus triticoides)*, Alkali Sacaton *(Sporobolus airoides)*, Pine Bluegrass *(Poa secunda ssp. secunda)* and Deergrass *(Muhlenbergia rigens)*, and a rich collection of annual and perennial forbs. Many native bunchgrasses and perennial forbs are known to respond favorably to fire with vigorous sprouting. Certain native annual forb species such as Variable Linanthus *(Linanthus parviflorus)*, Owl's Clover *(Orthocarpus attenuatus)*, Smallhead Clover *(Trifolium microcephalum)*, Chilean Bird's Foot Trefoil *(Lotus subpinnatus)*, Common Stickyseed *(Blennosperma nanum)*, California Goldfields *(Lasthenia californica)*, and Marigold Navarretia *(Navarretia tagetina)* increase in the post-fire environment.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Brodiaea spp.	Brodiaea	Top-Killed	Sprouter	Neutral
Leymus triticoides	Creeping Wildrye	Top-Killed	Sprouter	Neutral
Nassella pulchra	Purple Needlegrass	Top-Killed	Sprouter	Neutral
Navarretia tagetina	Marigold Navarretia	Top-Killed	Sprouter	Neutral
Poa secunda ssp. secunda	Sandberg/Pine/One-Sided Bluegrass	Killed	Dead	Enhanced Recruitment
Sporobolus airoides	Alkali Sacaton	Top-Killed	Sprouter	Neutral

262A.2 Riparian Forest and Woodland Ecological Zone

Riparian forests in the Central Valley harbor an impressive collection of winter-deciduous trees including Western Sycamore *(Platanus racemosa)*, Box Elder *(Acer negundo californicum)*, Fremont Cottonwood *(Populus fremontii)*, Goodding's Black Willow *(Salix gooddingii)*, and Valley Oak *(Quercus lobata)*. Plants of this riparian forest are not dependent on fire for regeneration. Most trees are capable of surviving low intensity fire, resprouting being somewhat variable. Moderate to high intensity fire events can top-kill with limited sprouting response.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Baccharis pilularis	Coyotebrush	Top-Killed	Sprouter	Enhanced Recruitment
Baccharis salicifolia	Mule Fat	Top-Killed	Sprouter	Neutral
Muhlenbergia rigens	Deergrass	Top-Killed	Sprouter	Neutral
Platanus racemosa	Western Sycamore	Top-Killed	Sprouter	Enhanced Recruitment
Populus balsamifera ssp. trichocarpa	Black Cottonwood	Top-Killed	Sprouter	Neutral
Salix spp.	Willow	Top-Killed	Sprouter	Enhanced Recruitment
Sambucus mexicana	Mexican Elderberry	Top-Killed	Sprouter	Enhanced Recruitment

262A.3 Freshwater Marsh Ecological Zone

This element of the valley has been nearly completely altered from the pre-settlement condition. Remnant species include Goodding's Black Willow *(Salix gooddingii)*, Red Willow *(Salix laevigata)*, Shining Willow *(Salix lucida lasiandra)*, Cattails *(Typha spp.)*, California Bulrush *(Scirpus californicus)*, and Slenderbeak Sedge *(Carex athrostachya)*, Mule Fat *(Baccharis glutinosa)*, Rushes *(Juncus spp.)*, Cord Grass *(Spartina spp.)*, and Saltgrass *(Distichlis spicata)*. Most species resprout if top-killed by fire.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Distichlis spicata	Saltgrass	Top-Killed	Sprouter	Neutral
Scirpus lacustris	Bulrush	Top-Killed	Sprouter	Neutral
Spartina spp.	Cord Grass	Top-Killed	Sprouter	Enhanced Recruitment
Typha spp.	Cattail	Top-Killed	Sprouter	Neutral

BIOREGION > **Central Coast**

USFS Section 261A > **Central California Coast**

LRR A MLRA 4 > **California Coastal Redwood Belt**

Because of the near total lack of fire-related studies throughout this Bioregion use generalities applicable to Ecological Zones within other Bioregions. For Chaparral and Coastal Sage Scrub Zones use the South Coast Bioregion; for Annual Grasslands and Blue Oak Woodlands use the Central Valley Bioregion.

261A.1 Coastal Grassland and Coastal Sage Scrub Ecological Zone

Characteristic species include Coyotebrush *(Baccharis pilularis)*, Seaside Woolly Sunflower *(Eriophyllum staechadifolium)*, Hairy Brackenfern *(Pteridium aquilinum pubescens)*, Tufted Hairgrass *(Deschampsia cespitosa holciformis)*, and California Oatgrass *(Danthonia californica)*.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Baccharis pilularis	Coyotebrush	Top-Killed	Sprouter	Enhanced Recruitment
Danthonia californica	California Oatgrass	Top-Killed	Sprouter	Enhanced Recruitment
Deschampsia cespitosa ssp. holciformis	Tufted Hairgrass	Top-Killed	Sprouter	Enhanced Recruitment
Festuca rubra	Red Fescue	Top-Killed	Sprouter	Enhanced Recruitment
Nassella pulchra	Purple Needlegrass	Top-Killed	Sprouter	Enhanced Recruitment

261A.2 Coast Redwood–Douglas-Fir–Mixed Evergreen Ecological Zone

The common trees include Coast Redwood *(Sequoia sempervirens)*, Douglas-Fir *(Pseudotsuga menziesii)*, Tanoak *(Lithocarpus densiflorus)*, Coast Live Oak *(Quercus agrifolia)*, Pacific Madrone *(Arbutus menziesii)*, and California Bay *(Umbellularia californica)*.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Acer macrophyllum	Bigleaf Maple	Top-Killed	Sprouter	Neutral
Arbutus menziesii	Pacific Madrone	Top-Killed	Sprouter	Enhanced Recruitment
Lithocarpus densiflorus	Tanoak	Top-Killed	Sprouter	Neutral
Pseudotsuga menziesii var. menziesii	Douglas-fir	Survive	Non-Sprouter	Enhanced Recruitment
Quercus chrysolepis	Canyon Live Oak	Top-Killed	Sprouter	Neutral
Quercus garryana	Oregon White Oak	Top-Killed	Sprouter	Enhanced Recruitment
Quercus kelloggii	California Black Oak	Top-Killed	Sprouter	Enhanced Recruitment
Umbellularia californica	California Bay	Top-Killed	Sprouter	Neutral

261A.3 Coastal Plain and Foothills Ecological Zone

This zone supports Coastal Grassland, Annual Grassland, Coastal Sage Scrub, Maritime Chaparral, Coast Live Oak Forests, Closed-Cone Forests. It has been extensively invaded by non-native plant species.

Coastal Sage Scrub is characterized by Coyote Brush *(Baccharis pilularis)*, California Sagebrush *(Artemisia californica)*, Blue Blossom Ceanothus *(Ceanothus thyrsiflorus)*, Goldenbush *(Ericameria ericoides)*, and Needlegrasses *(Nassella spp.)* and Melicgrasses *(Melica spp.)*.

Maritime Chaparral is dominated by Chamise *(Adenostoma fasciculatum)*, California-Lilac *(Ceanothus spp.)*, and Manzanita *(Arctostaphylos spp.)*. Many are obligate seeders that do not respout: Santa Barbara Ceanothus *(Ceanothus impressus)*, Sand Buck Brush *(Ceanothus cuneatus fasciculatus)*, La Purisima Manzanita *(Arctostaphylos purissima)*, Hooker's Manzanita *(Arctostaphylos hookeri)*, Pajaro Manzanita *(Arctostaphylos pajaroensis)*, Morro Manzanita *(Arctostaphylos morroensis)*. Sandmat Manzanita *(Arctostaphylos pumila)* is a facultative seeder that also resprouts. Fire-dependent shrubs include Blue-Blossom Ceanothus *(Ceanothus thyrsiflorus)*, Sand-Scrub Ceanothus *(Ceanothus dentatus)*, and Goldenbush *(Ericameria ericoides)*. Also present is an extensive occupation by introduced plant species.

Coast Live Oak *(Quercus agrifolia)* is one of the most fire-resistant oaks. Adult trees resprout vigorously and seedling and saplings survive low intensity fires. Seedling recruitment is continuous throughout fire-free intervals.

The Closed-Cone forests are edaphically and climatically localized. Conifers dependent upon fire for regeneration include Knobcone Pine *(Pinus attenuata)*, Sargent Cypress *(Cupressus sargentii)*, and Coulter Pine *(Pinus coulteri)*, which expresses a more highly serotinous cone habit in the chaparral setting than in forests. Other conifers that bear variously serotinous cones and thus enjoy some fire-free interval seedling recruitment in addition to a post-fire enhanced recruitment include Bishop Pine *(Pinus muricata)* and Monterey Pine *(Pinus radiata)*.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Adenostoma fasciculatum	Chamise	Top-Killed	Sprouter	Enhanced Recruitment
Arctostaphylos hookeri ssp. hookeri	Hooker's Manzanita	Killed	Dead	Enhanced Recruitment
Arctostaphylos morroensis	Morro Manzanita	Killed	Dead	Enhanced Recruitment
Arctostaphylos pajaroensis	Pajaro Manzanita	Killed	Dead	Enhanced Recruitment
Arctostaphylos purissima	La Purisima Manzanita	Killed	Dead	Enhanced Recruitment
Artemisia californica	California Sagebrush	Top-Killed	Sprouter	Enhanced Recruitment
Ceanothus cuneatus var. cuneatus	Buck Brush	Killed	Dead	Enhanced Recruitment
Ceanothus thyrsiflorus	Blue Blossom	Killed	Dead	Enhanced Recruitment
Cupressus sargentii	Sargent Cypress	Killed	Dead	Enhanced Release
Eriogonum fasciculatum	California Buckwheat	Killed	Dead	Enhanced Recruitment
Pinus attenuata	Knobcone Pine	Killed	Dead	Enhanced Release
Pinus coulteri	Coulter Pine	Killed	Dead	Enhanced Release
Pinus muricata	Bishop Pine	Killed	Dead	Enhanced Release
Pinus radiata	Monterey Pine	Killed	Dead	Enhanced Release
Pinus sabiniana	Foothill Pine	Killed	Dead	Enhanced Recruitment
Quercus agrifolia	Coast Live Oak	Top-Killed	Sprouter	Neutral
Quercus wislizenii	Interior Live Oak	Top-Killed	Sprouter	Neutral

BIOREGION > **Central Coast**

USFS Section M262A > **Central California Coast Ranges**

LRR C MLRA 15 > **Central California Coast Range**

M262A.1 Interior Valleys and Foothills Ecological Zone

Much zonation has been obscured by extensive conversion of shrublands to grassland. Remnants exist of:

1) a lower elevation grassland zone supporting annual grassland and California Sagebrush *(Artemisia californica)* with California Buckwheat *(Eriogonum fasciculatum)*; Valley Oak *(Quercus lobata)* occurs in some larger stream valleys;

2) a higher elevation Blue Oak Woodland-Chaparral zone with Blue Oak *(Quercus douglasii)*, Foothill Pine *(Pinus sabiniana)*, Scrub Oaks *(Quercus spp.)*, Chamise *(Adenostoma fasciculatum)*, Buck Brush *(Ceanothus cuneatus)*, and Eastwood's Manzanita *(Arctostaphylos glandulosa)*. Jeffrey Pine *(Pinus jeffreyi)* and Incense-Cedar *(Calocedrus decurrens)* occur in rather open stands.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Adenostoma fasciculatum	Chamise	Top-Killed	Sprouter	Enhanced Recruitment
Artemisia californica	California Sagebrush	Top-Killed	Sprouter	Enhanced Recruitment
Ceanothus cuneatus var. cuneatus	Buck Brush	Killed	Dead	Enhanced Recruitment
Eriogonum fasciculatum	California Buckwheat	Killed	Dead	Enhanced Recruitment
Pinus coulteri	Coulter Pine	Killed	Dead	Enhanced Release
Pinus sabiniana	Foothill Pine	Killed	Dead	Enhanced Recruitment
Quercus agrifolia	Coast Live Oak	Top-Killed	Sprouter	Neutral
Quercus douglasii	California Blue Oak	Top-Killed	Sprouter	Neutral
Quercus wislizenii	Interior Live Oak	Top-Killed	Sprouter	Neutral

M262A.2 Lower-Montane Zone Ecological Zone

This zone presents a mosaic of Chaparral, Coastal Sage Scrub, Coast Live Oak Woodlands and Forests, Serpentine Grasslands, Cypress Woodlands.

Sage scrub taxa that are either killed or merely top-killed with both resprout and increased recruitment from seed include California Sagebrush *(Artemisia californica)*, Black Sage *(Salvia mellifera)*, Purple Sage *(Salvia leucophylla)*, Bush Monkeyflower *(Mimulus aurantiacus)*, and Coastal Buckwheat *(Eriogonum latifolium)*. California Brittlebush *(Encelia californica)* and Saw-Toothed Goldenbush *(Hazardia squarrosa)* may be top-killed and resprout, but neither has a dormant seed bank from which to regenerate. Deerweed *(Lotus scoparius)* and California Buckwheat *(Eriogonum fasciculatum)* are usually killed by fire and re-establish from a dormant seed bank. Laurel Sumac *(Malosma laurina)* and Lemonade Berry *(Rhus integrifolia)* are woody shrubs that when top-killed, resprout. Laurel Sumac also has enhanced seedling recruitment post-fire.

Common chaparral species include Chamise *(Adeonstoma fasciculatum)* and Scrub Oaks *(Quercus durata; Quercus berberidifolia)* which can resprout under favorable conditions. Buck Brush *(Ceanothus cuneatus)* is killed by fire and has enhanced seedling recruitment.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Adenostoma fasciculatum	Chamise	Top-Killed	Sprouter	Enhanced Recruitment
Artemisia californica	California Sagebrush	Top-Killed	Sprouter	Enhanced Recruitment
Ceanothus cuneatus var. cuneatus	Buck Brush	Killed	Dead	Enhanced Recruitment
Eriogonum fasciculatum	California Buckwheat	Killed	Dead	Enhanced Recruitment
Lithocarpus densiflorus	Tanoak	Top-Killed	Sprouter	Neutral
Quercus agrifolia	Coast Live Oak	Top-Killed	Sprouter	Neutral
Quercus douglasii	California Blue Oak	Top-Killed	Sprouter	Neutral
Quercus wislizenii	Interior Live Oak	Top-Killed	Sprouter	Neutral

M262A.3 Upper-Montane Zone Ecological Zone

This zone supports Mixed Evergreen Forests, Coulter Pine Forests, Mixed Conifer Forests. Common and widespread species that can be top-killed and resprout include Canyon Live Oak *(Quercus chrysolepis)*, Interior Live Oak *(Quercus wislisenii)*, Pacific Madrone *(Arbutus menziesii)*, Tanoak *(Lithocarpus densiflorus)*, California Bay *(Umbellularia californica)*, and Bigleaf Maple *(Acer macrophyllum)*. Conifers present include Ponderosa Pine *(Pinus ponderosa)*, Coulter Pine *(Pinus coulteri)*, and Sugar Pine *(Pinus lambertiana)*. Santa Lucia Fir *(Abies bracteata)* is patchily distributed at mid to high elevations.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Abies bracteata	Santa Lucia Fir	Killed	Dead	Neutral
Acer macrophyllum	Bigleaf Maple	Top-Killed	Sprouter	Neutral
Adenostoma fasciculatum	Chamise	Top-Killed	Sprouter	Enhanced Recruitment
Arbutus menziesii	Pacific Madrone	Top-Killed	Sprouter	Neutral
Arctostaphylos hookeri ssp. hookeri	Hooker's Manzanita	Killed	Dead	Enhanced Recruitment
Ceanothus cuneatus var. cuneatus	Buck Brush	Killed	Dead	Enhanced Recruitment
Ceanothus thyrsiflorus	Blue Blossom	Killed	Dead	Enhanced Recruitment
Cupressus sargentii	Sargent Cypress	Killed	Dead	Enhanced Release
Eriogonum fasciculatum	California Buckwheat	Killed	Dead	Enhanced Recruitment
Lithocarpus densiflorus	Tanoak	Top-Killed	Sprouter	Neutral
Pinus attenuata	Knobcone Pine	Killed	Dead	Enhanced Release
Pinus coulteri	Coulter Pine	Killed	Dead	Enhanced Release
Pinus sabiniana	Foothill Pine	Killed	Dead	Enhanced Recruitment
Quercus agrifolia	Coast Live Oak	Top-Killed	Sprouter	Neutral
Quercus wislizenii	Interior Live Oak	Top-Killed	Sprouter	Neutral
Umbellularia californica	California Bay	Top-Killed	Sprouter	Neutral

BIOREGION > **South Coast**

USFS Section 261B > **Southern California Coast**

LRR C MLRA 19 > **Southern California Coastal Plain**

M261B.1 Coastal Sage Scrub-Grasslands Ecological Zone

The South Coast Bioregion is a complex mosaic of grassland, shrubland, forest, and woodland. There are two broad ecological zones: coastal valley-foothills and montane. The climatic gradient from the coast *(mild)* to the interior *(harsh)* is tempered by elevation increase in the montane region.

The response of the species to fire within this zone varies along a climatic gradient from the coast to the interior. Post-fire resprout is more successful in locations closer to the coast than within the more arid interior. Semi-deciduous *(summer drought response)* subshrubs dominate lower elevation along the coast and interior valleys, however the species composition varies.

Species that respond to fire through resprout only are common and include California Brittlebush *(Encelia californica)* and Saw-Toothed Goldenbush *(Hazardia squarrosa)*. Species that regenerate from both resprout and dormant seed banks are also common and include Coastal Buckwheat *(Eriogonum cinereum)*, California Buckwheat *(Eriogonum fasciculatum)*, Bush Monnkeyflower *(Mimulus aurantiacus)*, California Sagebrush *(Artemisia californica)*, Purple Sage *(Salvia leucophylla)*, and Black Sage *(Salvia mellifera)*. Deerweed *(Lotus scoparius)* is the only woody species with obligate seeding; seedling recruitment is massive in the first post-fire year from a dormant seed bank. Two evergreen shrubs with broad dispersion in coastal sage scrub and chaparral, Laurel Sumac *(Malosma laurina)*, Lemonadeberry *(Rhus integrifolia)*, are both are vigorous resprouters, but have different seed regeneration dynamics. Laurel Sumac has significant seedling recruitment following fire; Lemonadeberry recruits during fire-free intervals.

This zone contains small, highly fragmented remnants of native grasslands composed of mostly perennial bunchgrass, Needlegrasses *(Nassella spp.)*, Pine Bluegrass *(Poa secunda)*, Junegrass *(Koeleria macrantha)*, and Melicgrasses *(Melica spp.)*, and a rich diversity of annual and perennial forbs. Most perennials survive fire and resprout with the onset of rain.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Artemisia californica	California Sagebrush	Top-Killed	Sprouter	Enhanced Recruitment
Artemisia californica	California Sagebrush	Killed	Dead	Enhanced Recruitment
Encelia californica	California Brittlebush	Top-Killed	Sprouter	Enhanced Recruitment
Eriogonum fasciculatum	California Buckwheat	Top-Killed	Sprouter	Enhanced Recruitment
Eriogonum fasciculatum	California Buckwheat	Killed	Dead	Enhanced Recruitment
Hazardia squarrosa	Saw-toothed Goldenbush	Top-Killed	Sprouter	Enhanced Recruitment
Malosma laurina	Laurel Sumac	Top-Killed	Sprouter	Enhanced Recruitment
Mimulus aurantiacus	Bush Monkeyflower	Top-Killed	Sprouter	Enhanced Recruitment
Mimulus aurantiacus	Bush Monkeyflower	Killed	Dead	Enhanced Recruitment
Rhus integrifolia	Lemonadeberry	Top-Killed	Sprouter	Neutral
Salvia leucophylla	Purple Sage	Top-Killed	Sprouter	Enhanced Recruitment
Salvia leucophylla	Purple Sage	Killed	Dead	Enhanced Recruitment
Salvia mellifera	Black Sage	Top-Killed	Sprouter	Enhanced Recruitment
Salvia mellifera	Black Sage	Killed	Dead	Enhanced Recruitment

M262B.2 Interior Sage Scrub-Chaparral Ecological Zone

Within this zone, subshrubs resprout less vigorously than where coastal; resprout success may be greater when a plant is younger. The result is that species which when coastal are facultative seeders, behave more like obligate seeders in the interior, as fire-caused mortality of adults can often be 100% on interior sites. Thus, most regeneration is from seed, especially so with Black Sage *(Salvia mellifera)*, White Sage *(Salvia apiana)*, Deerweed *(Lotus scoparius)*, and Chaparral Mallow *(Malacothamnus fasciculatus)*.

Evergreen woody shrubs are present in more mesic locations such as north-facing slopes and canyon bottoms Resprouting occurs more often on less arid sites, such as north-facing slopes. Among the many species that can resprout are Chamise *(Adenostoma fasciculatum)*, Scrub Oak *(Quercus berberidifolia)*, California Coffeeberry *(Rhamnus californica)*, Redberry *(Rhamnus crocea)*, Holly-Leaf Cherry *(Prunus ilicifolia)*, Toyon *(Heteromeles arbutifolia)*, Silk Tassel Bush *(Garrya spp.)*, Birch-leaf Mountain-Mahogany *(Cercocarpus betuloides)*, and some California-Lilacs *(Ceanothus spp.)* and Manzanitas *(Arctostaphylos spp.)*. Many are also facultative seeders with massive seedling recruitment following a fire, e.g., Chamise, Eastwood's Manzanita *(Arctostaphylos glandulosa)*, Chaparral Whitethorn *(Ceanothus leucodermis)*, Greenbark Ceanothus *(Ceanothus spinosus)*, Yerba Santa *(Eriodictyon californicum)*, and Flannelbush *(Fremontodendron californicum)*. Those which are nearly always killed by fire do not have the capacity to resprout, but instead, regenerate from large dormant seed banks, include Hoaryleaf Ceanothus *(Ceanothus crassifolius)*, Big-Pod Ceanothus *(Ceanothus megacarpus)*, Hairy Ceanothus *(Ceanothus oliganthus)*, Otay Ceanothus *(Ceanothus otayensis)*, Wartleaf Ceanothus *(Ceanothus papillosus)*, Desert Ceanothus *(Ceanothus pauciflorus)*, and Bush Poppy *(Dendromecon rigida)*.

There is a stunning but ephemeral post-fire flora of herbacous species that have been characterized as "fire-followers" that is shared by sage scrub and chaparral communities. This ephermeral post-fire successional flora is composed of annuals equalling about 60% of species, constituting 25-50% of surface ground cover. Several dozen species are restricted to recently burned sites. These species are stimulated to germinate from a dormant seed bank in response to cues associated with fire *(e.g. smoke, charate, heat scarification)*. They are most abundant in the first growing season after a fire and decline in numbers with each subsequent year, nearly gone by the third postfire year.

Within various chaparral dominated landscapes, there are isolated stands of conifers with variably serotinous cones; some regenerate only after fire, Tecate Cypress *(Cupressus forbesii)* and Cuyamaca Cypress *(Cupressus arizonica stephensonii)* maintain a serotinous cone seed bank and recruit heavily in in the first post-fire spring. Torrey Pine *(Pinus torreyana)*, associated with coastal chaparral, has enhanced recruitment after a fire event, but can also recruit during fire-free intervals. In the eastern Transverse and northern Peninsular Ranges pockets of Knobcone Pine *(Pinus attenuata)*, a tree with strongly serotinous cones, is associated with chaparral plants. The cones of Coulter Pine *(Pinus coulteri)* are more serotinous when the species occurs in chaparral with recruitment synchronized to immediate post-fire environment; when it occurs in a forest matrix, the cones are less serotinous and recruitment can occur during fire-free intervals. Big Cone Douglas-Fir *(Pseudotsuga macrocarpa)*, a tree with a distribution within chaparral zones, behaves as a facultative seeder; it can resprout from buds present throughout the length of the bole and branches, but not from base; seedling recruitment is sporadic during fire-free periods.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Acourtia microcephala	Sacapellate	Top-Killed	Sprouter	Neutral
Acourtia microcephala	Sacapellate	Top-Killed	Sprouter	Enhanced Recruitment
Adenostoma fasciculatum	Chamise	Killed	Dead	Enhanced Recruitment
Adenostoma fasciculatum	Chamise	Top-Killed	Sprouter	Enhanced Recruitment
Arctostaphylos glandulosa	Eastwood Manzanita	Killed	Dead	Enhanced Recruitment
Arctostaphylos glandulosa	Eastwood Manzanita	Top-Killed	Sprouter	Enhanced Recruitment
Arctostaphylos glauca	Bigberry Manzanita	Killed	Dead	Enhanced Recruitment
Calochortus spp.	Mariposa Lily	Top-Killed	Sprouter	Neutral
Calochortus spp.	Mariposa Lily	Top-Killed	Sprouter	Enhanced Recruitment
Ceanothus greggii	Desert Ceanothus	Killed	Dead	Enhanced Recruitment
Ceanothus leucoderrnis	Chaparral Whitethorn	Killed	Dead	Enhanced Recruitment
Ceanothus leucoderrnis	Chaparral Whitethorn	Top-Killed	Sprouter	Enhanced Recruitment
Ceanothus spinosus	Greenbark Ceanothus	Killed	Dead	Enhanced Recruitment
Ceanothus spinosus	Greenbark Ceanothus	Top-Killed	Sprouter	Enhanced Recruitment
Ceanothus tomentosus	Woolyieaf Ceanothus	Killed	Dead	Enhanced Recruitment
Cercocarpus betuloides var. betuloides	Birch-leaf Mountain-mahogany	Killed	Dead	Neutral
Cercocarpus betuloides var. betuloides	Birch-leaf Mountain-mahogany	Top-Killed	Sprouter	Neutral
Chlorogalum pomeridianum	Soap Plant	Top-Killed	Sprouter	Neutral
Chlorogalum pomeridianum	Soap Plant	Top-Killed	Sprouter	Enhanced Recruitment
Cupressus forbesii	Tecate Cypress	Killed	Dead	Enhanced Recruitment
Cuptessus arizonica spp. stephensonii	Cuyamaca Cypress	Killed	Dead	Enhanced Recruitment
Delphinium spp.	Larkspur	Top-Killed	Sprouter	Neutral
Delphinium spp.	Larkspur	Top-Killed	Sprouter	Enhanced Recruitment
Dichelostemma capitatum	Blue Dicks	Top-Killed	Sprouter	Neutral
Dichelostemma capitatum	Blue Dicks	Top-Killed	Sprouter	Enhanced Recruitment
Eriodictyon californicum	Yerba Santa	Killed	Dead	Enhanced Recruitment
Eriodictyon californicum	Yerba Santa	Top-Killed	Sprouter	Enhanced Recruitment
Eriogonum fasciculatum	California Buckwheat	Killed	Dead	Enhanced Recruitment
Fremontodendron californicum	Flannelbush	Killed	Dead	Enhanced Recruitment
Fremontodendron californicum	Flannelbush	Top-Killed	Sprouter	Enhanced Recruitment
Garrya spp.	Silk Tassel Bush	Killed	Dead	Neutral
Garrya spp.	Silk Tassel Bush	Top-Killed	Sprouter	Neutral
Heteromeles arbutifolia	Toyon, Chaparral Holly	Killed	Dead	Neutral
Heteromeles arbutifolia	Toyon, Chaparral Holly	Top-Killed	Sprouter	Neutral
Lomatium spp.	Lomatium	Top-Killed	Sprouter	Neutral
Lomatium spp.	Lomatium	Top-Killed	Sprouter	Enhanced Recruitment
Lotus scoparius	Deerweed	Killed	Non-Sprouter	Enhanced Recruitment
Marah macrocarpus	Cucamonga Manroot	Top-Killed	Sprouter	Neutral
Marah macrocarpus	Cucamonga Manroot	Top-Killed	Sprouter	Enhanced Recruitment
Melica imperfecta	Smallflower Melicgrass	Top-Killed	Sprouter	Neutral
Melica imperfecta	Smallflower Melicgrass	Top-Killed	Sprouter	Enhanced Recruitment
Pinus attenuata	Knobcone Pine	Killed	Dead	Enhanced Recruitment
Pinus coulteri	Coulter Pine	Survive	Non-Sprouter	Enhanced Recruitment
Pinus coulteri	Coulter Pine	Killed	Dead	Neutral
Pinus torreyana	Torrey Pine	Survive	Non-Sprouter	Enhanced Recruitment
Pinus torreyana	Torrey Pine	Killed	Dead	Neutral
Prunus ilicifolia	Chaparral Cherry	Killed	Dead	Neutral
Prunus ilicifolia	Chaparral Cherry	Top-Killed	Sprouter	Neutral
Quercus berberidifolia	Scrub Oak	Killed	Dead	Neutral
Quercus berberidifolia	Scrub Oak	Top-Killed	Sprouter	Neutral
Rhamnus californica	California Coffeeberry	Killed	Dead	Neutral
Rhamnus californica	California Coffeeberry	Top-Killed	Sprouter	Neutral
Rhamnus ilicifolia	Holly-leaf Redberry	Killed	Dead	Neutral
Rhamnus ilicifolia	Holly-leaf Redberry	Top-Killed	Sprouter	Neutral
Salvia mellifera	Black Sage	Killed	Dead	Enhanced Recruitment
Zigadenus spp.	Death Camas	Top-Killed	Sprouter	Neutral
Zigadenus spp.	Death Camas	Top-Killed	Sprouter	Enhanced Recruitment

M262B.3 Riparian Woodland-Shrubland Ecological Zone

M262B.4 Oak and Walnut Woodlands Ecological Zone

In riparian areas the woody plant response to fire is consistent with vigorous resprouting. There are a few post-fire seed producers, but otherwise the seedbank in riparian zones is very short-lived.

The trees in Oak and Walnut Woodlands enjoy abundant seedling recruitment between fires. Engelmann Oak *(Quercus engelmannii)*, Coast Live Oak *(Quercus agrifolia)*, Valley Oak *(Quercus lobata)*, and California Black Oak *(Quercus kelloggii)* resprout from basally in youth and also epicormically when mature. California Walnut *(Juglans californica)* are vigorous basal resprouters as are many of the species associated with it.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Alnus rhombifolia	White Alder	Top-Killed	Sprouter	Neutral
Alnus rhombifolia	White Alder	Survive	Sprouter	Neutral
Baccharis salicifolia	Mule Fat	Top-Killed	Sprouter	Neutral
Baccharis salicifolia	Mule Fat	Survive	Sprouter	Neutral
Juglans californica	California Black Walnut	Top-Killed	Sprouter	Neutral
Juglans californica	California Black Walnut	Survive	Sprouter	Neutral
Platanus racemosa	Western Sycamore	Top-Killed	Sprouter	Neutral
Platanus racemosa	Western Sycamore	Survive	Sprouter	Neutral
Populus fremontii	Fremont Cottonwood	Top-Killed	Sprouter	Neutral
Populus fremontii	Fremont Cottonwood	Survive	Sprouter	Neutral
Pseudotsuga macrocarpa	Bigcone Douglas-fir	Top-Killed	Sprouter	Neutral
Pseudotsuga macrocarpa	Bigcone Douglas-fir	Survive	Sprouter	Neutral
Quercus agrifolia	Coast Live Oak	Top-Killed	Sprouter	Neutral
Quercus agrifolia	Coast Live Oak	Survive	Sprouter	Neutral
Quercus chrysolepis	Canyon Live Oak	Top-Killed	Sprouter	Neutral
Quercus chrysolepis	Canyon Live Oak	Survive	Sprouter	Neutral
Quercus engelmannii	Engelmann Oak	Top-Killed	Sprouter	Neutral
Quercus engelmannii	Engelmann Oak	Survive	Sprouter	Neutral
Rubus spp.	Blackberry	Top-Killed	Sprouter	Neutral
Rubus spp.	Blackberry	Survive	Sprouter	Neutral
Salix spp.	Willow	Top-Killed	Sprouter	Neutral
Salix spp.	Willow	Survive	Sprouter	Neutral
Toxicodendron diversilobum	Poison Oak	Top-Killed	Sprouter	Neutral
Toxicodendron diversilobum	Poison Oak	Survive	Sprouter	Neutral

M261E.5 Montane Coniferous Forests Ecological Zone

The trees, White Fir *(Abies concolor)*, Incense Cedar *(Calocedrus decurrens)*, Sugar Pine *(Pinus lambertiana)*, Jeffrey Pine *(Pinus jeffreyi)* have seedling recruitment that is not fire-dependent, but is often enhanced by fire-induced gaps; recruitment is episodic, continuing after and between fires. The seedling recruitment for Yellow Pines *(Pinus ponderosa, Pinus jeffreyi, Pinus coulteri)* is enhanced by gaps in the forest with exposed mineral soil.

Most understory shrubs are vigorous sprouters including Bush Chinquapin *(Chrysolepsis sempervirens)*, Huckleberry Oak *(Quercus vaccinifolia)*, Bitter Cherry *(Prunus emarginata)*, Mountain Whitethorn *(Ceanothus cordulatus)*. Many are also facultative seeders that recruit seedlings in large numbers after fire from dormant seed banks such as Mountain Whitethorn *(Ceanothus cordulatus)* and Deer Brush *(Ceanothus integerrimus)*.

The herbaceous understory is composed of mostly perennials that resprout after fire with seedling recruitment continuing until canopy closure.

BIOREGION > **South Coast**

USFS Section M261E > **Sierra Nevada**

LRR D MLRA 22 > **Sierra Nevada Range**

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Acourtia microcephala	Sacapellate	Top-Killed	Sprouter	Neutral
Acourtia microcephala	Sacapellate	Top-Killed	Sprouter	Enhanced Recruitment
Adenostoma fasciculatum	Chamise	Killed	Dead	Enhanced Recruitment
Adenostoma fasciculatum	Chamise	Top-Killed	Sprouter	Enhanced Recruitment
Arctostaphylos glandulosa	Eastwood Manzanita	Killed	Dead	Enhanced Recruitment
Arctostaphylos glandulosa	Eastwood Manzanita	Top-Killed	Sprouter	Enhanced Recruitment
Arctostaphylos glauca	Bigberry Manzanita	Killed	Dead	Enhanced Recruitment
Calochortus spp.	Mariposa Lily	Top-Killed	Sprouter	Neutral
Calochortus spp.	Mariposa Lily	Top-Killed	Sprouter	Enhanced Recruitment
Ceanothus greggii	Desert Ceanothus	Killed	Dead	Enhanced Recruitment
Ceanothus leucoderrnis	Chaparral Whitethorn	Killed	Dead	Enhanced Recruitment
Ceanothus leucoderrnis	Chaparral Whitethorn	Top-Killed	Sprouter	Enhanced Recruitment
Ceanothus spinosus	Greenbark Ceanothus	Killed	Dead	Enhanced Recruitment
Ceanothus spinosus	Greenbark Ceanothus	Top-Killed	Sprouter	Enhanced Recruitment
Ceanothus tomentosus	Woolyieaf Ceanothus	Killed	Dead	Enhanced Recruitment
Cercocarpus betuloides var. betuloides	Birch-leaf Mountain-mahogany	Killed	Dead	Neutral
Cercocarpus betuloides var. betuloides	Birch-leaf Mountain-mahogany	Top-Killed	Sprouter	Neutral
Chlorogalum pomeridianum	Soap Plant	Top-Killed	Sprouter	Neutral
Chlorogalum pomeridianum	Soap Plant	Top-Killed	Sprouter	Enhanced Recruitment
Cupressus forbesii	Tecate Cypress	Killed	Dead	Enhanced Recruitment
Cuptessus arizonica spp. stephensonii	Cuyamaca Cypress	Killed	Dead	Enhanced Recruitment
Delphinium spp.	Larkspur	Top-Killed	Sprouter	Neutral
Delphinium spp.	Larkspur	Top-Killed	Sprouter	Enhanced Recruitment
Dichelostemma capitatum	Blue Dicks	Top-Killed	Sprouter	Neutral
Dichelostemma capitatum	Blue Dicks	Top-Killed	Sprouter	Enhanced Recruitment
Eriodictyon californicum	Yerba Santa	Killed	Dead	Enhanced Recruitment
Eriodictyon californicum	Yerba Santa	Top-Killed	Sprouter	Enhanced Recruitment
Eriogonum fasciculatum	California Buckwheat	Killed	Dead	Enhanced Recruitment
Fremontodendron californicum	Flannelbush	Killed	Dead	Enhanced Recruitment
Fremontodendron californicum	Flannelbush	Top-Killed	Sprouter	Enhanced Recruitment
Garrya spp.	Silk Tassel Bush	Killed	Dead	Neutral
Garrya spp.	Silk Tassel Bush	Top-Killed	Sprouter	Neutral
Heteromeles arbutifolia	Toyon, Chaparral Holly	Killed	Dead	Neutral
Heteromeles arbutifolia	Toyon, Chaparral Holly	Top-Killed	Sprouter	Neutral
Lomatium spp.	Lomatium	Top-Killed	Sprouter	Neutral
Lomatium spp.	Lomatium	Top-Killed	Sprouter	Enhanced Recruitment
Lotus scoparius	Deerweed	Killed	Non-Sprouter	Enhanced Recruitment
Marah macrocarpus	Cucamonga Manroot	Top-Killed	Sprouter	Neutral
Marah macrocarpus	Cucamonga Manroot	Top-Killed	Sprouter	Enhanced Recruitment
Melica imperfecta	Smallflower Melicgrass	Top-Killed	Sprouter	Neutral
Melica imperfecta	Smallflower Melicgrass	Top-Killed	Sprouter	Enhanced Recruitment
Pinus attenuata	Knobcone Pine	Killed	Dead	Enhanced Recruitment
Pinus coulteri	Coulter Pine	Survive	Non-Sprouter	Enhanced Recruitment
Pinus coulteri	Coulter Pine	Killed	Dead	Neutral
Pinus torreyana	Torrey Pine	Survive	Non-Sprouter	Enhanced Recruitment
Pinus torreyana	Torrey Pine	Killed	Dead	Neutral
Prunus ilicifolia	Chaparral Cherry	Killed	Dead	Neutral
Prunus ilicifolia	Chaparral Cherry	Top-Killed	Sprouter	Neutral
Quercus berberidifolia	Scrub Oak	Killed	Dead	Neutral
Quercus berberidifolia	Scrub Oak	Top-Killed	Sprouter	Neutral
Rhamnus californica	California Coffeeberry	Killed	Dead	Neutral
Rhamnus californica	California Coffeeberry	Top-Killed	Sprouter	Neutral
Rhamnus ilicifolia	Holly-leaf Redberry	Killed	Dead	Neutral
Rhamnus ilicifolia	Holly-leaf Redberry	Top-Killed	Sprouter	Neutral
Salvia mellifera	Black Sage	Killed	Dead	Enhanced Recruitment
Zigadenus spp.	Death Camas	Top-Killed	Sprouter	Neutral
Zigadenus spp.	Death Camas	Top-Killed	Sprouter	Enhanced Recruitment

341D.1 High-Elevation Desert Shrubland and Woodland Ecological Zone

This zone predominates in the Mono area and occurs atop most Mojave Desert Mountains and along the margins of the Sierra Nevada, Transverse, and Peninsular Mountain Ranges where it transitions into Yellow Pine Forests.

Fire responses vary among species. Wyoming sagebrush *(Artemisia tridentata wyomingensis)* is typically killed but has good seedling recruitment. Cliffrose *(Purshia mexicana stansburyana)* is typically killed. Antelope Bitterbrush *(Purshia tridentata)* has some resprout when top-killed. Muller's Oak *(Quercus cornelius-mulleri)*, Scrub Live Oak *(Quercus berberidifolia)*, Birch-Leaf Mountain-Mahogany *(Cercocarpus betuloides)*, Bigberry Manzanita *(Arctostaphylos glauca)*, Eastwood's Manzanita *(Arctostaphylos glandulosa)* and Beargrass *(Nolina)* may resprout or reseed. The conifers, Singleleaf Pinyon Pine *(Pinus monophylla)*, Colorado Pinyon Pine *(Pinus edulis)*, Utah Juniper *(Juniperus osteosperma)*, and California Juniper *(Juniperus californica)*, are typically killed, with Junipers reseeding well.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Arctostaphylos glandulosa	Eastwood Manzanita	Killed	Dead	Enhanced Recruitment
Arctostaphylos glauca	Bigberry Manzanita	Killed	Dead	Enhanced Recruitment
Artemisia tridentatassp. wyomingenesis	Wyoming Big Sagebrush	Top-Killed	Sprouter	Unknown
Artemisia tridentatassp. wyomingenesis	Wyoming Big Sagebrush	Killed	Dead	Unknown
Cercocarpus betuloides var. betuloides	Birch-leaf Mountain-mahogany	Top-Killed	Sprouter	Neutral
Juniperus califomica	California Juniper	Killed	Dead	Enhanced Recruitment
Pinus edulis	Colorado Pinyon Pine	Killed	Dead	Neutral
Pinus monophylla	Singleleaf Pinyon Pine	Killed	Dead	Neutral
Purshia mexicana var. stansburyana	Cliffrose	Killed	Dead	Unknown
Purshia tridentata	Antelope Bitterbrush	Top-Killed	Sprouter	Unknown
Purshia tridentata	Antelope Bitterbrush	Killed	Dead	Unknown
Quercus berberidifolia	Scrub Oak	Top-Killed	Sprouter	Unknown
Quercus cornelius-mulleri	Muller's Oak	Top-Killed	Sprouter	Neutral

341D.2 Desert Montane Woodland Ecological Zone

The zone is limited mostly to Mono and Southeastern Great Basin. Bristlecone Pine *(Pinus longeava)* and Limber Pine *(Pinus flexilis)* suffer high mortality from fire, which rarely occurs. Most species in this zone are not adapted to recovery from fire.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Juniperus osteosperma	Utah Juniper	Killed	Dead	Enhanced Recruitment
Pinus flexilis	Limber Pine	Killed	Dead	Unknown
Pinus longaeva	Western Bristlecone Pine	Killed	Dead	Unknown

341F.1 High-Elevation Desert Shrubland and Woodland Ecological Zone

This zone predominates in the Mono area and occurs atop most Mojave Desert Mountains and along the margins of the Sierra Nevada, Transverse, and Peninsular Mountain Ranges where it tranitions into Yellow Pine Forests.

Fire responses vary among species. Wyoming sagebrush *(Artemisia tridentata wyomingensis)* is typically killed but has good seedling recruitment. Cliffrose *(Purshia mexicana stansburyana)* is typically killed. Antelope Bitterbrush *(Purshia tridentata)* has some resprout when top-killed. Muller's Oak *(Quercus cornelius-mulleri)*, Scrub Live Oak *(Quercus berberidifolia)*, Birch-Leaf Mountain-Mahogany *(Cercocarpus betuloides)*, Bigberry Manzanita *(Arctostaphylos glauca)*, Eastwood's Manzanita *(Arctostaphylos glandulosa)* and Beargrass *(Nolina)* may resprout or reseed. The conifers, Singleleaf Pinyon Pine *(Pinus monophylla)*, Colorado Pinyon Pine *(Pinus edulis)*, Utah Juniper *(Juniperus osteosperma)*, and California Juniper *(Juniperus californica)*, are typically killed, with Junipers reseeding well.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Arctostaphylos glandulosa	Eastwood Manzanita	Killed	Dead	Enhanced Recruitment
Arctostaphylos glauca	Bigberry Manzanita	Killed	Dead	Enhanced Recruitment
Artemisia tridentatassp. wyomingenesis	Wyoming Big Sagebrush	Top-Killed	Sprouter	Unknown
Artemisia tridentatassp. wyomingenesis	Wyoming Big Sagebrush	Killed	Dead	Unknown
Cercocarpus betuloides var. betuloides	Birch-leaf Mountain-mahogany	Top-Killed	Sprouter	Neutral
Juniperus califomica	California Juniper	Killed	Dead	Enhanced Recruitment
Pinus edulis	Colorado Pinyon Pine	Killed	Dead	Neutral
Pinus monophylla	Singleleaf Pinyon Pine	Killed	Dead	Neutral
Purshia mexicana var. stansburyana	Cliffrose	Killed	Dead	Unknown
Purshia tridentata	Antelope Bitterbrush	Top-Killed	Sprouter	Unknown
Purshia tridentata	Antelope Bitterbrush	Killed	Dead	Unknown
Quercus berberidifolia	Scrub Oak	Top-Killed	Sprouter	Unknown
Quercus cornelius-mulleri	Muller's Oak	Top-Killed	Sprouter	Neutral

341F.2 Desert Montane Woodland Ecological Zone

The zone is limited mostly to Mono and Southeastern Great Basin. Bristlecone Pine *(Pinus longeava)* and Limber Pine *(Pinus flexilis)* suffer high mortality from fire, which rarely occurs. Most species in this zone are not adapted to recovery from fire.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Juniperus osteosperma	Utah Juniper	Killed	Dead	Enhanced Recruitment
Pinus flexilis	Limber Pine	Killed	Dead	Unknown
Pinus longaeva	Western Bristlecone Pine	Killed	Dead	Unknown

BIOREGION > **Southeastern Deserts**

USFS Section 322A > **Mojave Desert**

LRR D MLRA 30 > **Sonoran Basin and Range**

Elevation is the primary determinant of vegetation zones, listed below in order of increasing elevation.

322A.1 Low-Elevation Desert Shrubland Ecological Zone

This is the predominant ecological zone of the Sonoroan Desert and in lower elevations of the Mojave Desert. Most shrubs are killed by fire. Some shrubs are only top-killed and resprout including Desert Willow *(Chilopsis linearis)*, Catclaw Acacia *(Acacia greggi)*, Smoke Tree *(Psorothamnus spinosus)*, Fourwing Saltbush *(Atriplex canescens)*, White Bursage *(Ambrosia dumosa)*, Rubber Rabbitbrush *(Chrysothamnus nauseosus)*, Cheesebush *(Hymenoclea salsola)*, and Creosote Bush *(Larrea tridentata)*.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Acacia greggi	Catclaw Acacia	Top-Killed	Sprouter	Neutral
Acacia greggi	Catclaw Acacia	Killed	Dead	Neutral
Ambrosia dumosa	White Bursage	Top-Killed	Sprouter	Neutral
Ambrosia dumosa	White Bursage	Killed	Dead	Neutral
Atriplex canescens	Fourwing Saltbush	Top-Killed	Sprouter	Neutral
Atriplex canescens	Fourwing Saltbush	Killed	Dead	Neutral
Chilopsis linearis	Desert-willow	Top-Killed	Sprouter	Neutral
Chilopsis linearis	Desert-willow	Killed	Dead	Neutral
Chrysothamnus nauseosus	Rubber Rabbitbrush	Top-Killed	Sprouter	Neutral
Chrysothamnus nauseosus	Rubber Rabbitbrush	Killed	Dead	Neutral
Encelia farinosa	Brittle Brush	Killed	Dead	Neutral
Hymenoclea salsola	Burrobrush, Cheesebrush	Top-Killed	Sprouter	Neutral
Larrea tridentata	Creosote Bush	Top-Killed	Sprouter	Neutral
Psorothamnus spinosus	Smoke Tree	Top-Killed	Sprouter	Neutral
Psorothamnus spinosus	Smoke Tree	Killed	Dead	Neutral

322A.2 Mid-Elevation Desert Shrubland and Grassland Ecological Zone

This is the predominant ecological zone in the Mojave Desert, Colorado and Southeastern Great Basin. There is a variety of responses to fire. Some shrubs do not burn readily and survive well such as Spiny Menodora *(Menodora spinescens)* and Mormon Tea *(Ephedra spp.)*. Joshua Tree *(Yucca brevifolia)*, Mojave Yucca *(Yucca schidigera)* and Our Lord's Candle *(Yucca whipplei)* are typically scorched but can resprout. Shadscale *(Atriplex confertifolia)* and Creosote Bush *(Larrea tridentata)* can resprout. Some shrubs are killed and rarely resprout including Blackbrush *(Coleogyne ramosissima)* and winterfat *(Kraschennikova lanata)*. Perennial grasses generally resprout, including Desert Needlegrass *(Achnatherum speciosum)*, Galleta Grass *(Pleuaphis jamesii)*, and Indian Ricegrass *(Achnatherum hymenoides)*.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Atriplex confertifolia	Shad Scale	Killed	Dead	Neutral
Coloegyne ramosissima	Blackbrush	Killed	Dead	Neutral
Grayia spinosa	Spiny Hopsage	Top-Killed	Sprouter	Neutral
Gutierrezia microcephala	Snakeweed	Killed	Dead	Neutral
Kraschennikovia lanata	Winterfat	Survive	Unknown	Neutral
Menodora spinescens	Spiny Menodora	Survive	Unknown	Neutral
Yucca brevifolia	Joshua Tree	Top-Killed	Sprouter	Neutral
Yucca schidigera	Mojave Yucca	Top-Killed	Sprouter	Neutral

322A.3 Riparian Woodland Ecological Zone

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Fraxinus velutina	Velvet Ash	Top-Killed	Sprouter	Neutral
Populus fremontii	Fremont Cottonwood	Top-Killed	Sprouter	Neutral
Prosopis glandulosa var. torreyana	Honey Mesquite	Top-Killed	Sprouter	Neutral
Salix spp.	Willow	Top-Killed	Sprouter	Neutral
Tamarix spp.	Tamarisk	Top-Killed	Sprouter	Neutral

BIOREGION > **Southeastern Deserts**

USFS Section 322B > **Sonoran Desert**

LRR D MLRA 30 > **Sonoran Basin and Range**

Elevation is the primary determinant of vegetation zones, listed below in order of increasing elevation.

322B.1 Low-Elevation Desert Shrubland Ecological Zone

This is the predominant ecological zone of the Sonoroan Desert and in lower elevations of the Mojave Desert. Most shrubs are killed by fire. Some shrubs are only top-killed and resprout including Desert Willow *(Chilopsis linearis)*, Catclaw Acacia *(Acacia greggi)*, Smoke Tree *(Psorothamnus spinosus)*, Fourwing Saltbush *(Atriplex canescens)*, White Bursage *(Ambrosia dumosa)*, Rubber Rabbitbrush *(Chrysothamnus nauseosus)*, Cheesebush *(Hymenoclea salsola)*, and Creosote Bush *(Larrea tridentata)*.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Acacia greggi	Catclaw Acacia	Top-Killed	Sprouter	Neutral
Acacia greggi	Catclaw Acacia	Killed	Dead	Neutral
Ambrosia dumosa	White Bursage	Top-Killed	Sprouter	Neutral
Ambrosia dumosa	White Bursage	Killed	Dead	Neutral
Atriplex canescens	Fourwing Saltbush	Top-Killed	Sprouter	Neutral
Atriplex canescens	Fourwing Saltbush	Killed	Dead	Neutral
Chilopsis linearis	Desert-willow	Top-Killed	Sprouter	Neutral
Chilopsis linearis	Desert-willow	Killed	Dead	Neutral
Chrysothamnus nauseosus	Rubber Rabbitbrush	Top-Killed	Sprouter	Neutral
Chrysothamnus nauseosus	Rubber Rabbitbrush	Killed	Dead	Neutral
Encelia farinosa	Brittle Brush	Killed	Dead	Neutral
Hymenoclea salsola	Burrobrush, Cheesebrush	Top-Killed	Sprouter	Neutral
Larrea tridentata	Creosote Bush	Top-Killed	Sprouter	Neutral
Psorothamnus spinosus	Smoke Tree	Top-Killed	Sprouter	Neutral
Psorothamnus spinosus	Smoke Tree	Killed	Dead	Neutral

322B.2 Mid-Elevation Desert Shrubland and Grassland Ecological Zone

This is the predominant ecological zone in the Mojave Desert, Colorado and Southeastern Great Basin. There is a variety of responses to fire. Some shrubs do not burn readily and survive well such as Spiny Menodora *(Menodora spinescens)* and Mormon Tea *(Ephedra spp.)*. Joshua Tree *(Yucca brevifolia)*, Mojave Yucca *(Yucca schidigera)* and Our Lord's Candle *(Yucca whipplei)* are typically scorched but can resprout. Shadscale *(Atriplex confertifolia)* and Creosote Bush *(Larrea tridentata)* can resprout. Some shrubs are killed and rarely resprout including Blackbrush *(Coleogyne ramosissima)* and winterfat *(Kraschennikova lanata)*. Perennial grasses generally resprout, including Desert Needlegrass *(Achnatherum speciosum)*, Galleta Grass *(Pleuaphis jamesii)*, and Indian Ricegrass *(Achnatherum hymenoides)*.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Atriplex confertifolia	Shad Scale	Killed	Dead	Neutral
Coloegyne ramosissima	Blackbrush	Killed	Dead	Neutral
Grayia spinosa	Spiny Hopsage	Top-Killed	Sprouter	Neutral
Gutierrezia microcephala	Snakeweed	Killed	Dead	Neutral
Kraschennikovia lanata	Winterfat	Survive	Unknown	Neutral
Menodora spinescens	Spiny Menodora	Survive	Unknown	Neutral
Yucca brevifolia	Joshua Tree	Top-Killed	Sprouter	Neutral
Yucca schidigera	Mojave Yucca	Top-Killed	Sprouter	Neutral

322B.3 Riparian Woodland Ecological Zone

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Fraxinus velutina	Velvet Ash	Top-Killed	Sprouter	Neutral
Platanus racemosa	California Sycamore	Top-Killed	Sprouter	Neutral
Populus fremontii	Fremont Cottonwood	Top-Killed	Sprouter	Neutral
Prosopis glandulosa var. torreyana	Honey Mesquite	Top-Killed	Sprouter	Neutral
Salix spp.	Willow	Top-Killed	Sprouter	Neutral
Tamarix spp.	Tamarisk	Top-Killed	Sprouter	Neutral

BIOREGION > **Southeastern Deserts**

USFS Section 322C > **Colorado Desert**

LRR D MLRA 31 > **Imperial Valley**

322C.1 Low-Elevation Desert Shrubland Ecological Zone

This is the predominant ecological zone of the Sonoroan Desert and in lower elevations of the Mojave Desert. Most shrubs are killed by fire. Some shrubs are only top-killed and resprout including Desert Willow *(Chilopsis linearis)*, Catclaw Acacia *(Acacia greggi)*, Smoke Tree *(Psorothamnus spinosus)*, Fourwing Saltbush *(Atriplex canescens)*, White Bursage *(Ambrosia dumosa)*, Rubber Rabbitbrush *(Chrysothamnus nauseosus)*, Cheesebush *(Hymenoclea salsola)*, and Creosote Bush *(Larrea tridentata)*.

		FIRE RESPONSE		
		Individual		Population
Botanical Name	Common Name	Survival	Vegetative	Seed
Acacia greggi	Catclaw Acacia	Top-Killed	Sprouter	Neutral
Acacia greggi	Catclaw Acacia	Killed	Dead	Neutral
Ambrosia dumosa	White Bursage	Top-Killed	Sprouter	Neutral
Ambrosia dumosa	White Bursage	Killed	Dead	Neutral
Atriplex canescens	Fourwing Saltbush	Top-Killed	Sprouter	Neutral
Atriplex canescens	Fourwing Saltbush	Killed	Dead	Neutral
Chilopsis linearis	Desert-willow	Top-Killed	Sprouter	Neutral
Chilopsis linearis	Desert-willow	Killed	Dead	Neutral
Chrysothamnus nauseosus	Rubber Rabbitbrush	Top-Killed	Sprouter	Neutral
Chrysothamnus nauseosus	Rubber Rabbitbrush	Killed	Dead	Neutral
Encelia farinosa	Brittle Brush	Killed	Dead	Neutral
Hymenoclea salsola	Burrobrush, Cheesebrush	Top-Killed	Sprouter	Neutral
Larrea tridentata	Creosote Bush	Top-Killed	Sprouter	Neutral
Psorothamnus spinosus	Smoke Tree	Top-Killed	Sprouter	Neutral
Psorothamnus spinosus	Smoke Tree	Killed	Dead	Neutral

Section 7

REFERENCES

Agee JK. 1993. Fire Ecology of the Pacific Northwest Forests. Island Press, Washington, D.C.

Amaranthus MP, Trappe JM, Perry DA. 1993. Soil moisture, native revegetation, and *Pinus lambertiana* seedling survival, growth and mycorrhiza formation following wildfire and grass seeding. Restoration Ecology 1: 188-195.

Bailey, R.G. 1995. Description of the Ecoregions of the United States. ed. 2. *USDA–Forest Service Miscellaneous Publication* 1391/995 (with map supplement at 1:7,500,000). Washington, D.C.: U.S. Department of Agriculture, Forest Service.

Baron FJ. 1962. Effects of different grasses on Ponderosa Pine seedling establishment. Res. Note PSW-199. Berkeley, CA, USDA Forest Service, Pacific Southwest Forest and Range Experiment Station.

Barro SC, Conard SG. 1987. Use of ryegrass seeding as an emergency revegetation measure in chaparral ecosystems. Gen. Tech. Rep. PSW-102, Berkeley, CA, USDA Forest Service, Pacific Southwest Forest and Range Experiment Station.

Bautista S, Bellot J, Vallejo VR. 1996. Mulching treatment for post-fire soil conservation in a semiarid ecosystem. Arid Soil Research and Rehabilitation 1-:235-242.

Beyers Jl, Wakeman CD, Wohlgemuth PM, Conard SG. 1998. Effects of postfire grass seeding on native vegetation in southern California chaparral. pp. 52-64 *In* Proceedings, Nineteenth Annual Forest Vegetation Management Conference: Wildfire Rehabilitation, January 20-22, 1998. Forest Vegetation Managment Conference, Reding, CA.

Beyers JL. 2004. Postfire seeding for erosion control: effectiveness and impacts on native plant communities. Conservation Biology 18:947-956.

Beyers JL. In press. Growth of Regreen, seeded for erosion control, in the Manter fire area, southern Sierra Nevada. *In* Narog MG (Tech, Coord.). Proceedings of the 2002 Fire Conference on Managing Fire and Fuels in the Remaining Wildlands and Open Spaces of the Southwestern United States, Dec 2-5, 2002, San Diego, CA. Gen. Tech. Rep. PSW-189. USDA Forest Service, Pacific Southwest Research Station, Albany, CA.

Brooks ML, Minnich RA. 2006. Southeastern Deserts Bioregion. pp. 391-414 *In* Sugihara NG, van Wagtendock JW, Shaffer KE, Fites-Kaufman J, Thode AE. Fire in California's Ecosystems. University of California Press, Berkeley.

California Department of Transportation (Caltrans). 2005a. Native Shrub Germination Relative to Compost Type, Application Method, and Layer Depth. CTSW-RT-05-069.06.2.

California Department of Transportation (Caltrans). 2005b. Performance of Erosion Control Treatments on Reapplied Topsoil. CTSW-RT-04-069.06.1.

Christ JH. 1934. Reseeding burned-over lands in northern Idaho. University of Idaho Agricultural Experiment Station Bulletin 201. University of Idaho, Moscow.

Collins LM, Johnston CE. 1995. Effectiveness of straw-bale dams for erosion control in the Oakland hills following the fire 1991. pp. 171-183 *In* Keeley JE, Scott T (eds.) Brushfires in California Wildlands: Ecology and Resource Managment. International Association of Wildland Fire, Fairfield, WA.

Conard SG, Beyers JL, Wohlgemuth PM. 1995. Impacts on postfire grass seeding on chaparral systems—what do we know and where do we go from here? pp. 149-161 *In* Keeley JE, Scott T (eds.), Brushfires in California Wildlands: Ecology and Resource Management. International Association of Wildland Fire, Fairfield, WA.

Conard SG, Regelbrugge JC, Wills RD. 1991. Preliminary effects of ryegrass seeding on postfire establishment of natural vegetation in two California ecosystems. pp. 314-321 *In* Andrews PL, Potts DF (eds.), Proceedings of the 11th Conference on Fire and Forest Meteorology, April 16-19, 1991, Missoula, MT. Society of American Foresters, Bethesda, MD.

Conrad CE. 1979. Emergency postfire seeding using annual grass. CHAPS Newsletter, March 1979, p.5-8. Chaparral Research and Development Program, Riverside, CA.

Costales EF. Jr., Costales AB. 1984. Determination and evaluation of some emergency measures for the quick rehabilitation of newly burned watershed areas in the pine forest. Sylvtrop Phillippine Forestry Res. 9:33-53.

Davis FW, Borchert MI. 2006. Central Coast Bioregion. pp. 321-349 *In* Sugihara NG, van Wagtendock JW, Shaffer KE, Fites-Kaufman J, Thode AE. Fire in California's Ecosystems. University of California Press, Berkeley.

DeByle NV. 1970a. Do contour benches reduce wet-mantle flood peaks? Res. Note INT-108. USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT.

DeByle NV. 1970b. Infiltration in contour benches in the Sierra Nevada. Res. Note INT-115. USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT.

Dyrness CT. 1976. Effect of wildfire on soil wetability in the High Cascades of Oregon. Research Paper PNW-202. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR.

Edwards L, Burney J, DeHaan R. 1995. Researching the effects of mulching on cool-period soil erosion in Prince Edward Island, Canada. Journal of Soil and Water Conservation 50:184-187.

Fites-Kaufman J, Bradley AF, Merrill AG. 2006. Fire and plant interactions. pp. 94-117 *In* Sugihara NG, van Wagtendock JW, Shaffer KE, Fites-Kaufman J, Thode AE. Fire in California's Ecosystems. University of California Press, Berkeley.

Furniss MJ, Ledwidth TS, Love MA, McFadin BC, Flanagan SA. 1998. Response of road-stream crossings to large flood events in Washington, Oregon, and northern California. USDA Forest Service, Technology and Development Program, 9877 1806-San Dimas Technology Development Center, San Dimas, CA.

Gautier CR. 1983. Sedimentation in burned chaparral watersheds: is emergency revegetation justified? Water Resources Bulletin 19:793-802.

Goldman SJ, Jackson K, Bursztynsky TA. 1986. Erosion and sediment control handbook. McGraw-Hill, San Francisco, CA.

Griffin JR. 1982. Pine seedlings, native ground cover, and Lolium multiflorum on t he Marble-Cone burn, Santa Lucia Range, California. Madroño 29:177-188.

Griffith RW. 1998. Burned area emergency rehabilitation. pp. 4-7 *In* Proceedings, Nineteenth Annual Forest Vegetation Management Conference: Wildfire Rehabilitation, January 20-22, 1998. Forest Vegetation Management Conference, Redding, CA.

Keeley JE 2004. Ecological impacts of wheat seeding after a Sierra Nevada wildfire. International Journal of Wildland Fire 13:73-78.

Keeley JE, Allen CD, Betancourt J, Chong GW, Fotheringham CJ, Safford HD. 2006. A 21^{st} century perspective on postfire seeding. Journal of Forestry 104:1-2.

Keeley JE. 1991. Seed germination and life history syndromes in the California chaparral. The Botanical Review 57:81-116.

Keeley JE. 2006. South Coast Bioregion. pp. 350-390 *in* Sugihara NG, van Wagtendock JW, Shaffer KE, Fites-Kaufman J, Thode AE. Fire in California's Ecosystems. University of California Press, Berkeley.

Keeley SC, Keeley JE, Hutchinson SM, Johnson AW. 1981. Postfire succession of herbaceous flora in southern California chaparral. Ecology 62:1608-1621.

Klock GO, Tiedemann AR, Lopushinsky W. 1975. Seeding recommendations for disturbed mountain slopes in north central Washington. Res. Note PNW-244. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR.

McCammon BP, Hughes D. 1980. Fire rehab in the Bend municipal watershed. pp. 252-259 *In* Proceedings of the 1980 Watershed Management Symposium, July 21-23, 1980, Boise, ID. American Society of Civil Engineers, New York.

McClure NR. 1956. Grass and legume seedings on burned-over forest lands in northern Idaho and adjacent Washington. Master's Thesis, University of Idaho, Moscow.

McDonald PM. 1986. Grasses in young conifer plantations—hinderance and help. Northwest Science 60(4):271-278.

McMahon G, Gregonis SM, Waltman SW, Omernik JM, Thorson TD, Freeouf JA, Rorick AH, and Keys JE. 2001. Developing a Spatial Framework of Common Ecological Regions for the Conterminous United States. Environmental Management 28(3): 293–316.

Miles, S.R.; **Goudey, C.B. 1997.** Ecological Subregions of California: Section and Subsection Descriptions. USDA Forest Service Pacific Southwest Region Technical Report R5-EM-TP-005.

Miles SR, Haskins DM, Ranken DW. 1989. Emergency burn rehabilitation: cost, risk, and effectiveness. pp. 97-102 *In* Berg NH (tech. coord.), Proceedings of the Symposium on Fire and Watershed Management, October 26-28, 1988, Sacramento, CA. Gen. Tech. Rep. PSW-109. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA.

Nadkarni NM, Odion DC. 1986. Effects of seeding an exotic grass *Lolium muliflorum* in native seedling regeneration following fire in a chaparral community. pp. 115-121 *In* Devries JJ (ed.), Proceedings of the Chaparral Ecosystems Research Conference, May 16-17 1985, Santa Barbara, CA. Report No. 62, California Water Resources Center, University of California, Davis.

Noble EL. 1965. Sediment reduction through watershed rehabilitation. pp. 114-123 *In* Sugihara NG, van Wagtendock JW, Shaffer KE, Fites-Kaufman J, Thode AE. Fire in California's Ecosystems. University of California Press, Berkeley.

Orr HK. 1970. Runoff and erosion control by seeded and native vegetation on a forest burn: Black Hills, South Dakota. Res. Paper RM-60. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Ratliff RD, McDonald PM. 1987. Postfire grass and legume seeding: what to seed and potential impacts on reforestation. pp. 111-123 *In* Proceedings, Ninth Annual Forest Vegetation Management Conference, November 3-5, 1987. Forest Vegetation Management Conference, Redding, CA.

Rice RM, Crouse RP, Corbett ES. 1965. Emergency measures to control erosion after a fire on the San Dimas Experimental Forest. pp. 123-130 *In* Proceedings of the Federal Inter-agency Sedimentation Conference, 1963. Miscellaneous Publication 970, USDA, Washington, D.C.

Richards RT, Chambers JC, Ross C. 1998. Use of native plants on federal lands: policy and practice. Journal of Range Management 51:625-632.

Riegel GM, Miller RF, Skinner CN, Smith SE. 2006. Northeastern Plateaus Bioregion. pp. 225-263 *In* Sugihara NG, van Wagtendock JW, Shaffer KE, Fites-Kaufman J, Thode AE. Fire in California's Ecosystems. University of California Press, Berkeley.

Robichaud PR, Beyers JL, Neary DG. 2000. Evaluating the effectiveness of postfire rehabilitation treatments. Gen. Tech. Rep. RMRS-GTR-63, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Ruby EC. 1989. Rationale for seeding grass on the Stanislaus Complex burn. pp. 125-130 *In* Berg NH (tech. coord.), Proceedings of the Symposium on Fire and Watershed Management, October 26-28, 1988, Sacramento, CA. Gen. Tech. Rep. PSW-109. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA.

Sampson AW. 1944. Plant succession on burned chaparral lands in northern California. California Agricultural Experiment Station Bulletin 685.

Schultz AM, Launchbaugh JL, Biswell HH. 1955. Relationship between grass density and brush seedling survival. Ecology 36:226-238.

Skinner CN, Taylor AH, Agee JK. 2006. Klamath Mountains Bioregion. pp. 170-194 *In* Sugihara NG, van Wagtendock JW, Shaffer KE, Fites-Kaufman J, Thode AE. Fire in California's Ecosystems. University of California Press, Berkeley.

Skinner CN, Taylor AH. 2006. Southern Cascades Bioregion. pp. 195-224 *In* Sugihara NG, van Wagtendock JW, Shaffer KE, Fites-Kaufman J, Thode AE. Fire in California's Ecosystems. University of California Press, Berkeley.

Stuart JD, Scott L. 2006. North Coast Bioregion. pp. 147-169 *In* Sugihara NG, van Wagtendock JW, Shaffer KE, Fites-Kaufman J, Thode AE. Fire in California's Ecosystems. University of California Press, Berkeley.

Sugihara NG, Barbour MG. 2006. Fire and California vegetation. pp. 1-12 *In* Sugihara NG, van Wagtendock JW, Shaffer KE, Fites-Kaufman J, Thode AE. Fire in California's Ecosystems. University of California Press, Berkeley.

Sugihara NG, van Wagtendock JW, Shaffer KE, Fites-Kaufman J, Thode AE. 2006a. Fire in California's Ecosystems. University of California Press, Berkeley.

Sugihara NG, van Wagtendock JW, Fites-Kaufman J. 2006b. Fire as an ecological process. pp. 58-74 *In* Sugihara NG, van Wagtendock JW, Shaffer KE, Fites-Kaufman J, Thode AE. Fire in California's Ecosystems. University of California Press, Berkeley.

Sweeney JR. 1956. Responses of vegetation to fire: a study of the herbaceous vegetation following chaparral fires. University of California Publications in Botany 28:143-249.

Taskey RD, Curtis CL, Stone J. 1989. Wildfire, ryegrass seeding, and watershed rehabilitation. pp. 149-161 *In* Berg NH (tech coord.), Proceedings of the Symposium on Fire and Watershed Management, October 26-28, 1988, Sacramento, CA. Gen. Tech. Rep. PSW-109. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA.

Thode AE, Kershner JL, Roby K, Decker LM, Beyers JL. 2006. Fire, Watershed Resources, and Aquatic Ecosystems. pp. 466-480 *In* Sugihara NG, van Wagtendock JW, Shaffer KE, Fites-Kaufman J, Thode AE. Fire in California's Ecosystems. University of California Press, Berkeley.

Tiedemann AR, Klock GO. 1976. Development of vegetation after fire, seeding, and fertilization on the Entiat Experimental Forest. pp. 171-191 *In* Proceedings, Annual Tall Timbers Fire Ecology Conference, Number 15: Pacific Northwest Tall Timbers Research Station, Tallahassee, FL.

USDA, Natural Resources Conservation Service. 2006. Land Resource Regions and Major Land Resource Areas of the United States. USDA Agriculture Handbook 296 (revised).

Van de Water R. 1998. Post-fire riparian zone management: the Salmon River experience. pp. 25-40 *In* Proceedings, Nineteenth Annual Forest Vegetation Management Conference: Wildfire Rehabilitation, January 20-22, 1998, Forest Vegetation Management Conference, Redding, CA.

van Wagtendock JW, Fites-Kaufman J. 2006. Sierra Nevada Bioregion. pp. 264-294 *In* Sugihara NG, van Wagtendock JW, Shaffer KE, Fites-Kaufman J, Thode AE. Fire in California's Ecosystems. University of California Press, Berkeley.

Wills, R. 2006. Central Valley Bioregion. pp. 295-320 *In* Sugihara NG, van Wagtendock JW, Shaffer KE, Fites-Kaufman J, Thode AE. Fire in California's Ecosystems. University of California Press, Berkeley.

Wohlgemuth PM, Beyers JL, Wakeman CD, Conard SG. 1998. Effects of fire and grass seeding on soil erosion in southern California chaparral. pp. 41-51 *In* Proceedings, Nineteenth Annual Forest Vegetation Management Conference: Wildfire Rehabilitation, January 20-22, 1998. Forest Vegetation Management Conference, Redding, CA.

Wohlgemuth PM, Hubbert K, Arbaugh MJ. 2006. Fire and physical environment interactions. pp. 75-93 *In* Sugihara NG, van Wagtendock JW, Shaffer KE, Fites-Kaufman J, Thode AE. Fire in California's Ecosystems. University of California Press, Berkeley.

Zedler PH, Gautier CR, McMaster GS. 1983. Vegetation change in response to extreme events: the effect of a short interval between fires in California chaparral and coastal scrub. Ecology 64:809-818.

APPENDIX H.2

NUTRIENT AUGMENTATION MANAGEMENT FOR HIGHWAY PLANTING

Roadside Erosion Control and Management Reviews

Nutrient Augmentation Management For Highway Planting

Relevant to:

Standard Specifications 2006

SECTION 20: EROSION CONTROL AND HIGHWAY PLANTING
20-2.02 COMMERCIAL FERTILIZER
20-2.03 SOIL AMENDMENT
20-2.05 IRON SULFATE
20-4.05 PLANTING

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Nutrient
Augmentation
Soil Fertility
Plant Nutrition
Compost
Organic Matter
C/N Ratio

Fertilizer
Gypsum
Nitrogen
Phosphorus
Potassium
Sulfur

Highway Planting
Revegetation
Hydroseeding
Soil Test

EXECUTIVE SUMMARY

Caltrans employs roadside vegetation as a significant component in an overall post-construction erosion control and stormwater pollution prevention strategy. On slopes with erosion potential, vegetation is typically installed using hydroseeding methods that include seedbed preparation, seed application, and ancillary soil stabilization measures. Disturbed roadside soils are typically hydromulched, augmented with chemical fertilizers, and seeded with species that are selected for their attributes of rapid growth and effectiveness in erosion control. This review examines the potential consequences of nutrient management, as currently practiced via hydroseeding, on post-construction revegetation requirements.

Of the essential plant nutrients in the soil, nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium, iron, magnesium, boron, copper, manganese, zinc, molybdenum, chlorine, only the fertilizer nutrients, N, P, K, and S are noted in the Caltrans Standard Specifications (May 2006). In North America N, P, and K constitute well over 90% of the fertilizers applied to soils. Nitrogen is most often the limiting nutrient in plant growth while phosphorus is frequently the second-most limiting nutrient. Potassium is the third most commonly added fertilizer nutrient, not because of low quantities in the soil, but owing to deficiencies caused by a low availability to plants at any one time.

Plant growth is influenced by both the total amount of nutrients applied and rate of release. Specification of nutrients for highway planting requires the identification of both factors. However, complex interrelationships among soils and plants throughout the vast geographical and ecological extent of California roadways preclude specification of universal values for augmenting soil nutrients.

Achieving a sustainable highway planting that can eliminate ongoing nutrient augmentation requires adequate levels of soil organic matter to support the level of nutrient cycling appropriate for the regional climatic conditions and the target highway planting vegetation.

Recommendations

Soil Testing

Establish routine testing of soil structure, soil texture, and plant nutrient availability for both pre-construction local reference soils and for post-construction soils to provide data necessary for informed decisions about nutrient augmentations and plant material selections.

Topsoil Harvesting and Stockpiling

Explore practical options for stockpiling and reapplying topsoil or duff to post-construction roadsides as the most effective way to retain organic matter, nitrogen and nutrient cycling within the soil ecosystem.

Nutrient Augmentation

Use hardcopy USDA-NRCS Soil Surveys, or the Web Soil Survey internet database [http://websoilsurvey.nrcs.usda.gov/app/] to obtain general soil nutrient data, where available, for soil types present at a specific project site.

Base augmentation of nutrients and organic matter on ecoregional context levels obtained through project site soil testing, not on levels recommended for agricultural crops. Where plant available nutrients are adequate chemical fertilizers may be reduced or eliminated.

Increase awareness that when either organic amendments (compost) or chemical fertilizers (rapid release and controlled slow release) are used, annual monitoring and reapplication will be required until an adequate amount of organic matter is present to sustain nutrient cycling. Reapplications may be necessary every 1 to 3 years to meet site-specific plant cover targets. Addition of organic materials that are less stable will need supplemental nutrition, especially N & P, immediately to compensate for nitrogen immobilization.

Increase awareness that high nitrogen applications can favor/promote the growth of annual weeds if they are present in the context vicinity.

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Section 1

INTRODUCTION

1.1. Context and Purpose

Caltrans employs roadside vegetation as a significant component in an overall post-construction erosion control and stormwater pollution prevention strategy. On slopes with erosion potential, vegetation is typically installed using hydroseeding methods that include seedbed preparation, seed application, and ancillary soil stabilization measures. Roadside soils are typically hydromulched, augmented with chemical fertilizers, and seeded with species that are selected for their attributes of rapid growth and effectiveness in erosion control (Rentch et al. 2005).

To achieve roadside vegetation-mediated erosion control, the hydroseed application process must foster both:

1) rapid coverage of the soil surface by vegetation, and
2) long-term persistent and consistent vegetative cover over the soil surface.

Beyond these, project- or site-dependent objectives may impose additional native plant revegetation conditions such as:

3) broadly-defined indigenous species selections, i.e., any ecologically appropriate plant species native to a defined region, or
4) specific context-dependent native plant assemblages, i.e., a designated plant community.

This review examines the potential consequences of nutrient management, as currently practiced via hydroseeding, on post-construction revegetation requirements.

The negative impacts of nutrient additions to both ground and surface water are well-documented, well known to many Caltrans personnel, and beyond the scope of this review. For a more detailed discussion of road construction impacts on soils and soil nitrogen; of major pathways of nitrogen input and loss; and of revegetation models used by Caltrans, see Section 4 of Caltrans (2006).

For the purpose of this review the following conditions regarding vegetation-mediated roadside erosion control as practiced by Caltrans are presumed.

— Roadside substrate conditions have sustained significant alteration and impacts during the construction process rendering surface soil fertility low.

— Physical conditions requiring geotechnical solutions for slope stabilization have been appropriately executed.

— Hydroseeding is an appropriate application technique for the physical and ecological conditions.

— Species selection is appropriate for the physical and ecological constraints of the site.

— Perennial, not annual, plants are the preferred life form (where possible ecologically) to provide consistent and persistent plant cover.

— Seed is viable, and applied in appropriate quantities, at the correct time of year, and at the correct depth for successful germination.

— Ancillary application materials (soil amendments or erosion control products) will not suppress seed germination either by chemical composition or physical position.

— Seed germination and seedling establishment may be dependent upon the vagaries of native precipitation without the aid of supplemental irrigation.

— Effectiveness of vegetation-mediated erosion control increases with the amount of vegetative cover contiguous with the soil surface (Caltrans 2001, 2002b, 2004), not with total biomass.

— Specifications for inorganic fertilizer application during hydroseeding of post-construction roadsides conform to the Caltrans Standard Specifications (May 2006) Section 20, Erosion Control and Highway Planting, Subsection 20-2.02, Commercial Fertilizer:

> Commercial fertilizer shall conform to the requirements of the California Food and Agricultural Code. Commercial fertilizer for erosion control work shall be in pelleted or granular form and shall have a guaranteed chemical analysis of 16 percent nitrogen, 20 percent phosphoric acid, 0 percent potash, and shall contain a minimum of 12 percent sulfur.

— Additional or subsequent nutrient inputs or reapplication of soil amendments are unlikely, as this is discouraged by the Manual, Chapter 900, Highway Planting Standards and Guidelines, Topic 902.3, “plants should not require ongoing maintenance other than irrigation”.

1.2. Highway Planting Definitions

Discrepancies exist in the use of terms in published academic literature in the disciplines of ecological reclamation and restoration versus that used in the *Caltrans Highway Design Manual* (CHDM version 9-1-2006; http://www.dot.ca.gov).

Highway Planting [CHDM Sections 62.5(2), 902.1, and 902.3]: refers to "vegetation placed for aesthetic, safety, environmental mitigation, stormwater pollution prevention, or erosion control purposes". It can consist of "any plants tolerant of local environmental conditions" and "proven to be durable adjacent to highways". Although there is no requirement for use of native plant species, incorporation of locally appropriate native species is encouraged.

Highway Planting Restoration [CHDM Sections 62.5(3)]: provides for "replacement, restoration, and rehabilitation of existing vegetation damaged by weather, acts of nature or deterioration, to integrate the facility with the adjacent community and surrounding environment." Although there is no requirement for use of native plant species, incorporation of locally appropriate native species is encouraged.

> In ecological literature and practice the term "restoration" refers to "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed. The restored ecosystem contains a characteristic assemblage of the species that occur in the reference ecosystem and that provide appropriate community structure suitably integrated into a larger ecological matrix or landscape, with which it interacts through abiotic and biotic flows and exchanges." (SERISPWG 2004). The key concept is restoration relative to a historical or current reference assemblage.

Highway Planting Revegetation [CHDM Sections 62.5(4)]: provides "planting as mitigation for native vegetation damaged or removed due to roadway construction". This indicates that plant species native to the local area would be the appropriate candidates for roadside planting.

> In ecological literature and practice the term "revegetation" is not always restricted to native plant species; it can refer to the intended establishment of any desired plant taxa. In this review the term "revegetation" will be qualified as to whether native or non-native.

Replacement Highway Planting [CHDM Sections 62.5(5)]: "replaces vegetation installed by the Department, or others, that has been damaged or removed due to transportation project construction." Although there is no requirement for use of native plant species, incorporation of locally appropriate native species is encouraged.

Required Mitigation Planting [CHDM Sections 62.5(6)]: "provides planting and other work necessary to mitigate environmental impacts due to roadway construction. The word 'required' indicates that the work is necessary to meet legally required environmental mitigation or permit requirements." This indicates that specific local native plant species, especially those identified as requiring mitigation for local loss of individuals, would be the appropriate candidates for roadside planting.

Section 2

PLANT NUTRIENT REQUIREMENTS

Post-construction roadside erosion control as mediated by vegetation cover requires that substrate conditions be adequate to promote seed germination, support initial rapid plant growth and sustain maximum plant coverage of the soil surface over a time frame of many years. To accomplish all this plants require an adequate supply of nutrients throughout their life span, most of which are obtained from the substrate in which they are rooted.

2.1. Soil Fertility

Soil fertility— the 13 chemical elements that constitute the essential plant nutrients available in the soil— is but one of the multiple factors affecting the magnitude and duration of plant growth. Of the essential plant nutrients in the soil, nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium, iron, magnesium, boron, copper, manganese, zinc, molybdenum, chlorine, only the fertilizer nutrients, N, P, K, and S are noted in the Caltrans Standard Specifications (May 2006). In North America N, P, and K constitute well over 90% of the fertilizers applied to soils (Munshower 1994). Nitrogen is most often the limiting nutrient in plant growth while phosphorus is frequently the second-most limiting nutrient (Miller & Donahue 1990). Potassium is the third most commonly added fertilizer nutrient, not because of low quantities in the soil, but owing to deficiencies caused by a low availability to plants at any one time. Sulfur is less often deficient than is potassium (Miller & Donahue 1990). In California grasslands N, P, K, and S can all be limiting to plant growth (Martin 1958, Jones and Martin 1964, Jones at al. 1970, Menke 1989, Harpole et al. 2007).

Soil fertility is a relative term (Chapin 1980). Physicochemical characteristics vary among soil types. Complex interrelationships of soil-plant systems throughout the vast geographical and ecological extent of California roadways preclude specification of universal values for augmenting soil nutrients. Minimum quantities of each essential nutrient needed to optimize and sustain plant growth depends on multiple interrelated factors including plant species, soil characteristics, environment, and goal (e.g., agriculture, horticulture, landscaping).

A generalized nutrient status range within which normal plant growth can be expected can be delineated (**Table 2-1**); altering substrate fertility to fall within these limits is recommended for general land rehabilitation purposes (Harris et al. 1996). Plant productivity becomes resource limited when the supply of one or more nutrients falls below species-specific minimum requirements to sustain growth (Harpole et al. 2007). Such resource limitations has important implications for plant competition, biological invasions, and ecosystem processes (Harpole et al. 2007).

Table 2-1. General Nutrient Ranges For Normal Plant Growth.

Nutrient	Range	Nutrient	Range
Available Nitrogen:		Phosphorus	5-20 ppm[1]
NH_4-N	2-20 ppm[1]		
NO_3-N	2-20 ppm[1]		
Mineralizable Nitrogen	50-200 ppm[1]	Potassium	100-300 ppm[1]
Total Nitrogen	0.1-1 %[1]	Sulfur	5-20 ppm[2]

[1] Harris et al. 1996; [2] Havlin et al. 1999

2.2. Nutrient Availability

Nutrients in soils occur in differing states of availability to plants. The total content of an element in the soil is many times greater than the plant available forms. Nutrients must exist in particular chemical forms which are soil soluble in order to be available for absorption through plant roots (**Table 2.2**).

Table 2.2. Plant-Available Forms of Some Major Nutrients.

Nutrient	Chemical Symbol	Common Plant-Available Forms: Ionic Forms (Munshower 1994)	Common Plant-Available Forms: Non-Ionic Forms (Alexander 2003)
Nitrogen	N	NO_3^-, NH_4^+	NO_3
Phosphorus	P	$H_2PO_4^-$, HPO_4^{2-}	P_2O_5
Potassium	K	K^+	K_2O
Sulfur	S	SO_4^{2-}	—

H = Hydrogen, O = Oxygen

Nutrients complexed in the soil organic fraction have varying degrees of availability. Soil organic matter includes organic materials in all stages of decomposition (Havlin et al. 1999). For the purpose of highway planting nutrient management, it is convenient to divide nutrient availability into the temporal categories of rapid or slow release rates. Rapid availability represents only a small portion of the total nutrient pool and is found in the soil solution in intimate contact with plant roots or their fungal symbionts. The status is short-lived as plants or microorganisms will quickly utilize these forms. Slow availability makes up the largest soil nutrient fraction and includes nutrients that are variously complexed but only gradually become available to plants through biochemical changes that release the nutrients to the solution.

►2.2.1. Nitrogen

Nitrogen is the key nutrient in plant growth and frequently the nutrient that is most limited in availability. Nitrogen deficiency results in reduced plant growth. In the context of roadside conditions this could translate into inadequate coverage over the soil surface with a correspondingly increased likelihood of sediment loss during rain events.

More than any other major plant nutrient, soil nitrogen is subject to a complex system of gains, losses and interrelated reactions (Miller & Donahue 1990; see **Figure 1**). Soil nitrogen occurs as inorganic and organic nitrogen in surface soils. The principal repository for nitrogen is soil organic matter, which holds more than 95% of soil nitrogen (Miller and Donahue 1990). Soil nitrogen availability is mediated by soil microorganims. Decomposition of organic matter by bacteria, fungi and actinomycetes renders nitrogen available for absorption by plants. At any given time only a small percentage of soil nitrogen occurs in forms available to plant roots (**Table 2.2**). Since organic matter provides most of the nitrogen reserve in soils—constituting typically 5% nitrogen mineralized at a rate of about 2% per year (Harris et al. 1996)—nitrogen reserves are poor when organic matter is insufficient. Thus, sustainable soil nitrogen availability relies on an adequate level of soil organic matter to provide the nutritional substrate for the ongoing support of soil microorganisms.

Analyses of nitrogen budgets of California Annual Grasslands have indicated that decomposition and nitrogen fixation often cannot meet plant demands for nitrogen, suggesting that nitrogen is made available from seedling thinning (die off) throughout the growing season (Woodmansee and Duncan 1980, Pendelton et al. 1983, Vaugn et al. 1986, Center et al. 1989, Heady et al. 1992). Because much of Caltrans roadsides are populated by these same annual species, the consequences of a 50-75% seedling death within the first seven weeks after germination (Bartolome 1979, Young et al. 1981) may diminish the collective effectiveness of such annual grasses for erosion control when nitrogen is a limiting factor.

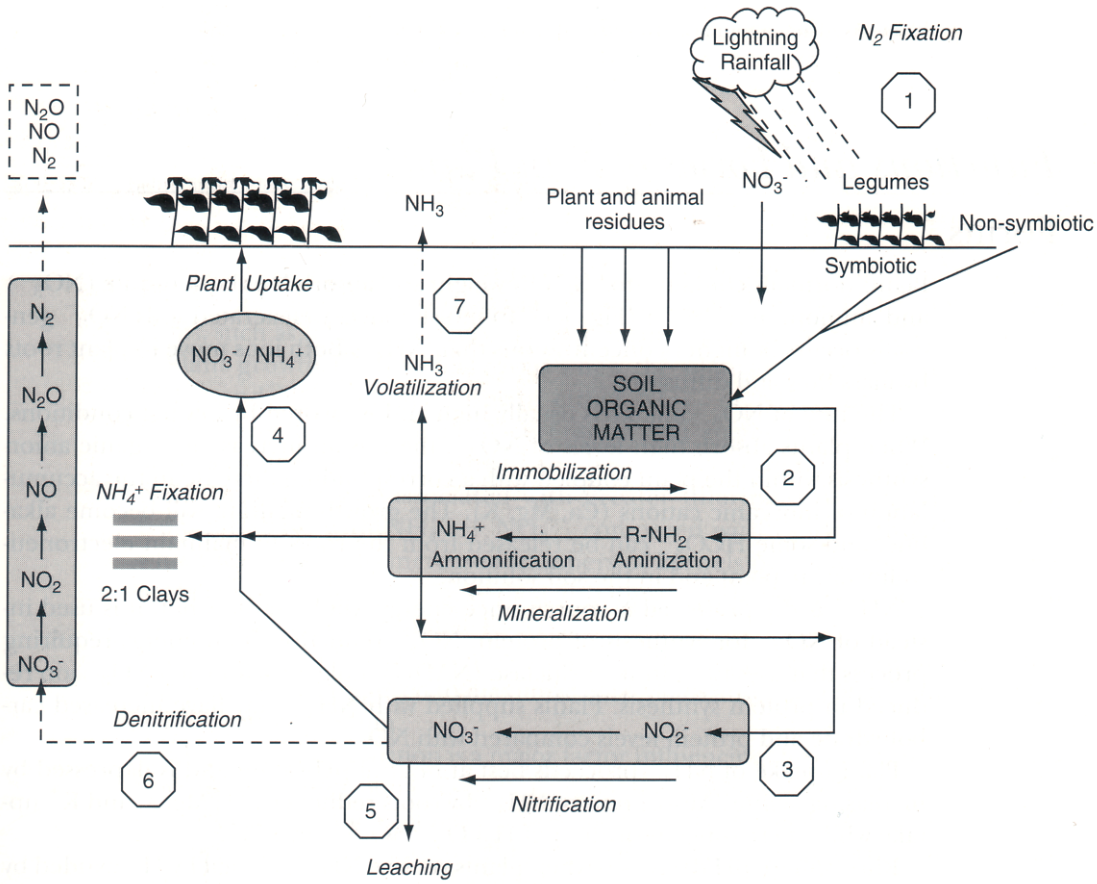

Figure 1. Nitrogen Cycle Schematic (Havlin et al. 1999)

►2.2.2. Phosophorus

Phosphorus (P) is a critical nutrient for plants as it is essential to effect energy storage and transfer. When phosphorus supplies are inadequate, young plants will fail to establish, while established plants will decline (Harris et al. 1996).

Phosphorus occurs less abundantly in soils than nitrogen or potassium (Halving et al. 1999). In addition, plant-available forms of the total phosphorus exist in low quantities (Miller & Donahue 1990). The various forms of phosphorus in soils are involved in complex interactions that influence P availability. Plants can absorb the inorganic forms $H_2PO_4^-$ and HPO_4^{2-} and certain organic phosphates. In general, P mineralization and immobilization are similar to those of N in that both processes occur simultaneously in soils (Halving et al. 1999). Much of the non-fertilizer phosphorus used by plants comes from organic phosphates released by the decomposition of organic matter. Soil organic P from plant and animal residues are degraded by soil micro flora, releasing inorganic P. Organic P cycling in soils, specifically immobilization and mineralization, is complicated by C, N, and S cycling (Halvin et al. 1999). Inorganic soil P that is not absorbed by plant roots or immobilized by microorganisms can be rendered unavailable to plants by fixation or retention.

Rock phosphate is the only important raw material for P fertilizers (Halvin et al. 1999). The commonly used granular P fertilizers are 90 to 100% water soluble and dissolve rapidly in moist soil. Added soluble phosphates will readily combine with Cations in soil solution to form low-solubility substances. The chemical characteristics of the soil and the P fertilizer source determine the soil-fertilizer reactions which influence fertilizer P availability to plants.

The principal storehouse for large amounts of nutrient anions is soil organic matter. Decomposition of soil organic matter by soil biota makes these nutrients available for absorption by plants (Miller & Donahue 1990). Promote maximum relatively fresh organic matter in the soil to release phosphorus as it decomposes (Miller & Donahue 1990).

►2.2.3. Potassium

In plants potassium affects cell division, carbohydrate formation, sugar translocation, enzymatic actions and osmosis regulation (Miller & Donahue 1990). The amount of total potassium in soils is usually many times greater than the fraction available to plants (Havlin et al. 1999). The unavailable form accounts for 90-98% of total soil potassium. Slowly available forms constitute 1-10% while readily available forms amount to only 0.1-2%.

Soil potassium can be categorized into four forms (from Havlin et al. 1999):

Form of Potassium	Quantity (ppm)	Plant Availability
Mineral	5,000 - 25,000	unavailable
Nonexhangeable	50 - 750	slightly available
Exchangeable	40 - 600	more available
Soil Solution	**1 - 10**	**most available**

The mineral sources of potassium in soils are only slowly soluble and at the same time mobility of potassium through soil is low.

Potassium cycling or transformations among potassium forms are dynamic. Transfer of potassium from the mineral fraction to any of the other three forms is slow in most soils. Even though nonexchangeable K reserves are not always immediately available, they do contribute to the labile K pool in soil. The rate of K supply or release to solutions is governed by the weathering of K-bearing micas and feldspars. Depletion of K by the plant or leaching may induce the release of K from nonexchangeable positions (Havlin et al. 1999). Most K^+ used by plants comes from exchangeable K^+ and soluble K^+ equally often (Miller & Donahue 1990).

Soil humus supplies little potassium during decomposition. Decaying organic matter is rapidly moved into soil solution and then bound onto cation exchange sites on clay particles and humus (Miller & Donahue 1990).

►2.2.4. Sulphur

Sulfur is an essential part of plant protein synthesis; ninety percent of the sulfur in plants is found in amino acids (Havlin et al. 1999). Plants require about the same quantities of sulfur as phosphorous (Havlin et al. 1999). Sulfur deficiencies have a pronounced retarding effect on plant growth and characterized by stunted, thin-stemmed, and spindly plants (Havlin et al. 1999).

Total sulfur levels in soils are extremely variable (Munshower 1994) as soils contain many sources of sulfur. Sulfur is supplied from decomposing organic matter as well as from several moderately soluble minerals. Although there are many inorganic sources of sulfur, 70-90 percent of the total sulfur of many surface soils is found in organic matter (Miller & Donahue 1990). The proportion of total sulfur existing in organic forms varies according to soil type and depth in the soil profile. There is a close relationship between organic carbon, total nitrogen and total sulfur in soils (Havlin et al. 1999). The availability of sulfur to plants is difficult to predict because, like nitrogen, major portions may come from soil organic matter and is, thus, released slowly and variably by microbial decompositional activity (Miller & Donahue 1990). Decomposition of organic matter can release major portions of sulfur and mineralization supplies the major portion of the plants' sulfur needs. However, because of the presence of various inorganic sulfur minerals that may also supply sulfur to plants, available sulfur is less dependent than is nitrogen upon microbial action (Miller & Donahue 1990).

Plant nutritional deficiencies may occur in sandy soils or in soils very low in organic matter. However, deficiencies of this element are not common in semiarid regions as western soils often contain gypsum or other oxidized sulfur compounds. Although barely soluble, they usually provide an adequate reserve for plant nutritional needs (Munshower 1994).

Sulphur augmentation may also improve physical properties of soils. Sulphur works best in soils that contain high levels of sodium or calcium, but where calcium is unavailable owing to insolubility. The conversion of sulphur to sulphuric acid by soil microorganisms can be used to reduce soil alkalinity.

2.3. Plant Nutrient Requirements Among Life History Stages

Plant nutrient requirements are not necessarily the same among the various life history stages of plants. The phases of germination, seedling establishment, initial growth, long-term persistence, and ecological succession may respond differently to augmentation of nutrient levels, possibly confounding the short- and long-term goals of highway planting for erosion control.

►2.3.1. Term Definitions

Germination.—Resumption of embryo growth during seed germination is initially supported by nutrients stored in the cells of the seed.

Seedling Establishment.—A seedling is considered to be established when it no longer is dependent upon the stored food reserves of the seed and is independently photosynthesizing (Raven et al. 1992). It is at this stage that nutrients must be available in the rooting environment of the plant or deficiencies will limit plant growth.

Initial Growth.—For the purpose of this review only, this arbitrarily delimited time frame spans the first growing season when rapid plant growth to maximize soil surface coverage is desired.

Persistence.—Roadside highway planting for erosion control is concerned with long-term sustainability and maintaining acceptable levels of perennial plant growth. The ability of a perennial plant to maintain itself for multiple years lends among year consistency to soil surface coverage. The decline or loss of a desired species may result in spontaneous replacement by one less effective at erosion control.

Ecological Succession.—This pertains only to those roadsides where native plant assemblages are one of the highway planting (i.e., native revegetation) goals. Ecological succession—change in community structure and plant species composition over time—is inherent in the re-establishment of ecosystem processes such as nutrient cycling after road construction disturbance. While many models of ecological succession exist, a deconstructed universal assembly rule cookbook for predictable successional trajectories has yet to be compiled.

2.3.2. Germination through Seedling Establishment

2.3.2.1. Benefits of Nutrient Augmentation

The effects of many kinds of inorganic ions on seed germination have been investigated; only nitrate and nitrite significantly influence seed dormancy rates (Baskin & Baskin 1998). Neither phosphorus, or potassium, or sulfur has been shown to significantly influence seed dormancy (Baskin and Baskin 1998).

The effects of nitrogen fertilizers on seed germination include stimulation in the breaking of seed dormancy, inhibition of germination, or no response (Baskin & Baskin 1998). This variation is the result, in part, from differences in environmental factors and individual species responses. An active soil nitrate pool has little impact on seed germination or seedling establishment (Munshower 1994).

2.3.2.2. Unintended Consequences of Nutrient Augmentation

High soil nitrate pools can directly increase the germination of weed seeds (Baskin & Baskin 1998). High concentrations of ammonium (NH_4^+) and nitrate (NO_3^-) can severely damage germinating seeds (Havlin et al. 1999). High osmotic potentials lead to desiccation. Along with a high osmotic potential high concentrations of nitrogen can also increase soil pH resulting in a partial and temporary sterilization of the soil within the contact zone (Havlin et al. 1999). Soil microbial activity is temporarily impeded.

2.3.3. Initial Growth

2.3.3.1. Benefits of Nutrient Augmentation

Nitrogen is important in early seedling vigor. There exists a significant correlation between plant species early growth rate and nitrogen growth enhancement (Catovsky et al. 2002). Some species undergo significant nitrogen-induced shifts in growth (Catovsky et al. 2002) and therefore, it is critical to understand the responses of individual species. An active soil nitrate pool has pronounced effects on seedling growth (Munshower 1994).

Phosphorus is particularly important during early seedling growth (Munshower 1994). Potassium requirements are high during periods of rapid growth. Plant tissue levels vary among species and seasons, but plants with high protein levels also have high sulfur levels (Munshower 1994).

2.3.3.2. Unintended Consequences of Nutrient Augmentation

Nutrient availability is a critical controller of plant species composition and productivity (Chapin et al. 2002). Maximizing plant cover at the soil surface within the first growing season demands that there be no shortage of available nutrients. However, soluble fertilizers used to augment nutrient levels and accelerate plant growth can alter plant establishment patterns. Soils characterized by high inorganic nitrogen levels can lead to the rapid establishment of annuals during the initial phase of revegetation (Esche et al. 2007). High levels of plant available nitrogen may encourage the rapid growth of ruderal species to the exclusion of slower growing species (Claassen & Marler 1998). Excess phosphorus can also be a barrier to the establishment of desirable species on sites undergoing restoration (Harris et al. 1996).

Low nutrient sites are often vegetated by slow-growing, stress-tolerant species that maximize nutrient acquisition via mycorrhizal relationships (Chapin 1980). A slow-growth response is unlikely to accomplish the short-term requirements for maximum plant cover to effect erosion control unless ancillary erosion control materials are also utilized.

►2.3.4. Persistence and Ecological Succession

▸▸2.3.4.1. Benefits of Nutrient Augmentation

Roadside planting failures can result from a lack of consideration of basic ecosystem processes. Even when germination, establishment, and initial growth are successful, long term persistence may falter without continual reapplication of nutrients. An initial single supplement of fertilizer alone often results in vegetation cover that deteriorates after the first growing season (Moore & Zimmerman 1977, Clary 1983, Parks & Nguyen 1984, Claassen & Hogan 2002). Where there is inadequate soil organic matter infrequent application of fertilizer can result in the immobilization of critical nutrients (Harris et al. 1996). It takes years (21-120) to accumulate an adequate amount of nutrients for an ecosystem to function sustainably from raw substrate (Harris et al. 1996). The rate of soil development depends principally on those factors governing the accumulation of organic matter and nutrient cycling (Harris et al. 1996). An approach of roadside highway planting that relies upon the development of organic matter through the slow accumulation of plant material after a single application of fertilizer has been shown to be ineffective some 30 percent of the time (Caltrans 2002a).

▸▸2.3.4.2. Unintended Consequences of Nutrient Augmentation

The impact of the fertility of a soil on the species which it will support is a powerful one (Harris et al. 1996). Nutrient effects on seedling growth and mortality can change overall plant community structure and dynamics (Catovsky et al. 2002). Some studies indicate that the availability of soil resources, such as nitrogen and phosphorus, influence successional dynamics (Tilman 1986, Catovsky et al. 2002). Plant competition is strongly influenced by available nitrogen levels (McLendon & Redente 1992; Wedin & Tilman 1996). Species differ in their ability to compete for soil nitrogen, some growing more successfully in a nitrogen-rich soil than others (Tilman 1986). Thus, fertilization can lead to dramatic shifts in species composition over time (Tilman 1986) that may result in non-compliance with legally mandated native revegetation goals of a project.

Unfortunately, nutrient parameters of most native plants *in situ* are little understood as compared with the known requirements for field agricultural crops. Agricultural fertilizer requirements based on continuous crop production and extraction are not directly applicable to native plant revegetation (Munshower 1994). Reference sites continue to be investigated for indices by which to define restoration goals for particular plant assemblages. Some have proposed that reference sites define nutrient levels for highway planting native revegetation (Claassen 2005). However, because ecosystems vary in complex ways at several spatial and temporal scales, because there are problematic unmeasured historical factors that confound interpretation, and because of the difficulty of demonstrating a close match in all relevant ecological dimensions over time (White & Walker 1997), providing specifications for nutrient levels that include successional processes would require a protracted research program.

— BIOINVASIONS —

Local disturbances, such as those that exist roadside, tend to promote occupation by invasive alien species (Hobbs et Huenneke 1992, D'Antonio et al. 1999). Once established these species will exert influence on ecosystem processes. Alien invasions can have profound and unpredictable effects on ecosystem processes and soil communities (Evans et al. 2001). The presence of these alien species may interfere with restoration efforts or alter successional trajectories (D'Antonio 2002). Competition from alien annual weeds can negatively impact establishment of native herbaceous perennials (Dyer et al. 1996, Bartolome & Gemmill 1981, Dyer & Rice 1997, Brown & Rice 2000) and shrubs (Marquez & Allen 1996, Eliason & Allen 1997).

In California many of these ruderal weeds exhibit an annual life cycle that does not meet the criteria for effective erosion control: persistent and consistent coverage of the substrate. Although annuals exhibit rapid growth rates, their germination can only follow the onset of seasonal rains, rendering them ineffective during initial rain events each year. The amount and distribution of substrate coverage by annuals can vary markedly among years (Talbot et al. 1939). As coverage by annuals is contingent upon weather patterns, some years are likely to suffer inadequate coverage. Plant architecture strongly influences sediment loss (Caltrans 2001, 2002b, 2004). Many of the most common annual ruderals in California (*Brassica, Avena, Vulpia myuros*) are characterized by an upright sparse phylotaxy that is ineffective at erosion control as compared with a densely-leaved prostrate growth habit.

Nutrient augmentation can benefit these annual alien species; as a functional group, many can take advantage of resource-rich environments. High nutrient content often favors ruderal species, potentially excluding slower growing perennial plants (Chapin 1980, Munshower 1994, Harris et al. 1996).

Plant species can influence ecosystem nutrient dynamics (Vitousek 1996, Vitousek & Walker 1989, Wedin et Tilman 1990, Van Cleve et al. 1991, Hobbie 1992, Chapin et al. 1995, Vinton & Burke 1995). Plant species differ in their effects on net nitrogen mineralization and nitrification rates (Eviner et al. 2006). Alterations in species can modify the food-web architecture and the flow of energy and nutrients (Ehrenfeld & Scott 2001, Evans et al. 2001). The available data suggest that invasive plant species frequently, but not always, increase biomass and net primary production, increase nitrogen availability, alter nitrogen fixation rates, and produce litter with higher decomposition rates than co-occurring natives (Ehrenfeld 2003). Changes in soil processes, primarily nitrogen and carbon dynamics, often follow invasions of alien plant species (Ehrenfeld & Scott 2001). The literature on plant-soil interactions strongly suggests that the introduction of a new plant species has the potential to change many components of the carbon, nitrogen, and other cycles of an ecosystem (Ehrenfeld 2003).

Alien invasive species can also have profound effects on the soil microbial community in both structure and function (Kourtev et al. 2002). The rhizospheric ecosystem interacts intimately in plant nutrient acquisition.

Section 3

CONSTRUCTION AFFECTS ON SOILS

3.1. Road Construction Affects On Soils

Road construction activity significantly alters the existing plant growing conditions on roadsides, usually resulting in severe disturbance to soils. Removal and redistribution of soil horizons as part of topographic reconfiguration brings about changes to physical, chemical and biological properties of soil. Topsoil is typically buried, exposing subsoil and parent material. Where severe damage has occurred, in which original soils are lost and subsoils are exposed, nutrient poor horizons will not support plant growth (Bradshaw 2004). Nutrient deficiencies are one of the most universal attributes of degraded soils (Munshower 1994).

Removal of all biological constituents, vegetation and soil biota in soil organic matter, all but arrests those biotically-mediated processes critical to the ecological functioning of terrestrial ecosystems: soil formation, nutrient cycling, energy transfers, plant re-establishment, and long-term sustainability (Mummey et al. 2002). Disruption of processes predicated on soil organic matter, critically impedes the rate at which disturbed ecosystems can begin recovery towards sustainable biological productivity (Logan 1989, Mummey et al. 2002). Thus, post-construction roadsides can present both immediate and protracted hostile plant growth environments. Of 57 Caltrans roadside revegetation failures, some 30% presented “low soil fertility” (Caltrans 2002a).

►3.1.1. Road Construction Affects on Nitrogen

Nitrogen is the key nutrient in plant growth (Miller & Donahue 1990) and the nutrient that plants require in the largest amounts. In revegetation efforts this can be problematic because, after water availability, N is generally considered to be the most limiting plant growth factor in arid and semi-arid ecosystems (Bolton et al. 1993). Soil N occurs in both inorganic and organic forms, with the cycling between the two mediated by soil biota (Whitford 1988). Soil disturbance, especially topsoil removal, disrupts this N cycling (DeGrood et al. 2005, Evans & Belnap 1999). Thus, the removal of topsoil results in both immediate and protracted severe N deficiencies because soil organic matter in topsoil is the main storage reservoir for terrestrial N (Bradshaw 2004), holding more than 95% of soil N (Havlin et al. 1999, Miller & Donahue 1990).

Nitrogen is found at extremely low plant available concentrations in most degraded land materials (Harris et al. 1996). Road excavations have reduced total N from 650mg N/kg soil in topsoils to <200mg N/kg soil in underlying parent material (Claassen & Zasoki 1998).When plant and microbial uptake of N are reduced, mineralized N is not cycled rapidly into the organic storage reservoir, leaving it vulnerable to hydrologic and atmospheric losses (Mummey et al. 2002). This exacerbates already low levels of N bioavailability (Vitousek et al. 2002), making successful revegetation unattainable for several decades. Total soil N and percentage organic matter are lower on filled-excavated sites, than on undisturbed sites even 7 decades after disturbance (Claassen & Hogan 2002). Other severe construction disturbance sites have documented lower levels of inorganic N availability versus predisturbance levels over similar timespans (Dancer et al. 1977, Stylinski & Allen 1999). In North Dakota, rates of N accumulation at strip-mined sites were calculated to require over 200 years to equal rates of undisturbed sites (Wali 1999).

Depletion of bioavailable N is often the limiting factor in revegetation (Munshower 1994, Van Kekeri & Kay 1986). Where topsoil has been lost, it has been necessary to apply at least 200kg/ha of a 20-10-10 NPK fertilizer as an immediate, but short-term, remedy for severe nutrient deficiencies (Bradshaw 2004). Without remediation of N-cycling further soluble inorganic additions are commonly required or growth collapses (Bloomfield et al. 1982, Bradshaw 2004). Mineralizable N, organic yet decomposable, needs to provide 30-70kg N/ha/ yr into the system to support annual plant growth (Claassen 2005).

While decomposition of organic matter is a major source of plant available N, notably, it is a very conservative process; organic matter contains about 5% by weight of N with only 1-3% of that released annually via decomposition (Miller & Donahue 1990). To maintain long-term sustainable plant growth for disturbed soils, threshold N values stored in soil organic matter are estimated to fall between 1000kg total N/ha (Bradshaw 2004) and 1500kg total N/ha (Claassen 2005).

►3.1.2. Road Construction Affects on Phosphorus

As with nitrogen, phosphorus is found at extremely low plant available concentrations in most degraded land materials (Harris et al. 1996). The major portion of the total soil phosphorus reserve is not plant available because it is complexed in soil organic matter. If soil organic matter is not present, phosphorus will become unavailable.

►3.1.3. Road Construction Affects on Potassium

Potassium is not usually deficient in disturbed soils of semiarid regions (Munshower 1994), but analyses to determine the amount of readily available potassium are advised.

►3.1.4. Road Construction Affects on Sulphur

The factors that affect low nitrogen availability, i.e., the loss of soil organic matter, have similar impacts on sulfur. However, owing to the presence of several inorganic sulfur minerals, the impact may be less severe.

Section 4

SOIL NUTRIENT AUGMENTATION

4.1. “Amendment” Or “Fertilizer”

Whether a material is considered a soil amendment or a fertilizer is usually determined by its effect on plant growth. Fertilizers affect plant growth directly by improving the supply of available nutrients in the soil. Amendments, on the other hand, influence plant growth indirectly via improvements in the soil’s physical condition (e.g., soil tilth, water infiltration). The distinction between these two concepts is clear when you compare materials such as ammonium nitrate (a fertilizer) and gypsum (an amendment). It is more difficult to distinguish between amendments and fertilizers when evaluating natural or organic products. Animal manure, for example, easily falls into either category depending on your reasons for applying it: manure can be a source of readily available nutrients, but it can also supply significant quantities of organic matter, which improves soil aeration and water retention. California State Fertilizing Materials Law eliminates some of the confusion by defining specific quality standards and characteristics for the production and sale of these materials.

When soil nutrient levels fall below the level needed for optimal plant growth a common remedy is augmentation with fertilizers. Manipulation of soil fertility is central to plant management (Harris et al. 1996). In agriculture, horticulture, landscaping, and reforestation, fertilization has been the typical remedy to counter low soil fertility. The use of fertilizers is also widespread in disturbed land rehabilitation (Munshower 1994). The addition of fertilizers has been considered a technique that can improve revegetation success by improving soil properties (Elmarsdottir et al. 2003; Tormo et al. 2006).

Fertilizers can be delivered from three source categories: synthetic, natural and organic preparations. The source determines 1) the quantity of available nutrients; 2) the timeframe over which nutrients are available (release rates); 3) the likelihood of nutrients washing off-slope; and 4) affects on soil quality.

Synthetic preparations are manufactured granular products that bind nutrients into salt compounds that readily dissolve in water. These provide immediate, but short-term, nutrient availability. The benefits of inorganic fertilizer application include the immediate plant availability and a precise application rate. They are manufactured with a high degree of quality control, resulting in consistency in nutrient application and a predictable rate of nutrient release (Chaney et al. 1992). Synthetic fertilizers feed the plants but not the soil. Without a sufficient amount of soil organic matter, however, ongoing nutrient reapplication is usually recommended. Excess amounts have the potential to damage plants and move off-site resulting in noncompliance with pollution standards.

Controlled slow-release variants of these chemical preparations are formulated to have less solubility. This prolongs lower release rates of nutrients with a reduced potential for excessive movement off-site. The rate of release can vary with product's water solubility, rate of microbial action, or rate of chemical hydrolysis. Nutrient reapplication needs remain similar to chemical preparations.

Natural preparations are geological materials like rock dusts or powders, such as rock phosphate, greensand and sulfur, mined from the physical earth. Depending upon the source, the nutrient contents are quite different. The amount of available nutrient at any one time is usually low as it is locked up in a mineral structure that breaks down slowly each year. Natural fertilizers do more than supply nutrients; the ingredients can also improve soil quality for plant growth such as modifying a soil's physical structure and water infiltration characteristics.

Organic preparations consist of carbon compounds specifically derived from living organisms. Nutrient content and duration of availability varies widely and is dependent upon both the source composition and decompositional status of the amendment at the time of application (**Table 4-1, Table 4-2**). The types of organic amendments and fertilizers include animal manures, concentrated animal by-products, sewage sludge, green manures, harvesting and processing residues, marine products, wood-derived materials and peat, and composts including any of these materials. With organic preparations nutrient release rates are protracted with a reduced potential for off-site nutrient movement as long as the carbon compounds are physically held securely in place. This also suggests that lesser amounts of nutrients may be initially available for plant growth when rapid growth is the desired goal. For this reason organic preparations are sometimes supplemented with chemical preparations to ensure adequate immediate nutrient availability. Annual reapplication of organic preparations is recommended until organic matter has accumulated in amounts sufficient to sustain nutrient cycling processes. Because of a lack of standards for characterizing and labeling organic amendments, it is important to obtain accurate data about the nutrient composition of each batch (Chaney et al. 1992).

Table 4-1. Major Nutrient Content of Organic Fertilizers
(Reich 2000)

Material	% N*	% P*	% K*	Plant Availability
Animal-By-Product Fertilizers				
bat guano	8-19	4-31	2	fast
bird guano	8-13	8-15	2	fast
blood meal	15	1	1	fast
bone meal	3-6	20	0	slow
fish emulsion	4-5	2-4	1-2	fast
fish meal	9	7	0	fast
leather meal	6-12	0	0	slow, long-lasting
manure, cow	0.25	0.15	0.25	moderately fast
manure, horse	0.3	0.15	0.5	moderately fast
manure, poultry	2-6	2-4	1-3	fast
worm castings	1	0	0	slow
Mined Amendments				
colloidal phosphate	0	20	0	slow, long-lasting
granite dust	0	0	5	slow, long-lasting
greensand	0	1	5-7	slow, long-lasting
rock phosphate	0	33	0	slow, long-lasting
Plant-Derived Fertilizers				
alfalfa meal	3	1	2	moderately fast
peat	1-3	0.25-0.5	0.5-1	very slow
seed meal (soy, cottonseed)	7	2	2	moderately slow to slow
kelp extract	1-2	0-1	5-13	fast
wood ash	0	1-2	3-7	fast
compost	1-3	5-1	1-3	slow

% N*= total nitrogen; **% P***= amount available during first year of application;
% K* = amount available during first year of application

Table 4-2. Nutrient Content (Dry) of Selected Manures and Composts (Chaney et al. 1992)

Material	Total N	Ammonium N	P_20_5	K_20	S
		lbs per ton			
Non-Composted Poultry					
turkey/rice hull liter	35	4	53	37	6
fresh broiler/rice hull	78	6	51	53	9
fresh layer	79	8	125	67	16
aged layer	43	9	164	79	14
Non-Composted Dairy/Steer					
fresh dairy separator solids	43	1	17	12	10
fresh dairy corral scrapings	47	2	26	141	12
aged dairy separator solids	41	1	13	8	9
aged dairy corral scrapings	26	5	31	66	8
Composts					
broiler/rice hull compost	38	2	86	50	11
dairy	27	1	27	57	9
dairy/gin trash	31	1	22	57	14
dairy/steer	33	0	17	51	9
dairy/poultry	34	2	39	66	10
gin trash	47	0	18	75	29

4.2. Nutrient Release Rates

Depending upon their form and formulation, fertilizers can supplement the immediately available nutrient pool or the pool of nutrients that more slowly enter the soil solution (Munshower 1994). Because plant growth is influenced by both the total amount of nutrients applied and rate of release, specification of nutrients for highway planting requires the identification of both factors.

Synthetic fertilizers have their nutrient release rates engineered into their formulations and, thus, are predictable within known variances. Natural amendments release nutrients slowly from their mineral complex. The rate of release depends on soil conditions, with increasing temperature, moisture, acidity, and organic matter all increasing the rate. Organic fertilizers and amendments have a much wider range of variability in nutrient release rates, especially nitrogen, varying primarily with source composition and age of material. Knowledge of the relative rates of nutrient release among amendment materials can help guide selection of amendments in accordance with vegetation goals of the highway planting project (Claassen & Carey 2007).

Achieving a sustainable highway planting that can eliminate ongoing nutrient augmentation requires adequate levels of soil organic matter to support the level of nutrient cycling appropriate for the regional climatic conditions and the target highway planting vegetation. Soil organic matter is composed of several nutrient release pools that differ in the rate of decomposition from rapid through recalcitrant. To be sustainable the various fractions of soil organic matter must be in a state of dynamic equilibrium; soil organic matter levels should remain fairly constant as new organic matter is added and decomposed.

4.3. Rhizosphere Interactions

Mycorrhizal symbioses facilitate plant uptake of soil resources. These associations between roots and fungi are best developed in infertile soils (Chapin 1980) and critical to plant nutrition in those conditions. Mycorrhizae provide the greatest benefit to plants in overcoming limitation by nutrients that diffuse slowly in soil especially nitrogen, phosphorus and potassium. Extremely nutrient-deficient sites are dominated by slowly growing stress-tolerant species these species maximize nutrient acquisition via mycorrhizal relationships; by contrast, nutrient-rich sites are occupied by rapidly growing competitive and ruderal species that often lack a mycorrhizal association (Chapin 1980).

► ***Does nutrient augmentation affect mycorrhizal associations?***

In order to clarify seemingly inconsistent data, a meta-analysis of 51 published investigations across 7 biomes (N:31; P:20) demonstrated that mycorrhizal abundance declines in response to fertilization with nitrogen and phosphorus (Treseder 2004). Across studies nitrogen augmentation reduced mycorrhizal abundance by an average of 15%, with significant variation among studies; phosphorus augmentation reduced mycorrhizal abundance by an average of 32%, with insignificant variation among studies. Variation among studies may be explained in part by among site differences in soils; mycorrhizal response to nutrient enrichment is mediated by ambient soil fertility (Collins Johnson et al. 2003). Mycorrhizae are more abundant where soil nutrients are limited and decline in response to nitrogen and phosphorous fertilization.

► ***Do mycorrhizal symbioses affect native revegetation?***

Fungal communities can directly influence the species composition of plant communities. Because nutrient enrichment changes mycorrhizal abundance and allocation, an alteration in mycorrhizal functioning may impact plant community composition and ecosystem function (Collins Johnson et al. 2003). Feedback effects between plants and soil organisms in one successional stage can result in a biotic legacy effect, which influences plant community processes in subsequent successional stages (Karol et al. 2007).

► ***How do organic versus synthetic soil fertility amendments affect soil microbial communities?***

There exist significant correlations between soil physico-chemical factors and soil microbial communities. The diversity and composition of bacterial taxa in the rhizosphere can be affected by soil nutrient management techniques such as inorganic versus organic amendments. In general the concentration of essential plant nutrients and microbial biomass are highest using organic amendments, specifically compost, whereas inorganic fertilizers had little effect (Tiquia 2002). Organic amendments improve soil quality for plant growth by increasing soil organic matter, total carbon, and cation exchange capacity, lowering bulk density (Bulluck 2002, Tiquia 2002), and enhancing beneficial soil microorganisms while reducing the activity of pathogenic populations (Bulluck 2002). With organic amendments microbial activity and nitrogen mineralization rates are higher (Bulluck 2002) as are concentrations of phosphorus and potassium (Clark et al. 1998).

4.4. C/N Ratio

Hydroseeding methods can include the application of a carbon organic component as seedbed or mulch which may have the effect of nitrogen immobilization. The consequences of nitrogen immobilization may be considered positive or negative depending on situational or site-specific goals.

If nitrogen immobilization results in a nitrogen deficiency that negatively impacts all plant growth during the initial stages of roadside revegetation, this could lead to inadequate soil surface coverage with a concomitant reduction in erosion control capability. Concentrations of 2% nitrogen added as a fertilizer have been sufficient to minimize immobilization of soil nitrogen in an agricultural context (Havlin et al. 1999).

Where the goal of revegetation comprises native plant species, nitrogen availability levels may influence the plant community composition. Carbon additions reduce soil nitrate availability. The ratio of % carbon to % nitrogen (C/N) defines the relative quantities of these two elements in organic materials. Whether nitrogen is mineralized and, thus, rendered plant available versus immobilized by microorganisms reflects the C/N ratio of the organic matter. When the C/N ratio of fresh material is greater than 30:1 nitrogen is immobilized during the early decomposition process; when the ratio is 20-30:1 there may be neither immobilization nor release of mineral nitrogen; when the ratio is less than 20:1 there is a release of mineral nitrogen in the early decomposition stages (Havlin et al. 1999).

Restoration ecologists have investigated the use of soil carbon amendments (sawdust, sucrose, starch, cellulose) as a countermeasure to reduce plant available nitrogen with the intent of excluding invasive alien species. Reduction of plant available nitrogen has the potential to alter competitive interactions among plants (D’Antonio 2002; Corbin & D’Antonio 2004). Results across a variety of ecological and soil conditions have lacked absolute consistency (Corbin & D’Antonio 2004). Threshold levels of carbon additions required to achieve inorganic soil nitrogen decreases (Blumenthal et al. 2003) and effectively direct community composition have yet to be proscribed; efficacy is likely linked to multiple soil attributes including initial soil fertility, quantity and form of C added, and biotic attributes such as functional group and life form affiliations or specific autecological responses to temporary reductions in soil nitrate. Carbon additions can reduce above-ground vegetation biomass and cover and alter vegetation composition by creating gaps in vegetation cover that facilitate the establishment of late-seral plant species (Esche et al. 2007).

Section 5

RECOMMENDATIONS

— CAVEAT —

Practical solutions for highway planting involve translation of primary ecological literature and results of targeted highway planting research into widely applicable design specifications. This process often requires major extrapolations beyond the scope intended by original experiments or reviews.

1. Base decisions to augment nutrients on the goals of each highway planting (native revegetation versus non-native landscaping) rather than on past practices.

2. Base augmentation of nutrients and organic matter on ecoregional context levels (e.g., coastal grassland, coastal scrub, montane pine-oak woodland, creosote bush scrub). *Where plant available nutrients are adequate chemical fertilizers may be reduced or eliminated.*

3. Evaluate post-construction substrate throughout each new project or highway planting restoration (redo) for standard soil-plant growth factors, especially fertility and organic matter. *Make soil nutrient tests a standard part of each post-construction process.*

4. Eliminate the general working model that plants can grow fast enough from seed during year one to provide adequate erosion control.

5. Use physical erosion control methods (terraces, wattles, jute netting) as an initial means to prevent sediment and stormwater pollution from moving off-site.

6. Increase awareness that high nitrogen applications can favor/promote the growth of annual weeds if they are present in the context vicinity.

7. Increase awareness that low nitrogen applications will not preclude the presence of annual weeds if they are present in the context vicinity, but they may be less dominant.

8. Increase awareness that when either organic amendments (compost) or chemical fertilizers (rapid release and controlled slow release) are used, annual monitoring and reapplication will be required until an adequate amount of organic matter is present to sustain nutrient cycling. Reapplications may be necessary every 1 to 3 years to meet site-specific plant cover targets. *Addition of organic materials that are less stable will need supplemental nutrition, especially N & P, immediately to compensate for nitrogen immobilization. It is necessary to know the quantity of macronutrients available in the organic amendments, the stability of the organic material, and the rate of mineralization for the organic material to specify proper nutrient augmentation.*

9. Eliminate the landscaping guideline that precludes follow-up maintenance after the initial application because both vegetation and soil require multi-year monitoring.

10. Monitor vegetation coverage annually as a surrogate to assess the adequacy of nutrient cycling.

Section 6
REFERENCES

Alexander, R. 2003. Landscape Architecture Specifications for Compost Utilization. Updated Edition.

Bartolome JW. 1979. Germination and seedling establishment in California Annual Grassland. Journal of Ecology 67:273-281.

Bartolome JW, Gemmill B. 1981. The ecological status of *Stipa pulchra* (Poaceae) in California. Madroño 28:172-184.

Baskin CC, Baskin JM. 1998. Seeds: Ecology, Biogeography, and Evolution of Dormancy and Germination. Academic Press, San Diego, CA.

Bloomfield HE, Handley JF, Bradshaw AD. 1982. Nutrient deficiencies and the aftercare of reclaimed derelict land. Journal of Applied Ecology 19:151-158.

Blumenthal DM, Jordan NR, Russelle MP. 2003. Soil carbon addition controls weeds and facilitates prairie restoration. Ecological Applications 13:605-615.

Bolton Jr H, Smith JL, Link SO. 1993. Soil microbial biomass and activity of a disturbed and undisturbed shrub-steppe ecosystem. Soil Biology and Biochemistry 25:545-554.

Bradshaw AD. 2004. The role of nutrients and the importance of function in the assembly of ecosystems. Pp 325-340 ***In*** Temperton VM, Hobbs RJ, Nuttle T, Halle S (eds.), Assembly Rules and Restoration: Bridging the Gap between Theory and Practice. Island Press, Washington DC.

Brown CS, Rice KJ. 2000. The Mark of Zorro: effects of the alien annual grass *Vulpia myuros* on California native perennial grasses. Restoration Ecology 8(1):10-17.

Bulluck LR III, Brosius M, Evanylo GK, Ristaino JB. 2002. Organic and synthetic fertility amendments influence soil microbial, physical and chemical properties on organic and conventional farms. Applied Soil Ecology 19:147-160.

California Department of Transportation (Caltrans). 2001. Vegetation Establishment for Erosion Control Under Simulated Rainfall. CTSW-RT-01-078.

California Department of Transportation (Caltrans). 2002a. Statewide Erosion Control Review. CTSW-RT-01-067.

California Department of Transportation (Caltrans). 2002b. Evaluating Hydroseeding and Plug Planting Techniques For Erosion Control & Improved Water Quality. CTSW-RT-02-052.

California Department of Transportation (Caltrans). 2004. Effectiveness of Planting Techniques for Minimizing Erosion. CTSW-RT-04-004.69.01.

California Department of Transportation (Caltrans). 2006. Legume Seed Inoculation for Highway Planting in California. CTSW-RT-06-167.01.2.

Catovsky S, Kobe RK, Bazzaz FA. 2002. Nitrogen-induced changes in seedling regeneration and dynamics of mixed conifer-broad-leaved forests. Ecological Applications 12(6):1611-1625.

Center FS, Vaugn CE, Jones MB. 1989. Effects of management on plant production and nutrient cycling on two annual grassland sites. Hilgardia 57:1-40.

Chaney DE, Drinkwater LE, Pettygrove GS. 1992. Organic Soil Amendments and Fertilizers. UC Division of Agriculture and Natural Resources Publication Number 21505.

Chapin FS III. 1980. The mineral nutrition of wild plants. Annual Reviews of Ecology and Systematics 11:223-260.

Chapin FS III, Lubchenco J, Reynolds HL. 1995. Biodiversity effects on patterns and processes of communities and ecosystems. Pp 289-330 ***In*** United Nations Environment Programme Global Biodiversity Assessment. Cambridge University Press, Cambridge UK.

Chapin FS III, Matson PA, Mooney HA. 2002. Principles of Terrestrial Ecosystem Ecology. Springer-Verlag, New York.

Claassen VP, ed. 2005. Soil Resource Evaluation. Final Report, *sn*, California Department of Transportation, Sacramento, CA.

Claassen VP, Carey JL. 2007. Comparison of slow-release nitrogen yield from organic soil amendments and chemical fertilizers and implications for regeneration of disturbed sites. Land Degradation and Development 18:119-132.

Claassen VP, Hogan MP. 2002. Soil nutrient pools associated with revegetation of disturbed sites in the Lake Tahoe area. Restoration Ecology 10:195-203.

Claassen VP, Marler M. 1998. Annual and perennial grass growth on nitrogen-depleted decomposed granite. Restoration Ecology 6(2):175-180.

Claassen VP, Zasoki RJ. 1998. A comparison of plant available nutrients on decomposed granite cut slopes and adjacent natural soils. Land Degradation and Development 9:35-46.

Clark MS, Horwath WR, Shennan C, Scow KM. 1998. Changes in soil chemical properties resulting from organic and low-inout farming practices. Agronomy Journal 90:662-671.

Clary RF. 1983. Planting techniques and materials for revegetation of California roadsides. California Department of Transportation, Sacramento, USDA LPMC-2.

Collins Johnson N, Rowland DL, Corkidi L, Egerton-Warburton LM, Allen EB. 2003. Nitrogen enrichment alters mycorrhizal allocation at five mesic to semiarid grasslands. Ecology 84(7):1895-1908.

Corbin JD, D'Antonio CM. 2004. Can carbon addition increase competitiveness of native grasses? A case study from California. Restoration Ecology 12(1):36-43.

D'Antonio CM, Meyerson LA. 2002. Alien plant species as problems and solutions in ecological restoration: a synthesis. Restoration Ecology 10(4):703-713.

D'Antonio CM, Dudley TL, Mack MC. 1999. Distribution and biological invasions: direct effects and feedbacks. Pp 413-452 ***In*** Walker L (ed.), Ecosystems of Disturbed Ground. Elsevier, Amsterdam.

Dancer WS, Handley JF, Bradshaw AD. 1977. Nitrogen accumulation in kaolin mining wastes in Cornwall. II Forage legumes. Plant and Soil 48:303-314.

DeGrood SH, Claassen VP, Scow KM. 2005. Microbial community composition on native and drastically disturbed serpentine soils. Soil Biology and Biochemistry 37:1427-1435.

Dyer AR, Rice KJ. 1997. Intraspecific and diffuse competition: the response of *Nassella pulchra* in a California grassland. Ecological Applications 7:484-492.

Dyer AR, Fossum H, Menke J. 1996. Emergence of survival of *Nassella pulchra* in a California grassland. Madroño 43:316-333.

Ehrenfeld JG. 2003. Effects of alien plant invasions on soil nutrient cycling processes. Ecosystems 6:503-523.

Ehrenfeld JG, Scott N. 2001. Invasive species and the soil: effects on organisms and ecosystems processes. Ecological Applications 11:1259-1260.

Eliason SA, Allen EB. 1997. Alien grass competition in suppressing native shrubland reestablishment. Restoration Ecology 5:245-255.

Elmarsdottir A, Aradottir AL, Trlica MJ. 2003. Microsite availability and establishment of native species on degraded and reclaimed sites. Journal of Applied Ecology 40:815-823.

Esche R, Mortimer SR, Lawson CS, Edwards AR, Brook AJ, Igual JM, Hedlund K, Schaffner URS. 2007. Carbon addition alters vegetation composition on ex-arable fields. Journal of Applied Ecology 44:95-104.

Evans RD, Belnap J. 1999. Long-term consequences of disturbance on nitrogen dynamics in an arid ecosystem. Ecology 80:150-160.

Evans RD, Rimer R, Sperry L, Belnap J. 2001. Alien plant invasion alters nitrogen dynamics in an arid grassland. Ecological Applications 11(5):1301-1310.

Eviner VT, Chapin FS III, Vaughn CE. 2006. Seasonal variations in plant species effects on soil nitrogen and phosphorus dynamics. Ecology 87(4):974-986.

Harpole, WS, Goldstein L, Aicher RJ. 2007. Resource limitation. Pp. 119-130 ***In*** Stromberg MR, Corbin JD, D'Antonio CM (eds), California Grasslands: Ecology and Management. University of California Press, Berkeley, CA.

Harris JA, Birch P, Palmer J. 1996. Land Restoration and Reclamation: Principles and Practice. Longman Ltd, Essex, England.

Havlin JL, Beaton JD, Tisdale SL, Nelson WL. 1999. Soil Fertility and Fertilizers. Prentice-Hall, Upper Saddle River, NJ.

Heady HF, Bartolome JW, Pitt MD, Savelle GD, Stroud MC. 1992. California Prairie. Pp. 313-315 ***In*** Coupland RT (ed.), Natural Grasslands. Ecosystems of the World. Vol 8A. Elsevier, New York.

Hobbie SE. 1992. Effects of plant species on nutrient cycling. Trends in Ecology and Evolution 7:336-339.

Hobbs RJ, Huenneke LF. 1992. Disturbance, diversity, and invasion: implications for conservation. Conservation Biology 6:324-337.

Jones, MB, Martin, WE. 1964. Sulfate-sulfur concentration as an indicator of sulfur status in various California dryland pasture species. Soil Science Society of America Proceedings 28:539-541.

Jones, MB, Lawler PW, Ruckman JE. 1970. Differences in annual clover response to phosphorus and sulfur. Agronomy Journal 62:439-442.

Kardol P, Cornips NJ, van Kempen MML, Tanja Bakx-Schotman JM, van der Putten WH. 2007. Microbe-mediated plant soil feedback causes historical contingency effects in plant community assembly. Ecological Monographs 77(2):147-162.

Kourtev PS, Ehrenfeld JG, Haggblom M. 2002. Alien plant species alter the microbial community structure and function in the soil. Ecology 83(11):3152-3166.

Logan TJ. 1989. Chemical degradation of the soil. Advances in Soil Science 11:187-222.

McLendon T, Redente EF. 1992. Effects of nitrogen limitation on species replacement dynamics during early secondary succession on a semiarid sagebrush site. Oecologia 91:312-317.

Marquez VJ, Allen EB. 1996. Ineffectiveness of two annual legumes as nurse plants for establishment of *Artemisia californica* in coastal sage scrub. Restoration Ecology 4:42-50.

Martin WE. 1958. Sulfur deficiency widespread in California soils. California Agriculture 12(Nov.):10-12.

Menke JW. 1989. Management controls on productivity. Pp. 173-200 ***In*** Huenneke LF, Mooney HA (eds.), Grassland, Structure, and Function: California Annual Grassland. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Miller RW, Donahue RL. 1990. Soils: an introduction to soils and plant growth. Prentice-Hall, Englewood Cliffs, NJ.

Moore TR, Zimmerman RC. 1977. Establishment of vegetation on serpentine asbestos mine wastes, south-eastern Quebec, Canada. Journal of Applied Ecology 14:589-599.

Mummey DL, Stahl PD, Buyer JS. 2002. Soil microbiological properties 20 years after surface mine reclamation: spatial analysis of reclaimed and undisturbed sites. Soil Biology and Biochemistry 34:1717-1725.

Munshower FF. 1994. Practical Handbook of Disturbed Land Revegetation. CRC Press, Boca Raton, Florida.

Parks DM, Nguyen MX. 1984. Revegetation of problem soils on road slopes. California Department of Transportation, Sacramento. FHWA/CA/TL-84-17.

Pendelton DF, Menke JW, Williams WA, Woodmansee RG. Annual grassland ecosystem model. Hilgardia 5:1-44.

Reich L. 2000. Natural food for plants. Fine Gardening. Nov-Dec:54-57.

Rentch JS, Fortney RH, Stephenson SL, Adams HS, Grafton WN, Anderson T. 2005. Vegetation-site relationships of roadside communities in West Virginia, USA. Journal of Applied Ecology 42:129-138.

Society for Ecological Restoration International Science & Policy Working Group (SERISPWG). 2004. The SER International Primer on Ecological Restoration. Version 2. Tucson, Society for Ecological Restoration International. www.ser.org.

Stylinski CD, Allen EB. 1999. Lack of native species recovery following severe alien disturbance in southern California shrublands. Journal of Applied Ecology 36:544-554.

Talbot MW, Biswell HH, Hormay AL. 1939. Fluctuations in the annual vegetation of California. Ecology 20:394-402.

Tilman D. 1986. Nitrogen-limited growth in plants from different successional stages. Ecology 67(2):555-563.

Tiquia SM, Lloyd J, Herms DA, Hoitink HAJ, Michel Jr FC. 2002. Effects of mulching and fertilization on soil nutirents, microbial activity and rhizosphere bacterial community structure determined by analysis of TRFLPs of PCR-amplified 16S rRNA genes. Applied Soil Ecology 21:31-48.

Tormo J, Bochet E, Garcia-Fayos P. 2006. Roadfill revgegetation in semiarid Mediterranean environments. Part II: topsoiling, species selection, and hydroseeding. Restoration Ecology 15(1):97-102.

Treseder KK. 2004. A meta-analysis of mycorrhizal responses to nitrogen, phorphorous and atmospheric CO_2 in field studies. New Phytologist 164:347-355.

Van Kekeri L, Kay BL. 1986. Revegetation of disturbed land in California: an element of mined land reclamation. Open-file Report 86-14SAC. California Department of Conservation, Division of Mines and Geology, Sacramento, CA.

VanCleve K, Chapin III FS, Dryness CT, Vireck LA. 1991. Element cycling in taiga forest: state-factor control. Bioscience 41:78-88.

Vaugn CE, Center DM, Jones MB. 1986. Seasonal fluctuations in nutrient availability in some Northern California annual range soils. Soil Science 141:43-51.

Vinton MA, Burke IC. 1995. Interactions between individual plant species and soil nutrient status in short-grass steppe. Ecology 76:1116-1133.

Vitousek PM. 1996. Biological invasions and ecosystem properties: can species make a difference? Pp 163-176 ***In*** Mooney HA, Drake JA (eds), Ecology of Biological Invasions of North America and Hawaii. Springer-Verlag, New York, NY.

Vitousek PM, Walker LR. 1989. Biological invasion by *Myrica faya* in Hawaii: plant demography, nitrogen fixation, ecosystem effects. Ecological Monographs 59:247-265.

Vitousek PM, Cassman K, Cleveland C, Crews T, Field CB, Grimm NB, Howarth RW, Marino R, Martinelli L, Rastetter EB, Sprent JI. 2002. Towards an ecological understanding of biological nitrogen fixation. Biogeochemistry 57/58:1-45.

Wali MK. 1999. Ecological succession and the rehabilitation of disturbed terrestrial ecosystems. Plant and Soil 213:195-220.

Wedin DA, Tilman D. 1996. Species effects on nitrogen cycling: a test with perennial grasses. Oecologia 84:433-441.

White PS, Walker JL. 1997. Approximating nature's variation: selecting and using reference information in restoration ecology. Restoration Ecology 5:338-349.

Whitford WG. 1988. Decomposition and nutrient cycling in disturbed ecosystems. Pp 136-161 ***In*** Allen EB (ed.), The Reconstruction of Disturbed Arid Lands:An Ecological Approach. Westview Press, Boulder, CO.

Woodmansee RG, Duncan DA. 1980. Nitrogen and phosphorus dynamics and budgets in annual grasslands. Ecology 61:893-904.

Young JA, Evans RA, Raguse CA, Larson JR. 1981. Germinable seeds and periodicityof germination in annual grasslands. Hilgardia 49:1-47.

Contract 43A0167 | Expert Assistance Task Area

Scoping Review Of
Some Potential Ecological Consequences From Compost Used For Revegetation of Native Plants Along California Highways

Technical Memo

Prepared For

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION

July 2006

1.0 Introduction

Land use categories adapted from Hobbs RJ. 1999. Restoration of Disturbed Ecosystems. pp. 673-687 *In* Walker LR (ed.), *Ecosystems of Disturbed Ground*. Amsterdam: Elsevier Science.

A conceptually useful way to view land use and the restoration of disturbed ecosystems is by the degree of modification by humans to existing or pre-existing native systems. Land use segregates into four primary categories with increasing modification to native systems: Conservation, Utilization, Replacement, or Removal.

CONSERVATION **No Intentional Modification of Native Systems**
- Wilderness Area
- Park
- Conservation Reserve
- Watershed Reserve

UTILIZATION **Intentional Exploitation of Native Systems**
- Non-Plantation Forestry
- Plant Harvesting
- Rangeland
- Hunting Area
- Recreation Area

REPLACEMENT
- **DESIGNED** **Intentional Management of Human-Designed Plant-Based Systems**
  - Agriculture
  - Horticulture
  - Silviculture
  - Highway Landscaping
- **RUDERAL** **Uncultivated Invasion Into Exploited Native or Human-Designed Systems**
  - Rangeland
  - Fallow Field
  - Roadside

REMOVAL **Intentional Management of Human-Built Non-Plant Systems**
- Urban
- Industry
- Mining
- Transportation

Beneficial use of compost to improve soil quality for plant growth has been documented for the following uses in Replacement land use contexts only:

Agriculture (orchards, vegetable production, vineyards, agronomy);
Horticulture (seedbed mixes, field-grown specimen cultivation, container-stock mixes);
Silviculture (tree plantations, reforestation); and
Highway Landscaping (wildflowers, grasses, woody perennials).

Standards exist for compost content and quality, but not for applications in specific ecological contexts.

While compost product standards and specifications for the purpose of landscaping roadsides are being delineated by Departments of Transportation at both State and National levels, the use of compost for revegetation with native plants in California involves a unique set of issues apart from those addressed by the currently proposed materials standards for compost content and quality.

1.0 Introduction

Use of compost for the sole purpose of native plant revegetation at the interface with Conservation lands, herein considered distinct from landscaping with native plants in the Urban/Suburban Replacement context, has received less documentation in the published literature. Reported studies suffer from short-term evaluation time frames, lack of standard protocols, and/or inconclusive results.

Results of this scoping review of pertinent literature indicate that inadequate data exist from which to delineate compost standards and specifications that apply specifically to native plant revegetation. While magnified detail of this literature is possible, it would fail to provide additional resolution of the fundamental data gap. However, these gaps in the literature have been identified and issues have become apparent. Such issues are briefly summarized below under three broad topic areas in an effort to guide future research aimed at delineation of use specifications.

Throughout this review "**compost**" is assumed to be organic material processed through controlled biological decomposition, sanitized through the generation of heat, and further stabilized for use a plant growth medium. According to specifications in development by Caltrans, "compost" must be obtained from a certified facility that follows all guidelines and procedures for production of compost meeting the environmental health standards of Title 14, California Code of Regulations, Division 7, Chapter 3.1, Article 7. The compost producer shall be a participant in United States Composting Council's (USCC) Seal of Testing Assurance (STA) program.

"Compost" is assumed to meet the USCC Test Methods for the Examination of Composting and Compost (TMECC) as part of the Compost Analysis Proficiency (CAP) Program.

Also assumed is that any "compost" applied by Caltrans would be free of viable weed seeds in conformance with Title 14, California Code of Regulations, Division 7, Chapter 3.1, Article 7, Section 17868.3, and would not contain concentration of metals that exceed the maximum metal concentrations listed in Title 14, California Code of Regulations, Division 7, Chapter 3.1, Section 17868.2.

2.0 Potential Ecological Consequences

2.1 Plant (Alien Weed) Invasion

More readily available nutrients in added compost frequently benefit alien weeds over native species.

Compost soil amendments are used to modify soil physical, chemical and biological characteristics for the broad purpose of supporting and sustaining plant growth. Conditions that are modified by the addition of compost to foster revegetation along roadsides are likely to support both native and alien species. In combination with disturbance of the substrate, additions of organic matter and nutrients can provide resource conditions that are advantageous to many alien weeds. Weedy alien species can prevent the establishment of native species or completely alter the structure of local or regional systems (e.g., alien annual grasses throughout lowland California, or Cheatgrass across the Great Basin).

Example References

Allen et Knight 1984	Claassen et Marler 1998
Hobbs et Atkins 1991	Pierce et al 1998
Hobbs et Huenneke 1992	Navas et al 1999
Humphries et al 1991	Newman et Redente 2001
McLendon et Redente 1991	Ewing 2002
D'Antonio et Vitousek 1992	Daehler 2003
Humphries 1993	Seabloom et al 2003
Allen et al 1996	Meyer et al 2004
Cook et Setterfield 1996	Paschke et al 2005
Stromberg et Griffin 1996	O'Dell et Claassen 2006

2.1.1 Potential Management Consequences

- increased costs of weed management programs, especially costly hand eradication in designated areas
- legal action over roadsides as source points for alien plant invasion on to adjacent lands

2.0 Potential Ecological Consequences

2.1 Plant (Alien Weed) Invasion

2.1.2 Alternative Management Strategies
(Where native revegetation is context-appropriate)

2.1.2.1 Topsoil harvest and reapplication

2.1.2.1.1 General Conditions

The benefits of harvesting topsoil prior to construction and reapplying it *in situ* afterwards have been documented.

Example References

Howard et Samuel 1979
Allen et Allen 1980
Bradshaw et Chadwick 1980
McGinnes et Nicholas 1980
Barth 1984
Claassen et Zasoski 1993
Allen et al 1999

2.1.2.1.2 Desert Conditions

In desert conditions where organic matter occurs as resource islands at the base of woody vegetation or rocks, the local harvest, culture, and re-application of a biological soil crust slurry may be more appropriate.

Example References

Johansen et al 1984
Allen et al 1999

2.0 Potential Ecological Consequences

2.1 Plant (Alien Weed) Invasion

2.1.2.2 Compost Formulated For Specific Context Soils

Use of low volume of compost amendment formulated with parameters consistent with ecologically appropriate context soils. This is a labor intensive and site specific technique.

Further study and research are required.

2.1.2.3 Compost Formulated With Specific C:N Ratios

Use a compost amendment formulated with an adjusted C:N ratio that favors targeted plant species. This temporarily reduces the availability of nitrogen through the addition of excess amounts of carbon and has sometimes been shown to reduce growth and competitiveness of alien plants. This soil and microbiota management technique of biological weed control is in early stages of investigation; results have been inconsistent.

Example References

McLendon et Redente 1992
Morgan 1994
Wilson et Gerry 1995
Seastedt et al 1996
Zink et Allen 1998
Reever Morghan et Seastedt 1999
Tilman et al 1999
Alpert et Maron 2000
Paschke et al 2000
Torok et al 2000
Cione et al 2002
Ewing 2002
Blumenthal et al 2003
Corbin et al 2004
Corbin et D'Antonio 2004

2.1.2.4 Compost Used To Inhibit Weed Germination

Use an immature compost amendment to act as a germination inhibitor, another form of biological weed control. However, effects are temporary. Presumes native plants are installed from container stock or flats.

Further study and research are required.

2.0 Potential Ecological Consequences

2.1 Plant (Alien Weed) Invasion References

Allen EB, Allen MF. 1980. Natural re-establishment of vesicular-arbuscular mycorrhizae following stripmine reclamation in Wyoming. Journal of Applied Ecology 17:139-147.

Allen EB, Knight DH. 1984. The effects of introduced annuals on secondary succession in sgaebrush-grassland, Wyoming. Southwest Naturalist 29:407-429.

Allen MF, Allen EB, Zink TA, Harney S, Yoshida LC, Siguenza C, Edwards F, Hinkson C, Rillig M, Bainbridge D, Doljanin C, MacAller R. 1999. Soil microorganisms *In* Walker LR (ed). Ecosystems of Disturbed Ground. Elsevier, Amsterdam, The Netherlands. Pp. 521-544.

Allen MF, Figueroa C, Weinbaum BS, Barlow SB, Allen EB. 1996. Differential production of oxalate my mycorrhizal fungi in arid ecosystems. Biology and Fertility of Soils 22:287-292.

Alpert P, Maron JL. 2000. Carbon addition as a counter-measure against biological invasion by plants. Biological Invasions 2:33-40.

Barth RC. 1984. Soil-depth requirements to re-establish perennial grasses on surface-mined areas in the northern Great Plains. Colorado School of Mines, Minerals and Energy Resources 27.

Blumenthal DM, Jordan NR, Ressulle MP. 2003. Soil carbon addition controls weeds and facilitates prairie restoration. Ecological Applications 13:605-615.

Bradshaw AD, Chadwick MJ. 1980. The Restoration of Land: the Ecology and Reclamation of Derelict and Degraded Land. University of California Press, Los Angeles.

Cione NK, Padgett PE, Allen EB. 2002. Restoration of a native shrubland impacted by exotic grasses, frequent fire, and nitrogen deposition in southern California. Restoration Ecology 10:376-384.

Claassen VP, Marler M. 1998. Annual and perennial grass growth on nitrogen-depleted decomposed granite. Restoration Ecology 6:175-180.

Claassen VP, Zasoski RJ. 1993. Enhancement of revegetation on construction fill by fertilizer and topsoil application: effects on mycorrhizal infection. Land Degradation and Rehabilitation 4:45-57.

Cook GD, Setterfield SA. 1996. Shrub invasion of a tropical wetland: implications for weed management. Ecological Applications 6:531-537.

Corbin JD, D'Antonio CM, Bainbridge S. 2004. Tipping the balance in restoration of native plants: experimental approaches to changing the exotic: native ratio in California grassland. *In* Gordon M, Bartol S (eds.). Experimental Approaches to Conservation Biology. University of California Press, Berkeley.

Corbin JD, D'Antonio CM. 2004. Can carbon addition increase competitiveness of native grasses? A case study from California. Restoration Ecology 12:36-43.

D'Antonio CM, Vitousek PM. 1992. Biological invasions by exotic grasses, the grass fire cycle and global change. Annual Review of Ecology and Systematics 23:63-87.

Daehler CC. 2003. Performance comparisons of co-occurring native and alien invasive plants: implications for conservation and restoration. Annual Review of Ecology, Evolution, and Systematics 34:183-211.

Ewing K. 2002. Effects of initial site treatments on early growth and three-year survival of Idaho fescue. Restoration Ecology 10:282-288.

Hobbs RJ, Atkins L. 1991. Interactions between annuals and woody perennials in a western Australia wheatbelt reserve. Journal of Vegetation Science 2:643-654.

Hobbs RJ, Huenneke LF. 1992. Disturbance, diversity, and invasion: implications for conservation. Conservation Biology 6:324-337.

Howard GS, Samuel MJ. 1979. The value of fresh stripped topsoil as a seed source of useful plants for surface mine revegetation. Journal of Range Management 32:76-77.

Humphries SE, Groves RH, Mitchell DS. 1991. Plant invasions of Australian ecosystems: a status review and management directions. *In* Kowari 2. Plant Invasions. The Incidence of Environmental Weeds in Australia. Australian National Parks and Wildlife Service. Canberra. Pp. 1-127.

Humphries SE. 1993. Environmental impact of weeds. *In* Proceedings of the 10th Australian Weeds Conference and 14th Asian Pacific Weed Society Conference. Vol. 2. Weed Society of Queensland, Brisbane. Pp. 1-11.

Johansen JR, St. Clair LL, Webb BL, Nebeker GT. 1984. Recovery patterns of cryptogamic soil crusts in desert rangelands following fire disturbance. Bryologist 87:238-243.

2.0 Potential Ecological Consequences

2.1 Plant (Alien Weed) Invasion References

McGinnes WJ, Nicholas PJ. 1980. Effects of topsoil thickness and nitrogen fertilizer on the revegetation of coal mine spoils. Journal of Environmental Quality 9:681-685.

McLendon T, Redente EF. 1992. Effects of nitrogen limitation on species replacement dynamics during early secondary succession on a semiarid sagebrush site. Oecologia 91:312-317.

Meyer VF, Redente EF, Barbarick KA, Brobst RB, Paschke MW, Miller AL. 2004. Plant and soil responses to biosolids applications following forest fire. Journal of Environmental Quality 33:873-881.

Morgan JP. 1994. Soil impoverishment: a little known technique holds potential for establishing prairie. Restoration Management Notes 12:55-56.

Navas A, Machin J, Navas B. 1999. Use of biosolids to restore the natural vegetation cover on degraded soils of Zaragosa (NE Spain). Bioresource Technology 69:199-205.

Newman GJ, Redente EF. 2001. Long-term plant community development as influenced by revegetation techniques. Journal of Range Management 54:717-724.

O'Dell RE, Claassen VP. 2006. Relative performance of native and exotic grass species in response to amendment of drastically disturbed serpentine substrates. Journal of Applied Ecology in press.

Paschke MW, McLendon T, Redente EF. 2000. Nitrogen availability and old-field succession in a short-grass steppe. Ecosystems 3:144-158.

Paschke MW, Topper K, Brobst RB, Redente EF. 2005. Long-term effects of biosolids on revegetation of disturbed sagebrush steppe in northwestern Colorado. Restoration Ecology 13:545-551.

Pierce BL, Redente EF, Barbarick KA, Brobst RB, Hegeman F. 1998. Plant biomass and elemental changes in shrubland forages following biosolids application. Journal of Environmental Quality 27:789-794.

Reever Morghan KJ, Seastadt TR. 1999. Effects of soil nitrogen reduction on nonnative plants in restored grasslands. Restoration Ecology 7:51-55.

Seabloom EW, Harpole WS, Reichman OJ, Tilman D. 2003. Invasion, competitive dominance, and resource use by exotic and native California grassland species. Proceedings of the National Academy of Sciences 100:13384-13389.

Seastedt TR, Duffy PA, Knight JN. 1996. Reverse fertilization experiment produces mixed results (Colorado). Restoration and Management Notes 14:64.

Stromberg MR, Griffin JR. 1996. Long-term patterns in coastal California grasslands in relation to cultivation, gophers, and grazing. Ecological Applications 6:1189-1211.

Tilman EA, Tilman D, Crawley MJ, Johnson AE. 1999. Biological weed control via nutrient competition: potassium limitation of dandelions. Ecological Applications 9:103-111.

Torok K, Szili-Kovacs T, Halassy M, Toth T, Hayek Z, Paschke MW, Wardell LJ. 2000. Immobilization of soil nitrogen as a possible method for the restoration of sandy grassland. Applied Vegetation Science 3:7-14.

Wilson SD, Gerry AK. 1995. Strategies for mixed-grass prairie restoration: herbicide, tilling, and nitrogen manipulation. Restoration Ecology 3:290-298.

Zink TA, Allen MF. 1998. The effects of organic amendments on the restoration of a disturbed coastal sage scrub habitat. Restoration Ecology 6:52-58.

2.0 Potential Ecological Consequences

2.2 Soil Alien Microbiota Invasion

Compost soil amendments are created through the decomposition of organic materials by a variety of microorganisms. When the compost has attained a stage of maturity that would allow its usage on roadsides for erosion control, or for revegetation, the product brings many of those same microorganisms to a site. **The fate of these microorganisms in roadside environments has not been addressed in the published literature. They may perish, persist, or thrive and disperse into the adjacent environment with unknown ecological consequences.**

Lessons from alien plant invasions along roadsides.

Roads have been shown to act as disturbances that promote occupation by alien plant species and it is suggested that, with enough time, roads often act as corridors for the spread of alien plant species into new landscapes, and that these immigrants result in significantly different plant community structure and function. Concern has been raised that alien soil biota, with their role as drivers of natural community organization, may have the same or even more pronounced affects, causing ecological change and degraded ecosystem services. For example, alien earthworms which have invaded the broadleaf forests of the northeastern U.S. are producing profound ecosystem changes such as rapid elimination of the forest floor, redistribution of fine roots and soil organic matter, disruption of the soil faunal community, and alteration of nutrient cycling.

Changes in the species composition of rhizosphere bacteria, nematodes, pathogenic fungi and mycorrhizal fungi that may accompany compost amendments could cause a vast suite of changes in the composition of the native soil community and, thus, plant-to-plant interactions. Awareness of this potential has already been raised with the use of mycorrhizal inoculants.

Example References

Armor et Stevens 1976
Schmidt 1989
Allen et Allen 1990
Hartnett et al 1993
Alban et Berry 1994
Burtelow et al 1998
Marler et al 1999
Mack et al 2000
Chapela et al 2001
Hamson et al 2002
Bever 2003
Klironomos 2003
Bohlen et al 2004
Reinhart et Callaway 2006
Suarez et al 2006

2.0 Potential Ecological Consequences

2.2 Soil Alien Microbiota Invasion

2.2.1 Potential Management Consequences

- increased costs if alien soil biota are shown to causes problems
- legal action over roadsides as source points for alien organism invasion on to adjacent lands

2.2.2 Alternative Management Strategies
(Where native revegetation is context-appropriate)

2.2.2.1 Topsoil harvest and reapplication

The benefits of harvesting topsoil prior to construction and reapplying it *in situ* afterwards have been documented. (see **2.1.2.1.1** for references).

2.2.2.2 Follow Fate of Microbiota Introduced Via Compost

Pursue research that evaluates the fate of compost microorganisms amended into roadside soil environments over time throughout the State. *Do they perish, persist or thrive and disperse to adjacent areas?*

2.0 Potential Ecological Consequences

2.2 Soil Alien Microbiota Invasion References

Alban DH, Berry EC. 1994. Effects of earthworm invasion on morphology, carbon, and nitrogen of a forest soil. Applied Soil Ecology 1:243-249.

Allen MF, Allen EB. 1990. The mediation of competition by mycorrhizae in successional and patchy environments. In Grace JB, Tilman D (eds.). Perspectives on plant competition. Academic Press, New York. Pp 367-389.

Armor RL, Stevens PL. 1976. Spread of weeds from a roadside into sclerophyll forests at Dartmouth, Australia. Weed Research 16:111-118.

Bever JD. 2003. Soil community feedback and the coexistence of competitors: conceptual frameworks and empirical tests. New Phytologist 157:465-473.

Bohlen PJ, Groffman PM, Fahey TJ, Fisk MC, Suarez E, Pelletier DM, Fahey RT. 2004. Ecosystem consequences of exotic earthworm invasion of north temperate forests. Ecosystems 7:1-12.

Burtelow AE, Bohlen PJ, Groffman PM. 1998. Influence of exotic earthworm invasion on soil organic matter, microbial biomass, and denitirification potential in forest soils of the northeastern United States. Appiled Soil Ecology 9:197-202.

Chapela IH, Osher LJ, Horton TR, Henn MR. 2001. Ectomycorrhizal fungi introduced with exotic pine plantations induce soil carbon depletion. Soil Biology and Biochemistry 33:1733-1740.

Hamson S, Hohn C, Ratay S. 2002. Distribution of exotic plants along roads in peninsular nature reserve. Biological Invasions 4:425-430.

Hartnett DC, Hetrick BAD, Wilson GWT, Gibson DJ. 1993. Mycorrhizal influence on intra- and inter-specific neighbor interactions among co-occurring prairie grasses. Journal of Ecology 81:787-795.

Klironomos JN. 2003. Variation in plant response to native and exotic mycorrhizal fungi. Ecology 84:2292-2301.

Mack RN, Simberloff D, Lonsdale WM, Evans H, Clout M, Bazzaz FA. 2000. Biotic invasions, causes, epidemiology, global consequences and control. Ecological Applications 10:689-710.

Marler MJ, Zabinski CA, Callaway RM. 1999. Mycorrhizae indirectly enhance competitive effects of an invasive forb on a native bunchgrass. Ecology 80:1180-1186.

Reinhart KO, Callaway RM. 2006. Soil biota and invasive plants. New Phytologist 170:445-457.

Schmidt W. 1989. Plant dispersal by motor cars. Vegetatio 80:147-152.

Schwartz MW, Hoeksema JD, Gehring CA, Johnson NC, Klironomos JN, Abbott LK, Pringle A. 2006. The promise and the potential consequences of the global transport of mycorrhizal inoculum. Ecology Letters 9:501-515.

Suarez ER, Fahey TJ, Groffman PM, Yavitt JB, Bohen PJ. 2006. Spatial and temporal dynamics of exotic earthworm communities along invasion fronts in a temperate hardwood forest in south-central New York (USA). Biological Invasions 8:553-564.

2.0 Potential Ecological Consequences

2.3 Ecological Succession

Although recorded for more than 100 years in the ecological literature, the patterns and processes of ecological succession remain enigmatic. No general theory encompasses the complexity of species replacements across a wide range of habitats.

Because compost amendments alter physical, chemical, and biological properties of soil, these influence those autecological and synecological components that may determine plant successional pathways. Compost applications have long-term effects on plant community development via the soil biotic community. The composition, structure, diversity, and function of the soil microbial community affects the entire food web, catabolic capacities and nutrient cycling. Documenting the effects of organic amendments on soil characteristics and plant community change over time is further complicated by the interaction of both a specific compost feedstock and a specific soil type.

Thus, in the context of native plant revegetation contiguous with conservation lands, the use of compost may result in faster and more abundant vegetation cover, but the roadside may not resemble the contiguous plant assemblage in structure or function.

Example References

Luken 1990
McLendon et Redente 1991
Berendese 1998
Allen et al 1999
Navas et al 1999
Walker 1999
Perry et al 2000
Sydnor et Redente 2000
Newman et Redente 2001
Schipper et al 2001
Daehler 2003
Ros et al 2003
Sullivan et al 2003
Walker 2003
Bardgett et Walker 2004
Innes et al 2004
Meyer et al 2004
Carney et Matson 2005
Paschke et al 2005
Hawkes et al 2006
Perez-Piqueres et al 2006
Wardle et al 2006

2.0 Potential Ecological Consequences

2.3 Ecological Succession

2.3.1 Potential Management Consequences

- roadside community may not comply with requirements for structural similarity with contiguous vegetation on conservation lands

2.3.2 Alternative Management Strategies
(Where native revegetation is context-appropriate)

2.3.2.1 Topsoil harvest and reapplication

The benefits of harvesting topsoil prior to construction and reapplying it *in situ* afterwards have been documented. (see **2.1.2.1.1** for references).

2.3.2.2 Install Live Container Stock From Local Genetic Sources

Revegetate with transplants from container stock derived from local genetic propagules, as revegetation from seed may not attain structural similarity to target vegetation goals.

2.3.2.3 Achieve Best Compromise With Context Land Managers

For both 2.3.2.1 and 2.3.2.2 above, achieve agreement among conservation land managers that the structural similarity with contiguous vegetation may not be attained on the roadside even when local genetic propagules have been used in the revegetation effort.

2.0 Potential Ecological Consequences

2.3 Ecological Succession References

Allen MF, Allen EB, Zink TA, Harney S, Yoshida LC, Siguenza C, Edwards F, Hinkson C, Rillig M, Bainbridge D, Doljanin C, MacAller R. 1999. Soil microorganisms. In Walker LR (ed.). Ecosystems of Disturbed Ground. Elsevier Science, Amsterdam, The Netherlands. Pp.521-544.

Bardgett RD, Walker LR. 2004. Impact of colonizer plant species on the development of decomposer microbial communities following deglaciation. Soil Biology and Biochemistry 36:555-559.

Berendese F. 1998. Effects of dominant plant species on soils during succession in nutrient-poor ecosystems. Biogeochemistry 42:73-88.

Carney KM, Matson PA. 2005. Plant communities, soil microorganisms, and soil carbon cycling: Does altering the world belowground matter to ecosystem functioning? Ecosystems 8:928-940.

Daehler CC. 2003. Performance comparisons of co-occurring native and alien invasive plants: implications for conservation and restoration. Annual Review of Ecology, Evolution, and Systematics 34:183-211.

Hawkes CV, Belnap, J, D'Antonio C, Firestone M. 2006. Arbuscular mycorrhizal assemblages in native plant roots change in the presence of invasive exotic grasses. Plant and Soil 281:369-380.

Innes L, Hobbs PJ, Bardgett RD. 2004. The impacts of individual plant species on rhizosphere microbial communities in soils of different fertility. Biology and Fertility of Soils 40:7-13.

Luken JO. 1990. Directing Ecological Succession. Chapman and Hall, New York.

McLendon T, Redente EF. 1991. Nitrogen and phosphorous effects on secondary succession dynamics on a semi-arid sagebrush site. Ecology 76:2016-2024.

Meyer VF, Redente EF, Barbarick KA, Brobst RB, Paschke MW, Miller AL. 2004. Plant and soil responses to biosolids application following forest fire. Journal of Environmental Quality 33:873-881.

Navas A, Machin J, Navas B. 1999. Use of biosolids to restore the natural vegetation cover on degraded soils in the badlands of Zaragosa (NE Spain). Bioresource Technology 69:199-205.

Newman GJ, Redente EF. 2001. Long-term plant community development as influenced by revegetation techniques. Journal of Range Management 54:717-724.

Paschke MW, Topper K, Brobst RB, Redente EF. 2005. Long-term effects of biosolids on revegetation of disturbed sagebrush steppe in northwestern Colorado. Restoration Ecology 13:545-551.

Pérez-Piqueres A, Edel-Hermann V, Alabouvette C, Steinberg C. 2006. Response of soil microbial communities to compost amendments. Soil Biology and Biochemistry 38:460-470.

Perry MC, Osenton PC, Gough GA, Lohnes JR. 2000. Establishment of warm season grasses with and wihtou the use of compost soil amendments. In Proceedings of the Second Eastern Native Grass Symposium. ARS, NRCS, Beltsville MD. P. 360.

Ros M, Hernandez MT, Garcia C. 2003. Soil microbial activity after restoration of a semiarid soil by organic amendments. Soil Biology and Biochemistry 35:463-469.

Schipper LA, Degens BP, Sparling GP, Duncan LC. 2001. Changes in microbial heterotrophic diversity along five plant successional sequences. Soil Biology and Biochemistry 33:2093-2103.

Sullivan DM, Bary AI, Nartea TJ, Myrhe EA, Cogger CG, Fransen SC. 2003. Nitrogen availability seven years after a high-rate food waste compost application. Compost Science and Utilization 11:265-275.

Sydnor RS, Redente EF. 2000. Long-term plant community development on topsoil treatments overlying a phytotoxic growth medium. Journal of Environmental Quality 29:1778-1786.

Walker LR. 1999. Patterns and processes in primary succession. In Walker LR (ed.), Ecosystems of Disturbed Ground. Elsevier Science, Amsterdam, The Netherlands. Pp585-610.

Walker LR. 2003. Comparison of organic and chemical soil amendments used in the reforestation of a harsh Sierra Nevada site. Restoration Ecology 11:466-474.

Wardle DA, Yeates GW, Barker GM, Bonner KI. 2006. The influence of plant litter diversity on decomposer abundance and diversity. Soil Biology and Biochemistry 38:1052-1062.

APPENDIX H.3

ADVISORY REGARDING IDENTIFICATION AND PROVENANCE OF PLANT MATERIALS PRESENTLY SOLD IN CALIFORNIA

Advisory Regarding Identification and Provenance of Plant Materials Presently Sold in California

Identification and provenance of the following are much confused by plant materials vendors. The term LIKELY is used here to indicate a very strong likelihood of what the correct assignment to species is, but be advised that some material in the SOLD AS column may be labeled correctly. Check to make sure that you get what you ordered.

SOLD AS English	SOLD AS Cultivar	SOLD AS Scientific	LIKELY IS Scientific	LIKELY IS English	LIKELY Provenance
California Brome	'Cucamonga'	Bromus carinatus Hook. & Arn. var. carinatus	Bromus arizonicus (Shear) Stebbins	Arizona Brome	Cucamonga, San Bernardino Co.
Seaside Brome	—	Bromus carinatus Hook. & Arn. var. maritimus (Piper) C.L. Hitchc.	Bromus sitchensis Trin.	Sitka Brome	??? [Alaska to N. California]
Berkeley Sedge	—	Carex tumulicola Mackenzie	Carex divulsa Stokes	Grey Sedge	Eurasia
Idaho Fescue	—	Festuca idahoensis Elmer Festuca idahoensis Elmer var. roemeri Pavlick Festuca ingrata (Hack. ex Beal) Rydb. Festuca ovina L. var. ingrata Hack. ex Beal	Festuca rubra L.	Red Fescue	Eurasia
Mokelumne Blue Fescue	'Mokelumne Blue'	Festuca idahoensis Elmer Festuca ovina L. var. ingrata Hack. ex Beal Festuca ovina L. var."integra" (no such epithet, should be "ingrata")	Festuca rubra L.	Red Fescue	Eurasia
Siskiyou Blue Fescue	'Siskiyou Blue'	Festuca idahoensis Elmer Festuca ovina L. var. ingrata Hack. ex Beal Festuca ovina L. var."integra" (no such epithet, should be "ingrata")	Festuca rubra L.	Red Fescue	Eurasia
Western Fescue	'Mokelumne Blue'	Festuca occidentalis Hook.	Festuca rubra L.	Red Fescue	Eurasia
Western Fescue	'Siskiyou Blue'	Festuca occidentalis Hook.	Festuca rubra L.	Red Fescue	Eurasia
Blue Molate Fescue	'Molate Blue'	Festuca rubra L.	Festuca rubra L.	Red Fescue	Pt Molate, Contra Costa Co.; NATIVE ???
Molate Fescue	'Molate'	Festuca rubra L.	Festuca rubra L.	Red Fescue	Pt Molate, Contra Costa Co.; NATIVE ???
Dwarf Barley	—	Hordeum depressum (Scribn. & J.G. Sm.) Rydb.	Hordeum intercedens Nevski	Bobtail Barley	??? [Southern California]
Big Bluegrass	'Sherman'	Poa secunda Presl. (broad sense) Poa secunda Presl. ssp juncifolia (Scribner) R.Soreng	Poa ampla Merr.	Big Bluegrass	Umatilla Plateau, near Moro, Sherman Co., OR
Pine Bluegrass	'Canbar'	Poa secunda Presl. (broad sense) Poa secunda Presl. ssp. secunda	Poa canbyi (Scribn.) T.J. Howell	Canby Bluegrass	Blue Mtns, Columbia Co., WA

26 May 2006

APPENDIX H.4

A QUALITATIVE ASSESSMENT OF POST-CONSTRUCTION REVEGETATION SUCCESS ON CUESTA GRADE

Contract 43A0167 | Expert Assistance Task Area

A Qualitative Assessment of Post-Construction Revegetation Success on Cuesta Grade

Prepared For

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION

Project Post-Construction Review

US HIGHWAY 101

San Luis Obispo County

KP 52.1 to 57.1
MP 32.4 to 35.5

Contract 05-345414

June 2006

At the request of Tim Richards, Resident Engineer, and Dennis Reeves, Senior Landscape Architect, for the US 101 Project Cuesta Grade (**Figure 1**), this qualitative assessment of post-construction revegetation success on Cuesta Grade was prepared under the Expert Assistance Task Area of the Roadside Erosion Control & Maintenance Study in progress through the Earth and Soil Sciences Department at Cal Poly State University, San Luis Obispo, under contract with the Office of Water Programs at Sacramento State University, and Caltrans Division of Design.

1. Purpose

This brief assessment of post-construction revegetation along the Cuesta Grade is intended to communicate a "snapshot" of vegetation succession as of June 2006, and appraisals of revegetation treatments that did or did not produce intended results.

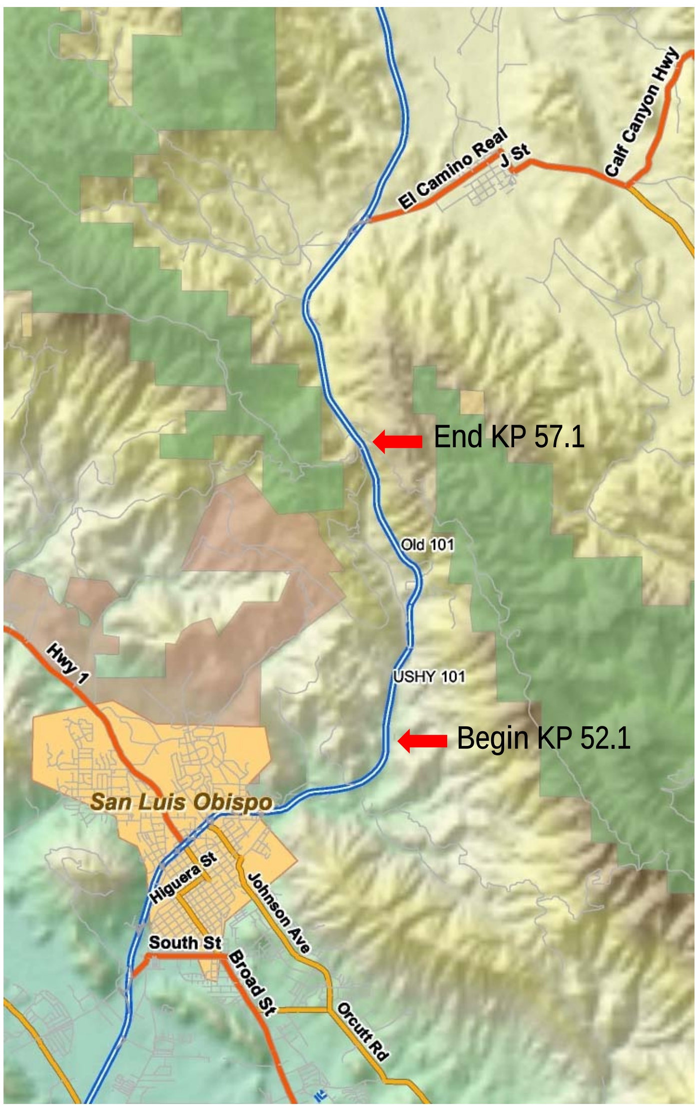

Figure 1. General Location of US 101 Project Cuesta Grade, San Luis Obispo County

2. Erosion Control Specifications

The following treatments were applied to slopes, as well as some other "spot" treatments at equipment staging areas or as called for by the resident engineer.

2.1 Slopes Flatter Than 1:1.5 (V:H)

A Type C (Incorporated Straw/Stabilizing Emulsion) specification consisting of incorporated native grass straw [*Bromus carinatus* (California Brome), *Melica californica* (California Melic), *Stipa cernua* (Nodding Stipa), *Stipa pulchra* (Purple Needlegrass), alone or combined], seed (see **2.3**), fertilizer fiber, and stabilizing emulsion. See **Appendix A** for a facsimile of the specification.

The following quantities were specified:

Material	kg / ha (slope)	lb / ac (slope)	Method
Legume Seed	4	3.6	Hand Broadcast
Non-Legume Seed	14	12.5	Hydro
Commercial Fertilizer	200	178.4	Hydro
Fiber	500	446.1	Hydro
Stabilizing Emulsion	375	334.6	Hydro

2.2 Slopes 1:1.5 (V:H) or Steeper and Cut Slopes

2.2.1 Erosion Control Blanket

An Erosion Control Blanket specification consisting of straw or coconut fiber, seed (see **2.3**), and fertilizer. See Appendix A for a facsimile of the specification.

The following quantities were specified:

Material	kg / ha (slope)	lb / ac (slope)	Method
Legume Seed	4	3.6	Hand Broadcast
Non-Legume Seed	14	12.5	Hydro
Commercial Fertilizer	200	178.4	Hydro

2.2.2 Bonded Fiber Matrix (BFM)

A limited amount of BFM was applied to a few highly erosive slopes. The specification was not made available, but from what remains on-site it is likely that about 4000 kg / ha (3569 lb / ac) was applied over the seed (see **2.3**).

2.3 Basic Seed Mix

The species and quantities of pure live seed (PLS = % pure seed x % germinable seed) applied are listed below.

Name Scientific	Name English	Family	KgPLS/ha	PLS/m2 (approx)	Percent_of_Mix (count)
Legume Shrub					
Lupinus albifrons Benth. ex Lindl.	Silver Bush Lupine	FABACEAE	1.0	**3**	0.5%
Legume Annual Forb					
Lotus purshianus F.E. & E.G. Clem.	Spanish Lotus	FABACEAE	3.0	**61**	10.5%
Non-Legume Shrub					
Artemisia californica Less.	California Sagebrush	ASTERACEAE	0.7	**68**	11.7%
Baccharis pilularis DC. var. **consanguinea** (DC.) Kuntze	Coyote Brush	ASTERACEAE	0.1	**82**	14.1%
Eriogonum fasciculatum Benth. var. **fasciculatum**	Coastal California Buckwheat	POLYGONACEAE	1.1	**10**	1.7%
Eriophyllum confertiflorum (DC.) Gray	Golden Yarrow	ASTERACEAE	1.0	**109**	18.8%
Mimulus aurantiacus W.Curtis	Bush Monkeyflower	PHYRMACEAE	0.1	**9**	1.5%
Salvia mellifera Greene	Black Sage	LAMIACEAE	1.0	**34**	5.9%
Non-Legume Annual Forb					
Eschscholzia californica Cham.	California Poppy	PAPAVERACEAE	1.0	**53**	9.2%
Perennial Grass					
Bromus carinatus Hook. et Arn.	California Brome	POACEAE	4.0	**43**	7.3%
Hordeum brachyantherum Nevski	Meadow Barley	POACEAE	3.0	**50**	8.6%
Melica californica Scribn.	California Melic	POACEAE	1.0	**35**	6.0%
Nassella pulchra (A.S. Hitchc.) Barkworth	Purple Needlegrass	POACEAE	1.0	**24**	4.2%
			18.0	**582**	100.0%

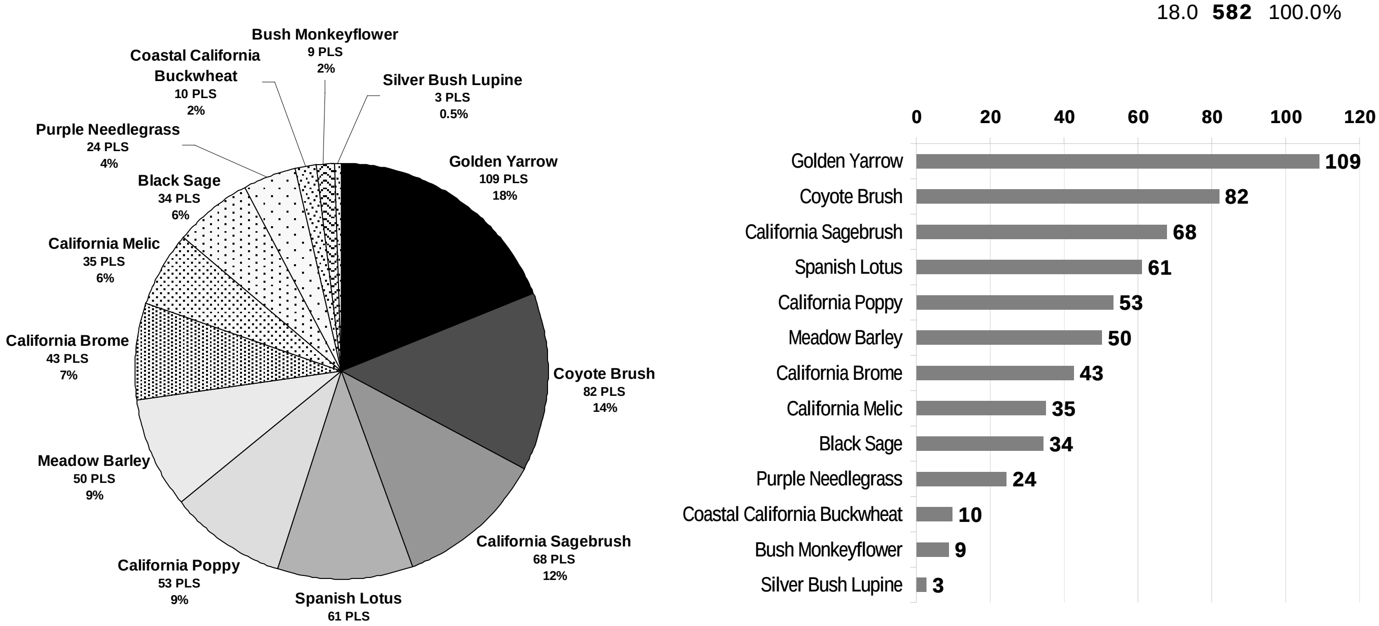

Figure 2. Approximate Specified PLS per Square Meter.

3. Assessment Methods

A general site visit was made on 13 June 2006 from 9 am to 12 pm. Stops were made at several sites on the northbound (uphill) side where revegetation work had been done, and at one large site on the southbound side. Vegetation cover and composition were qualitatively evaluated based on years of familiarity with local vegetation and plant species. An inventory was made of the most conspicuous plant species within the right-of-way.

The assessments made herein are preliminary qualitative rankings of approximate numbers and relative dispersion of individual plants and stands observed. No quantitative transect or quadrat data were gathered.

3.1 Personnel

Plant identifications and site evaluations were made by:

Michael Curto, MS
Senior Research Associate
Earth and Soil Sciences
Cal Poly State University
San Luis Obispo, CA 93407
(805) 474-1309
mcurto@calpoly.edu

Tim Richards, PE
Resident Engineer
Caltrans
Davenport Creek Construction Office
4485 Vachell Lane
San Luis Obispo, CA 93401
(805) 542-4765
tim.richards@dot.ca.gov

4. Results and Discussion

Conspicuous plants within the right-of-way are listed by provenance and lifeform in **Table 1**, and by ranked relative abundance and lifeform in **Table 2**. These lists are not comprehensive given the limited time in the field, but include most of the visually obvious species. Of the 79 species listed, 44 are native and 35 are alien. Counts and percentages of species by provenance and lifeform are shown as **Figure 3**. Counts and percentages of species by relative abundance and lifeform are shown as **Figure 4**.

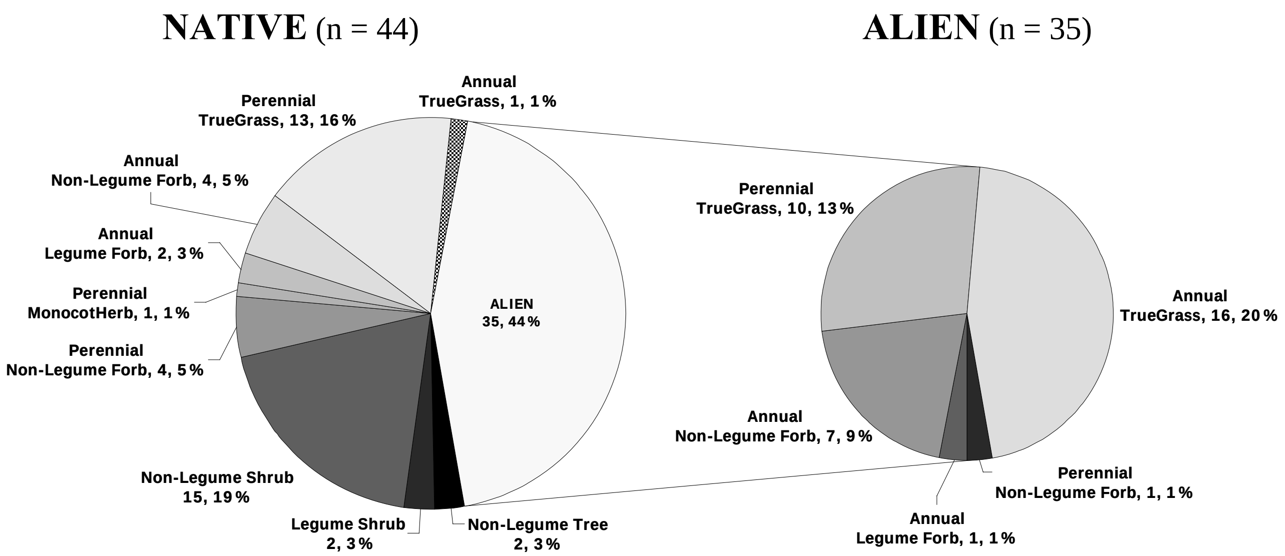

Figure 3. Counts of Conspicuous Species By Provenance and Lifeform.

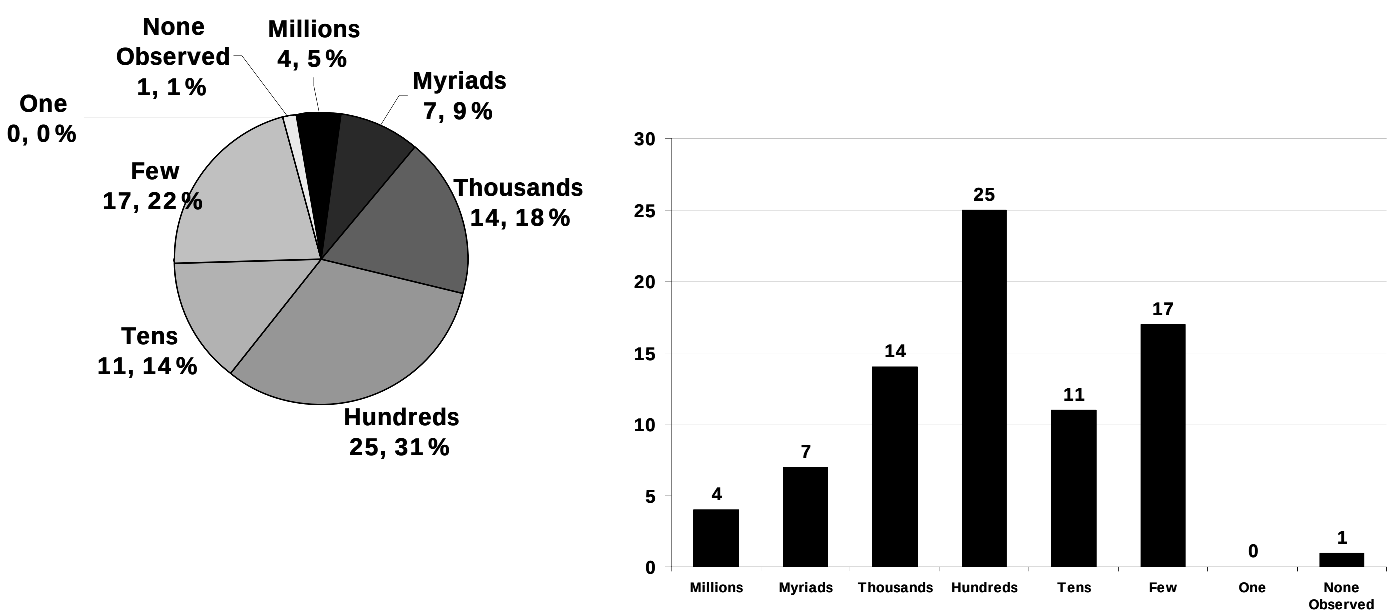

Figure 4. Counts of Conspicuous Species By Relative Abundance and Lifeform.

TABLE 1. Conspicuous Plants of Cuesta Grade Right-of-Way: Provenance and Lifeform.

Shading indicates specification as part of seed mix.

Family	Name Scientific	Name English	Density	Dispersion
	Native Trees			
FAGACEAE	Quercus agrifolia Née	California Live Oak	Tens	Patchy
PLATANACEAE	Platanus racemosa Nutt.	California Sycamore	Few	Patchy
	Native Legume Shrubs			
FABACEAE	Lotus scoparius (Nutt.) Ottley	Common Deer Lotus	Thousands	Patchy
FABACEAE	**Lupinus albifrons Benth. ex Lindl.**	**Silver Bush Lupine**	**Hundreds**	**Patchy**
	Native Non-Legume Shrubs			
ANACARDIACEAE	Toxicodendron diversilobum (Torr. & Gray) Greene	Poison Oak	Hundreds	Patchy
ASTERACEAE	**Artemisia californica Less.**	**California Sagebrush**	**Myriads**	**Patchy**
ASTERACEAE	**Baccharis pilularis DC.**	**Coyote Brush**	**Thousands**	**Patchy**
ASTERACEAE	**Eriophyllum confertiflorum (DC.) Gray**	**Golden Yarrow**	**Thousands**	**Patchy**
CONVOLVULACEAE	Calystegia macrostegia (Greene) Brummitt	Common Bindweed	Tens	Patchy
FAGACEAE	Quercus durata Jepson	Leather Oak	Few	Patchy
LAMIACEAE	Salvia apiana Jepson	White Sage	Hundreds	Patchy
LAMIACEAE	**Salvia mellifera Greene**	**Black Sage**	**Thousands**	**Patchy**
PHYRMACEAE	**Mimulus aurantiacus W.Curtis**	**Bush Monkeyflower**	**Thousands**	**Patchy**
POLYGONACEAE	**Eriogonum fasciculatum Benth.**	**California Buckwheat**	**Thousands**	**Patchy**
RHAMNACEAE	Ceanothus cuneatus (Hook.) Nutt.	Buckbrush	Few	Patchy
RHAMNACEAE	Rhamnus californica Eschsch.	California Coffeeberry	Few	Patchy
RHAMNACEAE	Rhamnus crocea Nutt.	Redberry	Few	Patchy
ROSACEAE	Prunus ilicifolia (Nutt. ex Hook. et Arn.) D.Dietr.	Holly-leaved Cherry	Few	Patchy
SALICACEAE	Salix lasiolepis Benth.	Arroyo Willow	Few	Patchy
	Native Perennial Forbs			
ASTERACEAE	Achillea millefolium L.	Common Yarow	Few	Patchy
POLYGONACEAE	Eriogonum elongatum Benth.	Longstem Buckwheat	Tens	Patchy
POLYGONACEAE	Eriogonum vimineum Dougl. ex Benth.	Wickerstem Buckwheat	Hundreds	Patchy
VERBENACEAE	Verbena lasiostachys Link	Western Vervain	Hundreds	Patchy
	Native Annual Legume Forbs			
FABACEAE	**Lotus purshianus F.E. & E.G. Clem.**	**Spanish Lotus**	**None Observed**	**None Observed**
FABACEAE	Lupinus nanus Dougl. ex Benth.	Sky Lupine	Tens	Patchy
	Native Annual Non-Legume Forbs			
ASTERACEAE	Layia platyglossa (Fisch. & C.A. Mey.) Gray	Tidy Tips	Few	Patchy
ONAGRACEAE	Clarkia bottae (Spach) H.F. & M.E. Lewis	Botta's Clarkia	Hundreds	Patchy
ONAGRACEAE	Epilobium ciliatum Raf.	Fringed Willowherb	Thousands	Patchy
PAPAVERACEAE	**Eschscholzia californica Cham.**	**California Poppy**	**Hundreds**	**Patchy**
	Alien Perennial Forbs			
APIACEAE	Conium maculatum L.	Poison Hemlock	Myriads	Patchy
BRASSICACEAE	Hirschfeldia incana (L.) Lagrèze-Fossat	Summer Mustard	Hundreds	Patchy
	Alien Annual Legume Forbs			
FABACEAE	Melilotus indicus (L.) All.	Annual Yellow Sweetclover	Myriads	Patchy
	Alien Annual Non-Legume Forbs			
ASTERACEAE	Carduus pycnocephalus L.	Italian Plumeless Thistle	Thousands	Patchy
ASTERACEAE	Centaurea solstitialis L.	Yellow Star-thistle	Hundreds	Patchy
ASTERACEAE	Onopordum acanthium L.	Scotch Cotton Thistle	Hundreds	Patchy
ASTERACEAE	Silybum marianum (L.) Gaertn.	Milkthistle	Hundreds	Patchy
BRASSICACEAE	Brassica nigra (L.) W.D.J. Koch	Black Mustard	Millions	Patchy

TABLE 1. (Cont.)

Family	Name Scientific	Name English	Density	Dispersion
	Native Perennial Monocot Herbs			
TYPHACEAE	Typha sp. (vegetative)	Cattail	Tens	Patchy
	Native Perennial Grasses			
POACEAE	**Bromus carinatus Hook. et Arn.**	**California Brome**	**Hundreds**	**Patchy**
POACEAE	Elymus elymoides (Raf.) Swezey [Elymus multisetus M.E. Jones]	Bottlebrush Squirreltail	Tens	Patchy
POACEAE	Elymus glaucus Buckley ssp. glaucus	Blue Wild Rye	Hundreds	Patchy
POACEAE	**Hordeum brachyantherum Nevski**	**Meadow Barley**	**None Observed**	**None Observed**
POACEAE	Hordeum californicum Covas et Stebbins	California Barley	Few	Patchy
POACEAE	Koeleria macrantha (Ledeb.) J.A.Schultes	Junegrass	Few	Patchy
POACEAE	Leymus condensatus (J.Presl) A.Löve	Giant Wildrye	Few	Patchy
POACEAE	**Melica californica Scribn.**	**California Melic**	**Hundreds**	**Patchy**
POACEAE	Melica imperfecta Trin.	Coast Range Melic	Tens	Patchy
POACEAE	Nassella cernua (Stebbins & R.M. Love) Barkworth	Nodding Needlegrass	Hundreds	Patchy
POACEAE	Nassella lepida (A.S.Hitchc.) Barkworth	Foothill Needlegrass	Tens	Patchy
POACEAE	**Nassella pulchra (A.S. Hitchc.) Barkworth**	**Purple Needlegrass**	**Myriads**	**Patchy**
POACEAE	Poa scabrella (Thurb.) Benth. ex Vasey	Pine Bluegrass	Few	Patchy
	Native Annual Grasses			
POACEAE	Vulpia microstachys (Nutt.) Munro	Small Fescue	Myriads	Patchy
	Alien Perennial Grasses			
POACEAE	Achnatherum miliaceum (L.) Beauv.	Smilo	Hundreds	Patchy
POACEAE	Bromus catharticus Vahl	Rescue Grass	Hundreds	Patchy
POACEAE	Dactylis glomerata L.	Orchardgrass	Thousands	Patchy
POACEAE	Festuca arundinacea Schreb.	Tall Fescue	Hundreds	Patchy
POACEAE	Lolium perenne L.	Perennial Ryegrass	Hundreds	Patchy
POACEAE	Pennisetum setaceum (Forsk.) Chiov.	Fountain Grass	Hundreds	Patchy
POACEAE	Pennisetum villosum R.Br. ex Fresen	Feathertop	Hundreds	Patchy
POACEAE	Phalaris aquatica L.	Harding Grass	Hundreds	Patchy
POACEAE	Polypogon monspeliensis (L.) Desf.	Rabbitsfoot Grass	Hundreds	Patchy
POACEAE	Polypogon viridis (Gouan) Breistr.	Water Bent Grass	Thousands	Patchy
	Alien Annual Grasses			
POACEAE	Avena barbata Pott ex Link	Slender Wild Oat	Thousands	Patchy
POACEAE	Avena fatua L.	Common Wild Oat	Myriads	Patchy
POACEAE	Brachypodium distachyon (L.) Beauv.	Annual False Brome	Thousands	Patchy
POACEAE	Bromus diandrus Roth	Ripgut	Thousands	Patchy
POACEAE	Bromus hordeaceus L. [Bromus mollis L.]	Soft Chess	Myriads	Patchy
POACEAE	Bromus madritensis L.	Spanish Brome	Hundreds	Patchy
POACEAE	Bromus rubens L.	Red Brome	Millions	Even
POACEAE	Hordeum glaucum Steud.	Glaucous Barley	Tens	Patchy
POACEAE	Hordeum leporinum Link	Hare Barley	Thousands	Patchy
POACEAE	Hordeum vulgare L.	Cereal Barley	Few	Patchy
POACEAE	Lamarckia aurea (L.) Moench	Goldentop Grass	Few	Patchy
POACEAE	Lolium multiflorum Lam.	Annual Ryegrass	Millions	Patchy
POACEAE	Poa annua L.	Annual Bluegrass	Thousands	Patchy
POACEAE	Secale cereale L.	Cereal Rye	Tens	Patchy
POACEAE	Triticum aestivum L.	Common Wheat	Tens	Patchy
POACEAE	Vulpia myuros (L.) K.C. Gmel.	Rattail Fescue	Millions	Patchy

TABLE 2. Conspicuous Plants of Cuesta Grade Right-of-Way: Abundance and Lifeform.

Shading indicates specification as part of seed mix.

Provenance	Duration	Legume	Lifeform	Name Scientific	Name English	Density	Dispersion
Alien	Annual	No	Forb	Brassica nigra (L.) W.D.J. Koch	Black Mustard	Millions	Patchy
Alien	Annual	No	TrueGrass	Bromus rubens L.	Red Brome	Millions	Even
Alien	Annual	No	TrueGrass	Lolium multiflorum Lam.	Annual Ryegrass	Millions	Patchy
Alien	Annual	No	TrueGrass	Vulpia myuros (L.) K.C. Gmel.	Rattail Fescue	Millions	Patchy
Native	**Perennial**	**No**	**Shrub**	**Artemisia californica Less.**	**California Sagebrush**	**Myriads**	**Patchy**
Alien	Perennial	No	Forb	Conium maculatum L.	Poison Hemlock	Myriads	Patchy
Alien	Annual	Yes	Forb	Melilotus indicus (L.) All.	Annual Yellow Sweetclover	Myriads	Patchy
Alien	Annual	No	TrueGrass	Avena fatua L.	Common Wild Oat	Myriads	Patchy
Alien	Annual	No	TrueGrass	Bromus hordeaceus L. [Bromus mollis L.]	Soft Chess	Myriads	Patchy
Native	**Perennial**	**No**	**TrueGrass**	**Nassella pulchra (A.S. Hitchc.) Barkworth**	**Purple Needlegrass**	**Myriads**	**Patchy**
Native	Annual	No	TrueGrass	Vulpia microstachys (Nutt.) Munro	Small Fescue	Myriads	Patchy
Native	**Perennial**	**No**	**Shrub**	**Baccharis pilularis DC.**	**Coyote Brush**	**Thousands**	**Patchy**
Native	**Perennial**	**No**	**Shrub**	**Eriogonum fasciculatum Benth.**	**California Buckwheat**	**Thousands**	**Patchy**
Native	**Perennial**	**No**	**Shrub**	**Eriophyllum confertiflorum (DC.) Gray**	**Golden Yarrow**	**Thousands**	**Patchy**
Native	Perennial	Yes	Shrub	Lotus scoparius (Nutt.) Ottley	Common Deer Lotus	Thousands	Patchy
Native	**Perennial**	**No**	**Shrub**	**Mimulus aurantiacus W.Curtis**	**Bush Monkeyflower**	**Thousands**	**Patchy**
Native	**Perennial**	**No**	**Shrub**	**Salvia mellifera Greene**	**Black Sage**	**Thousands**	**Patchy**
Alien	Annual	No	Forb	Carduus pycnocephalus L.	Italian Plumeless Thistle	Thousands	Patchy
Native	Annual	No	Forb	Epilobium ciliatum Raf.	Fringed Willowherb	Thousands	Patchy
Alien	Annual	No	TrueGrass	Avena barbata Pott ex Link	Slender Wild Oat	Thousands	Patchy
Alien	Annual	No	TrueGrass	Brachypodium distachyon (L.) Beauv.	Annual False Brome	Thousands	Patchy
Alien	Annual	No	TrueGrass	Bromus diandrus Roth	Ripgut	Thousands	Patchy
Alien	Perennial	No	TrueGrass	Dactylis glomerata L.	Orchardgrass	Thousands	Patchy
Alien	Annual	No	TrueGrass	Hordeum leporinum Link	Hare Barley	Thousands	Patchy
Alien	Annual	No	TrueGrass	Poa annua L.	Annual Bluegrass	Thousands	Patchy
Alien	Perennial	No	TrueGrass	Polypogon viridis (Gouan) Breistr.	Water Bent Grass	Thousands	Patchy
Native	**Perennial**	**Yes**	**Shrub**	**Lupinus albifrons Benth. ex Lindl.**	**Silver Bush Lupine**	**Hundreds**	**Patchy**
Native	Perennial	No	Shrub	Salvia apiana Jepson	White Sage	Hundreds	Patchy
Native	Perennial	No	Shrub	Toxicodendron diversilobum (Torr. & Gray) Greene	Poison Oak	Hundreds	Patchy
Alien	Annual	No	Forb	Centaurea solstitialis L.	Yellow Star-thistle	Hundreds	Patchy
Native	Annual	No	Forb	Clarkia bottae (Spach) H.F. & M.E. Lewis	Botta's Clarkia	Hundreds	Patchy
Native	Perennial	No	Forb	Eriogonum vimineum Dougl. ex Benth.	Wickerstem Buckwheat	Hundreds	Patchy
Alien	Annual	No	Forb	Erodium botrys (Cav.) Bertol.	Longbeak Stork's Bill	Hundreds	Patchy
Native	**Annual**	**No**	**Forb**	**Eschscholzia californica Cham.**	**California Poppy**	**Hundreds**	**Patchy**
Alien	Annual	No	Forb	Hirschfeldia incana (L.) Lagrèze-Fossat	Summer Mustard	Hundreds	Patchy
Alien	Annual	No	Forb	Onopordum acanthium L.	Scotch Cotton Thistle	Hundreds	Patchy
Alien	Annual	No	Forb	Silybum marianum (L.) Gaertn.	Milkthistle	Hundreds	Patchy
Native	Perennial	No	Forb	Verbena lasiostachys Link	Western Vervain	Hundreds	Patchy
Alien	Perennial	No	TrueGrass	Achnatherum miliaceum (L.) Beauv.	Smilo	Hundreds	Patchy
Native	**Perennial**	**No**	**TrueGrass**	**Bromus carinatus Hook. et Arn.**	**California Brome**	**Hundreds**	**Patchy**
Alien	Perennial	No	TrueGrass	Bromus catharticus Vahl	Rescue Grass	Hundreds	Patchy
Alien	Annual	No	TrueGrass	Bromus madritensis L.	Spanish Brome	Hundreds	Patchy
Native	Perennial	No	TrueGrass	Elymus glaucus Buckley ssp. glaucus	Blue Wild Rye	Hundreds	Patchy
Alien	Perennial	No	TrueGrass	Festuca arundinacea Schreb.	Tall Fescue	Hundreds	Patchy
Alien	Perennial	No	TrueGrass	Lolium perenne L.	Perennial Ryegrass	Hundreds	Patchy
Native	**Perennial**	**No**	**TrueGrass**	**Melica californica Scribn.**	**California Melic**	**Hundreds**	**Patchy**
Native	Perennial	No	TrueGrass	Nassella cernua (Stebbins & R.M. Love) Barkworth	Nodding Needlegrass	Hundreds	Patchy
Alien	Perennial	No	TrueGrass	Pennisetum setaceum (Forsk.) Chiov.	Fountain Grass	Hundreds	Patchy
Alien	Perennial	No	TrueGrass	Phalaris aquatica L.	Harding Grass	Hundreds	Patchy
Alien	Perennial	No	TrueGrass	Polypogon monspeliensis (L.) Desf.	Rabbitsfoot Grass	Hundreds	Patchy

TABLE 2. (Cont.)

Provenance	Duration	Legume	Lifeform	Name Scientific	Name English	Density	Dispersion
Native	Perennial	No	Tree	Quercus agrifolia Née	California Live Oak	Tens	Patchy
Native	Perennial	No	Shrub	Calystegia macrostegia (Greene) Brummitt	Common Bindweed	Tens	Patchy
Native	Perennial	No	Forb	Eriogonum elongatum Benth.	Longstem Buckwheat	Tens	Patchy
Native	Annual	Yes	Forb	Lupinus nanus Dougl. ex Benth.	Sky Lupine	Tens	Patchy
Native	Perennial	No	MonocotHerb	Typha sp. (vegetative)	Cattail	Tens	Patchy
Native	Perennial	No	TrueGrass	Elymus elymoides (Raf.) Swezey [E. multisetus M.E. Jones]	Bottlebrush Squirreltail	Tens	Patchy
Alien	Annual	No	TrueGrass	Hordeum glaucum Steud.	Glaucous Barley	Tens	Patchy
Native	Perennial	No	TrueGrass	Melica imperfecta Trin.	Coast Range Melic	Tens	Patchy
Native	Perennial	No	TrueGrass	Nassella lepida (A.S.Hitchc.) Barkworth	Foothill Needlegrass	Tens	Patchy
Alien	Annual	No	TrueGrass	Secale cereale L.	Cereal Rye	Tens	Patchy
Alien	Annual	No	TrueGrass	Triticum aestivum L.	Common Wheat	Tens	Patchy
Native	Perennial	No	Tree	Platanus racemosa Nutt.	California Sycamore	Few	Patchy
Native	Perennial	No	Shrub	Ceanothus cuneatus (Hook.) Nutt.	Buckbrush	Few	Patchy
Native	Perennial	No	Shrub	Prunus ilicifolia (Nutt. ex Hook. et Arn.) D.Dietr.	Holly-leaved Cherry	Few	Patchy
Native	Perennial	No	Shrub	Quercus durata Jepson	Leather Oak	Few	Patchy
Native	Perennial	No	Shrub	Rhamnus californica Eschsch.	California Coffeeberry	Few	Patchy
Native	Perennial	No	Shrub	Rhamnus crocea Nutt.	Redberry	Few	Patchy
Native	Perennial	No	Shrub	Salix lasiolepis Benth.	Arroyo Willow	Few	Patchy
Native	Perennial	No	Forb	Achillea millefolium L.	Common Yarow	Few	Patchy
Native	Annual	No	Forb	Layia platyglossa (Fisch. & C.A. Mey.) Gray	Tidy Tips	Few	Patchy
Native	**Annual**	**Yes**	**Forb**	**Lotus purshianus F.E. & E.G. Clem.**	**Spanish Lotus**	**Few**	**Patchy**
Native	Perennial	No	TrueGrass	Hordeum californicum Covas et Stebbins	California Barley	Few	Patchy
Alien	Annual	No	TrueGrass	Hordeum vulgare L.	Cereal Barley	Few	Patchy
Native	Perennial	No	TrueGrass	Koeleria macrantha (Ledeb.) J.A.Schultes	Junegrass	Few	Patchy
Alien	Annual	No	TrueGrass	Lamarckia aurea (L.) Moench	Goldentop Grass	Few	Patchy
Native	Perennial	No	TrueGrass	Leymus condensatus (J.Presl) A.Löve	Giant Wildrye	Few	Patchy
Alien	Perennial	No	TrueGrass	Pennisetum villosum R.Br. ex Fresen.	Feathertop	Few	Patchy
Native	Perennial	No	TrueGrass	Poa scabrella (Thurb.) Benth. ex Vasey	Pine Bluegrass	Few	Patchy
Native	**Perennial**	**No**	**TrueGrass**	**Hordeum brachyantherum Nevski**	**Meadow Barley**	**None Observed**	**None Observed**

4.1 General Observations

Overall, post-construction revegetation within the right-of-way is progressing very well. Aside from the areas where geotechnical solutions are required to stabilize slopes where water continues to emerge from hillside seeps (**Figure 5**), the erosion control treatments have performed well. Vegetation establishment is generally excellent after only three or four years. Stratification of a shrub layer over forbs and grasses is developing well over much of the upper grade slopes on the northbound side. Canopy cover over most slopes appears to be about 70% or greater. Where grass cover has established well, cover is greater than 70% at the soil surface.

4.2 Causes for Success of Treatments

Direct attribution of cause for the remarkable vegetation establishment is not possible given the many interactions among weather, landform, soil, and biological variables. Speculations include the following:

- cut slopes had little or no seed bank—hence little or no competition for water between shrub seedlings and aggressive annuals;
- minimal fiber (500 kg/ha) used to merely carry seed—thus, seed of burial intolerant shrub species was not buried too deeply, as is often the case;
- rainfall during the establishment period has been mostly above the thirty-year average of 31.87 in (at Santa Margarita Booster), with 55.32 in (+23.45 in) during the 2004-2005 water year, and 34.16 (+2.29 in) during the 2005-2006 water year; since January 2002 at least 145 in of precipitation have been recorded (see **Figure 6**)
- winter temperatures during the establishment period were not extreme and cool temperatures extended well into late spring and early summer lessening water stress.

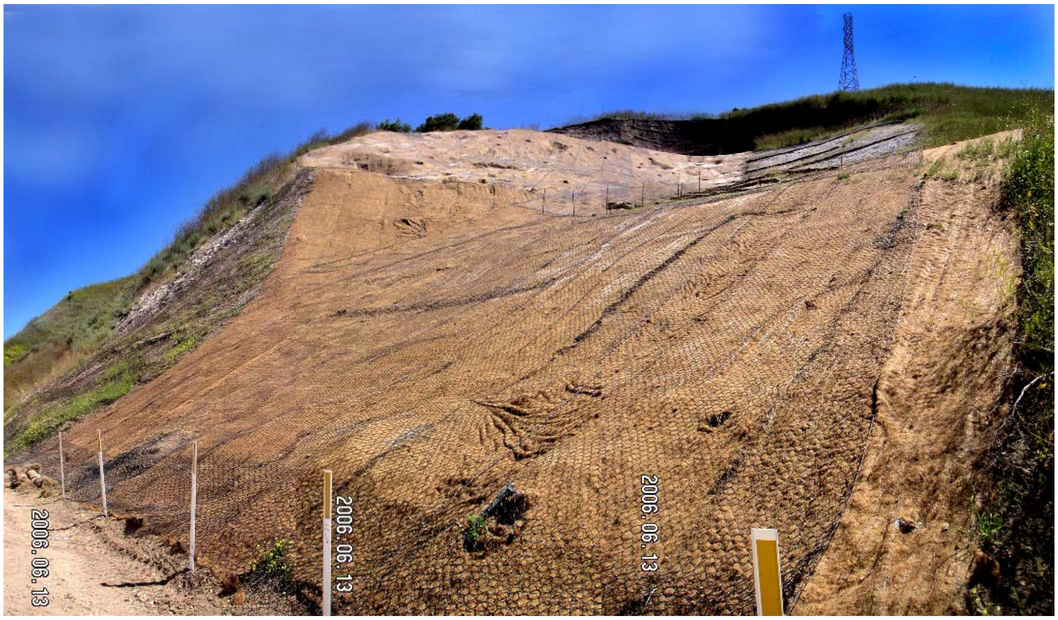

Figure 5. Slope Treatment Using Chain Link, Coconut Fiber, and Hand Broadcast of Seed. Treatment includes drain manifold to dewater a hillside seep.

Water Year	Months	Data Set	PPT (in)
1	Jan 02 - Jun 02	Incomplete	**5.36**
2	Jul 02 - Jun 03	Complete	**29.80**
3	Jul 03 - Jun 04	Complete	**20.08**
4	Jul 04 - Jun 05	Complete	**55.32**
5	Jul 05 - Jun 06	Complete	**34.16**
			144.72

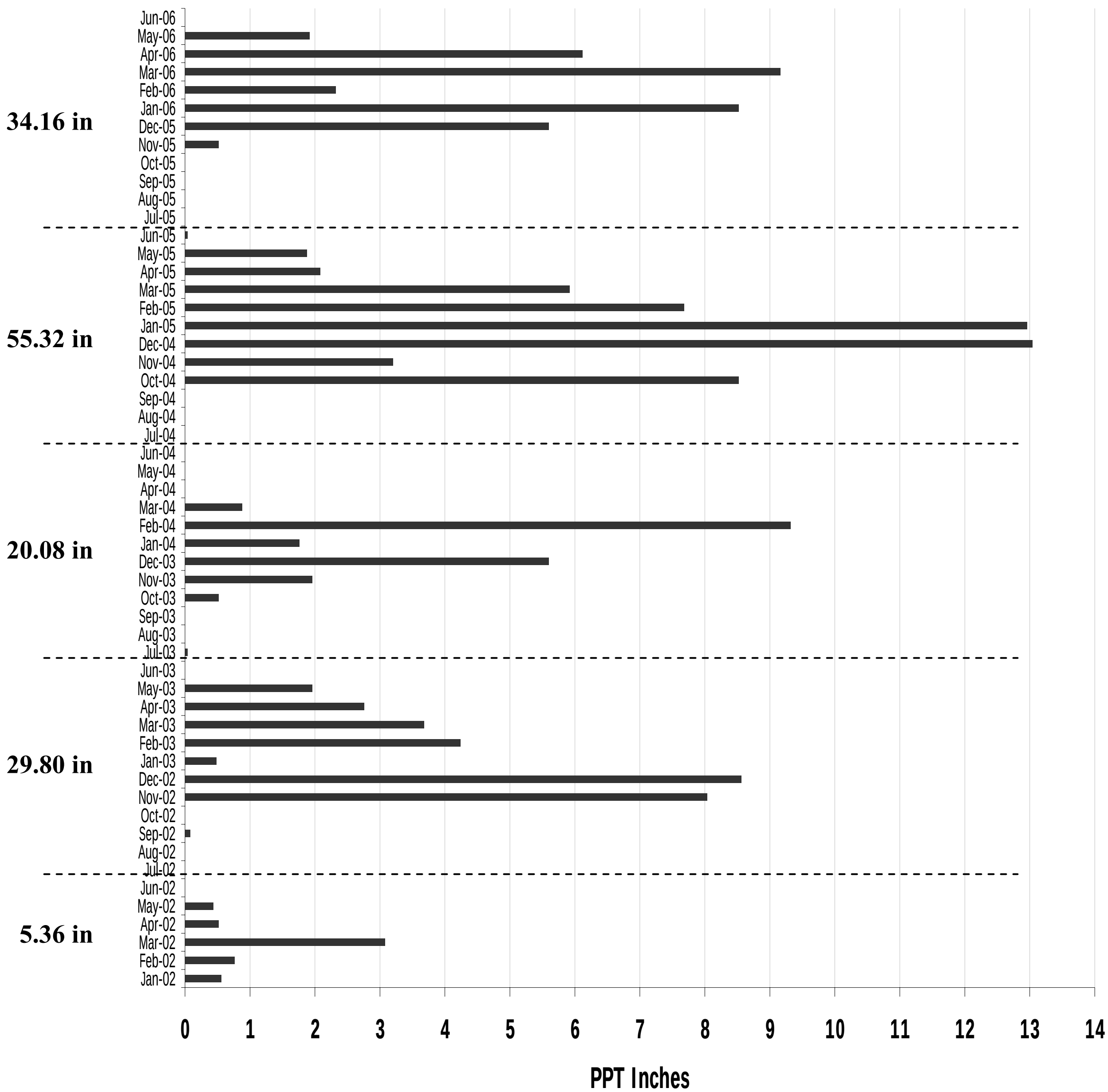

Figure 6. Precipitation Data from Santa Margarita Booster January 2002 to June 2006.
Station is about 1.5 miles NNW of Cuesta Pass near 35°22′N, 120°38′W, 1200 ft.

4.2.1 Shrubs

Shrub establishment far exceeds expectations based on recent seedings in District 5. The numbers of individuals and cover exhibited by California Sagebrush (*Artemisia californica* Less.), Coastal California Buckwheat (*Eriogonum fasciculatum* Benth.), Common Deer Lotus (*Lotus scoparius* (Nutt.) Ottley), Golden Yarrow (*Eriophyllum confertiflorum* (DC.) Gray), Bush Monkeyflower (*Mimulus aurantiacus* W.Curtis), Black Sage (*Salvia mellifera* Greene), and Coyote Brush (*Baccharis pilularis* DC.) is very impressive with thousands of shrubs now become visually obvious over most slopes especially along the higher northbound side (see **Figure 7** for a typical view).

Three issues are notable with regard to shrubs now on Cuesta Grade.

1. The amount of Common Deer Lotus (*Lotus scoparius*) and paucity of the specified annual Spanish Lotus (*Lotus purshianus*) suggests that perhaps Common Deer Lotus was a substitution for Spanish Lotus in the seed mix.

2. The presence of numerous White Sage (*Salvia apiana*) shrubs (**Figures 14** and **15**), a species not specified in the seed mix, nor known previously from Cuesta Grade, suggests that White Sage was a partial substitution for some portion of the quantity of Black Sage in the seed mix, or was an addition by the contractor. According to floristic resources (Consortium of California Herbaria Website 2006; Hickman 1993; Hoover 1970; Matthews 1997) the native range of White Sage does not extend north of the Cuyama River. The species is not especially tolerant of temperatures below 10F, so it remains to be seen whether these shrubs will persist through the next arctic air event.

3. The presence of scattered individual Bush Monkeyflower (*Mimulus aurantiacus*) with very red-orange corollas suggest that these are from seed collected in San Diego County where Bush Monkeyflower exhibits a color range from buff yellow to red-orange to deep red, sometimes on the same shrub. The deep red plants have been treated as a separate species, Red Bush Monkeyflower (*Mimulus puniceus*). Bush Monkeyflower of south coastal San Luis Obispo County is remarkably uniformly yellow-orange with no shade of red. Thus, it seems that some Southern California seed of Bush Monkeyflower was applied. Much like White Sage, Red Bush Monkeyflower is not tolerant of temperatures below 10F, so it also remains to be seen whether these shrubs will persist through the next arctic air event.

4.2.1 Native Grasses

Also impressive are the dense stands (1-3 plants per ft^2) of Purple Needlegrass (*Stipa/Nassella pulchra*) that apparently established from hydroseedings along both the northbound and southbound slopes (see **Figures 9** and **13**). Some Native Nodding Needlegrass (*Stipa/Nassella cernua*) is present with the Purple Needlegrass on the northbound slopes established either from hydroseedings as a substitution or “contaminant”, or from seed rain downslope of existing stands higher on Cuesta Grade.

As an understory to Needlegrass, or in separate patches, are dense stands of native Small Fescue (*Festuca/Vulpia microstachys* complex including *Festuca/Vulpia pacifica* and *Festuca/Vulpia reflexa*). The species was not specified in the basic seed mix, but the amount and density present suggests either an addition to the mix, or a substitution for Meadow Barley (*Hordeum brachyantherum*), a species not observed on Cuesta Grade, nor likely to grow in any but the wettest drainages.

Grasses had a difficult time establishing through the BFM applications, with few plants per ft^2 (**Figures 16** and **17**), but this is typical for BFM as it is intended primarily as a temporary physical erosion control blanket.

Figure 7. California Sagebrush – Coyote Brush / Fountain Grass – Wild Oat.

Figure 8. Planted Coast Live Oak / Coyote Brush – Black Sage.

Figure 9. Dense stand of Purple Needlegrass among planted shrubs.

Figure 10. Planted Coast Live Oak in wire cage.

Figure 11. Established Coastal California Buckwheat and White Sage.

Figure 12. California Sagebrush – Bush Monkeyflower - Coastal California Buckwheat – White Sage / Black Mustard.

Figure 13. Revegetated Fill Slope on Southbound Side Near 330 meter Elevation.

Figure 14. White Sage (*Salvia apiana* Jepson) now on Cuesta Grade.

Figure 15. White Sage (*Salvia apiana* Jepson) at Gaviota.

Figure 16. BFM with fiber rolls.

Figure 17. BFM with sparse annuals.

5. Conclusions

The general success of native shrub establishment on Cuesta Grade is notable and encouraging for future attempts to establish these native shrubs from seed. The specifications for native grass straw and minimal fiber seemed to work well and could be repeated elsewhere in District 5 on similar cut slopes where minimal or no seedbank of weedy annuals is present. Given minimal burial and adequate water these common native shrubs can germinate and establish in abundance.

Continued monitoring of the ongoing revegetation of Cuesta Grade would provide more information about longer term succession as the shrubs grow in height and width to shade out many of the weedy forbs and annual grasses present among them now. As shrub stands increase in aerial cover over the next five years, the Cuesta Grade will begin to appear much as it did before the latest construction.

6. References

Caltrans. 2003. Guidance for Temporary Soil Stabilization. Technical Report. Sacramento: State of California, Department of Transportation (Caltrans).

Consortium of California Herbaria Website (CHSC, DAV, IRVC, JEPS, RSA-POM, SBBG, SJSU, UC, UCR, UCSB, UCSC). Accessed 13 June 2006. http://ucjeps.berkeley.edu/consortium/

Hickman, JC. (ed.) 1993. *The Jepson Manual: Higher Plants of California*. Berkeley, CA: University of California Press.

Hoover, RF. 1970. *The Vascular Plants of San Luis Obispo County, California*. Berkeley: University of California Press.

Matthews, MA. 1997. *An Illustrated Field Key to the Flowering Plants of Monterey County: and Ferns, Fern Allies, and Conifers*. Sacramento: California Native Plant Society.

Appendix A: Erosion Control Specifications

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APPENDIX H.5

A REVIEW OF SOIL RESOURCE EVALUATION

Contract 43A0167 | Expert Assistance Task Area

A Review of

Soil Resource Evaluation

A Stepwise Process for Regeneration and Revegetation of Drastically Disturbed Soils

edited by V. Claassen

CTSW-RT-05-073.20.1 (Final Report)

Prepared For

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION

May 2006

Contents

1.0 Introduction

1.1 Objective

By request, this review of "Soil Resource Evaluation: A Stepwise Process for Regeneration and Revegetation of Drastically Disturbed Soils", CTSW-RT-05-073.20.1 (Final Report), edited by V. Claassen, was prepared under the Expert Assistance Task Area of the Roadside Erosion Control & Maintenance Study in progress through the Earth and Soil Sciences Department at Cal Poly State University, San Luis Obispo, under contract with the CSU Office of Water Programs at Sacramento State University, and Caltrans Division of Design.

The general objectives of this editorial peer review are:

- To evaluate form, style, and content of the final document and website;
- To evaluate whether the document functions as a training manual for Caltrans Landscape Architects.

1.2 Format of This Review

Comments are listed under major headings relating to:

Format—Structure of the work, overall layout, sections, headings;

Style—Grammar, punctuation, spelling, reference citations;

Content—Substance, concepts, ideas, meaning, data, analysis.

2.0 Document Review

2.1 General Comments

2.1.1 Audience

Evaluation of the Soil Resource Evaluation (SRE) format is from the point-of-view of the identified audience: landscape architects and revegetation practitioners. These professionals have a diverse educational background and experience base. Most are very familiar with the general format of training manuals, technical writing, specifications, and web sites.

2.1.2 Format

The hardcopy report is merely a direct print of a rudimentary web site presently accessible through the Caltrans Landscape Architecture Program at http://www.dot.ca.gov/hq/LandArch/research/es_site_0522/index.html (accessed 16 May 2006).

The web site is divided into five exceedingly lengthy sections, mostly as long scrolls. Minimal use of basic navigational hyperlinks makes the site tedious for even the most-patient user. The web site needs a thorough redesign using the navigational aids, rollover menus, and popups that users have now come to expect in web sites.

As presently formatted, this text-dense version is cumbersome and redundant. Simplification of the presentation format would make it shorter and more direct.

The numbering system is not consistent throughout the document, making some comments difficult to reference.

2.1.3 Style

This document appears to be a very rough draft that does not meet quality standards for a Final Report, or for a Training Manual. Many pages were inserted twice. There appears to have been no proof-reading, editing, or spell-checking. Some Sections are incomplete. Many plant binomials are misspelled or formatted incorrectly (correct format is: genus name capitalized, specific epithet lower case; entire name italicized or underlined).

2.1.4 Content

The proposal of a systematic, data-acquisition approach to evaluation and remediation of substrates to support vegetation on roadsides is commendable. A step-wise evaluation of the limiting factors for plant growth on severely altered roadsides should substantially increase the successful establishment of vegetation cover.

Some problems with key elements of the Soil Evaluation Resource Expert System are discussed next.

2.0 Document Review

Reference Site Concept

Although the Soil Evaluation Resource Expert System is supposedly data driven and intends to offer target values for key soil properties necessary for successful revegetation, the System relies primarily on the long-standing concept of a "Reference Site" as a multifactorial surrogate for all of the unrecoverable historical data about the climate, weather extremes, geology, terrain, soils, biota, disturbance history, and ecological succession trajectories that produced any specific extant Reference Site. Both the Reference Site and the Revegetation Site have unique and unrecoverable site histories. The distance between these sites in space and time represents the Distance Decay of Similarity (aka Tobler's First Law of Geography; Tobler, WR. 1970. *Economic Geography* 46: 234-240). No single Reference Site can at present exhibit all of the synergistic site variation possible given the same set of components. Thus, the limitations of using Reference Sites should be explicitly presented, especially how *unmeasured* factors confound present interpretations of historical changes to any site.

White and Walker ("Approximating nature's variation: selecting and using reference information in restoration ecology", *Restoration Ecology* 5:338-349. 1997) discuss the limitations and difficulties with using the reference site system. Most notably, "…selecting and using reference information requires that we address a fundamental issue in ecology: understanding the nature, cause, and function of variation in ecosystems…". Achieving comparative levels of some substrate attributes will not necessarily sustain a specific "acceptable" vegetation assemblage.

The practical consequence of all this theory is that the Reference Site concept is not useful for Caltrans or any other revegetation practitioner as an engineered target because the Revegetation Site will have a new ecological succession trajectory initiated by the act of revegetation that will not match the Reference Site in the short-term, or ever. Instead, the use of **several** local Reference Sites as places to gather quantifiable data about soil properties may provide a more direct means to identify minimum threshold values for establishment of adequate context-dependent plant cover. Recommending the use of a Reference Site as a surrogate for minimum threshold soil property data is analogous to the NRCS or a local Farm Advisor suggesting to a farmer that he drive around and visit area farms until he finds one that looks similar to his own in order to see what crops he might grow on his farm. This scenario sounds ludicrous because many millions of research dollars have led to recommendations for augmenting soil nutrient levels to minimums required by specific crops grown under various field conditions.

2.0 Document Review

Two obvious Reference Site limitations not addressed are:

- **Absence of a Reference Site,** as evidenced by three of the four case studies where no comparable Reference Site was available. For Caltrans, presence of comparable Reference Sites is a function of a road traversing similar topography, geology, soils, vegetation, and historical landuse such that a number of slopes with the same combination of these site factors are present, and that one or more has revegetated with "acceptable" vegetation to satisfactory cover values.
- **Imported fill soils** that may have no similarity to local soils in soil properties, soil biota, or soil seed bank;

Soil Data Relative to Revegetation

Overall, the Soil Evaluation Resource Expert System lacks the data needed for Caltrans to design minimum threshold values into Standard Specifications. Many data values are lacking from the "Case Studies" altogether, or reported qualitatively as "sufficient", a descriptor with little meaning or analytical value.

Without data the Expert System distills to three steps for site remediation:

1) stabilize slope geotechnically,

2) add tons of compost,

3) plug-plant native grasses.

High-Cost System

The Soil Evaluation Resource Expert System is predominantly a geotechnical solution with a plant veneer. While geotechnical solutions to chronic erosion problems are necessary, they are also very expensive remedial solutions probably best designed into a construction project from the outset. After a long, steep slope of highly erosive soil is recontoured as terraces backfilled with copious compost, covered completely by coir, fitted with drains, buttressed by a gabion toe, and finally plug-planted with local native perennials, it is not surprising that vegetation cover is nearly complete after two years. Obviously, the expensive geotechnical work is the solution to such problem slopes, not the revegetation.

Because little or none of the field work proposed in the Expert System is executable by most Caltrans Landscape Architects, implementation requires the most costly approach to slope stabilization and revegetation available to Caltrans. Outside contractors would be needed to effect much of the work throughout the entire process.

2.0 Document Review

2.2 "Contents"

2.2.1 Format

Should stand alone on one page

2.2.2 Style

- Should number entries for ease of locating parts within color-coded sections;
- Color-coding was completely misapplied in this review copy;
- Tab dividers should be used to better discriminate sections.

2.2.3 Content

- Rudimentary, not enough detail for a manual;
- Each color-coded section should list additional detail.

2.0 Document Review

2.3 "Soil Resource Evaluation: Expert System"

'Yellow Section' (Pink in this copy)

2.3.1 Format

Versions of the "Expert System"
The three versions addressing the same list of factors, but with increasing detail, could be reduced to two.

The first version could function, not as a key, but as a one page, annotated checklist of factors to evaluate as a synopsis of the objectives and overall systematic process. The present multi-page format causes the user to wander off-track with too many details wrapped into each step.

The second version could incorporate a multiple column or box format, rather than a key. The key is implicit as one works through the logical series of factors to evaluate. Factors, evaluation test, and remediation procedures that are now co-mingled in places, and somewhat confounded, should be visibly segregated. Smaller discrete units are much easier to assimilate than long detailed text. The applied aspects should be visually separated more effectively from the background educational discourse. Only one factor should be considered per page, so there should be ample room to provide sidebar explanatory information or hyperlinks that pertain to each factor.

Procedural Testing Details
Remove procedural testing details from the evaluation column and substitute the precise name of the commercial test that is required. Most landscape architects and revegetation practitioners would outsource this to a qualified laboratory. Use a sidebar to explain the test or consolidate test details into an Appendix. Provide an Appendix that summaries the quantifiable range of test results that would qualify as deficient, adequate, or optimal for specific biogeographical and soil contexts.

Reference Site
Using the Vegetation Reference Site as the first couplet in the key Section I, p. 2/29 is confusing after stating that only soil and substrate factors will be evaluated. The Reference Site premise and objectives are not explained until Section III, p. 7/29-8/29. If the entire system is based on a Reference Site, then this explanation needs to be explicitly detailed up front.

2.0 Document Review

2.3.2 Style

There are a number of placeholders, indicated as X, XX, XXX, that require replacement with numerical values or plant names:

p. 8/29-9/29, 1.1.0.

p. 14/29 3.1.6.

p. 20/29 4.1.3.

p. 23/29, 5.1.3., 5.2.1.

p. 24/29, 5.2.2., 5.2.4.

Documentation missing:

p. 17/29, 3.2.1.	"from literature values" without citation;
p. 21/29, 4.2.3.	"literature values from around the world" without citation

Citations incomplete:

p. 4/29, 8.	Calflora.org not listed in bibliography, Native Grass database not listed in bibliography;
p. 20/29, 4.1.3.	Munshower- *s.d.*;
p. 21/29, 4.2.1.	Claassen 1998- either this is missing from the bibliography or it should read (Claassen and Hogan 1998) which is in the bibliography;
p. 28/29	Bibliography: Claassen & Hogan 2002 missing Journal Volume and page number;

NADP 2004 missing website address;

Rusmore 2004 missing title, university name, location;

Bibliographic citations which do not appear in the Expert System text:

Hemsath & Mazurak 1974

Kelsey 1978

Sidle et al 1985

Varnes 1981

Typographical errors created by printing a hard copy from html format:

p. 25/29, Step 6, Objectives

p. 26/29, 6.1.2., Response

Grammatically awkward sentences:
There are many sentences that would read better as short, bulleted phrases.

2.0 Document Review

2.3.3 Content

The soil factors listed for evaluation and remediation comprise the standard attributes required for sustainable plant growth. The attributes identified are not consistently the ones evaluated in the case studies, so there is a disconnect somewhere. Guidance as to the threshold and optimal values for the factors of Soil Organic Matter, N, C, and other nutrients are not well documented or presented.

p. 7/29-8/29 Reference Site Concept (p. 5/72-6/72 in Soils Course Section): While the concept of the Reference Site is generally used, it is presented here as though this is a quick and easy selection process without any limitations. (see this report **General Comments 2.2.3 Content**)

p. 8/29, 1.1.0 "acceptable vs. unacceptable" vegetation community: This is a site-specific, context-dependent, and purpose-dependent concept with little generality. The terms "acceptable" and "unacceptable" are not defined here.

p. 8/29, 1.1.0 "Plant Types": This classification system does not conform to any standard. It has confounded provenance, life form, longevity, physiology, etc., and is error-ridden, e.g., Turkey Mullein is a native forb, not an "exotic" forb. On p. 8/29, 1.1.0 (Expert System), these lists are exactly the same for two very different ecoregions, Central Valley/Coast Range versus Sierra/East side. On p. 6-7/72, 1.1.0 (Soils Course), the lists are different and the list for the Great Basin/Mojave Desert is lacking any examples in either category of acceptable or unacceptable.

p. 9/29: "Because of lack of fire, many grasslands are currently dominated by annuals even though rooting depths are great enough to support perennials" No documentation provided; the statement is simply not supportable by data.

p. 9/29, 3.2.1: Documentation lacking for literature values provided for plant summer water needs; these values cannot possibly address all species in all ecoregions of the state. Define exactly which geographic ecoregions of the state these values pertain to. Each ecoregion should have its own set of values.

p. 25/29, 6.0: "What is critically important is providing habitat and substrate for microbes"; this is never evaluated; need to assay soil microbial activity rather than VAM.

p. 26/29, 6.1.3: checking for N_2 fixation by examining roots for nodules can be misleading; it only confirms nodulation, but there may be a complete lack of N_2 fixation occurring.

p.27/29: "Plant growth of native species is slow for first several seasons" - no documentation; not a universal, should be strongly qualified or, better yet,

2.0 Document Review

deleted; clearly not the case for rapidly growing native perennial grasses such as California Brome (*Bromus carinatus* complex), Blue Wild Rye (*Elymus glaucus* complex), and many other native perennials. Native annuals are not mentioned at all, despite the importance of native annual in the arid ecoregions.

2.4 "Soil Resource Evaluation: Soils Course"

'Green Section' (Yellow in this copy)

2.4.1 Format

This section is misnamed as a "Soils Course". The section starts out with material taken from a general soils course, but quickly becomes an explanation of the field procedures for the soil and vegetation evaluation steps of the Expert System. This section should be renamed to reflect the nature of its reference function.

Too text dense; reorganize and reformat presentation.
Could be an effective support tool for the Expert System, if reconfigured to be more readable.

Translations of data or information into application or actionable remediation procedures are buried within the text. These very procedural adaptations need reformatting to make each clearly evident. A summary tabular compilation should be provided.

p. 4/72: "Target levels for sufficiency are suggested"; **these are the MOST IMPORTANT part of the entire document and it is CRITICAL that they be compiled into tables provided in the appropriate parts of the Expert System Section.** The data are obfuscated in text. Trying to extract them from text is very time consuming.

2.4.2 Style

Contains the same error categories of omission and commission as in the Expert System section:

Placeholders, indicated as X, XX, XXX, that require replacement:

p. 6/72, 1.1.0.	the Central Valley/Coast Range list
p. 23/72, 2.1.0.	post mile replacement cue
p. 50/72, 3.2.0.	(previous numerical value; this section needs value)-km/hr
p. 54/72, 4.1.0.	"Approximately **xx** % of the soil organic carbon in a natural soil is thought to be decomposable (Stevenson, 19**xx**). In a rough calculation, this would be comparable to **xx** kg/ha compost per year, but the decomposition rate of the finer and coarser fragments would have to be accounted for."

2.0 Document Review

Documentation missing:

p. 11/72, 1.5.0.7. Reference to Appendix 7 (345-350) that is not provided in this document; if not provided, it is unlikely that landscape architects will access it. This manual should be complete and stand alone with necessary supplements.

p. 47/72, 3.2.0. Plant Water Use Targets: no documentation or citation beyond "literature values"

p. 61/72, 4.2.0. (scn7)- "These data are from a Caltrans state wide survey . . ." without citation

Bibliographic Citations incomplete:

Curtis et al. 2004.

Citations omitted from the Bibliography:

Belnap, J. at www.soilcrust.org
Belnap and Furman 1997.
Brandt and Hendrickson. 1991.
Calflora website
Caltrans Native Grass Data Base CD.
Christensen 1996.
Claassen and Hogan 2002.
Elzinga et al. 1998.
Hingston 1982.
Integrated Fertility Management 1995.
Jackson et al. 1988.
Jastro and Miller *s.d.*
Moldenke et al. 1994.
Morrison et al. 1995.
Newton and Claassen 1989.
NRCS 2001b.
NRCS 1997.
Perry and Amaranthus 1990.
Redente 1993.
Rodale 1961.
Sidle et al. 1985.
Stevenson 19xx.
Tietjen and Hart 1969.
Tisdall and Oades *s.d.*
Trappe 1977.
Water and Oades *s.d.*
Zasoski, pers. comm.

2.0 Document Review

Typographical errors;

p. 49/72, 3.2.0. (previous numerical value; this section needs value)- (xxxcopy to ES)

p. 70/72 (SRE step 6)- (scbiocrust)

Grammatically awkward sentences:
There are many sentences that would read better as short, bulleted phrases.

2.4.3 Content

As stated above under format, this section is misnamed as a "Soils Course" because the content is the field procedures for the soil and vegetation evaluation steps of the Expert System.

Good discussion of the physicochemical properties of soil.
Good discussion and graphics of geotechnical remediation.
Good discussion about expediting nutrient cycling processes as the goal of substrate remediation.

Delete as much tangential content as possible without compromising the integrity of the reference information provided, e.g., history of soil science . The soils course section is very long.

p. 4/72 "Target levels for sufficiency are suggested": these are the MOST IMPORTANT part of the entire document and it is CRITICAL that they be compiled into tables provided in the Expert System Section.

p. 7/72: "Because of lack of fire, many grasslands are currently dominated by annuals even though rooting depths are great enough to support perennials"- see Expert System Section.

p. 9/72, 1.4.0. **Site History:** The point is well taken, but where are the data upon which to make a decision? If this is the support or reference part of the document, this should be where the data are presented or a compilation of the data can be easily accessed.

p. 10/72, 1.5.0. Plant cover and diversity monitoring: The methods described here are far more complex than necessary. **These are methods for assessing changes in cover and composition over time at the same sample site.** *What is the purpose of gathering these detailed vegetation cover and composition data for a Reference Site when values at the Revegetation Site will not be comparable for many years, if ever?*

p. 47/72, 3.2.0: Documentation lacking for literature values provided for plant summer water needs; these values cannot possibly address all species in all

2.0 Document Review

ecoregions of the state. Define exactly which geographic ecoregions of the state these values pertain to. Each ecoregion should have its own set of values. How are summer dormant taxa being identified? Are these values to establish or sustain established vegetation?

p.69/72, Step 6, Soil Biology: checking for N_2 fixation by examining roots for nodules can be misleading; it only confirms nodulation, but there may be a complete lack of N_2 fixation occurring.

p. 71/72, Step 8, Site Appropriate Plant Materials: "This additional section is included to provide information on soil and plant interactions." This section is all but nonexistent; it consists of three sentences, all of questionable validity and all undocumented.

2.5 "Soil Resource Evaluation: Case Studies"

'Gold Section' (Lilac in this copy)

2.5.1 Format

A "case study" is a **qualitative,** spatiotemporally and context-dependent description of a particular individual, event, or process that by definition has no general application as a larger theory or practice (for a detailed discussion see http://writing.colostate.edu/guides/research/casestudy/)

While the details of the four project "case studies" may be interesting, two major problems exist with this approach:

1) Each case is unique; no general specifications are made from them;

2) Each case did not consistently employ the Expert System

- one case (Colusa) used a "Native", rather than a "Recently Disturbed, But Revegetated" Reference Site, and
- two cases (Willits and Blue Canyon) did not use a Reference Site at all;
- critical soils and vegetation data are lacking, but these minimal threshold values are required to make data-driven decisions (*are levels adequate?*) in the Expert System Evaluation Keys.

2.5.2 Style

Contains the same error categories of omission and commission as in the Expert System section:

Placeholders, indicated as X, XX, XXX, that require replacement

Species Names and Author Citations misspelled.

2.0 Document Review

2.5.3 Content

Reference site data are missing.
Since the document stated that the “Reference Site should give a working example of the soil conditions needed to support vegetation” the lack of data for reference site comparison is disappointing. The attribute values that would provide target or threshold levels were not forthcoming.

Critical soil fertility data are missing.
There are ample data regarding the physical and geotechnical aspects of the site reconfigurations and some physical properties of the soil. The absence of data involve many of the properties critical to soil fertility, nutrient cycling, and soil factor thresholds to support and sustain plant growth.

Critical vegetation data are missing.
No plant cover data were provided in Case Studies—*isn’t this one of the most important indicators for surface erosion control?*

Case Study 1

4. Organics, C, N - no data

5. Non-N nutrients- “sufficient” - no values provided

6. Soil Biology- AMF colonized - the more important data are the soil microbial biomass values because the nutrient cycling process must be re-instated to sustain plant cover.

Case Study 2

Reference site was native/undisturbed.

4. Organics, C, N - values stated as “near zero”; a more appropriate reference would a “less than (<) value

5. Non-N nutrients- no values provided

6. Soil Biology- AMF non-colonized - the more important data are the soil microbial biomass values because the nutrient cycling process must be re-instated to sustain plant cover.

Case Study 3-4

No reference sites.

The data for factors 3,4,5,6 are thin.

2.0 Document Review

2.6 "Soil Resource Evaluation: Application Examples"

'Blue Section' (Orange in this copy)

2.6.1 Format

This section is apparently an attempt to propose Standard Specifications. As such, it is a very important part of the document and needs completion. Proposed specifications should be related to existing Standard Specification section numbering, such as within "**20-4 HIGHWAY PLANTING**".

2.6.2 Style

Not enough content to assess style.

2.6.3 Content

This section is incomplete and not yet ready for release.

Seven of the eight topics are blank:

2) Erosion Control Fabrics
3) Geotextiles
4) Inoculation
5) Mulches
6) Site Analysis Forms
7) Soil Amendments
8) Soil Sampling and Testing

APPENDIX H.6

A REVIEW OF LEGUME SEED INOCULATION FOR HIGHWAY PLANTING IN CALIFORNIA

APPENDIX H.7

RECOMMENDATIONS REGARDING EROSION CONTROL ALONG THE UNION ROAD SEGMENT

Contract 43A0167 | Expert Assistance Task Area

Recommendations Regarding Erosion Control Along the Union Road Segment

Prepared For

STATE OF CALIFORNIA

DEPARTMENT OF TRANSPORTATION

Project Plans For Construction On

STATE HIGHWAY 46

In San Luis Obispo County
In and Near Paso Robles
From Airport Road To 1.4 Km West
of Whitley Gardens Drive

(MP 32.15 / KM 51.74 TO MP 39.31 / KM 63.27)

January 2006

1 Introduction

1.1 Purpose

At the request of Scott Dowlan, District 5 Associate Landscape Architect and Project Landscape Architect for the Union Road Segment (Post Mile 32.15 to 39.31) of the State Route 46 Corridor Improvement Project (**Figure 1**), these recommendations regarding erosion control along the Union Road Segment were prepared under the Expert Assistance Task Area of the Roadside Erosion Control & Maintenance Study in progress through the Earth and Soil Sciences Department at Cal Poly State University, San Luis Obispo, under contract with the Office of Water Programs at Sacramento State University, and Caltrans Division of Design.

Recommendations refer to the following treatments proposed by Caltrans for implementation along the Union Road Segment of SR46.

- **Disturbed Slopes and Medians**
  - **Hydroseeding**: Type C, Type D, and Type D with jute netting.
  - **Live Plants**: flats of grasses or forbs as toe treatments.
- **Detention Basin Bottoms**
  - **Hydroseeding**: species tolerant of inundation during the winter rain season and of soil water depletion during summer.

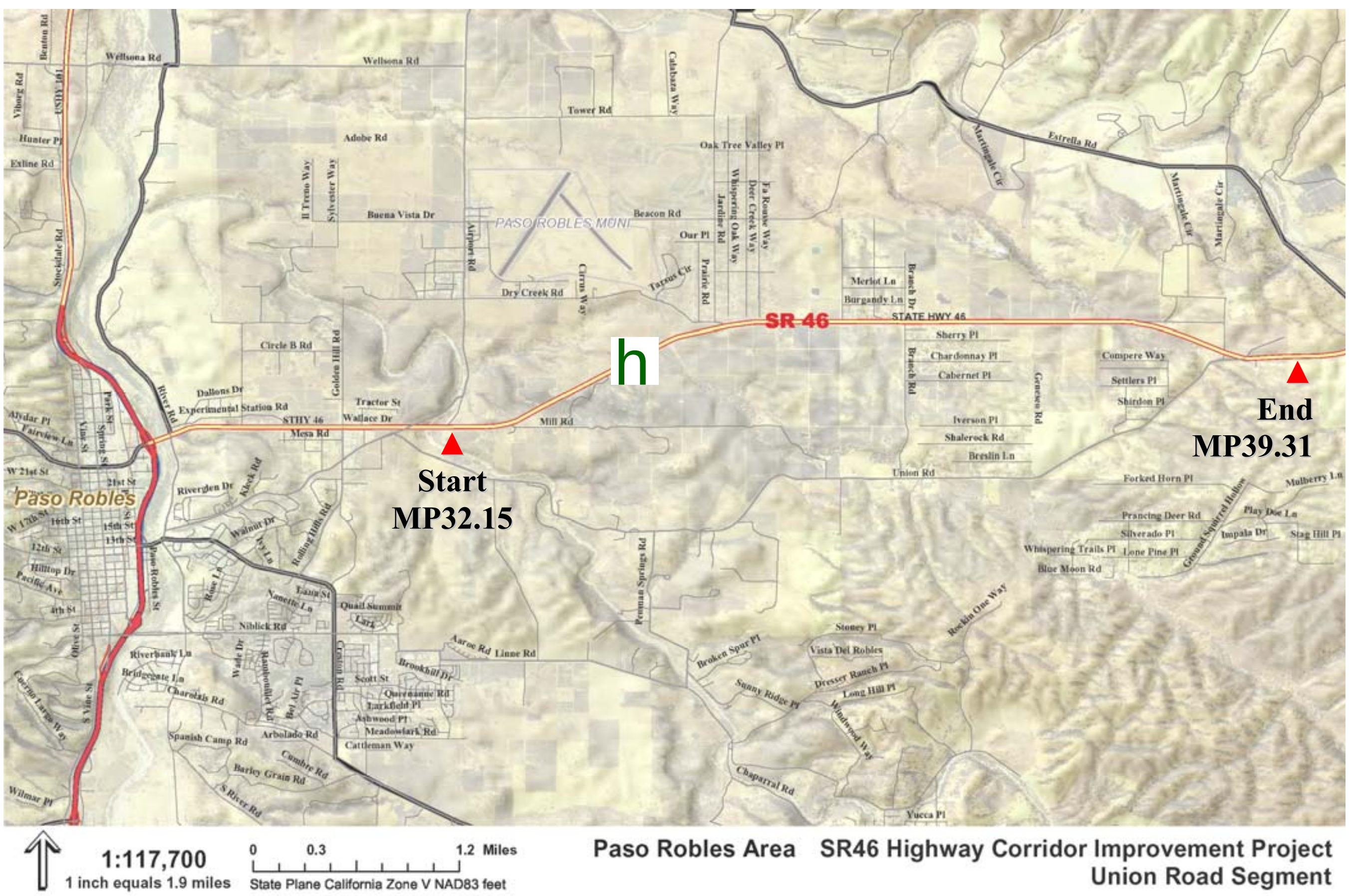


Figure 1. Union Road Segment of SR46 Corridor Improvement Project.

1 Introduction

1.2 Methods

Recommendations offered are based on: 1) site visits to the Union Road Segment; 2) research conducted under the previous Vegetation Establishment and Maintenance Study (CTSW-RT-01-078, CTSW-RT-01-079, CTSW-RT-02-052, CTSW-RT-04-004.69.01, CTSW-RT-04-069.06.1-D1, CTSW-RT-05-069.06.2); and 3) years of general and local experience held by the observers.

1.3 Site Attributes

This section provides a brief synopsis of the existing soils, vegetation, flora, and landuse along the Union Road Segment of SR46 as of January 2006.

1.3.1 Climate

Climate is hot-summer, arid Mediterranean (Rivas-Martínez et al 1999; Trewartha and Horn 1983). Paso Robles averages over 90 days annually above 32C (90F) and highs above 43C (110F) are not uncommon. Winter averages over 65 nights below 0C (32F), with extremes ranging to -14C (7F). Annual precipitation averages about 375 mm (14.75 in), with extremes from 741 mm (29.19 in) to 108mm (4.24 in). January through March is the only season of reliable precipitation, but totals can be meager (all climate data obtained from the Western Regional Climate Center, http://www.wrcc.dri.edu).

1.3.2 Soils

Soils along the Union Road Segment of SR46 consist of a heterogeneous complex of eleven soil types largely derived from mixed rock alluvium or weathered sandstone of old river terraces (Lindsey 1983). The Arbuckle-Positas-San Ysidro complex and Nacimiento-Ayar Series constitute about three-fourths of the soils along the Union Road Segment. All soil types are considered poor roadfill and fair to poor topsoil based on problems associated with drainage, erodibility, shrink/swell, or combinations thereof. **Table 1** lists the soils and attributes, and **Figure 2** shows the linear representation of these soil types along the Union Road Segment.

Table 1. Soil Types Along the Union Road Segment of SR46.

Field Metadata

Field	Definition	Source
% of Total	Percent of total Union Road Segment represented by that soil type	Calculated from GIS
ID	Unique identifier	SCS Soil Survey (Lindsey 1983)
Soil Name	Taxonomic name	SCS Soil Survey (Lindsey 1983)
Slope %	Slope range	SCS Soil Survey (Lindsey 1983)
Parent Material	Predominant geologic parent material	SCS Soil Survey (Lindsey 1983)
pH Surface	pH of the top few inches of depth	SCS Soil Survey (Lindsey 1983)
Drainage	General drainage properties	SCS Soil Survey (Lindsey 1983)
Erodibility	General erodibility	SCS Soil Survey (Lindsey 1983)
Shrink/Swell	General shrink/swell potential	SCS Soil Survey (Lindsey 1983)
Roadfill	Suitability as Roadfill	SCS Soil Survey (Lindsey 1983)
Topsoil	Suitability as Topsoil	SCS Soil Survey (Lindsey 1983)

1 Introduction

Table 1. (contd.)

% of Total	ID	Soil Name	Slope%	Parent Material	pH (surface)	Drainage	Erodibility	Shrink/Swell	Roadfill	Topsoil
2%	102	**Arbuckle-Positas Complex**	9-15	Alluvium from Mixed Rocks	6.1-7.3	Very Poor to Moderate	Moderate	Low	Poor	Fair
11%	104	**Arbuckle-Positas Complex**	30-50	Alluvium from Mixed Rocks	5.6-7.3	Very Poor to Moderate	Moderate	Low	Poor	Poor
2%	105	**Arbuckle-Positas Complex**	50-75	Alluvium from Mixed Rocks	5.6-7.3	Very Poor to Moderate	Moderate	Low	Poor	Poor
14%	106	**Arbuckle-San Ysidro Complex**	2-9	Alluvium from Mixed Rocks	5.6-7.3	Moderately Well	Moderate	Moderate	Poor	Fair
14%	109	**Ayar and Diablo Soils**	9-15	Weathered Sandstone and Shale	7.4-8.4	Very Poor	Moderate	High	Poor	Poor
4%	134	**Dibble Clay Loam**	9-15	Weathered Sandstone and Shale	5.6-6.5	Poor	High	Moderate	Poor	Poor
3%	149	**Hanford And Greenfield Gravelly Sandy Loams**	0-2	Alluvium from Mixed Rocks	6.1-7.3	Moderate	Low	Low	Poor	Poor
31%	179	**Nacimiento-Los Osos Complex**	9-30	Weathered Sandstone and Shale	5.6-9.4	Poor	Moderate	Moderate	Poor	Poor
2%	188	**Rincon Clay Loam**	2-9	Alluvium from Sedimentary Rocks	6.1-7.3	Poor	Moderate	Moderate	Poor	Fair
1%	196	**San Ysidro Sandy Loam**	2-9	Alluvium from Mixed Rocks	5.6-7.3	Moderate	High	Low	Poor	Good
10%	200	**Sesame Sandy Loam**	9-30	Alluvium from Granitic Rocks	5.6-6.5	Poor	Moderate	Low	Poor	Poor

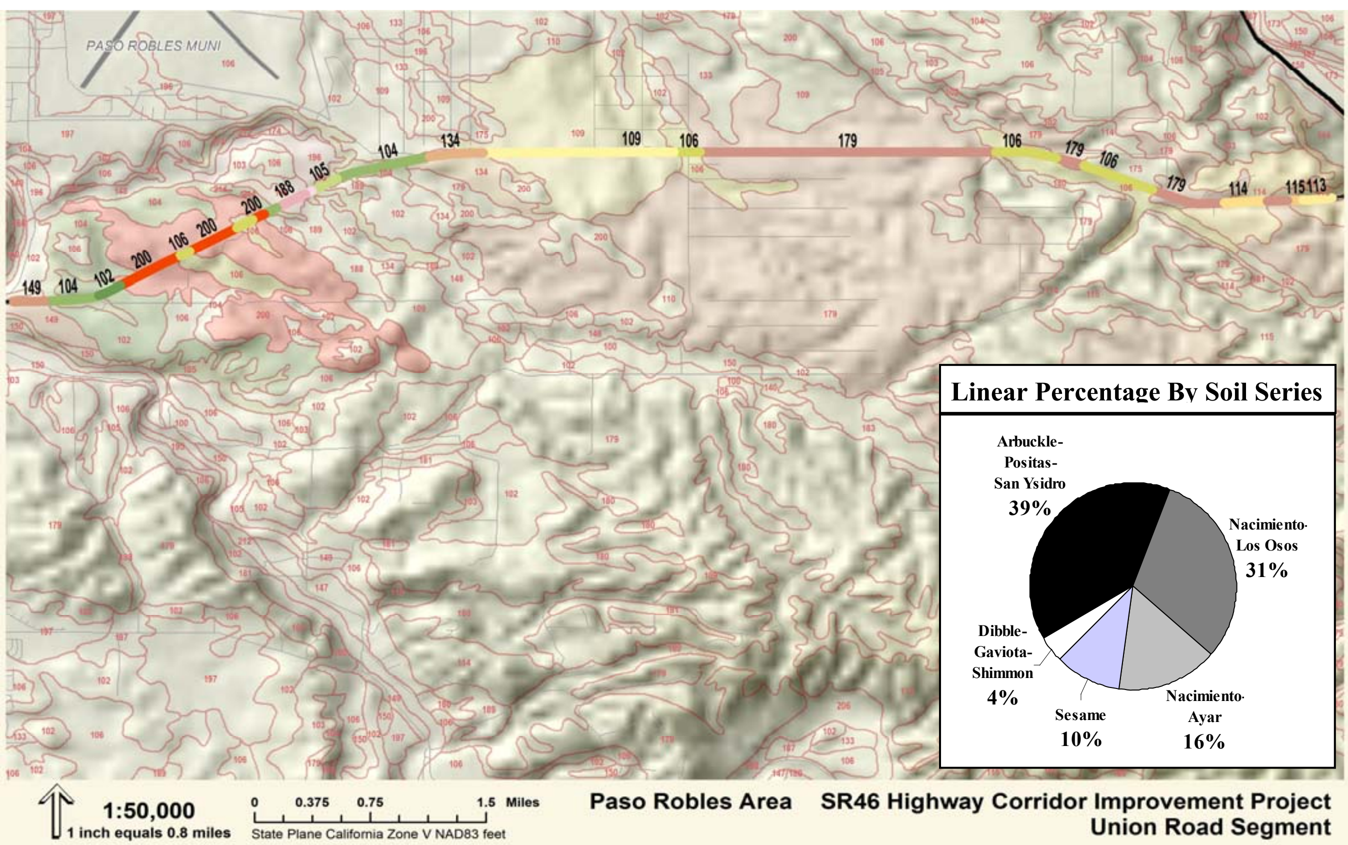


Figure 2. Soil Types Along the Union Road Segment.

1.3.3 Existing Vegetation

Existing vegetation cover along the Union Road Segment right-of-way is largely Ruderal Herbland of mostly alien annuals. Some native trees, such as Blue Oak and Fremont Cottonwood, and some native shrubs, such as Chaparral Broom, occur on some slopes and along seasonal streams. Much of the Ruderal Herbland is dominated by the alien grasses Common Wild Oats, Soft Chess, Annual Ryegrass, and Rattail Fescue, and by the alien forbs Black Mustard, Annual Yellow Sweetclover, Rose Clover, and Hairy Vetch. Stands of Yellow Star Thistle and Tocalote, both state listed noxious weeds (List C), do occur, but populations are not large. **Table 2** lists the conspicuous plants present.

Table 2. Conspicuous Plants Along the SR46 Union Road Segment.
Nomenclature follows Hickman 1993.

Taxon Name	Common Name
Native Trees	
Populus fremontii S.Wats.	Fremont Cottonwood
Quercus douglasii Hook. et Arn.	Blue Oak
Alien Trees	
Prunus dulcis (Miller) D.A.Webb	Almond
Native Shrubs	
Baccharis pilularis DC.	Chaparral Broom, Coyote Bush
Native Perennial Forbs	
Asclepias fascicularis Dcne.	Mexican Whorled Milkweed
Eriogonum elongatum Benth.	Longstem Buckwheat
Alien Perennial Forbs	
Hirschfeldia incana (L.) Lagrèze-Fossat	Perennial Mustard
Native Annual Forbs	
Clarkia purpurea (W.Curtis) A.Nels. et J.F.Macbr.	Winecup Clarkia
Conyza canadensis (L.) Cronq.	Canadian Horseweed
Eremocarpus setigerus (Hook.) Benth.	Doveweed
Alien Annual Forbs	
Brassica nigra (L.) W.D.J.Koch	Black Mustard
Carduus pycnocephalus L.	Italian Plumeless Thistle
Centaurea melitensis L.	Tocalote
Centaurea solstitialis L.	Yellow Star-Thistle
Erodium cicutarium (L.) L'Hér. ex Ait.	Redstem Filaree
Lactuca serriola L.	Prickly Lettuce
Medicago polymorpha L.	Burclover
Melilotus indicus (L.) All.	Annual Yellow Sweetclover
Trifolium hirtum All.	Rose Clover
Vicia villosa Roth	Hairy Vetch
Native Perennial Grass	
Nassella cernua (Stebbins & Love) Barkworth	Nodding Needle Grass
Nassella pulchra (A.S.Hitchc.) Barkworth	Purple Needle Grass
Alien Perennial Grass	
Cynodon dactylon (L.) Pers.	Bermuda Grass
Native Annual Grass	
Vulpia microstachys (Nutt.) Munro *sensu amplo*	Small Fescue
Alien Annual Grass	
Avena fatua L.	Common Wild Oats
Bromus diandrus Roth	Ripgut Brome
Bromus hordeaceus L.	Soft Chess
Gastridium phleoides (Nees & Meyen) C.E. Hubb.	Nit Grass
Lolium multiflorum Lam.	Annual Ryegrass
Vulpia myuros (L.) K.C.Gmel. var. *hirsuta* Hack.	Rattail Fescue

1.3.4 Potential Natural Vegetation

Based on regional and local interactions among climate, topography, and soils, the potential natural vegetation of the recent past was largely summer-dry herbland with patches of open oak woodland or open riparian woodland along seasonal streams. The herbland matrix was formerly dominated by native annual forbs (Buckwheats, Gilias, Goldfields, Lupines, Phacelias, Tidy Tips), native annual grasses (Fescues), and native perennial grasses (Needlegrasses, Melic Grasses, Malpais Bluegrass) in association with oaks (Hoover 1970; Twisselmann 1956). Decades of dryland farming and grazing have thoroughly converted these former native herblands/grasslands to an assemblage of Eurasian annual grasses and forbs now naturalized over millions of hectares of cismontane California (Baker 1989; Huenneke 1989).

1.3.5 Landuse

The context landuse along the Union Road Segment of SR46 is a mix of agriculture (vineyards or rangeland) and rural homesites or businesses. No state park or national forest lands occur anywhere in proximity. **Figure 3** shows the general character of SR46 east of Paso Robles including the new vineyards converted from rangeland that replaced dryland grain farms carved into the summer-dry herblands and open oak woodlands.

Figure 3. General Character of State Route 46 East of Paso Robles.
From FHWA & Caltrans 2003.

2 Erosion Control Recommendations

Recommendations refer to the following treatments proposed by Caltrans for implementation along the Union Road Segment of SR46.

- **Disturbed Slopes and Medians**
  - **Hydroseeding**: Type C, Type D, and Type D with jute netting.
  - **Live Plants**: flats of grasses or forbs as toe treatments.
- **Detention Basin Bottoms**
  - **Hydroseeding**: species tolerant of inundation during the winter rain season and of soil water depletion during summer.

Note: If drill seeding is employed, then seed mixes should use grasses only because seed sizes and burial depths for the forbs recommended are inappropriate for drilling.

2.1 Conditions and Limitations

Roadside revegetation projects present substantial challenges to successful development of desired plant associations and vegetation structure. Cut or fill slopes are often steeply inclined, highly compacted, and lacking topsoil. Given the arid climate and contracted season of favorable growing temperatures in conjunction with adequate rainfall, planned revegetation is inherently precarious at best. The Route 46 Corridor Improvement Project will necessitate erosion control and revegetation measures on several challenging cut and fill slopes in this unpredictable environment.

2.1.1 Supplemental Irrigation

The climate of eastern San Luis Obispo County is extremely varied and unpredictable. Rainfall is unreliable, and 30- to 60-day episodes with no measurable precipitation are possible during the only season of reliable rainfall from December through March. Low humidity events associated with hot or cold temperatures are frequent in the arid interior, as well. If plant establishment from seed or live material is attempted during the dry season, or even during rain seasons with inconsistent precipitation, poor establishment or failure is likely. Therefore, the recommendations that follow assume near average rain seasons with no dry periods longer than 14 days. Supplemental irrigation may be necessary during the rain season, and is required when establishment is attempted during the dry season.

2.1.2 Reapplied Topsoil

Excavated topsoil is sometimes stockpiled for reapplication of pre-existing organic matter, soil microbes, and seed as both an inexpensive means of erosion control, and as a method to re-establish vegetation consistent with the surrounding context. However, stockpiled seedbanks may include undesirable, weedy species that inhibit establishment of desired native species.

If high quantities of viable seed from naturalized species exist in reapplied topsoil, addition of purchased seed of non-local "native" species may be wholly ineffective at establishing against aggressive competition for water from naturalized species.

In a landscape context dominated by naturalized alien species, re-establishment of native plants should focus on sites where specific management objectives necessitate promotion of local native genotypes, especially if local native plant genotypes are known to be host plants or food sources for locally important wildlife species.

2 Erosion Control Recommendations

2.2 Type C (Two Step): Incorporated Straw

This treatment is intended for areas deemed appropriate for incorporated straw.

☑ **Straw** ☐ Jute ☐ Compost ☑ **Fiber** ☑ **Stabilizing Emulsion** ☑ **Seed**

Contexts: **All** Sites: **Fill Slopes, Medians** Slope Direction: **0º to 360º**

APPLICATION 1

	Kilograms per Hectare		Pounds per Acre	
	Rate Low	**Rate High**	**Rate Low**	**Rate High**
Straw (Wheat/Barley)	**4000**	**4500**	**8800**	**9900**

APPLICATION 2

	Kilograms per Hectare		Pounds per Acre	
	Rate Low	**Rate High**	**Rate Low**	**Rate High**
Straw	0	0	0	0
Compost	0	0	0	0
Fiber	**1000**	**1500**	**892**	**1338**
Stabilizing Emulsion	**100**	**125**	**89**	**112**
Seed (Mix 1)	**56**	**56**	**50**	**50**

TOTALS

	Kilograms per Hectare		Pounds per Acre	
	Rate Low	**Rate High**	**Rate Low**	**Rate High**
Straw (Wheat/Barley)	**4000**	**4500**	**8800**	**9900**
Compost	0	0	0	0
Fiber	**1000**	**1500**	**892**	**1338**
Stabilizing Emulsion	**100**	**125**	**89**	**112**
Seed (Mix 1)	**56**	**56**	**50**	**50**

2 Erosion Control Recommendations

2.3 Type D (Two Step): Jute Netting

This treatment is intended for any cut or fill slope deemed appropriate for jute netting. Topsoil may be reapplied or not. **Where greater suppression of undesirable weeds is warranted, such as with reapplied topsoil known to contain noxious weeds, fiber rates in Application 1 may be doubled and Seed Mix 2 (Alien Annual Grasses) may be substituted.**

☐ Straw ☑ **Jute** ☐ Compost ☑ **Fiber** ☐ Stabilizing Emulsion ☑ **Seed**

Contexts: **All** Sites: **Cut Slopes, Fill Slopes** Slope Direction: **0º to 360º**

APPLICATION 1

	Kilograms per Hectare		Pounds per Acre	
	Rate Low	Rate High	Rate Low	Rate High
Straw	0	0	0	0
Compost	0	0	0	0
Fiber	**1500**	**2500**	**1338**	**2230**
Stabilizing Emulsion	0	0	0	0

Jute Applied

APPLICATION 2

	Kilograms per Hectare		Pounds per Acre	
	Rate Low	Rate High	Rate Low	Rate High
Straw	0	0	0	0
Compost	0	0	0	0
Fiber	**500**	**1000**	**446**	**892**
Stabilizing Emulsion	0	0	0	0
Seed (Mix 1)	**56**	**56**	**50**	**50**

TOTALS

	Kilograms per Hectare		Pounds per Acre	
	Rate Low	Rate High	Rate Low	Rate High
Straw	0	0	0	0
Compost	0	0	0	0
Fiber	**2000**	**3500**	**1784**	**3122**
Stabilizing Emulsion	0	0	0	0
Seed (Mix 1)	**56**	**56**	**50**	**50**

2 Erosion Control Recommendations

2.4 Type D (Two Step): No Jute Netting

This treatment is intended for any cut or fill slope deemed appropriate for jute netting. Topsoil may be reapplied or not. **Where greater suppression of undesirable weeds is warranted, such as with reapplied topsoil known to contain noxious weeds, fiber rates in Application 1 may be doubled and Seed Mix 2 (Alien Annual Grasses) may be substituted.**

☐ Straw ☐ Jute ☐ Compost ☑ **Fiber** ☑ **Stabilizing Emulsion** ☑ **Seed**

Contexts: **All** Sites: **Cut Slopes, Fill Slopes, Medians** Slope Direction: **0º to 360º**

APPLICATION 1

	Kilograms per Hectare		Pounds per Acre	
	Rate Low	Rate High	Rate Low	Rate High
Straw	0	0	0	0
Compost	0	0	0	0
Fiber	**1500**	**2500**	**1338**	**2230**
Stabilizing Emulsion	0	0	0	0

APPLICATION 2

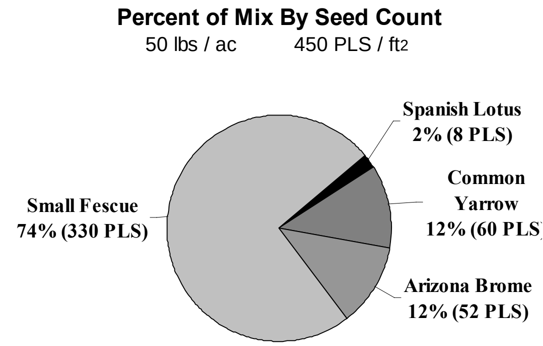
	Kilograms per Hectare		Pounds per Acre	
	Rate Low	Rate High	Rate Low	Rate High
Straw	0	0	0	0
Compost	0	0	0	0
Fiber	**500**	**1000**	**446**	**892**
Stabilizing Emulsion	**75**	**100**	**165**	**220**
Seed (Mix 1)	**56**	**56**	**50**	**50**

TOTALS

	Kilograms per Hectare		Pounds per Acre	
	Rate Low	Rate High	Rate Low	Rate High
Straw	0	0	0	0
Compost	0	0	0	0
Fiber	**2000**	**3500**	**1784**	**3122**
Stabilizing Emulsion	**75**	**100**	**165**	**220**
Seed (Mix 1)	**56**	**56**	**50**	**50**

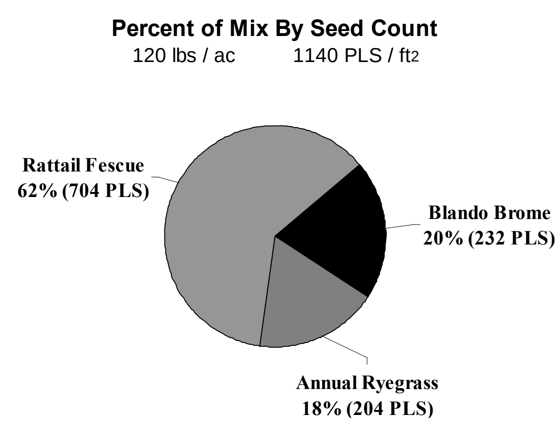
2 Erosion Control Recommendations

2.5 Hydroseed Mixes



2.5.1 Seed Mix 1: Native Forbs & Grasses

SCIENTIFIC NAME	COMMON NAME	CULTIVAR	Rate_lb-PLS/ac	Percent_of_Mix_weight	Rate_PLS/ft2	Percent_of_Mix_count	Rate_lb-Gross/ac	Avg$/lb_Gross_2005	Avg$/lb_PLS_2005	Avg$/ac_2005	Seeds_Gross/lb	Seeds_PLS/lb	Purity_%	Germination_%	PLS_%
Native Annual Legume Forbs															
Lotus purshianus (Benth.) Clem. & Clem.	Spanish Lotus	*unspecified*	4	8%	8	1.9%	4.55	$35.00	$39.77	$159.25	105000	92400	90%	98%	88%
Native Perennial Non-Legume Forbs															
Achillea millefolium L.	Common Yarrow	(Interior races)	1	2%	60	11.9%	1.04	$35.00	$36.46	$36.40	2700000	2592000	98%	98%	96%
Native Annual Grasses															
Bromus arizonicus (Shear) Stebbins	Arizona Brome	Cucamonga	25	50%	52	11.7%	26.88	$7.50	$8.06	$201.60	100000	93000	98%	95%	93%
Vulpia microstachys (Nutt.) Benth.	Small Fescue	*unspecified*	20	40%	330	73.3%	22.22	$35.00	$38.89	$777.70	800000	720000	95%	95%	90%
			50	100%	450	100.0%	54.69			$1,174.95					



2.5.2 Seed Mix 2: Alien Annual Grasses

SCIENTIFIC NAME	COMMON NAME	CULTIVAR	Rate_lb-PLS/ac	Percent_of_Mix_weight	Rate_PLS/ft2	Percent_of_Mix_count	Rate_lb-Gross/ac	Avg$/lb_Gross_2005	Avg$/lb_PLS_2005	Avg$/ac_2005	Seeds_Gross/kg	Seeds_PLS/lb	Purity_%	Germination_%	PLS_%
Alien Annual Grasses															
Bromus hordeaceus L.	Soft Chess	Blando	40	33.3%	232	20.4%	41.67	$7.50	$7.81	$312.53	584224	254400	98%	98%	96%
Lolium multiflorum Lam.	Annual Ryegrass	*unspecified*	40	33.3%	204	17.9%	41.67	$7.50	$7.81	$312.53	507063	220800	98%	98%	96%
Vulpia myuros (L.) K.C. Gmelin	Rattail Fescue	Zorro	40	33.3%	704	61.8%	41.67	$7.50	$7.81	$312.53	1763696	768000	98%	98%	96%
			120	100.0%	1140	100.0%	125.01			$937.59					

2 Erosion Control Recommendations

2.6 Hydroseeding Detention Basin Bottoms

This treatment is intended for hydroseeding detention basin bottoms only. The plant species used are tolerant of inundation during the winter rain season and of soil water depletion during summer. Seed mix options for provenance and height are listed below. Visual uniformity and a longer green season are favored over diversity. Seed should be applied with minimal fiber (1120 kg/ha | 1000 lbs/ac) and no stabilizing emulsion or fertilizer.

2.6.1 All Native Perennials < 2 feet tall

SCIENTIFIC NAME	COMMON NAME	CULTIVAR	Rate_lb-PLS/ac	Percent_of_Mix_weight	Rate_PLS/ft2	Percent_of_Mix_count	Rate_lb-Gross/ac	Avg$/lb_Gross_2005	Avg$/lb_PLS_2005	Avg$/ac_2005	Seeds_Gross/lb	Seeds_PLS/lb	Purity_%	Germination_%	PLS_%
Native Perennial Non-Legume Forbs															
Achillea millefolium L.	Common Yarrow	(Interior races)	2	4.8%	119	63.6%	2.08	$30.00	$31.25	$62.40	2700000	2592000	98%	98%	96%
Native Perennial Grasses															
Hordeum californicum Covas & Stebbins	California Barley	*unspecified*	40	95.2%	68	36.4%	52.63	$15.00	$19.74	$789.45	100000	76000	95%	80%	76%
			42	100.0%	187	100.0%	54.71			$851.85					

2.6.2 All Native Perennials < 5 feet tall

SCIENTIFIC NAME	COMMON NAME	CULTIVAR	Rate_lb-PLS/ac	Percent_of_Mix_weight	Rate_PLS/ft2	Percent_of_Mix_count	Rate_lb-Gross/ac	Avg$/lb_Gross_2005	Avg$/lb_PLS_2005	Avg$/ac_2005	Seeds_Gross/lb	Seeds_PLS/lb	Purity_%	Germination_%	PLS_%
Native Perennial Non-Legume Forbs															
Achillea millefolium L.	Common Yarrow	(Interior races)	2	4.8%	119	67.2%	2.08	$30.00	$31.25	$62.40	2700000	2592000	98%	98%	96%
Native Perennial Grasses															
Hordeum californicum Covas & Stebbins	California Barley	*unspecified*	20	47.6%	34	19.2%	26.32	$15.00	$19.74	$394.80	100000	76000	95%	80%	76%
Leymus triticoides (Buckley) Pilger	Creeping Wildrye	Rio	20	47.6%	24	13.6%	40.82	$20.00	$40.82	$816.40	110000	53900	50%	98%	49%
			42	100%	177	100%	69.22			$1,273.60					

2.6.3 Native and Alien Perennials < 5 feet tall

SCIENTIFIC NAME	COMMON NAME	CULTIVAR	Rate_lb-PLS/ac	Percent_of_Mix_weight	Rate_PLS/ft2	Percent_of_Mix_count	Rate_lb-Gross/ac	Avg$/lb_Gross_2005	Avg$/lb_PLS_2005	Avg$/ac_2005	Seeds_Gross/lb	Seeds_PLS/lb	Purity_%	Germination_%	PLS_%
Native Perennial Non-Legume Forbs															
Achillea millefolium L.	Common Yarrow	(Interior races)	1	1.9%	60	43.8%	1.04	$30.00	$31.25	$31.20	2700000	2592000	98%	98%	96%
Native Perennial Grasses															
Hordeum californicum Covas & Stebbins	California Barley	*unspecified*	15	28.8%	26	18.8%	19.74	$15.00	$19.74	$296.10	100000	76000	95%	80%	76%
Leymus triticoides (Buckley) Pilger	Creeping Wildrye	Rio	21	40.4%	25	18.5%	42.86	$20.00	$40.82	$857.20	110000	53900	50%	98%	49%
Alien Perennial Grasses															
Thinopyrum intermedium (Host) Barkworth & D.R. Dewey	Intermediate Wheatgrass	Tegmar	15	28.8%	26	18.8%	17.44	$15.00	$17.44	$261.60	88000	75680	95%	90%	86%
			52	100%	136	100%	81.08			$1,446.10					

2 Erosion Control Recommendations

2.7 Live Plant Applications

2.7.1 Slope Toe Treatments

Listed below are plant materials suitable for application as flats (“sod strips”) of living plants at slope toes to filter sediment. Materials are grouped relative to growth habitat as a rhizomatous sod-former, or as a tufted bunch former. Appropriate alien grasses are included also.

Flats are typically the 16″ to 18″ square ground-cover flats grown by wholesale nurseries. Flats are produced by installing from nine to thirty-six 1.5″ to 2″ plugs into planting mix over coir or burlap matting. Nursery production of > 90% plant cover typically requires 60 to 120 days.

Other possibilities include contract-growing of larger vegetated erosion control mats, such as the 4′ x 66′ mats custom grown ($2.00 per linear ft) for revegetation by the National Park Service (van der Grinten and Gregory 2000).

			“Weed” Status in California		
SCIENTIFIC NAME	COMMON NAME	CULTIVAR	CalEPPC	CDFA	TNC_Invasive
Native Perennial Rhizomatous Non-Legume Forbs					
Achillea millefolium L.	Common Yarrow	(Interior races)	---	---	---
Native Perennial Rhizomatous Grasses					
Hordeum brachyantherum Nevski	Meadow Barley	'Prostrate'	---	---	---
Leymus triticoides (Buckl.) Pilger	Creeping Wildrye	'Rio'	---	---	---
Native Perennial Bunch Grasses					
Muhlenbergia rigens (Benth.) A.S. Hitchc.	Deergrass		---	---	---
Alien Perennial Rhizomatous Grasses					
Festuca arundinacea Schreb.	Tall Fescue	'Arid'	Medium	---	High
Thinopyrum intermedium (Host) Barkworth & D.R. Dewey	Intermediate Wheatgrass	'Tegmar'	---	---	Medium
Thinopyrum ponticum (Podp.) Barkworth & D.R. Dewey	Tall Wheatgrass	'Jose'	---	---	Medium

CIPC = California Invasive Plant Council CDFA = California Department of Food and Agriculture TNC = The Nature Conservancy

3 References

Baker, HG. 1989. Sources of the naturalized grasses and herbs in California grasslands. pp. 29-38 *In* Huenneke, LF; Mooney, H. (eds.), *Grassland Structure and Function: California Annual Grassland*. Dordrecht: Kluwer Academic Publishers.

California Department of Transportation (Caltrans). 2001. Vegetation Establishment For Erosion Control Under Simulated Rainfall. CTSW-RT-01-078.

California Department of Transportation (Caltrans). 2001. District 5 Advisory Guide To Plant Species Selection For Erosion Control. CTSW-RT-01-079.

California Department of Transportation (Caltrans). 2002. Evaluating Hydroseeding & Plug Planting Techniques For Erosion Control & Improved Water Quality. CTSW-RT-02-052.

California Department of Transportation (Caltrans). 2004. Effectiveness of Planting Techniques for Minimizing Erosion. CTSW-RT-04-004.69.01.

California Department of Transportation (Caltrans). 2005. Performance of Erosion Control Treatments on Reapplied Topsoil. CTSW-RT-04-069.06.1-D1

California Department of Transportation (Caltrans). 2005. Native Shrub Germination relative to Compost Type, Application Method, and Layer Depth. CTSW-RT-05-069.06.2.

Dyer AR; Fossum HC; and Menke JW. 1996. Emergence and survival of *Nassella pulchra* in a California grassland. *Madroño* 43(2): 316-333.

Hickman, JC. (ed.) 1993. *The Jepson Manual: Higher Plants of California*. Berkeley, CA: University of California Press.

Hoover, RF. 1970. *The Vascular Plants of San Luis Obispo County, California*. Berkeley: University of California Press.

Huenneke, LF. 1989. Distribution and regional patterns of California grasslands. pp. 1-12 *In* Huenneke, LF; Mooney, H. (eds.), *Grassland Structure and Function: California Annual Grassland*. Dordrecht: Kluwer Academic Publishers.

Lindsey, WC. 1983. Soil Survey of San Luis Obispo County, California, Paso Robles Area. USDA Soil Conservation Service/University of California Agricultural Experiment Station. 20 Maps: USGS 7.5 minute (1:24000) quadrangles.

Rivas-Martínez, S; Sánchez-Mata, D; Costa, M. 1999. North American Boreal and Western Temperate Forest Vegetation. Syntaxonomical synopsis of the potential natural plant communities of North America II. *Itinera Geobot.* 12: 5-316.

Trewartha, GT; Horn, LH. 1983. *An Introduction to Climate*. ed. 5. New York: McGraw-Hill.

van der Grinten, M.; Gregory, LL. 2000. Vegetated erosion control mats for site stabilization. *Native Plants Journal* **1**(2): 121-122.

United States Department of Transportation Highway Administration (FHA) and California Department of Transportation (Caltrans). 2003. Route 46 Corridor Improvement Project Environmental Assessment/Draft Environmental Impact Report. San Luis Obispo, CA: District 5.

Rebuttal to Criticism of SR 46 Corridor Improvement Project Erosion Control Specifications

30 October 2008

Recent criticism of erosion control specifications proposed by Scott Dowlan, Landscape Architect, District 5, for the Union Road Segment (Post Mile 32.15 to 39.31) of the State Route 46 Corridor Improvement Project, prompted Scott to contact me for my reaction to the critical comments made (see attached email history). Scott developed these SR46 erosion control specifications based on species/cultivar recommendations that I prepared January 2006 under the Expert Assistance Task Area of the Roadside Erosion Control & Maintenance Study in progress and conducted by the Earth and Soil Sciences Department at Cal Poly State University, San Luis Obispo, under contract with the Office of Water Programs at Sacramento State University, and Caltrans Division of Design.

Thus, I have constructed this rebuttal to quell any uproar within Caltrans that "`…this NSSP appears to have serious problems…`" (email 04/12/2007, William Andersen to Mike Ferrara).

All remarks made here are mine. I am not speaking for Dr. Brent Hallock, PI for RECMS, for Misty Scharff, Soil Scientist for the Sacramento State Office of Water Programs, or for anyone within Caltrans.

Below are point-by-point comments based on data gathered from the disciplines of ecography, plant ecology, plant geography, plant taxonomy, and plant physiology. Rather than hyperbole and histrionics, I'll stick to the facts surrounding the SR46 Corridor Improvement Project.

Context Landscape

Climate

Climate is hot-summer arid Mediterranean (Rivas-Martínez et al 1999; Trewartha and Horn 1983). Paso Robles Airport averages over 86 days annually above 32C (90F) and highs above 43C (110F) are not uncommon. Winter (Dec - Mar) day highs average 16C (61F), and lows average 1.7C (35F). Winter averages over 53 nights below 0C (32F) with extremes ranging to -13C (8F). Annual calendar-year precipitation from 1948 through 2006 averaged about 330 mm (13 in) with extremes from 649 mm (25.56 in) to 121mm (4.78 in). The mode and median are also about 330 mm (13 in). **January through March is the only season of reliable precipitation, but totals can be meager** (all climate data obtained from the Western Regional Climate Center, http://www.wrcc.dri.edu). **Thus far, the 2006-2007 water-year has recorded a mere 97 mm (3.81 in), with 55mm (2.18 in) falling this January through April.** Of course, average temperatures and average precipitation are relatively coarse drivers of site vegetation structure and composition. Extreme values cause immediate plant death in the short-term, especially for establishing seedlings.

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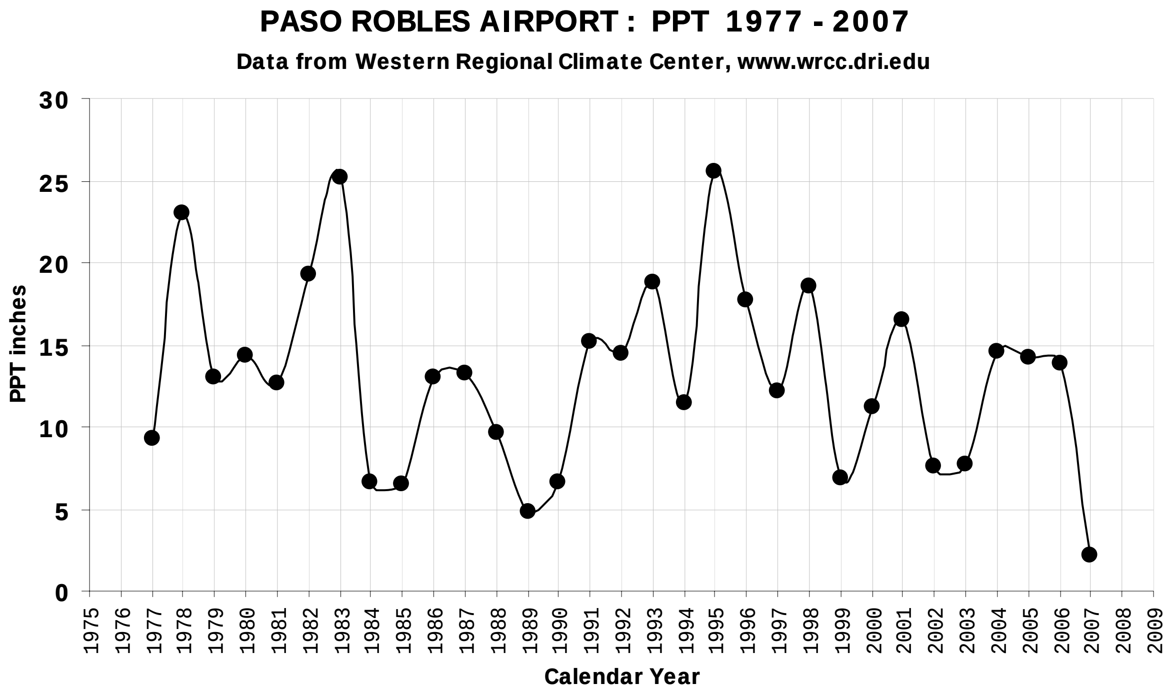

Soils

Soils along the Union Road Segment of SR46 consist of a heterogeneous complex of eleven soil types largely derived from mixed rock alluvium or weathered sandstone of old river terraces (Lindsey 1983). The Arbuckle-Positas-San Ysidro complex and Nacimiento-Ayar Series constitute about three-fourths of the soils along the Union Road Segment. All soil types are considered poor roadfill and fair to poor topsoil based on problems associated with drainage erodibility shrink/swell or combinations thereof.

Potential Natural Vegetation

Based on regional and local interactions among climate, topography, and soils, the potential natural vegetation of the recent past was largely summer-dry herbland with patches of open oak woodland or open riparian woodland along seasonal streams. The herbland matrix was formerly dominated by native annual forbs (Buckwheats, Gilias, Goldfields, Lupines, Phacelias, Tidy Tips), native annual grasses (Fescues), and native perennial grasses (Needlegrasses, Melic Grasses, Malpais Bluegrass) in association with oaks (Hoover 1970; Twisselmann 1956). Decades of dryland farming and grazing have thoroughly converted these former native herblands/grasslands to an assemblage of Eurasian annual grasses and forbs now established over millions of hectares of cismontane California (Baker 1989; Huenneke 1989).

Landuse

The context landuse along the Union Road Segment of SR46 is a mix of agriculture (vineyards or rangeland) and rural homesites or businesses. No state park or national forest lands occur anywhere in proximity. Vineyards have now thoroughly converted rangeland that replaced dryland grain farms carved into the summer-dry herblands and open oak woodlands.

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Existing Vegetation

Existing vegetation cover along the Union Road Segment right-of-way is largely Ruderal Herbland of mostly alien annuals. Some native trees, such as Blue Oak and Fremont Cottonwood, and some native shrubs, such as Chaparral Broom, occur on some slopes and along seasonal streams. Much of the Ruderal Herbland is dominated by the alien grasses Common Wild Oats, Soft Chess, Annual Ryegrass, and Rattail Fescue, and by the alien forbs Black Mustard, Annual Yellow Sweetclover, Rose Clover, and Hairy Vetch. Stands of Yellow Star Thistle and Tocalote, both state listed noxious weeds (List C), do occur, but populations are not large.

Conspicuous Plants Along the SR46 Union Road Segment.

Nomenclature follows Hickman 1993.

Taxon Name	Common Name
Native Trees	
Populus fremontii S.Wats.	Fremont Cottonwood
Quercus douglasii Hook. et Arn.	Blue Oak
Alien Trees	
Prunus dulcis (Miller) D.A.Webb	Almond
Native Shrubs	
Baccharis pilularis DC.	Chaparral Broom, Coyote Bush
Native Perennial Forbs	
Asclepias fascicularis Dcne.	Mexican Whorled Milkweed
Eriogonum elongatum Benth.	Longstem Buckwheat
Alien Perennial Forbs	
Hirschfeldia incana (L.) Lagrèze-Fossat	Perennial Mustard
Native Annual Forbs	
Clarkia purpurea (W.Curtis) A.Nels. et J.F.Macbr.	Winecup Clarkia
Conyza canadensis (L.) Cronq.	Canadian Horseweed
Eremocarpus setigerus (Hook.) Benth.	Doveweed
Alien Annual Forbs	
Brassica nigra (L.) W.D.J.Koch	Black Mustard
Carduus pycnocephalus L.	Italian Plumeless Thistle
Centaurea melitensis L.	Tocalote
Centaurea solstitialis L.	Yellow Star-Thistle
Erodium cicutarium (L.) L'Hér. ex Ait.	Redstem Filaree
Lactuca serriola L.	Prickly Lettuce
Medicago polymorpha L.	Burclover
Melilotus indicus (L.) All.	Annual Yellow Sweetclover
Trifolium hirtum All.	Rose Clover
Vicia villosa Roth	Hairy Vetch
Native Perennial Grass	
Nassella cernua (Stebbins & Love) Barkworth	Nodding Needle Grass
Nassella pulchra (A.S.Hitchc.) Barkworth	Purple Needle Grass
Alien Perennial Grass	
Cynodon dactylon (L.) Pers.	Bermuda Grass
Native Annual Grass	
Vulpia microstachys (Nutt.) Munro *sensu amplo*	Small Fescue
Alien Annual Grass	
Avena fatua L.	Common Wild Oats
Bromus diandrus Roth	Ripgut Brome
Bromus hordeaceus L.	Soft Chess
Gastridium phleoides (Nees & Meyen) C.E. Hubb.	Nit Grass
Lolium multiflorum Lam.	Annual Ryegrass
Vulpia myuros (L.) K.C.Gmel. var. *hirsuta* Hack.	Rattail Fescue

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Species Selection & Provenance

The Route 46 Corridor Improvement Project will necessitate erosion control and revegetation measures on several challenging cut and fill slopes in a very unpredictable revegetation environment. Given the arid climate and contracted season of favorable growing temperatures in conjunction with adequate rainfall, planned revegetation is inherently precarious at best. Based on the relatively high abundance of alien annual grass and forb seeds in the existing soils along the project corridor, and the high likelihood that imported fill will contain millions of aliens annuals as well, fill-slopes will very predictably revegetate with the same alien annual dominated matrix that exists there now. Winter-annual grasses (*Avena, Bromus, Lolium, Vulpia*) will surely return to dominance within the first growing season. Addition of any seed on fill-slopes, be it "native" or alien, will likely have no appreciable affect on erosion control success.

As usual, greatest concern for rapid cover is on the steeper cut-slopes with no appreciable soil seed bank. Initially, some biologists within District 5 argued for seeding with Purple Needlegrass (*Stipa/Nassella pulchra*) and Nodding Needlegrass (*Stipa/Nassella cernua*) to serve as both rapid cover and long-term "native grassland". While both Purple Needlegrass and Nodding Needlegrass are present along the SR 46 Corridor, their relative abundance is now very much reduced and patchy. Both of these perennial grass species can be very long-lived, but recruitment of new individuals is episodic only when soil water is both adequate and consistent for germination and establishment. Bugg et al. (1997) reported excellent establishment of Needlegrass near Winters in Yolo County during the winter-spring of 1992 when more than 915 mm (36 in) of rainfall fell from January through April. In contrast, Dyer et al. (1996) found that seedling survival of hand-planted seeds of Purple Needlegrass was 1.1%, 0.3%, and 0.1% from 1987 to 1989 respectively when Solano County received about 62%, 95%, 68% of its 100-year average of 436mm (17.2 in) of annual precipitation.

Owing to the unpredictability of what the short-term weather may be at the time of erosion control seeding for the Route 46 Corridor Improvement Project, a safer strategy is to use a mix highly skewed toward local native annuals capable of establishment during meager rain seasons. Thus, I initially recommended using two native annual grasses exclusively: Small Fescue, *Vulpia microstachys* (Nutt.) Benth., and Arizona Brome, *Bromus arizonicus* (Shear) Stebbins 'Cucamonga' (see below under Provenance). After discussions with Scott, we added a native annual legume, Spanish Lotus, *Lotus purshianus* (Benth.) Clem. & Clem., [to satisfy the penchant within Caltrans to add legumes to mixes owing to the generally accepted belief that doing so augments available soil nitrogen community-wide; evidence is weak, see below under Legume Inoculation], and a native rhizomatous perennial, Western Yarrow, *Achillea millefolium* L. ssp. *lanulosa* (Nutt.) Piper [≡ *Achillea lanulosa* Nutt.], to provide its sediment-trapping leaf cover at the soil surface. The mix (50lbs/ac, 450 PLS/ft2) is heavily biased toward Small Fescue (74%, 330 PLS/ft2), with Arizona Brome (12%, 52 PLS/ft2), Western Yarrow (13%, 60 PLS/ft2), and Spanish Lotus (2%, 8 PLS/ft2).

All of these species/cultivars germinate best with minimal burial (< 7 mm, 0.25 in) owing to requirements for far-red light (700 to 800 nm) to break dormancy (Baskin and Baskin 1998). Thus the need to apply seeds on top of any physical erosion control measures, e.g., fiber or compost with a jute netting overlay.

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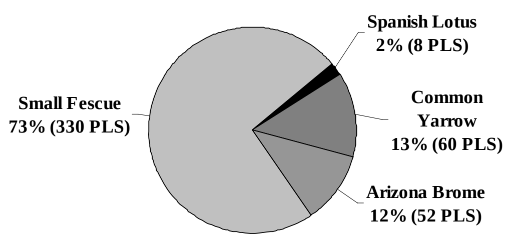
SCIENTIFIC NAME	COMMON NAME	CULTIVAR	Rate_lb-PLS/ac	Percent_of_Mix_weight	Rate_PLS/ft2	Percent_of_Mix_count	Rate_lb-Gross/ac
Native Annual Legume Forbs							
Lotus purshianus (Benth.) Clem. & Clem.	Spanish Lotus	*unspecified*	4	8%	8	1.9%	4.55
Native Perennial Non-Legume Forbs							
Achillea millefolium L. ssp. *lanulosa* (Nutt.) Piper	Western Yarrow	(Interior races)	1	2%	60	13.3%	1.04
Native Annual Grasses							
Bromus arizonicus (Shear) Stebbins	Arizona Brome	Cucamonga	25	50%	52	11.5%	26.88
Vulpia microstachys (Nutt.) Benth.	Small Fescue	*unspecified*	20	40%	330	73.3%	22.22
			50	100%	450	100.0%	54.69

Percent of Mix By Seed Count
50 lbs / ac 450 PLS / ft2



Provenance

Bromus arizonicus (Shear) Stebbins

Doubt raised (`"…its [it's] oblivious [obvious] one [`*`Bromus arizonicus`*`] is a foreigner…"`; email 04/12/2007, John Haynes to William Andersen) over the local native status of this annual grass merely owing to the specific epithet "arizonicus" shows an appalling lack of understanding of plant nomenclature that I expect in freshman taxonomy students, but not in veteran landscape architects with years of experience specifying plant materials for California roadsides. General application of such a simplistic rule would call in to question the native status of numerous taxa considered native within California, such as *Lupinus arizonicus, Plagiobothrys arizonicus, Agrostis oregonensis, Claytonia washingtoniana, Festuca idahoensis, Ephedra nevadensis, Agave utahensis, Amelanchier utahensis, Sambucus mexicana, Muhlenbergia mexicana, Calamagrostis canadensis,* and many more. In 1900, when C.L. Shear named *Bromus carinatus* H.&A. var. *arizonicus* based on specimens collected near Tucson, AZ in 1884 by C.G. Pringle, he had vague knowledge of the geographic extent of the entity that he classified as a variety of the Pacific Coastal *Bromus carinatus* H.&A. As is often the case with epithets connoting geographic circumscription, they are misinterpreted once a taxon is found beyond the implied boundary. The bottom-line on geographic epithets is that they do not necessarily imply native provenance within the area indicated. Our native Jojoba, *Simmondsia chinensis* (Link) C.K.Schneid. does not occur in China, but the nomenclatural rules did not prevent Link from naming the species *Buxus chinensis* Link.

Over the last 123 years, *Bromus arizonicus* has been collected in various Central and Southern California locations: **Paso Robles 1899, 1900**; San Luis Obispo 1899; Tulare 1897; Bakersfield 1896; Liebre Mts 1896; Pasadena 1894, 1902, 1904; Altadena 1900; Claremont 1902; San Bernardino 1889; Redlands 1902, San Diego 1884, 1896; Santa Cruz Island 1888; Santa Catalina Island 1890; and others (data from Consortium of California Herbaria, ucjeps.berkeley.edu/consortium/). Munz (1959) in *A California Flora*, Twisselmann (1967) in *A Flora of Kern County, California*, Hoover (1970) in *The Vascular Plants of San Luis Obispo County*, Munz (1974) in *A Flora of Southern California*, Wilken and Painter (1993) in *The Jepson Manual*, and Pavlick and Anderton (2006) for *Flora North America*, all considered *Bromus arizonicus* to be a California native.

Confusion surrounding *Bromus arizonicus* still exists owing to assignment of the cultivar 'Cucamonga', collected from near Cucamonga, CA in 1939, to *Bromus carinatus* by the SCS. *Bromus carinatus* is part of a widespread allooctoploid ($2n = 8x = 56$) complex of *Bromus* subgenus *Ceratochloa* that extends from Alaska to the Andes. *Bromus arizonicus* is assigned to *Ceratochloa* based on general morphology, but is an allododecaploid ($2n = 12x = 84$) resulting from hybridization between hexaploid ($2n = 6x = 42$) *B. catharticus* and hexaploid ($2n = 6x = 42$) *B. berteroanus* (Stebbins et al. 1944). **The correct assignment for the cultivar 'Cucamonga' is *Bromus arizonicus* (C.L.Shear) Stebbins 'Cucamonga'**.

***Achillea millefolium* L. ssp. *lanulosa* (Nutt.) Piper**

Many subspecies and varieties have been segregated within the highly morphologically and ecologically variable circumboreal *Achillea millefolium* complex. At least nine infraspecific names have been applied to native California *Achillea*. This is the Western Yarrow or Common Yarrow subspecies native to Western North America, as opposed to ssp. *millefolium* native to Europe. The complex was used in the 1940s by Clausen, Keck, and Hiesey for their classic studies of speciation. Following Cronquist (1994) in the *Intermountain Flora* (5: 134), all native tetraploids ($2n = 36$) are assigned to ssp. *lanulosa* [≡ *Achillea lanulosa* Nutt.]. This subspecies is represented throughout San Luis Obispo County, but now lesser so in the formerly grain-farmed areas around Paso Robles.

I have stressed for years that ssp. *lanulosa* is an excellent plant for erosion control owing to its rhizomatous habit and sediment-trapping leaves, a fact demonstrated in rainfall simulator trials using SR 46 soils (see Caltrans 2005. CTSW-RT-04-069.06.1). The problem is with obtaining truly native material because much of what is sold in California as just *Achillea millefolium* is European. S&S Seed sells "native" *Achillea lanulosa*, and three cultivars of alien *Achillea millefolium*. If the native ssp. *lanulosa* [≡ *Achillea lanulosa* Nutt.] is not specified by Caltrans, then most likely the more readily available and cheaper alien *Achillea millefolium* will be purchased by landscape contractors.

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Cool-Season vs Warm-Season Grass Germination Temperatures

`"To my knowledge, cool season grasses do not germinate better in cool seasons than warm season grasses.  The[y] both germinate at about the same temperatures, just at different seasons."` (email 04/12/2007, John Haynes to William Andersen)

Much confusion exists over the terms "cool-season grass" and "warm-season grass". Cool versus Warm are merely poor surrogate terms for the real photosynthetic pathway differences that exist among phylogenetic groups within the grass family. Cool-Season grasses are those that use the C_3 photosynthetic pathway where three-carbon phosphoglycerate (PGA) is the first product of carbon fixation catalysed by ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBisCO). RuBisCO is a relatively poor enzyme and its oxygenase capacity leads to ribulose-1,5-bisphosphate combining with O_2 and the ultimate release of CO_2 in a photosynthetically wasteful process termed *photorespiration*. In contrast, Warm-Season grasses use C_4 pathways where the first product of CO_2 fixation is a four-carbon acid, typically oxaloacetate (OAA), further converted to malate, then decarboxylated after transport into close proximity to RuBisCO and other components of the C_3 pathway (*photosynthetic carbon reduction* [PCR] cycle). Plants that use C_4 often exhibit distinctive leaf anatomy that promotes segregation of the PCR cycle into bundle sheath cells containing many chloroplasts. Although C_4 apparently evolved as an adaptation to severe CO_2 deficits or water stress, C_4 plants are most common in situations where the coincidence of high light/high temperature/high moisture is greatest, as many species (e.g., maize, sorghum) are unable to tolerate severe water stress.

Cool-Season (C_3) grasses exhibit both a germination and growth temperature optimum between 20 and 25 C (68 and 77 F); whereas, Warm-Season (C_4) grasses exhibit both a germination and growth temperature optimum between 30 and 35 C (86 and 95 F) [Jones 1992; Sage and Monson 1999]. Cool-Season (C_3) grasses include Bamboos, Rice, Stipoids, Melicoids, Pooids, Avenoids, Bromoids, and Triticoids. In San Luis Obispo County, 92% of all perennial grasses, and 86% of all annuals, are Cool-Season (C_3) grasses. Warm-Season (C_4) grasses are few owing to the near absence of rainfall between May and September when hot-temperature active C_4 grasses need water for photosynthesis, growth, and reproduction. It is simply too dry for C_4 grasses in summer, and too cold in winter when soil water is present. Only two Chloridoid species, Deer Grass, *Muhlenbergia rigens*, and Saltgrass, *Distichlis spicata*, are capable of persisting through the dry summer confined to watercourses or high water tables. Thus, Warm-Season (C_4) grasses are inappropriate for SR 46 erosion control.

Timing of Seed Application

`"There is damn little chance of getting ANY seed to germinate in much of the state during December through February."` (email 04/12/2007, John Haynes to William Andersen)

This statement is obvious hyberbole and absurd on its face. In the lower elevations (non-montane) of California that experience a Semi-Arid to Arid Mediterranean climate, the months of December through February are the only months of reliable precipitation. Native and alien plant species adapted to such climate regimes do germinate during those months if sufficient soil water is not available before December because in the lower elevations soils do not freeze during winter. The California Floristic Province exhibits an unusually high percentage of native annuals for any continental province in the world with over 1100 species or over 27% of the native flora (Raven and Axelrod 1978). The flora now includes hundreds of alien annual species including over 50 common annual grasses that now dominate the ruderal grasslands that constitute over 15% of the state's present landcover (Huenneke 1989). Owing the compressed and inconsistent rainfall season experienced over much of these cismontane grasslands, including locations such as Paso Robles, if these annuals did not germinate during December through February then we would not see the hills turn from tawny to green during an entire year.

Most of the familiar alien C_3 annual grasses (*Avena, Bromus, Lolium, Vulpia*), and some of our native C_3 annuals (*Bromus, Vulpia*), are capable of germination in the presence of sufficient water once a critical high temperature threshold (> 30C, 86F) is reached for a sufficient duration, usually a few weeks (Baskin and Baskin 1998). As many people have experienced anecdotally in their own yards, farms, or ranches, these annuals do germinate and will go during hotter summer temperatures if adequate soil water is present.

As for germination by native perennial grasses during winter, a case-in-point is the highly successful establishment of native stands near Winters cited previously (Bugg et al. 1997) where the authors state that on 14 January 1992 seed of the 12 native and 3 Cool-Season perennial grasses sown was hand-broadcasted and incorporated using a harrow. By 22-25 May 1992 canopy cover was grown enough for cover assessments to be made as measurement of success.

As for the contract language in question

> ("Erosion control applied during December thru March which have failed to germinate after 25 working days shall be re-seeded. Erosion control applied during April thru November which have failed to germinate after 40 working days shall be re-seeded."),

I suggest altering the language to read "Erosion control applied during November thru April which have failed to germinate after 25 working days shall be re-seeded." If the contractor is required to irrigate enough to enable sufficient germination by the native grasses of the seed mix, and whatever else may be in the soil seed bank, then there should be no problem meeting the 25 working day stipulation during November thru April. The 40 working day stipulation during the dry season can be removed, if this appears unreasonable, but the annual grasses specified and present on-site are capable of germinating during April thru November if both **adequate and consistent water** is applied for germination and growth. A one-shot application of water in July or August when high temperatures are consistently above 90F would be just enough to cause germination followed by certain death for all seedlings.

Legume Seed Inoculation

Here is an excerpt from Legume Seed Inoculation for Highway Planting in California. CTSW-RT-06-167.01.2. I recommend that every Caltrans Landscape Architect read at least the Executive Summary to understand why the following problems with present practices argue against the cost effectiveness of continuing to require legume seed inoculation under SS 22-2.10:

1) the largely undocumented effectiveness of non-native cultured rhizobia at augmenting N_2-fixation for native legume species seeded by Caltrans;
2) the likely desiccation and death of rhizobia before, during, and after application of legume seed;
3) the typically low legume seeding rates (0.2-3 plants per ft^2) on most projects;
4) the very negative effects on rhizobia when inoculated seed is hydroapplied; and
5) the contravening use of commercial N fertilizer to promote rapid plant cover that inhibits rhizobial inoculation and nodulation.

Rebuttal to Criticism of
SR 46 Corridor Improvement Project Erosion Control Specifications
30 October 2008

Closing Comments

As I write this rebuttal after a full week at my 40+ hr/week job setting-up lab exercises for courses in Botany, Plant Taxonomy, and Physiology (where I literally wash dishes, sweep floors, and take out the trash so I can keep a "permanent" State job with benefits), I can't help but shake my head at the situational irony where landscape architects working for the Department of Transportation in the state with the world's fifth-largest economy are arguing about issues that they should have resolved long ago, and have to appeal to an outside "authority" who put his time in, read the primary literature and the "big books", earned 184 quarter-units of science coursework and a Master of Science degree in Biology, taught himself grass taxonomy, and spent thirty-years doing fieldwork. Why? Because, they can't or won't find and evaluate for themselves the information necessary. Thus, these matters become battles of "experts".

There is a hard truth that Caltrans needs to face and it is this: the majority of Landscape Architects in the agency have inadequate backgrounds in basic plant biology, ecology, identification, taxonomy, and nomenclature to effectively execute revegetation projects, especially those that interface with wildland, or use native species/cultivars.

I suggest that Caltrans seriously consider 1) hiring one or more real plant ecologists with appropriate backgrounds to oversee and review revegetation specifications and project plans; and 2) use these plant ecologists to conduct ongoing in-house training for landscape architects in the basic plant biology, ecology, identification, taxonomy, and nomenclature that they lack.

References

Baskin CC, and Baskin JM. 1998. *Seeds: Ecology, Biogeography, and Evolution of Dormancy and Germination*. San Diego: Academic Press.

Bugg RL; Brown CS; and Anderson JH. 1997. Restoring native perennial grasses to rural roadsides in the Sacramento Valley of California: establishment and evaluation. *Restoration Ecology* 5(3): 214-228.

California Department of Transportation (Caltrans). 2001. Vegetation Establishment For Erosion Control Under Simulated Rainfall. CTSW-RT-01-078.

California Department of Transportation (Caltrans). 2002. Evaluating Hydroseeding & Plug Planting Techniques For Erosion Control & Improved Water Quality. CTSW-RT-02-052.

California Department of Transportation (Caltrans). 2004. Effectiveness of Planting Techniques for Minimizing Erosion. CTSW-RT-04-004.69.01.

California Department of Transportation (Caltrans). 2005. Performance of Erosion Control Treatments on Reapplied Topsoil. CTSW-RT-04-069.06.1-D1

California Department of Transportation (Caltrans). 2001. District 5 Advisory Guide To Plant Species Selection For Erosion Control. CTSW-RT-01-079.

California Department of Transportation (Caltrans). 2005. Native Shrub Germination relative to Compost Type, Application Method, and Layer Depth. CTSW-RT-05-069.06.2.

California Department of Transportation (Caltrans). 2006. Legume Seed Inoculation for Highway Planting in California. CTSW-RT-06-167.01.2.

Hickman JC. (ed.) 1993. *The Jepson Manual: Higher Plants of California*. Berkeley, CA: University of California Press.

Hoover RF. 1970. *The Vascular Plants of San Luis Obispo County, California*. Berkeley: University of California Press.

Huenneke LF. 1989. Distribution and regional patterns of California grasslands. pp. 1-12 In Huenneke, LF; Mooney, H. (eds.), *Grassland Structure and Function: California Annual Grassland*. Dordrecht: Kluwer Academic Publishers.

Jones HG. 1992. *Plants and Microclimate: A Quantitative Approach to Environmental Plant Physiology*. ed. 2. Cambridge: Cambridge University Press.

Lindsey WC. 1983. Soil Survey of San Luis Obispo County, California, Paso Robles Area. USDA Soil Conservation Service/University of California Agricultural Experiment Station. 20 Maps: USGS 7.5 minute (1:24000) quadrangles.

Raven PH, and Axelrod DI. 1978. Origins and relationships of the California Flora. *University of California Publications in Botany* **72**: 1-134.

Rivas-Martínez S; Sánchez-Mata D; Costa M. 1999. North American Boreal and Western Temperate Forest Vegetation. Syntaxonomical synopsis of the potential natural plant communities of North America II. *Itinera Geobot.* 12: 5-316.

Sage RF; Monson RK (eds). 1999. *C_4 Plant Biology*. San Diego: Academic Press.

Stebbins GL; Tobgy HA; and Harlan JR. 1944. The cytogenetics of hybrids in *Bromus*: *Bromus carinatus* and *Bromus arizonicus*. *Proc. Calif. Acad. Sci.*, Ser IV, 25(13): 307-322.

Trewartha GT; Horn LH. 1983. *An Introduction to Climate.* ed. 5. New York: McGraw-Hill.

Twisselmann, E. C. 1956. A flora of the Temblor Range and the neighboring part of the San Joaquin Valley. *Wasmann J. Biol*. 14: 161-300.

United States Department of Transportation Highway Administration (FHA) and California Department of Transportation (Caltrans). 2003. Route 46 Corridor Improvement Project Environmental Assessment/Draft Environmental Impact Report. San Luis Obispo, CA: District 5.

APPENDIX H.8

RECOMMENDATIONS REGARDING PRE-CONSTRUCTION EROSION CONTROL TRIALS

Contract 43A0167 | Expert Assistance Task Area

Recommendations Regarding Pre-Construction Erosion Control Trials

Prepared For

STATE OF CALIFORNIA

DEPARTMENT OF TRANSPORTATION

Project Plans for Pre-Construction on

Prunedale Improvement Project (PIP)

US HIGHWAY 101

Monterey County

DRAFT

June 2006

1.1 Purpose

At the request of Project Landscape Architects for the US 101 Prunedale Improvement Project (PIP), **Figure 1**, these recommendations regarding **pre-construction erosion control trials** were prepared under the Expert Assistance Task Area of the Roadside Erosion Control & Maintenance Study in progress through the Earth and Soil Sciences Department at Cal Poly State University, San Luis Obispo, under contract with the Office of Water Programs at Sacramento State University, and Caltrans Division of Design.

The primary purpose of establishing pre-construction erosion control trials is to take advantage of pilot construction along the Echo Valley Road realignment west of US 101 to evaluate combined erosion control and vegetation establishment methods that may be effective throughout the US 101 Prunedale Improvement Project corridor after project construction is initiated.

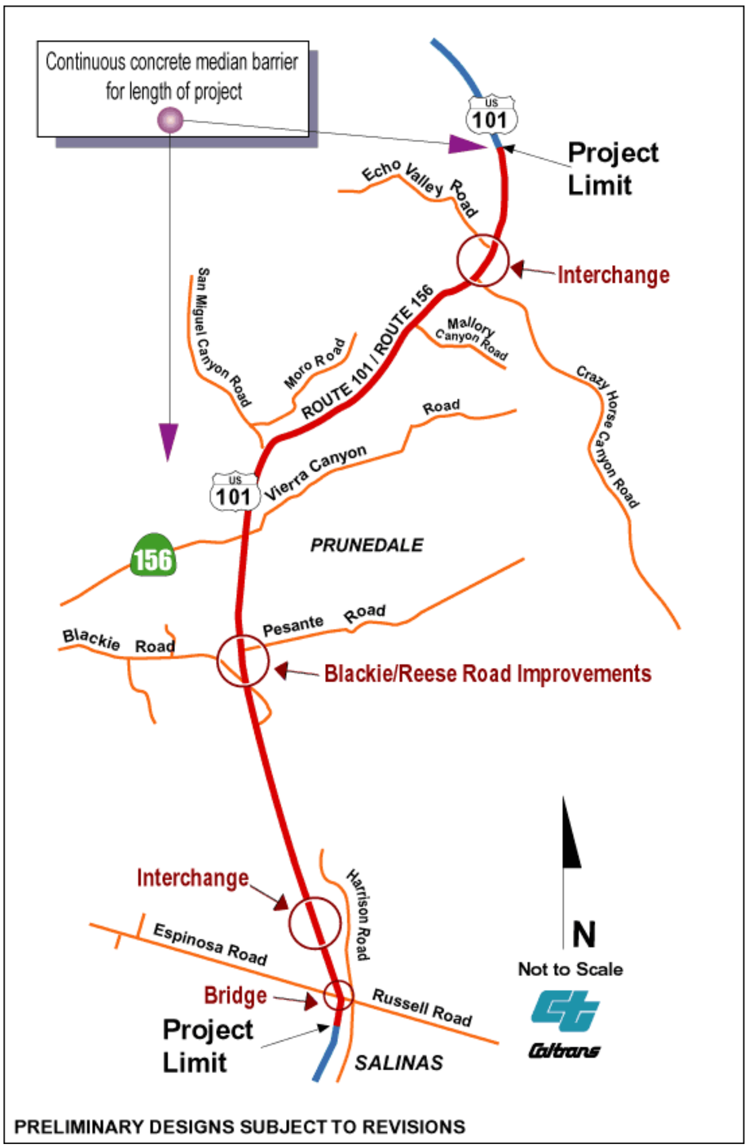


Figure 1. US 101 Prunedale Improvement Project Preliminary Designs.

1.2 Basis for Recommendations

Recommendations offered are based on: **1**) site visits to the proposed US 101 Prunedale Improvement Project segments; **2**) research conducted under the previous Vegetation Establishment and Maintenance Study (CTSW-RT-01-078, CTSW-RT-01-079, CTSW-RT-02-052, CTSW-RT-04-004.69.01, CTSW-RT-04-069.06.1-D1, CTSW-RT-05-069.06.2); and **3**) years of general and local experience held by the observers.

1.3 Conditions and Limitations

Roadside revegetation projects present substantial challenges to successful development of desired plant associations and vegetation structure. Cut or fill slopes are often steeply inclined, highly compacted, and lacking topsoil. Given the typically contracted season of favorable growing temperatures in conjunction with adequate rainfall, planned revegetation is inherently precarious at best. The US 101 Prunedale Improvement Project will necessitate erosion control and revegetation measures on steep slopes of highly erosive soils.

1.3.1 Reapplied Topsoil

Excavated topsoil is sometimes stockpiled for reapplication of pre-existing organic matter, soil microbes, and seed as both an inexpensive means of erosion control, and as a method to re-establish vegetation consistent with the surrounding context. However, stockpiled seedbanks may include undesirable, naturalized alien species that inhibit establishment of desired native species.

If high quantities of viable seed from naturalized alien species exist in reapplied topsoil, addition of seed of native species, whether from local or non-local sources, may be wholly ineffective at establishing against aggressive competition for water from naturalized alien species.

In a landscape context dominated by naturalized alien species, re-establishment of native plants should focus on sites where specific management objectives necessitate promotion of local native genotypes, especially if local native plant genotypes are known to be host plants or food sources for locally important wildlife species.

1.3.2 Compost

For these trials, “compost’ refers to an approved and mature municipal or commercial compost derived from agricultural, food, or industrial residuals, biosolids (treated sewage sludge), yard trimmings, source-separated, or mixed solid waste, and that is well-decomposed, stable, and weed free (adapted from Alexander 2003).

According to Caltrans specifications, the compost producer shall be fully permitted in accordance with requirements of the California Integrated Waste Management Board (CIWMB), Local Enforcement Agencies (LEA) and any other State and Local Agencies that regulate Solid Waste Facilities. If exempt from State permitting requirements, the composting facility shall certify that it follows all guidelines and procedures for production of compost meeting the environmental health standards of Title 14, California Code of Regulations, Division 7, Chapter 3.1, Article 7.

Compost shall be derived from any single, or mixture of the following feedstock materials:

A. Green material consisting of chipped, shredded, or ground vegetation; or clean processed recycled wood products.
B. Class A, exceptional quality biosolids composts, conforming to the requirements in United States Environmental Protection Agency (EPA) regulation 40 CFR, Part 503b.
C. Manure.
D. Mixed food waste.

Feedstock materials shall be composted to reduce weed seeds, pathogens and deleterious materials in conformance with Title 14, California Code of Regulations, Division 7, Chapter 3.1, Article 7, Section 17868.3

Compost shall not be derived from mixed municipal solid waste and shall be reasonably free of visible contaminates. Compost shall not contain paint, petroleum products, herbicides, fungicides or any other chemical residues harmful to animal life or plant growth. Compost shall possess no objectionable odors.

Metal concentrations in compost shall not exceed the maximum metal concentrations listed in Title 14, California Code of Regulations, Division 7, Chapter 3.1, Section 17868.2.
Physical contaminants (man-made inerts) shall be less than 1% when measured by dry weight basis.

Compost shall conform to the following:

Physical/Chemical Requirements		
Property	**Test Method**	**Requirement**
pH	TMECC 04.11-A, "1:5 Slurry pH"	6.0–8.5
Soluble Salts	TMECC 04.10-A, "1:5 Slurry Method, Mass Basis"	0-10.0 dS/m
Moisture Content	TMECC 03.09-A "Total Solids and Moisture at 70+/- 5 degrees C"	30-60%
Organic Matter Content	TMECC 05.07-A, "Loss-On-Ignition Organic Matter Method"	25–65% (dry mass)
Maturity (Bioassay)	TMECC 05.05-A, "Seedling Emergence and Relative Growth"	> 80%
Stability (Respirometry)	TMECC 05.08-B, "Carbon Dioxide Evolution Rate"	8 or below
Particle Size	TMECC 02.02-B, "Sample Sieving for Aggregate Size Classification"	Millimeters — Percent Passing 25.00 — 85-100% 12.50 — 65-80% 6.35 — 40-70% 2.38 — 20-50% 1.50 — 0-35% Maximum particle length 100 mm
Pathogen (Fecal Coliform)	TMECC 07.01-B, "Fecal Coliforms"	Pass
Trace Metals	TMECC 04.06, **"**Heavy Metals and Hazardous Elements":	Pass
	4.06-As, Arsenic 4.06-Cd, Cadmium 4.06-Cu, Copper 4.06-Pb, Lead 4.06-Hg, Mercury 4.06-Mo, Molybdenum 4.06-Ni, Nickel 4.06-Se, Selenium 4.06-Zn, Zinc	

TMECC refers to "Test Methods for the Examination of Composting and Compost," published by the United States Department of Agriculture and the United States Compost Council (USCC).

Prior to compost application, the Contractor shall provide the Engineer with a copy of the compost producer's Compost Technical Data Sheet and a copy of the compost producers STA certification. The Compost Technical Data Sheet shall include laboratory analytical test results, directions for product use, and a list of product ingredients.

Prior to compost application, the Contractor shall provide the Engineer with a Certificate of Compliance in conformance with the provisions in Section 6-1.07, "Certificates of Compliance," of the Standard Specifications.

Compost shall conform to the following:

Property	**Test Method**	**Hydroseed**
pH	TMECC 04.11-A “1:5 Slurry pH”	6.0-8.5
Soluble Salts (Electrical Conductivity)	TMECC 04.10-A “1:5 Slurry Method, Mass Basis”	0-10.0 dS/m
Secondary Content	TMECC 04.05 “Secondary and Micro-Nutrient Content” % by Weight 04.05-Na Sodium 04.05-Cl Chloride	< 0.5% < 0.5%
Moisture Content	TMECC 03.09-A "Total Solids and Moisture at 70+/- 5 degrees C” %, Wet weight basis	30-60%
Organic Matter Content	TMECC 05.07-A “Loss-On-Ignition Organic Matter Method (LOI)” %, Dry weight basis	30–65% (dry mass)
Maturity (Bioassay)	TMECC 05.05-A “Germination and Vigor” Seed Emergence Seedling Vigor % Relative to positive control	80-100% 80-100%
Stability (Respirometry)	TMECC 05.08-B “Carbon Dioxide Evolution Rate” mg CO_2-C per g OM per day	8 or below
Particle Size	TMECC 02.02-B “Sample Sieving for Aggregate Size Classification” % Dry Weight Basis	Inches % Pass 5/8 95% 3/8 70%
Pathogen (Fecal Coliform)	TMECC 07.01-B “Fecal Coliforms”	Pass <1000 MPN/gram
Pathogen (Salmonella)	TMECC 07.02 “Salmonella”	Pass <3 MPN/4 grams of TS
Physical Contaminants (Man-made inerts)	TMECC 02.02-C “Man Made Inert Removal and Classification” Plastic, Glass & Metals Sharps % > 4 mm fraction	< 1% None Detected

1.4 Trial Design

This trial is intended to evaluate compost versus fiber soil blankets, the effectiveness of grasses and sedges as sediment filters, and establishment from seed of selected native plant species.

Specifically, the design is an attempt to assess the following.

- **Sediment Detachment**
  Effectiveness of a 2 inch topical layer of mature compost (screened to particles ≤ ¼ inch) covered with 1 inch jute netting as an erosion control blanket.

  Effectiveness of a topical layer of fiber (2000 lb/ac) covered with 1 inch jute netting as an erosion control blanket.

- **Sediment Filtration**
  Effectiveness of grass or sedge sod strips (*Agrostis pallens, Carex praegracilis, Hordeum brachyantherum*) as sediment filters when positioned at the toe of a 30 ft slope run.

  Effectiveness of a sedge sod strip (*Carex praegracilis*) in conjunction with a large tussock grass (*Muhlenbergia rigens*) as a sediment filter when positioned at midslope of a 30 ft slope run.

- **Seed Bed**
  Effectiveness of a 2 inch topical layer of mature compost (screened to particles ≤ ¼ inch) as a seedbed for hydroseeding.

  Effectiveness of a topical layer of fiber as a seedbed for hydroseeding.

1.4.1 Treatments

Trtmnt	EC Blanket	Jute	ToeStrip	ToeGrassRov	SideGrassRow	Seed
1	Fiber (@ 2000 lb / ac	**OVER**	Absent	**Present**	**Present**	Mix 1 OVER (fiber @ 500 lb / ac
2	Fiber (@ 2000 lb / ac	**OVER**	AGROpall	**Present**	**Present**	Mix 1 OVER (fiber @ 500 lb / ac
3	Fiber (@ 2000 lb / ac	**OVER**	CAREprae	**Present**	**Present**	Mix 1 OVER (fiber @ 500 lb / ac
4	Fiber (@ 2000 lb / ac	**OVER**	HORDbrac	**Present**	**Present**	Mix 1 OVER (fiber @ 500 lb / ac
5	Compost (2 in layer)	**OVER**	AGROpall	**Present**	**Present**	Mix 1 OVER (fiber @ 500 lb / ac
6	Compost (2 in layer)	**OVER**	CAREprae	**Present**	**Present**	Mix 1 OVER (fiber @ 500 lb / ac
7	Compost (2 in layer)	**OVER**	HORDbrac	**Present**	**Present**	Mix 1 OVER (fiber @ 500 lb / ac
8	Compost (2 in layer)	**OVER**	Absent	**Present**	**Present**	Mix 1 OVER (fiber @ 500 lb / ac
9	Fiber (@ 2000 lb / ac	**OVER**	Absent	Absent	Absent	Mix 1 OVER (fiber @ 500 lb / ac
10	Fiber (@ 2000 lb / ac	**OVER**	AGROpall	Absent	Absent	Mix 1 OVER (fiber @ 500 lb / ac
11	Fiber (@ 2000 lb / ac	**OVER**	CAREprae	Absent	Absent	Mix 1 OVER (fiber @ 500 lb / ac
12	Fiber (@ 2000 lb / ac	**OVER**	HORDbrac	Absent	Absent	Mix 1 OVER (fiber @ 500 lb / ac
13	Compost (2 in layer)	**OVER**	AGROpall	Absent	Absent	Mix 1 OVER (fiber @ 500 lb / ac
14	Compost (2 in layer)	**OVER**	CAREprae	Absent	Absent	Mix 1 OVER (fiber @ 500 lb / ac
15	Compost (2 in layer)	**OVER**	HORDbrac	Absent	Absent	Mix 1 OVER (fiber @ 500 lb / ac
16	Compost (2 in layer)	**OVER**	Absent	Absent	Absent	Mix 1 OVER (fiber @ 500 lb / ac

1.4.2 Design Configuration

Each Plot (ft) L	W	ft2	Plots	Total ft2	Total acre
30	10	300	16	**4800**	**0.11**

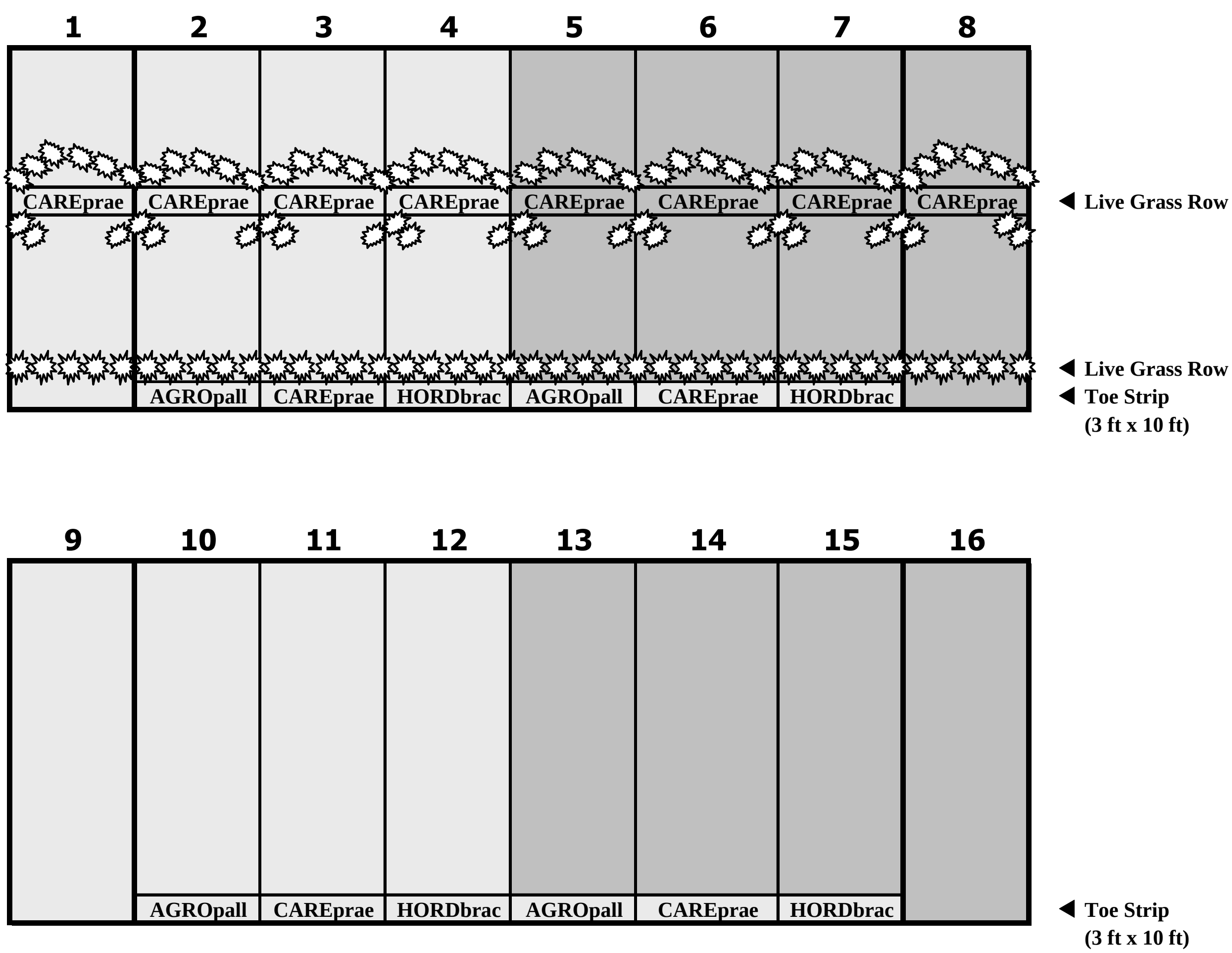
Fiber @ 2000 lbs / ac

Compost (2 in deep layer)
≈ 16 yd3 (2460 ft2 x 2 in deep x 0.0031)
Screened to ≤ 0.25 inch particles

CAREprae **Sod Strip (3 ft x 10 ft)**

Muhlenbergia rigens @ 1 gallon
at 2 ft on center

AGROpall **Agrostis pallens (diegoensis)**
CAREprae **Carex praegracilis**
HORDbrac **Hordeum brachantherum**

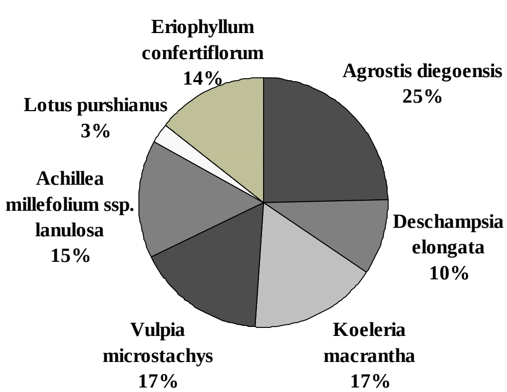


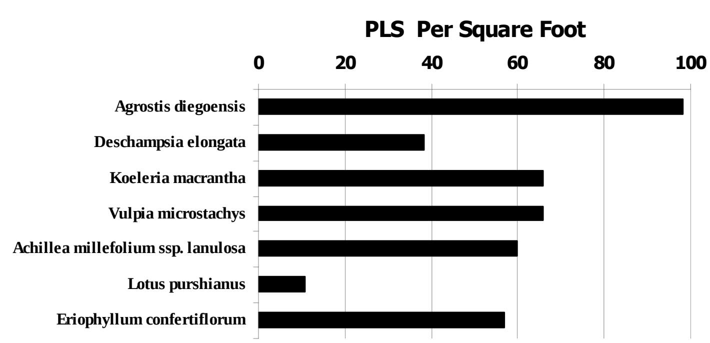
1.4.3 Seed Mix 1: Native Grasses, Forbs, Shrubs

Taxonomic References: Hickman 1993; Matthews 1997

SCIENTIFIC NAME	ENGLISH NAME	CULTIVAR	FAMILY	Percent_of_Mix_count	Percent_of_Mix_weight	PLS/ft2	lb-PLS/ac
Native Perennial Rhizomatous Grass							
Agrostis diegoensis Vasey	Thingrass	unspecified	Poaceae	25%	5%	98	**1**
Native Perennial Tufted Grass							
Deschampsia elongata (Hook.) Munro	Slender Hairgrass	unspecified	Poaceae	10%	5%	38	**1**
Koeleria macrantha (Ledeb.) Schult.	Junegrass	unspecified	Poaceae	17%	23%	66	**5**
Native Annual Grass							
Vulpia microstachys (Nutt.) Benth.	Small Fescue	unspecified	Poaceae	17%	18%	66	**4**
Native Perennial Rhizomatous Forb							
Achillea millefolium L. ssp. **lanulosa** (Nutt.) Piper	Common Yarrow	unspecified	Asteraceae	15%	5%	60	**1**
Native Annual Forb							
Lotus purshianus (Benth.) Clem. & Clem.	Spanish Lotus	unspecified	Fabaceae	3%	23%	11	**5**
Native Shrub							
Eriophyllum confertiflorum (DC) A.Gray	Golden Yarrow	unspecified	Asteraceae	14%	23%	57	**5**
				100%	**100%**	**396**	**22**

Percent of Mix By Seed Count Per Ft^2





1.4.4 Slope Toe Treatments

Listed below are plant materials suitable for application as flats ("sod strips") of living plants at slope toes to filter sediment. All are rhizomatous sod-formers.

Flats are typically the 16″ to 18″ square ground-cover flats grown by wholesale nurseries. Flats are produced by broadcasting seed, or by installing from nine to thirty-six 1.5″ to 2″ plugs into planting mix over coir or burlap matting. Nursery production of > 90% plant cover typically requires 60 to 120 days.

Other possibilities include contract-growing of larger vegetated erosion control mats, such as the 4′ x 66′ mats custom grown ($2.00 per linear ft) for revegetation by the National Park Service (van der Grinten and Gregory 2000).

Caltrans is developing a sod-strip specification written first for the SR46 Improvement Project. (See Linda Baker, LA, District 5)

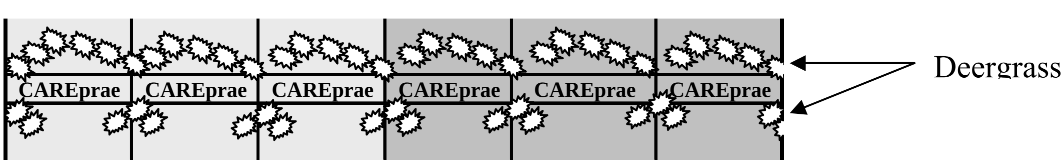
SCIENTIFIC NAME	ENGLISH NAME	CULTIVAR	FAMILY
Native Perennial Rhizomatous Grass			
Agrostis diegoensis Vasey	Thingrass	unspecified	Poaceae
Hordeum brachyantherum Nevski	Meadow Barley	unspecified	Poaceae
Native Perennial Rhizomatous Sedge			
Carex praegracilis W.Boott	Clustered Field Sedge	unspecified	Cyperaceae

1.4.5 Side-Slope Plantings

1.4.5.1 Mid-Slope Grass Filter-Rows

To form the side-slope grass filter-rows, flats or strips of Clustered Field sedge would be stapled on top of the jute-compost or BFM in a contiguous strip across the slope face. Deergrass would be installed two feet apart on the uphill side of the sedge strips, and in triads every 10 feet on the downhill side of the sedge strip.

SCIENTIFIC NAME	ENGLISH NAME	CULTIVAR	FAMILY
Native Perennial Rhizomatous Sedge			
Carex praegracilis W.Boott	Clustered Field Sedge	unspecified	Cyperaceae
Native Perennial Tufted Grass			
Muhlenbergia rigens (Benth.) A.S. Hitchc.	Deer Grass	unspecified	Poaceae



1.4.5.2 Optional Shrubs

Listed below are some optional plant materials suitable for planting from 4-inch, 5½ inch, or 1-gallon containers. Other species or cultivars may be suitable also. Exact numbers of plants required and spacing are dependent on size of the trial plots to be determined by the experimental site selected.

SCIENTIFIC NAME	ENGLISH NAME	CULTIVAR	FAMILY
Native Shrubs			
Artemisia californica Less.	California Sagebrush	'Montara'	Asteraceae
Ceanothus thyrsiflorus Eschsch. var. **griseus** Trelease	Carmel Ceanothus	'Yankee Point'	Rhamnaceae
Rhamnus californica Eschsch.	California Coffeeberry	'Mound San Bruno'	Rhamnaceae
Salvia mellifera Greene	Black Sage	'Aromas'	Lamiaceae

1.5 References

Alexander, R. 2003. Landscape Architect Specifications for Compost Utilization. Technical Report. CWC/PNWER and The US Composting Council.

California Department of Transportation (Caltrans). 2001. Vegetation Establishment For Erosion Control Under Simulated Rainfall. CTSW-RT-01-078.

California Department of Transportation (Caltrans). 2001. District 5 Advisory Guide To Plant Species Selection For Erosion Control. CTSW-RT-01-079.

California Department of Transportation (Caltrans). 2002. Evaluating Hydroseeding & Plug Planting Techniques For Erosion Control & Improved Water Quality. CTSW-RT-02-052.

California Department of Transportation (Caltrans). 2004. Effectiveness of Planting Techniques for Minimizing Erosion. CTSW-RT-04-004.69.01.

California Department of Transportation (Caltrans). 2005. Performance of Erosion Control Treatments on Reapplied Topsoil. CTSW-RT-04-069.06.1-D1

California Department of Transportation (Caltrans). 2005. Native Shrub Germination relative to Compost Type, Application Method, and Layer Depth. CTSW-RT-05-069.06.2.

Hickman, JC. (ed.) 1993. *The Jepson Manual: Higher Plants of California*. Berkeley, CA: University of California Press.

Matthews, M. A. 1997. *An Illustrated Field Key to the Flowering Plants of Monterey County: and Ferns, Fern Allies, and Conifers*. Sacramento: California Native Plant Society.

van der Grinten, M.; Gregory, LL. 2000. Vegetated erosion control mats for site stabilization. *Native Plants Journal* **1**(2): 121-122.

Scott,

Here are my brief answers to your questions about the trials conducted for the Prunedale Improvement Project. I have extracted and paraphrased your questions as I understand them.

Are there any conclusions or lessons learned that we can gather or assume from this [poor germination of native seed mix hand-broadcast under barley/wheat straw and jute]?

First, I want to state that the establishment method used for these preliminary trials of hand-broadcasting a "native" seed mix under barley/wheat straw and jute is not a method I recommended, nor would ever recommend for the mix of species/cultivars that I suggested. On page seven, section 1.4.1, of the "Recommendations Regarding Pre-Construction Erosion Control Trials, Project Plans for Pre-Construction on Prunedale Improvement Project (PIP), US Highway 101, Monterey County", I specified that the mix be applied over a two-inch layer of compost, or fiber at 2000 lbs/ac (either covered by jute netting), because the species/cultivars suggested are intolerant of burial greater than a quarter-inch or so. Thus, I am not surprised that these species/cultivars show poor germination and/or survival, especially given the straw mulch and the inadequate and inconsistent precipitation during the past six months: Aromas 10.47 in; Salinas 8.84 in; San Juan Bautista 8.80 in, when all three average 14 in to 18 in annually. Please note the coincidence of mid-day shadow and greener, denser grass growth that I outlined on the photo of Location B that you emailed (last page of this PDF).

Lessons Learned:

1) **do not apply these natives under straw, 2” of compost, or thick fiber, BFM, etc.;**
2) **irrigate if at least 1” of rainfall has not occurred within each two-week period.**

Which is better [2" thick compost or temporary irrigation to establish native grasses and minimize erosion]?

As for the 2” of compost versus temporary irrigation at 15 minutes per day total, I’d opt for the 2” of compost. A 2” layer is intended primarily to protect from intense raindrop splash, to hold water from running off, to hold water for seed imbibition, germination, and growth, and to provide longer term, slower release nutrient additions.

Also, will native seeds germinate in 2" of compost or is it too hot?

Heat generated within a 2" of compost would be not be enough to kill live seed, and would likely aid germination of most natives during the cool-season. **But again, if you are going to specify application of seed under the 2" compost, then the species/cultivars must be those tolerant of such burial, not the seed mix that I specified for the trials.**

Would removal and reapplication of oak duff blended 50/50 with compost negatively affect germination or plant growth?

Mixing imported compost 50/50 with salvaged oak duff seems reasonable in that the existing soil seed bank, existing soil bacteria, and existing beneficial soil fungi (mycorrhizae-forming associates) will be returned to the site to presumably accelerate revegetation.

Is there a potential that after a certain amount of time a 4" layer of woodchips would breakdown prior to a landscape planting contract 3-4 years after chip application and not be effective for controlling erosion?

Certainly some breakdown would occur over 3-4 years, but given that breakdown is relatively slow in regions with dry-summer climates where the coincidence of adequate water and warm temperatures is brief, I do not see where a majority of wood chips would breakdown so far as to ineffective for erosion protection. Wood varies greatly among species in hardness (lignin content) and its resistance to breakdown by fungi capable of "breaking down" lignin.

Michael Curto
805-756-2164
mcurto@calpoly.edu
Biological Sciences
Cal Poly State University
San Luis Obispo, CA 93407

Mike and Brent,
Are you still available for consultation under Expert Assistance Contract #43A0167 for Prunedale Improvement Project Erosion Control?

If so here are my questions.....

In June of 2006 Mike prepared the document, "Recommendations Regarding Pre-Construction Erosion Control Trials". I implemented an abbreviated version of the pre-construction EC trials on site in mid-November 2006.
Due to budget constraints and construction issues we were limited to hand application techniques only. Although this does not simulate the proposed installation techniques for the main contract, I thought we could at least use this opportunity to see how the seed mix performed. Attached is the specification and site photos (before and after).

On March 21st I visited the site and was pleased to see minor erosion on the 2:1 cut slopes with seed, straw and jute netting, probably due to low intensity and infrequent rain events between November and March, however was disappointed to see minimal germination and growth of the native grasses. Are there any conclusions or lessons learned that we can gather or assume from this?

Also, I have been doing a lot of research on compost application, including your research results, and I am very excited about this technique to control erosion by increasing water holding capacity which minimizes water run-off, conditioning the soil to enhance plant growth, and increasing soil moisture content to promote seed germination. Based on this I am inclined to apply 2" thick compost on all cut slopes and potentially fill slopes. I have discussed this with various contractors and it is definitely feasible and cost effective at $60/cyd (supply and install). Prior to this revelation(?), I was proposing to install a temporary on-grade irrigation system on all cut and fill slopes greater than 12ft in height and apply compost only on the 100 ft cut slopes (with irrigation).

Because I can not afford to do both everywhere I am thinking to isolate the temporary irrigation for the big 100 ft cut slopes and apply compost on everywhere else (within reason). The benefit of this proposal is the ability to use a recyclable material (compost), minimize water use when water availability is a concern in the area and for California and minimize the waste of irrigation materials for a temporary application. Basically, instead of relying of temporary irrigation to establish native grasses and minimize erosion I would be relying on compost to minimize erosion. So my question is, if I had to choose one over the other, which is better????
Also, will native seeds germinated in 2 inches of compost or is it too hot?

I am also interested in using the Duff and chipped material from the large oak woodland that will be removed. It is a great resource and provides a great opportunity to re-use rather than take to a landfill or bury. I am also considering to blend this with the compost 50/50 however have concerns that the duff and chipped material may rob nitrogen from the soil and prohibit germination and plant growth. Is this a valid concern?

One last question. In talking with the contractors regarding pneumatic application of compost, they also mentioned pneumatic application of wood chips at $30/cyd. At 4 inches thick, would this be an effective erosion control application on isolated 2:1 fill slopes where ornamental landscape planting will be installed 3 - 4 years after application? After the plants are installed an additional 4" of wood chips would be applied. Is there a potential that after a certain amount of time the woodchips would breakdown prior to the planting contract and not be effective for controlling erosion?

Any insight or recommendations you can give are much appreciated. Thanks,

(See attached file: EC Recommendations_11-7-06.doc)(See attached file: Location B_2 After.JPG)(See attached file: Location B_2 Before.jpg)(See attached file: Location A_1 After.JPG)(See attached file: Location A_1 Before.JPG)(See attached file: Location A_2 After.JPG) (See attached file: Location B_1 After.JPG)(See attached file: Location B_1 Before.JPG)

SCOTT DOWLAN
LANDSCAPE ARCHITECT
Caltrans – District 5
Landscape Architecture Branch
50 Higuera Street, San Luis Obispo, CA 93401 805.542.4750
805.542.4746 fax

APPENDIX H.9

SEED MIXES FOR BIOSWALES

Contract 43A0167 | Expert Assistance Task Area

Seed Mixes for Bioswales

Prepared For

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION

CA HIGHWAY 118

Simi Valley

Ventura County

EA 116791

July 2006

1. Purpose

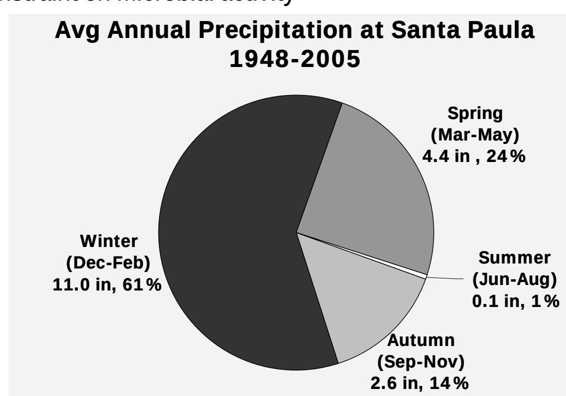
At the request of Joe Millman, District 7 Associate Landscape Architect, and Dennis Cadd, Headquarters Senior Landscape Architect and Task Manager for the Roadside Erosion Control & Maintenance Study, these recommendations regarding appropriate seed mixes for proposed bioswales along SR 118 in Simi Valley, Ventura County, were prepared under the Expert Assistance Task Area of the Roadside Erosion Control & Maintenance Study in progress through the Earth and Soil Sciences Department at Cal Poly State University, San Luis Obispo, under contract with the Office of Water Programs at Sacramento State University, and Caltrans Division of Design.

2. Seed Mix for Bioswales

2.1 Plant Materials Selection Parameters

Guidance on selection of appropriate species/cultivars for bioswales along VEN 118 is based on the following parameters. Hydroseed applications should use minimal fiber (500 to 700 lbs / ac) to avoid deep burial of seed.

Purpose	Bioswale
Sediment Retention	Likely to be high
Bioremediation	Slow given length of dry season constraint on microbial activity
Climate	
Precipitation	
Annual Average	14-20 in
Annual Range	5-38 in
Dry Season (<0.5 in/mo)	May through October
Temperature	
Day High Temp Max F	109
Days High Temp > 90F	16 to 20
Days Frost-Free	275 to 325
Ecoregion	
USFS Subsection	261Be (Simi Valley - Santa Susana Mountains)
NRCS MLRA	19d, 20d
Materials	
Provenance	
Species	Native of Simi Valley
Cultivar	Native of California
Installation Method	
Method	HydroSeed
Fiber Rate Maximum	500 to 700 lbs / ac
Water	
Establishment Regime	Native Precipitation
Supplemental Irrigation	None



2.2 Candidate Species/Cultivars

Given the parameters listed above, the five species listed below are the best candidates for bioswales along VEN 118. All are rhizomatous perennials capable of rapid establishment and lateral growth given at least 12 inches of annual precipitation. All are capable of tolerating seasonal inundation and drying. Given the typical May through October dry season (< 0.5 in PPT) in Simi Valley, together with many days above 85 F, all are expected to go summer-dormant, with little or no green herbage visible. Tall Fescue, a European alien, is listed as an option owing to its broad ecological tolerances, availability as many turf cultivars, and relatively low cost.

Name Scientific	Name English	Cultivar	"Weed" Status CIPC	"Weed" Status CDFA	"Weed" Status TNC
Perennial Forbs: Native					
Achillea millefolium L. ssp. **lanulosa** (Nuttall) Piper *syn*. Achillea millefolium L. var. californica (Pollard) Jepson *syn*. Achillea millefolium L. var. lanulosa (Nuttall) Piper Make sure that seed is subspecies *lanulosa* from a California location. The species ranges to Europe and some material sold is European.	**Common Yarrow**		---	---	---
Perennial Graminoids: Native					
Carex praegracilis W. Boott	**Clustered Field Sedge**		---	---	---
Perennial Grasses: Native					
Hordeum californicum Covas et Stebbins *syn*. Hordeum brachanytherum Nevski ssp. californicum (Covas et Stebbins) R.v.Bothmer, N.Jacobsen, O.Seberg Make sure that seed is *Hordeum californicum*, not *Hordeum brachyantherum* ssp. *brachyantherum* that is less tolerant of dry soil.	**California Barley**		---	---	---
Leymus triticoides (Buckl.) Pilger *syn*. Elymus triticoides Buckley	**Creeping Wildrye**	'Santa Paula' 'Rio'	---	---	---
Perennial Grasses: Alien					
Festuca arundinacea Schreb. *syn*. Lolium arundinaceum (Schreb.) S.J.Darbyshire *syn*. Schedonorus arundinaceus (Schreb.) Dumort., nomen cons.	**Tall Fescue**	'Arid' 'Bolero' 'Vista Dwarf'	Medium	---	High

"Weed" Status in California

CIPC = California Invasive Plant Council **CDFA** = California Department of Food and Agriculture **TNC** = The Nature Conservancy

California Department of Food and Agriculture Pest Ratings of Noxious Weed Species and Noxious Weed Seed

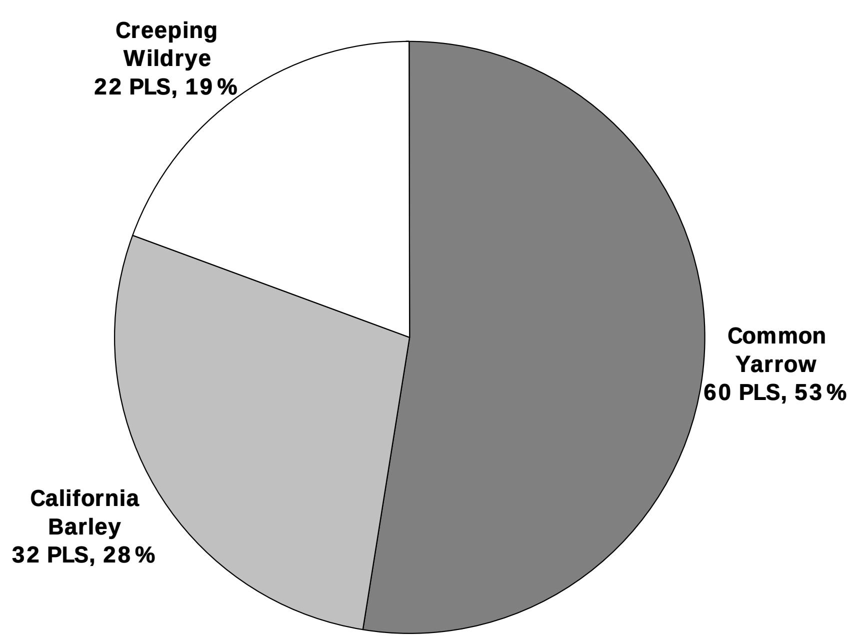
List	Explanation
A	Eradication, containment, rejection, or other holding action at the state-county level. Quarantine interceptions to be rejected or treated at any point in the state.
B	Eradication, containment, control or other holding action at the discretion of the commissioner.
C	State endorsed holding action and eradication only when found in a nursery; action to retard spread outside of nurseries at the discretion of the commissioner; reject only when found in a crop seed for planting or at the discretion of the commissioner.
Q	Temporary "A" action outside of nurseries at the state-county level pending determination of a permanent rating. Species on List 2, "Federal Noxious Weed Regulation" are given an automatic "Q" rating when evaluated in California

2.3 Seed Mix 1

Seed Mix 1 is better suited to drier, more saline, more sandy substrates. Ultimate height is likely 4 to 5 feet tall with Creeping Wildrye in the mix. The Creeping Wildrye cultivar 'Santa Paula' is the closest in geography and ecology to Simi Valley.

Species and quantities of pure live seed (PLS = % pure seed x % germinable seed) applied are listed below.

NAME SCIENTIFIC	NAME ENGLISH	CULTIVAR	lb-PLS / ac	kg-PLS / ha	PLS / ft2	PLS / m2	Percent_of_Mix_weight	Percent_of_Mix_count
Achillea millefolium L. ssp. lanulosa (Nutt.) Piper	Common Yarrow	unspecified	1.00	1.12	60	640	2.4%	52.4%
Hordeum californicum Covas et Stebbins	California Barley	unspecified	20.00	22.42	32	344	48.8%	28.2%
Leymus triticoides (Buckley) Pilger	Creeping Wildrye	'Santa Paula', 'Rio'	20.00	22.42	22	237	48.8%	19.4%
			41.00	45.95	114	1222	100.0%	100.0%

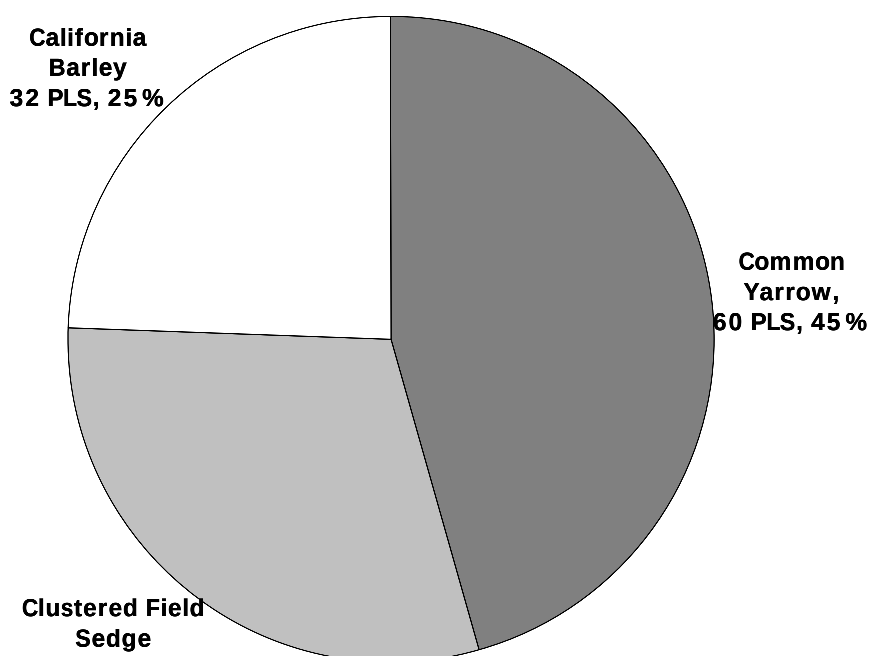


2.4 Seed Mix 2

The substitution of Clustered Field Sedge for Creeping Wildrye makes Seed Mix 2 an option for wetter, less saline, more silty or clayey substrates where ultimate height is desired at 2 to 3 feet tall.

Species and quantities of pure live seed (PLS = % pure seed x % germinable seed) applied are listed below.

NAME SCIENTIFIC	NAME ENGLISH	CULTIVAR	lb-PLS / ac	kg-PLS / ha	PLS / ft2	PLS / m2	Percent_of_Mix_weight	Percent_of_Mix_count
Achillea millefolium L. ssp. lanulosa (Nutt.) Piper	Common Yarrow	unspecified	1.00	1.12	60	640	4.0%	45.6%
Carex praegracilis W. Boott	Clustered Field Sedge	unspecified	4.00	4.48	39	420	16.0%	29.9%
Hordeum californicum Covas et Stebbins	California Barley	unspecified	20.00	22.42	32	344	80.0%	24.5%
			25.00	28.02	131	1405	100.0%	100.0%



3. Maintenance of Bioswale Vegetation

If necessary for function or aesthetics, mowing is a management option. All of the candidate species listed are tolerant of annual mowing to a height of 6 to 8 inches. If the bioswale substrate is relatively weed-free at initial establishment, and if adequate water is available for establishment and growth, then the candidate species listed should produce full cover and exclude most weed species such that weed control beyond mowing is typically not required.

4. References

Consortium of California Herbaria Website (CHSC, DAV, IRVC, JEPS, RSA-POM, SBBG, SJSU, UC, UCR, UCSB, UCSC). Accessed 12 July 2006. http://ucjeps.berkeley.edu/consortium/

Hickman JC. (ed.) 1993. *The Jepson Manual: Higher Plants of California*. Berkeley, CA: University of California Press.

Mason HL. 1957. *A Flora of the Marshes of California*. Berkeley: Univ. California Press.

Raven PH, Thompson HJ, Prigge, BA. 1986. *Flora of the Santa Monica Mountains, California*. ed. 2. Southern California Botanists Special Publication No. 2.

Smith CF. 1998. *A Flora of the Santa Barbara Region, California*. ed. 2. Santa Barbara: Santa Barbara Mus. Nat. Hist.

Roadside Erosion Control and Management Study (RECMS)

Candidate Plants for Orange County I5 PM 3.9/4.3 and SR73 PM 12.5/15.6

Draft 1 - 2006-09-19

			"Weed" Status			
Name Scientific	**Name English**	**Cultivar**	**CEPPC**	**CIPC**	**CDFA**	**TNC**
Perennial Forbs: Native						
Achillea millefolium L. ssp. lanulosa (Nutt.) Piper	Common Yarrow		---	---	---	---
Iva hayesiana Gray	San Diego Povertyweed		---	---	---	---
Perennial Forbs: Alien						
Drosanthemum floribundum (Haw.) Schwant.	Showy Dewflower		---	---	---	---
Gazania linearis (Thunb.) Druce.	Treasureflower		---	---	---	Insignificant
Gazania rigens (L.) Gaertn.	Treasureflower		---	---	---	---
Lampranthus spectabilis (Haw.) N.E. Br	Trailing Ice Plant		---	---	---	---
Osteospermum fruticosum (L.) Norl.	Shrubby Daisybush		---	---	---	---
Thymus serpyllum L.	Creeping Thyme		---	---	---	---
Perennial Grasses: Native						
Muhlenbergia rigens (Benth.) A.S. Hitchc.	Deergrass		---	---	---	---
Shrubs: Native						
Atriplex lentiformis (Torr.) Wats. ssp. breweri (Wats.) Hall et Clements	Quail Bush		---	---	---	---
Artemisia californica Less.	California Sagebrush	'Montara'	---	---	---	---
Baccharis pilularis DC.	Dwarf Chaparral Broom	'Twin Peaks'	---	---	---	---
Eriogonum parvifolium Sm. in Rees	Coast Buckwheat		---	---	---	---
Shrubs: Alien						
Acacia redolens Maslin	Prostrate Acacia	'Prostratus'	---	---	---	---
Lantana montevidensis (Spreng.) Briq.	Trailing Lantana	*many available*	---	---	---	---
Myoporum parvifolium R. Br.	Myoporum	'Prostratum'	---	---	---	---
Myoporum x (hybrid)	Myoporum	'Pacificum'	---	---	---	---
Rosmarinus officinalis L.	Rosemary	'Prostratus'	---	---	---	---

"Weed" Status in California

CEPPC	= California Exotic Pest Plant Council	**CDFA**	= California Department of Food and Agriculture
CIPC	= California Invasive Plant Council	**TNC**	= The Nature Conservancy

California Department of Food and Agriculture Pest Ratings of Noxious Weed Species and Noxious Weed Seed

List	Explanation
A	Eradication, containment, rejection, or other holding action at the state-county level. Quarantine interceptions to be rejected or treated at any point in the state.
B	Eradication, containment, control or other holding action at the discretion of the commissioner.
C	State endorsed holding action and eradication only when found in a nursery; action to retard spread outside of nurseries at the discretion of the commissioner; reject only when found in a crop seed for planting or at the discretion of the commissioner.
Q	Temporary "A" action outside of nurseries at the state-county level pending determination of a permanent rating. Species on List 2, "Federal Noxious Weed Regulation" are given an automatic "Q" rating when evaluated in California

Roadside Erosion Control and Management Study (RECMS)

Candidate Plants for
Orange County I5 PM 3.9/4.3 and SR73 PM 12.5/15.6

Draft 1 - 2006-09-19

Name Scientific	Name English	Cultivar	Form	Use	Install Method: Seed	Install Method: Live
Perennial Forbs: Native						
Achillea millefolium L. ssp. lanulosa (Nutt.) Piper	Common Yarrow		Groundcover	Slope Face	4	4
Iva hayesiana Gray	San Diego Povertyweed		Groundcover	Slope Face	4	4
Perennial Forbs: Alien						
Drosanthemum floribundum (Haw.) Schwant.	Showy Dewflower		Groundcover	Slope Face		4
Gazania linearis (Thunb.) Druce.	Treasureflower		Groundcover	Slope Face	4	4
Gazania rigens (L.) Gaertn.	Treasureflower		Groundcover	Slope Face	4	4
Lampranthus spectabilis (Haw.) N.E. Br	Trailing Ice Plant		Groundcover	Slope Face		4
Osteospermum fruticosum (L.) Norl.	Shrubby Daisybush		Groundcover	Slope Face		4
Thymus serpyllum L.	Creeping Thyme		Groundcover	Slope Face		4
Perennial Grasses: Native						
Muhlenbergia rigens (Benth.) A.S. Hitchc.	Deergrass		Mounded	Slope Toe		4
Shrubs: Native						
Atriplex lentiformis (Torr.) Wats. ssp. breweri (Wats.) Hall et Clements	Quail Bush		Mounded	Slope Face	4	4
Artemisia californica Less.	California Sagebrush	'Montara'	Mounded	Slope Face	4	4
Baccharis pilularis DC.	Dwarf Chaparral Broom	'Twin Peaks'	Mounded	Slope Face		4
Eriogonum parvifolium Sm. in Rees	Coast Buckwheat		Mounded	Slope Face	4	4
Shrubs: Alien						
Acacia redolens Maslin	Prostrate Acacia	'Prostratus'	Mounded	Slope Face		4
Lantana montevidensis (Spreng.) Briq.	Trailing Lantana	*many available*	Mounded	Slope Face		4
Myoporum parvifolium R. Br.	Myoporum	'Prostratum'	Groundcover	Slope Face		4
Myoporum x (hybrid)	Myoporum	'Pacificum'	Groundcover	Slope Face		4
Rosmarinus officinalis L.	Rosemary	'Prostratus'	Mounded	Slope Face		4

Review of:	Title	**Summary of Literature Review for the Scoping and Siting of Ornamental Vegetation Types in Biostrips and Bioswales for Storm Water Treatment**
	Date	**April 2006**
	Authors	**EDAW, Tatsumi and Partners**
	Client	**State of California, Caltrans**
	Status	**Draft**

1. OBJECTIVES

These are the objectives as I see them, but I have not seen the Scope of Work.

1. **To evaluate whether existing "ornamental" roadside vegetation functions adequately as water quality treatment for stormwater runoff relative to California regulatory standards;**

   > "The primary goal of the Ornamental Vegetation Study is to evaluate existing ornamental vegetation and determine whether existing vegetated areas serve as water quality treatment best management practices (BMPs). The ultimate results of the proposed study would also assist in the development of data for assisting with the selection of ornamental vegetation species for future plantings."

2. **Identify individual or combinations of plant species/cultivars presently on roadsides that function best as biofilters**

   > "Ornamental vegetation (exotic herbaceous and woody species) is also thought to be beneficial in the treatment of soil and water quality; however, there is insufficient research done on biofilters using ornamental vegetation. There is a need to increase the number of appropriate types of vegetation for use in biostrips (for treatment of sheet flow) and bioswales (for treatment and conveyance of flows). This study is focused on identifying ornamental types of vegetation for storm water treatment to increase the plant palette for Caltrans landscape architects."

2. FORM

As the document is formatted now, **it is an annotated bibliography, not a literature review**. A literature review is a systematic critical evaluation of current knowledge about a topic, method, theory, or discipline, usually structured thematically into a few primary subject areas. The goal is to convert discrete data into synthetic information, to identify unifying patterns, to identify knowledge gaps, and to provide direction for future investigations.

The document needs to be reformatted as a review paper with major thematic categories clearly identified. Perhaps organized in categories of filter types, or of vegetation types.

1. Filtration
   - 1.1 Grass Filters
   - 1.2 Mixed Grasses and Forbs
   - 1.3 Leaf Succulents
   - 1.4 Shrubs
2. Detention Basins
   - 2.1 Grasses/Graminoids
   - 2.2 Mixed Grasses and Forbs
   - 2.3 Leaf Succulents
   - 2.4 Shrubs
3. Phytoremediation
   - 3.1 Grasses/Graminoids
   - 3.2 Mixed Grasses and Forbs
   - 3.3 Leaf Succulents
   - 3.4 Shrubs

1. Grasses / Graminoids
   - 1.1 Filtration
   - 1.2 Detention Basins
   - 1.3 Phytoremediation
2. Mixed Grasses / Graminoids and Forbs
   - 2.1 Filtration
   - 2.2 Detention Basins
   - 2.3 Phytoremediation
3. Leaf Succulents
   - 3.1 Filtration
   - 3.2 Detention Basins
   - 3.3 Phytoremediation
4. Shrubs
   - 4.1 Filtration
   - 4.2 Detention Basins
   - 4.3 Phytoremediation

Vegetation types are important because California differs from other states in the use of leaf succulents (e.g., A*ptenia, Carpobrotus, Delosperma, Lampranthus*) as groundcover along highways where the climate permits as these South African species do not tolerate prolonged freezing. California also uses more shrubs (e.g., *Acacia*, *Baccharis*, *Ceanothus*, *Lantana*, *Myoporum*, *Rosmarinus*) from Mediterranean climates with warm winters. The comparative filtration effectiveness of vegetation types needs discussion, and why some types may be more appropriate in some Caltrans Districts and not others, primarily owing to climate.

Review of:	Title	**Summary of Literature Review for the Scoping and Siting of Ornamental Vegetation Types in Biostrips and Bioswales for Storm Water Treatment**
	Date	**April 2006**
	Authors	**EDAW, Tatsumi and Partners**
	Client	**State of California, Caltrans**
	Status	**Draft**

3. CONTENT

3.1 Literature

Relevance of the literature cited is mostly on target (the Cal Poly shrub germination study is tangential), but the breadth requires much augmentation. Many more relevant papers and reports exist on the subject of vegetation biofilters. Most pertain to grass filters, but these can be related to potential filtration by existing vegetation along California roads.

The literature review contained within the Orange County Stormwater Program 2003 Drainage Area Management Plan (DAMP) includes some relevant material.
http://www.ocwatersheds.com/StormWater/PDFs/2003_Appendix_E/2003_Appendix_E1_BMP_Effectiveness.pdf

3.2 Term Definitions

Ornamental Vegetation. The scope of this project seems to be "ornamental vegetation" (again, I have not seen the Scope of Work statements). This is an apparent attempt to differentiate alien ("exotic") herbs and woody plants intentionally planted for highway "landscaping" from those aliens or natives of whatever function existing along highways as well. "Ornamental" is an aesthetic term applicable to both alien and native plants used in landscaping or gardening. If this project intends to evaluate native as well as alien plants, then a different term is necessary. Perhaps the title should simply be "Existing Vegetation as Storm Water Treatment Along California Highways".

Naturalized. In this document the term "naturalized" is used in the sense of "acclimatized". Individual organisms acclimatize to short-term environmental conditions through phenotypic plasticity within tolerances controlled by genotype. The term "naturalized" has a long-standing biological usage that refers specifically to alien species accidentally or deliberately introduced into a flora, now reproducing and maintaining viable populations that disperse propagules beyond the population or populations of original establishment [e.g., Nesom, G. 2000. SIDA 19(1): 189-193.]

3.3 Synthesis

Critical evaluation of thematic topics need much elaboration to convert this document into a literature review that identifies how existing highway vegetation assemblages or monoculture are or are not likely functioning as a biofilters for stormwater.

30 October 2008

Michael Curto
mcurto@calpoly.edu

Senior Research Associate
Earth and Soil Sciences
Cal Poly State University
San Luis Obispo, CA 93407
805-474-1309

APPENDIX H.10

ASSESSMENT OF POTENTIAL SITES ALONG SR46 TO OBTAIN STOCKPILE TOPSOIL FOR REAPPLICATION

Expert Assistance

Assessment of Potential Sites Along SR46 to Obtain or Stockpile Topsoil For Reapplication

Prepared For

STATE OF CALIFORNIA

DEPARTMENT OF TRANSPORTATION

Project Plans For Construction On

STATE HIGHWAY 46

In San Luis Obispo County
In and Near Paso Robles
From Airport Road To 1.4 Km West
of Whitley Gardens Drive

(MP 32.15 / KM 51.74 TO MP 39.31 / KM 63.27)

December 2005

Purpose

At the request of Scott Dowlan, District 5 Associate Landscape Architect and Project Landscape Architect for the Union Road segment (Post Mile 32.15 to 39.31) of the State Route 46 Corridor Improvement Project, a field visit was made on 15 December 2005 to six sites along SR46 specified as potential sources for the collection of topsoil ("duff"), or for stockpiling of collected topsoil during construction (see **Figure 1**).

Site soil and vegetation attributes were qualitatively evaluated. Collections of soil were made for germination and rainfall simulation trials to be conducted at the Cal Poly Erosion Research Facility under the Roadside Erosion Control & Maintenance Study. Results will aid design of erosion control by providing data about plant cover, density, and composition anticipated when topsoil containing an existing seed bank is reapplied as a post-construction treatment on fill slopes.

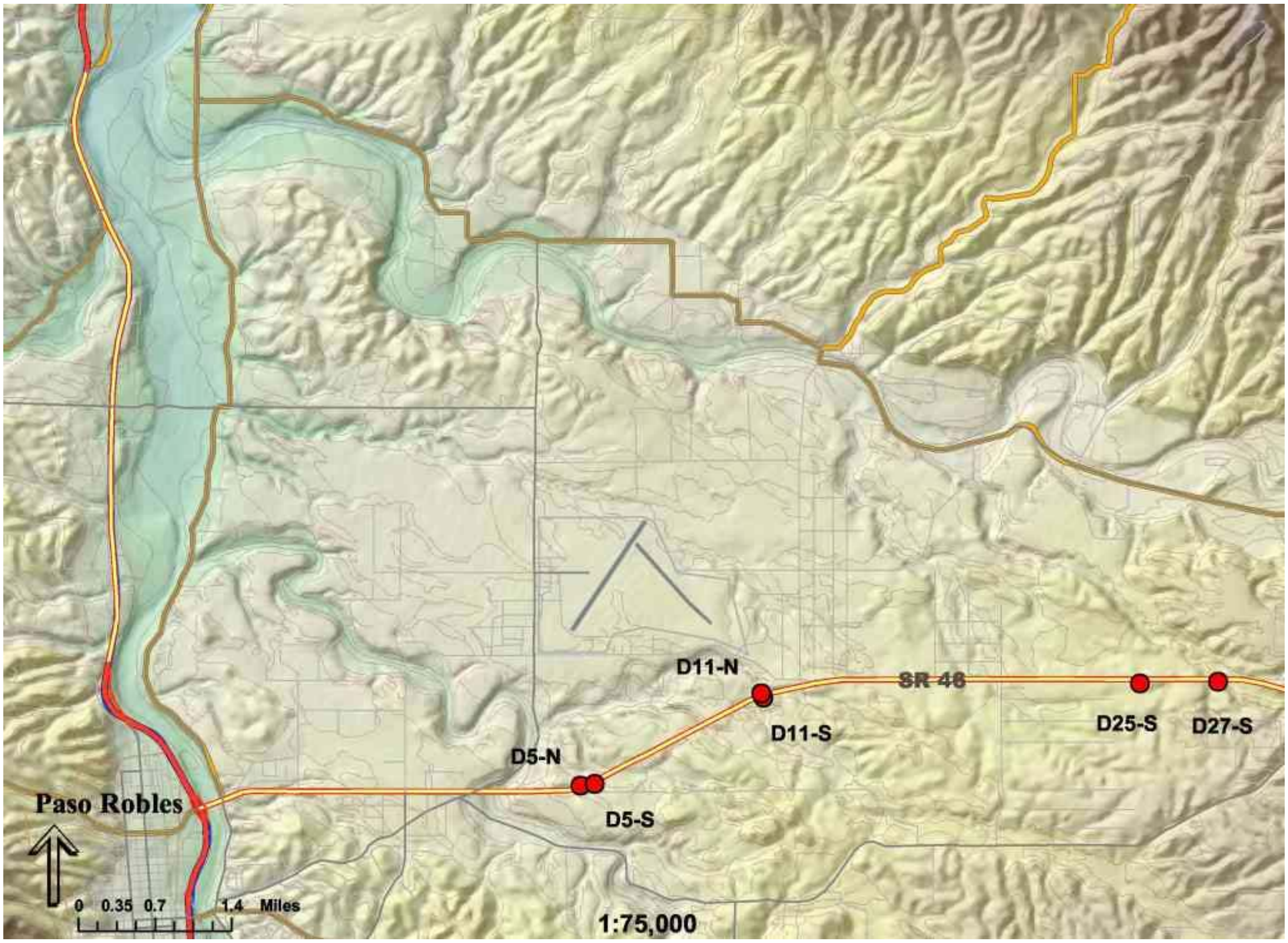


Figure 1. General Locations of Soil Assessment Sites Along SR46.

Personnel

Sites were evaluated by:

Brent Hallock, PhD, CPSS, CPESC
Professor
Earth and Soil Sciences
Cal Poly State University
San Luis Obispo, CA 93407
(805) 756-2436
bhallock@calpoly.edu

Michael Curto, MS
Senior Research Associate
Earth and Soil Sciences
Cal Poly State University
San Luis Obispo, CA 93407
(805) 474-1309
mcurto@calpoly.edu

Methods

Site soil and vegetation attributes were qualitatively evaluated based on years of familiarity with local soils, vegetation, and plant species. An inventory was made of the most conspicuous plant species at each site. Collections of soil were made at sites D-5N (~ 3 ft^3 of soil) and D-25S (~ 4 $ft^3$of soil). GPS positions were obtained using a resource grade Garmin eTrex Vista WAAS-enabled receiver with positional accuracy of ± 5 meters.

Results

Sites for Topsoil Collection

Based on soil suitability and lesser amounts of listed noxious weeds (e.g., Yellow Star Thistle), Sites **D-11S**, **D-25S**, and **D-27S** are the most-appropriate sites for collection of topsoil.

Sites for Stockpiles

Based on soil suitability, lesser amounts of listed noxious weeds (e.g., Yellow Star Thistle), and safety concerns, the SE corner of SR46 and Geneseo Rd west of Site **D-25S** is likely the most-appropriate location for stockpiling collected topsoil.

Synoptic findings from each site follow. Table 1 lists the most conspicuous plants present at assessed topsoil collection or stockpile sites.

Site D-5N

LOCATION

Site	**D-5N**	Route	**SR46**
X_Long	**-120.63449200**	Direction	**Westbound**
Y_Lat	**35.64552000**	PostMile	**33.15**
Datum	**NAD83**		

SOIL

Source	**NRCS Soil Survey Paso Robles Area**
Year	**1983**
Scale	**1:24,000**
Soil Name	**Arbuckle-Positas Complex**
Percent Slope	**9-15**
Drainage	**VERY POORLY TO MODERATELY**
Erodibility	**MODERATE**
Shrink Swell	**LOW**

SOIL SUITABILITY

Topsoil Excavation	**SUITABLE**
Topsoil Stockpiling	**POOR LOCATION**
Topsoil Reapplication	**SUITABLE**

EXISTING VEGETATION

Vegetation Type	**Annual Ruderals**
Native Cover	**< 1%**
Alien Cover	**> 99%**
Listed Noxious Weed Cover	**< 5%**

POST REAPPLICATION VEGETATION

Vegetation Type	**Annual Ruderals**
Native Cover	**< 1%**
Alien Cover	**> 99%**
Listed Noxious Weed Cover	**< 10%**

EXISTING CONSPICUOUS SPECIES

Taxon Name	Common Name	Cover
Alien Annual Forbs		
Brassica nigra (L.) W.D.J.Koch	Black Mustard	L
Centaurea solstitialis L.	Yellow Star-Thistle	L
Erodium cicutarium (L.) L'Hér. ex Ait.	Redstem Filaree	L
Lactuca serriola L.	Prickly Lettuce	L
Melilotus indicus (L.) All.	Annual Yellow Sweetclover	L
Trifolium hirtum All.	Rose Clover	**H**
Alien Annual Grass		
Avena fatua L.	Common Wild Oats	**H**
Bromus hordeaceus L.	Soft Chess	**H**
Gastridium phleoides (Nees & Meyen) C.E. Hubb.	Nit Grass	L
Lolium multiflorum Lam.	Annual Ryegrass	**H**
Vulpia myuros (L.) K.C.Gmel. var. hirsuta Hack.	Rattail Fescue	**H**

Local Cover Rank: **H**) High; M) Moderate; L) Low.

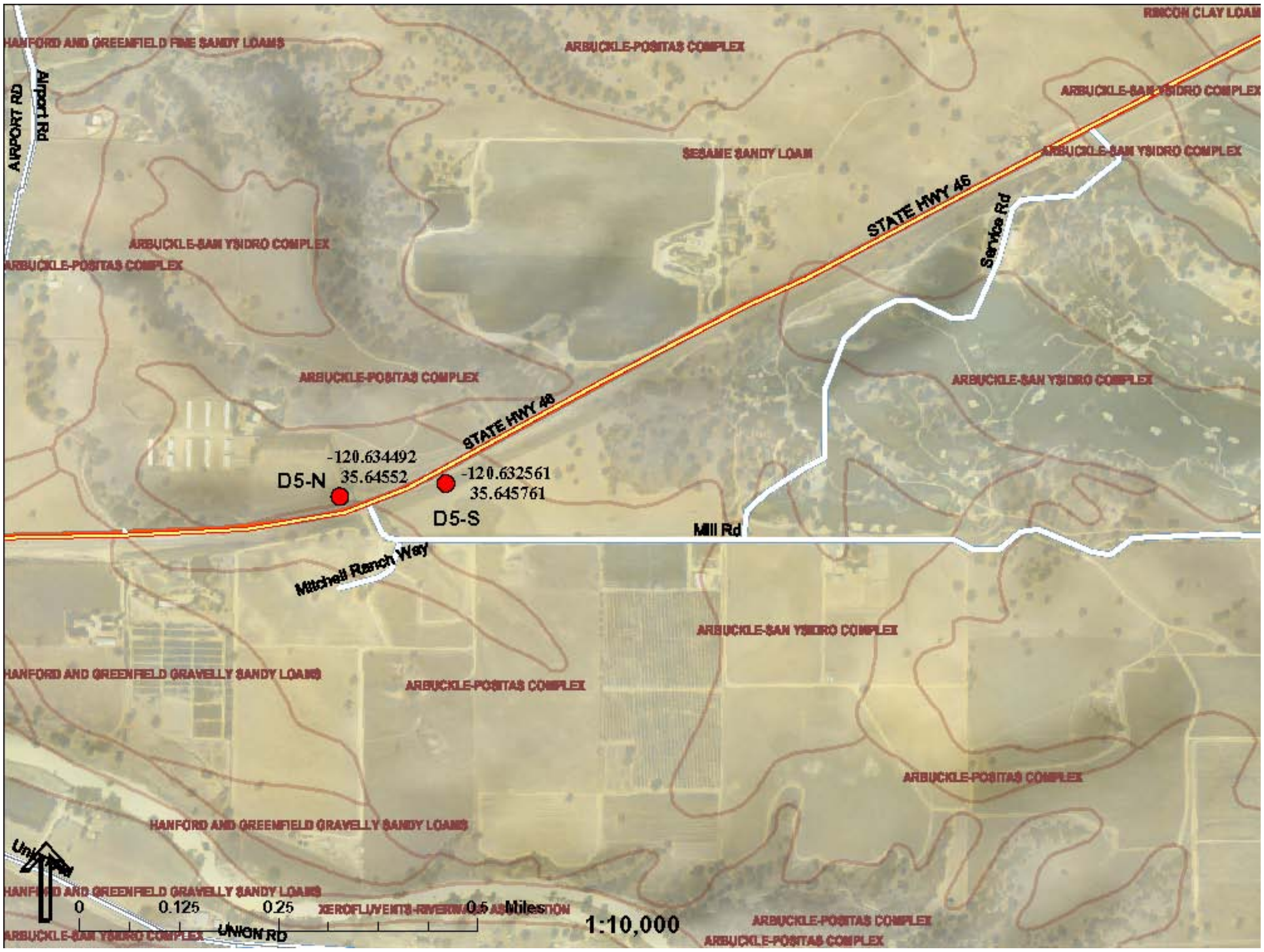


Figure 2. Sites D-5N and D-5S along SR46.

Site D-5S

LOCATION

Site	**D-5S**	Route	**SR46**
X_Long	**-120.63256093**	Direction	**Eastbound**
Y_Lat	**35.64576090**	PostMile	**33.15 to 33.55**
Datum	**NAD83**		

SOIL

Source	**NRCS Soil Survey Paso Robles Area**
Year	**1983**
Scale	**1:24,000**
Soil Name	**Arbuckle-Positas Complex**
Percent Slope	**9-15**
Drainage	**VERY POORLY TO MODERATELY**
Erodibility	**MODERATE**
Shrink Swell	**LOW**

SOIL SUITABILITY

Topsoil Excavation	**SUITABLE**
Topsoil Stockpiling	**POOR LOCATION**
Topsoil Reapplication	**SUITABLE**

EXISTING VEGETATION

Vegetation Type	**Annual Ruderals**
Native Cover	**< 1%**
Alien Cover	**> 99%**
Listed Noxious Weed Cover	**< 5%**

POST REAPPLICATION VEGETATION

Vegetation Type	**Annual Ruderals**
Native Cover	**< 1%**
Alien Cover	**> 99%**
Listed Noxious Weed Cover	**< 10%**

EXISTING CONSPICUOUS SPECIES

Taxon Name	Common Name	Cover
Native Trees		
Quercus douglasii Hook. et Arn.	Blue Oak	L
Native Shrubs		
Baccharis pilularis DC.	Chaparral Broom	L
Alien Annual Forbs		
Brassica nigra (L.) W.D.J.Koch	Black Mustard	L
Centaurea solstitialis L.	Yellow Star-Thistle	L
Erodium cicutarium (L.) L'Hér. ex Ait.	Redstem Filaree	L
Lactuca serriola L.	Prickly Lettuce	L
Trifolium hirtum All.	Rose Clover	**H**
Alien Perennial Grass		
Cynodon dactylon (L.) Pers.	Bermuda Grass	L
Alien Annual Grass		
Avena fatua L.	Common Wild Oats	**H**
Bromus hordeaceus L.	Soft Chess	**H**
Gastridium phleoides (Nees & Meyen) C.E. Hubb.	Nit Grass	L
Lolium multiflorum Lam.	Annual Ryegrass	**H**
Vulpia myuros (L.) K.C.Gmel. var. hirsuta Hack.	Rattail Fescue	**H**

Local Cover Rank: **H**) High; M) Moderate; L) Low.

Site D-11N

LOCATION

Site	**D-11N**	Route	**SR46**
X_Long	**-120.610527346**	Direction	**Westbound**
Y_Lat	**35.6577835047**	PostMile	**34.50 to 34.60**
Datum	**NAD83**		

SOIL

Source	**NRCS Soil Survey Paso Robles Area**
Year	**1983**
Scale	**1:24,000**
Soil Name	**Arbuckle-Positas Complex**
Percent Slope	**30-50**
Drainage	**VERY POORLY TO MODERATELY**
Erodibility	**MODERATE**
Shrink Swell	**LOW**

SOIL SUITABILITY

Topsoil Excavation	**SUITABLE**
Topsoil Stockpiling	**POOR LOCATION**
Topsoil Reapplication	**SUITABLE**

EXISTING VEGETATION

Vegetation Type	**Annual Ruderals**
Native Cover	**< 5%**
Alien Cover	**> 95%**
Listed Noxious Weed Cover	**< 3%**

POST REAPPLICATION VEGETATION

Vegetation Type	**Annual Ruderals**
Native Cover	**< 1%**
Alien Cover	**> 99%**
Listed Noxious Weed Cover	**< 20%**

EXISTING CONSPICUOUS SPECIES

Taxon Name	Common Name	Cover
Native Shrubs		
Baccharis pilularis DC.	Chaparral Broom	L
Native Annual Forbs		
Clarkia purpurea (W.Curtis) A.Nels. et J.F.Macbr.	Winecup Clarkia	L
Alien Annual Forbs		
Brassica nigra (L.) W.D.J.Koch	Black Mustard	L
Carduus pycnocephalus L.	Italian Plumeless Thistle	L
Centaurea melitensis L.	Tocalote	L
Centaurea solstitialis L.	Yellow Star-Thistle	L
Erodium cicutarium (L.) L'Hér. ex Ait.	Redstem Filaree	L
Alien Annual Grass		
Avena fatua L.	Common Wild Oats	**H**
Bromus diandrus Roth	Ripgut Brome	L
Lolium multiflorum Lam.	Annual Ryegrass	H
Vulpia myuros (L.) K.C.Gmel. var. hirsuta Hack.	Rattail Fescue	H

Local Cover Rank: **H**) High; M) Moderate; L) Low.

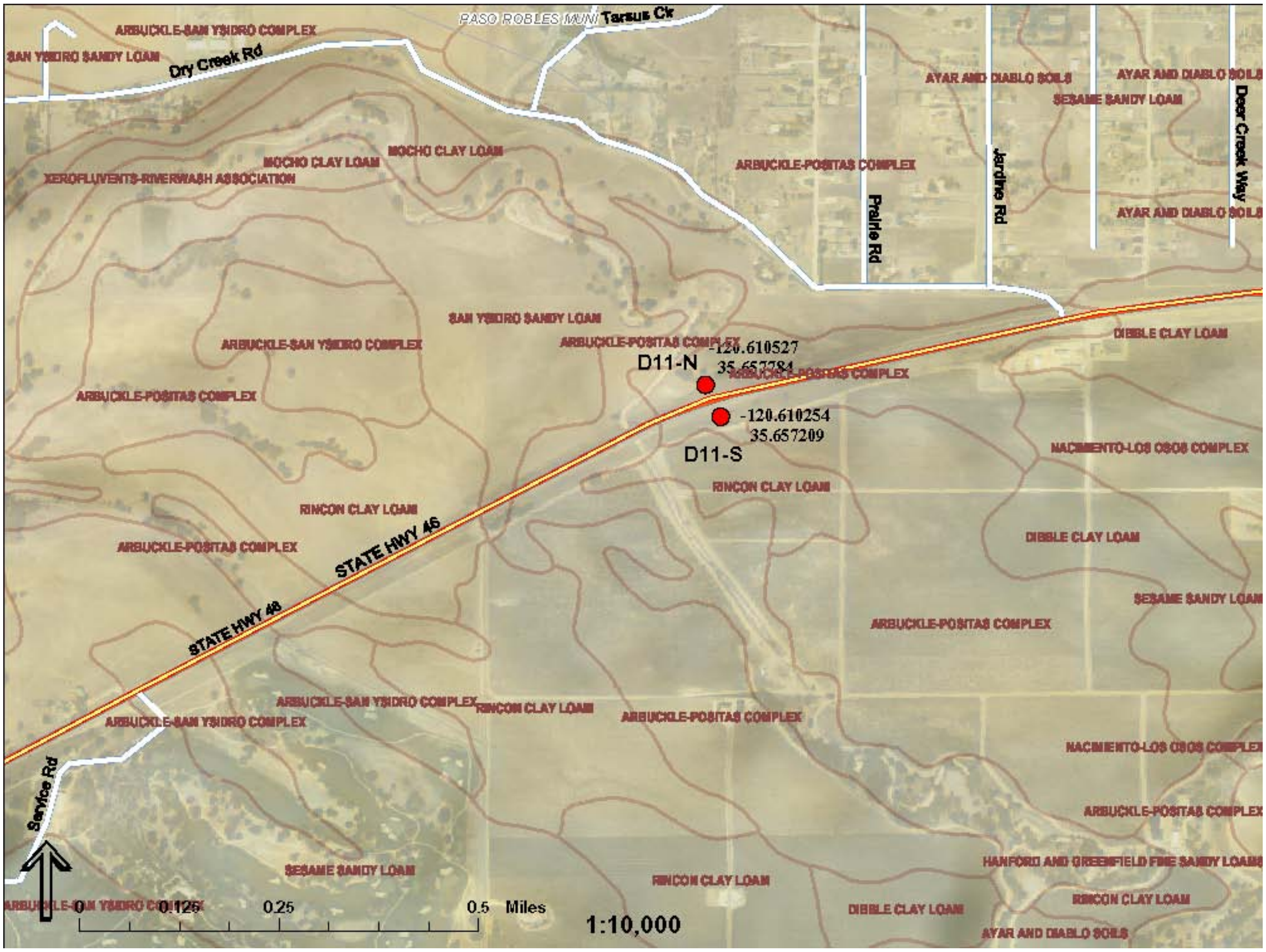


Figure 3. Sites D-11N and D-11S along SR46.

Site D-11S

LOCATION

Site	**D-11S**	Route	**SR46**
X_Long	**-120.610253986**	Direction	**Eastbound**
Y_Lat	**35.6572094488**	PostMile	**34.50 to 34.60**
Datum	**NAD83**		

SOIL

Source	**NRCS Soil Survey Paso Robles Area**
Year	**1983**
Scale	**1:24,000**
Soil Name	**Arbuckle-Positas Complex**
Percent Slope	**30-50**
Drainage	**VERY POORLY TO MODERATELY**
Erodibility	**MODERATE**
Shrink Swell	**LOW**

SOIL SUITABILITY

Topsoil Excavation	**SUITABLE**
Topsoil Stockpiling	**POOR LOCATION**
Topsoil Reapplication	**SUITABLE**

EXISTING VEGETATION

Vegetation Type	**Annual Ruderals**
Native Cover	**< 15%**
Alien Cover	**> 75%**
Listed Noxious Weed Cover	**< 3%**

POST REAPPLICATION VEGETATION

Vegetation Type	**Annual Ruderals**
Native Cover	**< 1%**
Alien Cover	**> 99%**
Listed Noxious Weed Cover	**< 20%**

EXISTING CONSPICUOUS SPECIES

Taxon Name	Common Name	Cover
Native Trees		
Populus fremontii S.Wats.	Fremont Cottonwood	L
Alien Trees		
Prunus dulcis (Miller) D.A.Webb	Almond	L
Native Shrubs		
Baccharis pilularis DC.	Chaparral Broom	L
Native Annual Forbs		
Clarkia purpurea (W.Curtis) A.Nels. et J.F.Macbr.	Winecup Clarkia	L
Alien Annual Forbs		
Centaurea melitensis L.	Tocalote	L
Centaurea solstitialis L.	Yellow Star-thistle	L
Erodium cicutarium (L.) L'Hér. ex Ait.	Redstem Filaree	M
Trifolium hirtum All.	Rose Clover	L
Vicia villosa Roth	Hairy Vetch	**H**
Alien Annual Grass		
Avena fatua L.	Common Wild Oats	**H**
Bromus diandrus Roth	Ripgut Brome	L
Bromus hordeaceus L.	Soft Chess	**H**
Lolium multiflorum Lam.	Annual Ryegrass	**H**
Vulpia myuros (L.) K.C.Gmel. var. hirsuta Hack.	Rattail Fescue	**H**

Local Cover Rank: **H**) High; M) Moderate; L) Low.

Site D-25S

LOCATION

Site	**D-25S**	Route	**SR46**
X_Long	**-120.560348451**	Direction	**Eastbound**
Y_Lat	**35.6590715493**	PostMile	**37.50 TO 37.70**
Datum	**NAD83**		

SOIL

Source	**NRCS Soil Survey Paso Robles Area**
Year	**1983**
Scale	**1:24,000**
Soil Name	**Nacimiento-Los Osos Complex**
Percent Slope	**9-30**
Drainage	**NOT WELL DRAINED**
Erodibility	**MODERATE**
Shrink Swell	**MODERATE**

SOIL SUITABILITY

Topsoil Excavation	**SUITABLE**
Topsoil Stockpiling	**GOOD LOCATION**
Topsoil Reapplication	**SUITABLE**

EXISTING VEGETATION

Vegetation Type	**Annual Ruderals**
Native Cover	**< 2%**
Alien Cover	**> 98%**
Listed Noxious Weed Cover	**< 5%**

POST REAPPLICATION VEGETATION

Vegetation Type	**Annual Ruderals**
Native Cover	**< 1%**
Alien Cover	**> 99%**
Listed Noxious Weed Cover	**< 20%**

EXISTING CONSPICUOUS SPECIES

Taxon Name	Common Name	Cover
Native Perennial Forbs		
Eriogonum elongatum Benth.	Longstem Buckwheat	L
Alien Perennial Forbs		
Hirschfeldia incana (L.) Lagrèze-Fossat	Perennial Mustard	L
Native Annual Forbs		
Conyza canadensis (L.) Cronq.	Canadian Horseweed	L
Eremocarpus setigerus (Hook.) Benth.	Doveweed	M
Alien Annual Forbs		
Brassica nigra (L.) W.D.J.Koch	Black Mustard	M
Centaurea solstitialis L.	Yellow Star-Thistle	L
Erodium cicutarium (L.) L'Hér. ex Ait.	Redstem Filaree	L
Lactuca serriola L.	Prickly Lettuce	L
Medicago polymorpha L.	Burclover	L
Melilotus indicus (L.) All.	Annual Yellow Sweetclover	M
Alien Annual Grass		
Avena fatua L.	Common Wild Oats	**H**
Bromus diandrus Roth	Ripgut Brome	L
Bromus hordeaceus L.	Soft Chess	**H**
Lolium multiflorum Lam.	Annual Ryegrass	**H**
Vulpia myuros (L.) K.C.Gmel. var. hirsuta Hack.	Rattail Fescue	**H**

Local Cover Rank: **H**) High; M) Moderate; L) Low.

Site D-27S

LOCATION

Site	**D-27S**	Route	**SR46**
X_Long	**-120.549969066**	Direction	**Westbound**
Y_Lat	**35.6592752268**	PostMile	**38.10**
Datum	**NAD83**		

SOIL

Source	**NRCS Soil Survey Paso Robles Area**
Year	**1983**
Scale	**1:24,000**
Soil Name	**Nacimiento-Los Osos Complex**
Percent Slope	**30-50**
Drainage	**NOT WELL DRAINED**
Erodibility	**MODERATE**
Shrink Swell	**MODERATE**

SOIL SUITABILITY

Topsoil Excavation	**SUITABLE**
Topsoil Stockpiling	**POOR LOCATION**
Topsoil Reapplication	**SUITABLE**

EXISTING VEGETATION

Vegetation Type	**Annual Ruderals**
Native Cover	**< 5%**
Alien Cover	**> 95%**
Listed Noxious Weed Cover	**< 5%**

POST REAPPLICATION VEGETATION

Vegetation Type	**Annual Ruderals**
Native Cover	**< 1%**
Alien Cover	**> 99%**
Listed Noxious Weed Cover	**< 20%**

EXISTING CONSPICUOUS SPECIES

Taxon Name	Common Name	Cover
Native Trees		
Quercus douglasii Hook. et Arn.	Blue Oak	L
Native Shrubs		
Baccharis pilularis DC.	Chaparral Broom	L
Alien Perennial Forbs		
Hirschfeldia incana (L.) Lagrèze-Fossat	Perennial Mustard	L
Native Annual Forbs		
Eremocarpus setigerus (Hook.) Benth.	Doveweed	M
Alien Annual Forbs		
Brassica nigra (L.) W.D.J.Koch	Black Mustard	M
Centaurea solstitialis L.	Yellow Star-Thistle	L
Erodium cicutarium (L.) L'Hér. ex Ait.	Redstem Filaree	L
Lactuca serriola L.	Prickly Lettuce	L
Medicago polymorpha L.	Burclover	L
Melilotus indicus (L.) All.	Annual Yellow Sweetclover	M
Alien Annual Grass		
Avena fatua L.	Common Wild Oats	**H**
Bromus diandrus Roth	Ripgut Brome	L
Bromus hordeaceus L.	Soft Chess	**H**
Lolium multiflorum Lam.	Annual Ryegrass	**H**
Vulpia myuros (L.) K.C.Gmel. var. hirsuta Hack.	Rattail Fescue	**H**
Native Annual Grass		
Vulpia microstachys (Nutt.) Munro	Small Fescue	L

Local Cover Rank: **H**) High; M) Moderate; L) Low.

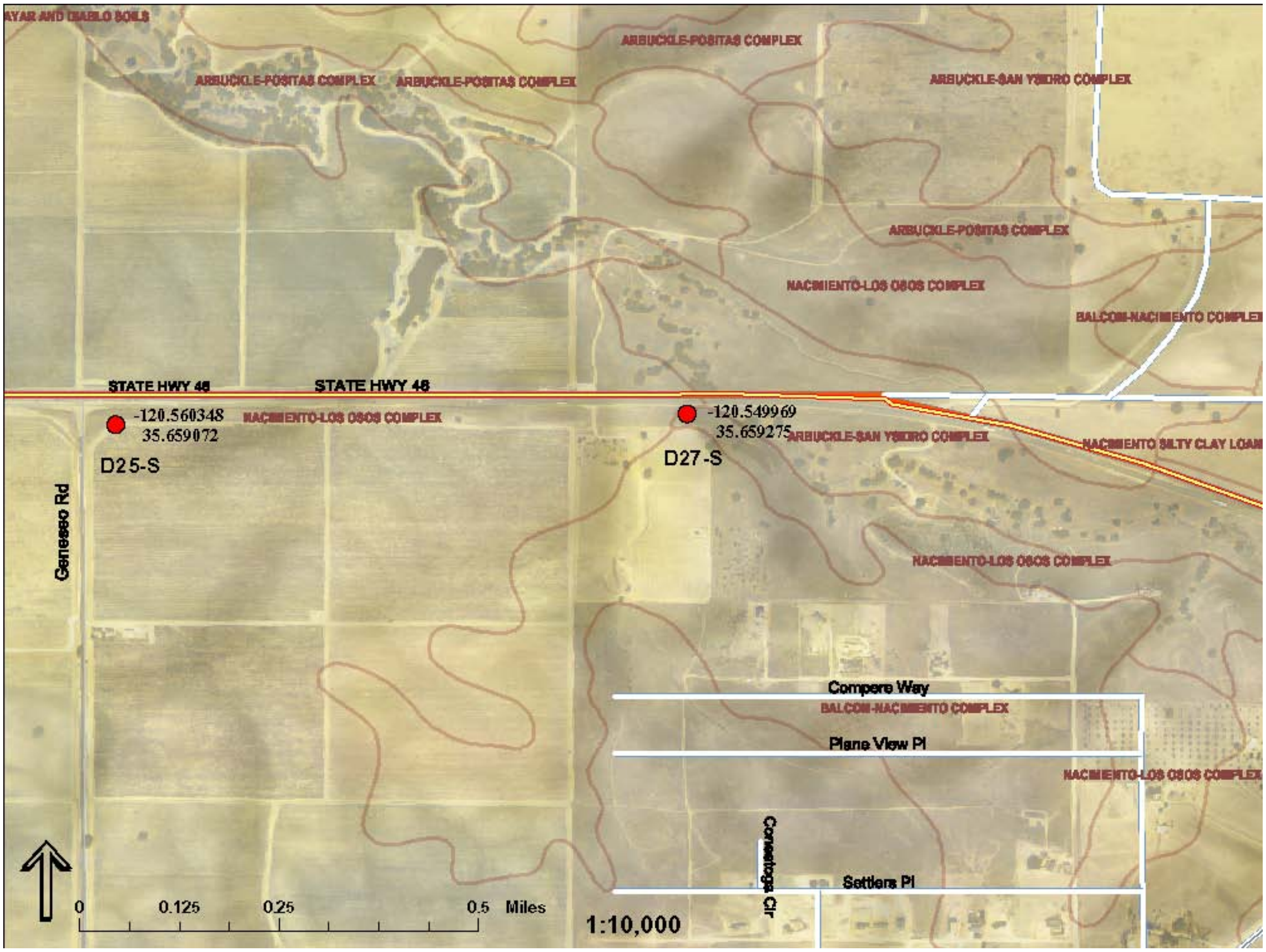


Figure 4. Sites D-25S and D-27S along SR46.

Table 1. Conspicuous Plants At Assessed Topsoil Collection or Stockpile Sites.

Local Cover Rank: **H**) High; M) Moderate; L) Low.

Taxon Name	Common Name	D-5N	D-5S	D-11N	D-11S	D-25S	D-27S
Native Trees							
Populus fremontii S.Wats.	Fremont Cottonwood				L		
Quercus douglasii Hook. et Arn.	Blue Oak		L				L
Alien Trees							
Prunus dulcis (Miller) D.A.Webb	Almond				L		
Native Shrubs							
Baccharis pilularis DC.	Chaparral Broom			L	L		L
Native Perennial Forbs							
Asclepias fascicularis Dcne.	Mexican Whorled Milkweed				L		
Eriogonum elongatum Benth.	Longstem Buckwheat					L	
Alien Perennial Forbs							
Hirschfeldia incana (L.) Lagrèze-Fossat	Perennial Mustard				L	L	L
Native Annual Forbs							
Clarkia purpurea (W.Curtis) A.Nels. et J.F.Macbr.	Winecup Clarkia			L	L		
Conyza canadensis (L.) Cronq.	Canadian Horseweed					L	
Eremocarpus setigerus (Hook.) Benth.	Doveweed					M	M
Alien Annual Forbs							
Brassica nigra (L.) W.D.J.Koch	Black Mustard	L	L	L		M	M
Carduus pycnocephalus L.	Italian Plumeless Thistle			L			
Centaurea melitensis L.	Tocalote			L	L		
Centaurea solstitialis L.	Yellow Star-thistle	L	L	L	L	L	L
Erodium cicutarium (L.) L'Hér. ex Ait.	Redstem Filaree			L	M	L	L
Lactuca serriola L.	Prickly Lettuce				L	L	L
Medicago polymorpha L.	Burclover				L	L	L
Melilotus indicus (L.) All.	Annual Yellow Sweetclover				L	M	M
Trifolium hirtum All.	Rose Clover	**H**	**H**		L		
Vicia villosa Roth	Hairy Vetch				**H**		
Alien Perennial Grass							
Cynodon dactylon (L.) Pers.	Bermuda Grass		L				
Alien Annual Grass							
Avena fatua L.	Common Wild Oats	**H**	**H**	**H**	**H**	**H**	**H**
Bromus diandrus Roth	Ripgut Brome			L	L	L	L
Bromus hordeaceus L.	Soft Chess	**H**	**H**	**H**	**H**	**H**	**H**
Gastridium phleoides (Nees & Meyen) C.E. Hubb.	Nit Grass	L	L				
Lolium multiflorum Lam.	Annual Ryegrass	**H**	**H**	**H**	**H**	**H**	**H**
Vulpia myuros (L.) K.C.Gmel. var. hirsuta Hack.	Rattail Fescue	**H**	**H**	**H**	**H**	**H**	**H**
Native Annual Grass							
Vulpia microstachys (Nutt.) Munro	Small Fescue				M		L