1.0 Introduction

The California Department of Transportation (Caltrans) has identified a need to develop a Statewide Erosion Control Review Report. The primary goal of this work is to provide a comprehensive, data-rich, and timely review of common Caltrans erosion control problem sites throughout the State of California. Initial work involved significant effort to develop a detailed, user-friendly, Excel-based site evaluation program designated as the Highway Erosion Assessment Tool (HEAT). Development of the HEAT program resulted in multiple review iterations by Caltrans staff and researchers from California Polytechnic State University (Cal Poly). Concurrent with this effort, the research team made contacts with individual district personnel for identification of sites meeting the site selection criteria. This research effort focused on problem slopes, and only a small sampling of the state's total roadway slopes was considered. Field evaluations began in December 2000 and were completed at the end of March 2001. Results summarization and interpretation continued through June 2001. This comprehensive field review will result in recommendations for improved erosion control practices on varied sites throughout California.

1.1 Objectives

Caltrans identified a need to improve erosion control practices on sites throughout California. The objectives of the Statewide Erosion Control Review project include the following:

- To account for extreme variability (e.g., climatic conditions, soils, plant growth, and elevation) across California and develop statewide trends for causes of soil loss from sites assisted by vegetative cover.
- To identify trends of unsuccessful erosion control practices across the entire state and/or within district, climatic, or geographic boundaries.
- To identify, evaluate, quantify (when possible), and summarize the results of the state-wide review to assist Caltrans in the continued improvement of statewide erosion control standards. This was to be performed through the development of a comprehensive set of site selection and evaluation criteria, which would establish recommendations for remedying current erosion control problems and suggest changes to future approaches.
- To utilize the extensive collection of historical information and studies about erosion control practices on specific construction efforts and general practices currently used by Caltrans. This information will be incorporated into the study as applicable to build on existing research efforts.

2.0 Methods and Materials

2.1 Work Plan Development

The first task required for this statewide erosion evaluation effort was the development of an overall project work plan. The work plan identified four tasks that encompassed all work efforts. The tasks involved in this Statewide Erosion Control Review effort included the following:

1. **Pre-fieldwork efforts –** Reviewing existing documents and other information sources, establishing site selection and evaluation criteria, finalizing a comprehensive site evaluation form (HEAT), contacting district personnel, coordinating with Cal Poly researchers, and developing a plan of work.

2. **Statewide site evaluations –** Identifying and prioritizing existing erosion control problems, quantifying erosion problems when possible, evaluating site-specific erosion control practices, and performing cooperative field efforts with Caltrans and Cal Poly.

3. **Results summarization –** Compiling, analyzing, summarizing, and developing conclusions including results of the pre-fieldwork and statewide site evaluations.

4. **Final report preparation –** Summarizing all findings from the pre-fieldwork efforts and statewide site evaluations. Recommendations were developed for incorporation into future Caltrans specifications or for a general knowledge base for future construction projects. Recommendations were also developed regarding modifications to existing practices and policies that are based on the quantitative and qualitative findings of this statewide review.

2.2 Literature Review

The research team performed a literature review to determine the types and applicability of predictive field models and unique measurement methodologies in an attempt to maximize quantifiable site-specific information. A variety of erosion control-related topics were reviewed with specific focus on vegetative control studies and models. The following predictive models and field measurement methodologies were reviewed in the literature and used as described:

- Morgan, Morgan, and Finney (Morgan et al., 1984; Morgan et al., 1986) – Many of the predictive models reviewed were developed for agricultural systems and were not directly applicable to the different characteristics of roadside (cut/fill) sites. The Morgan, Morgan, and Finney model is an example of an agriculturally based model that may be applicable to roadside sites. The literature, however, indicated that this model was flexible enough to account for relatively barren soils and steeper slopes. Therefore, this predictive model was included in the assessment as a potential predictive tool.

- Revised Universal Soil Loss Equation (USDA-ARS, 1994) – The Revised Universal Soil Loss Equation (RUSLE) is the historically classic model for predicting soil losses from a site. RUSLE was also developed for agricultural systems, but it has had substantial modifications rendering the prediction tool applicable to roadside sites. Some of the parameters and calculations for this modification were obtained from the Cal Poly research program.

- Water Erosion Prediction Project (WEPP, 2001) – The WEPP model was developed by the USDA-Agricultural Research Service and Purdue University primarily for agricultural systems, but has capabilities to account for range and forest lands. The model predicts sediment production rates using parameters that relate to soil, vegetation, climate, and geographic location. It can be extrapolated to a broad range of conditions, which makes it applicable to many of the Caltrans sites. It includes a wider range of input parameters than RUSLE and other models, including a management layer that provides detailed assessment of rangeland sites that closely match many of the characteristics of Caltrans sites. The model is easily modified to include as many site-specific parameters as possible.

- Channel Erosion Calculator (Hudson, 1995) – The Channel Erosion Calculator is a volumetric method of estimating soil loss from a single channel. This actual field measurement methodology was utilized when channels were found on the site. The technique was modified to evaluate many channels within different areas of a site that were of different size. This allowed summation of soil loss across an entire roadside area whether channels existed across the entire site or only within certain boundaries.

- Measurements of erosion by elevation differences (Moir, 2000; Bourmas and Day, 1993) – A review of techniques measuring soil loss through elevation differences was conducted. Although these methods are very effective and can be relatively accurate, they were not used in this study because of the schedule constraints of the statewide assessment.

- Vegetative coverage estimations (Lal and Stocking, 1994; Department of the Interior, 1985) – The most applicable vegetative cover estimation tool utilized for this study was the Step Point Transect Method developed by the Department of the Interior – Bureau of Land Management. This methodology was modified to include litter, bedrock, and other commonly found surficial materials on roadside sites.

- Rainfall simulators (Kinnell, 2000; and Cerda, 1999) – A variety of rainfall simulators have been utilized for a number of years to measure and evaluate sediment runoff and erosion control methods. The literature and ideas developed during a tour of the Cal Poly rainfall simulator research project resulted in the development of a simple portable rainfall simulator. The simulator was constructed and implemented on some sites in an attempt to quantify soil loss as influenced by slope and soil texture.

- Other qualitative assessments (Kosmas et al., 2000a; Kosmas et al., 2000b) – A simple qualitative assessment was modified from the literature and used for this study. It included developing a standardized list of common characteristics causing soil erosion. This list was developed by the research team after all of the sites were assessed. Each site

was then evaluated according to this list, and the most commonly occurring site characteristics contributing to erosion losses were noted with supporting examples.

- Additional resources (Hudson, 1995) – The literature search resulted in some very useful documents. Perhaps one of the most comprehensive and significant resources discovered was the book *Soil Conservation* (Hudson, 1995). This textbook provided a lot of information on many facets of vegetative soil erosion control and also listed for the reader many additional references for gaining more detailed information about erosion control practices that were mentioned but not discussed in detail. (Many vegetative soil erosion control discussions were not comprehensive, thus this textbook functioned primarily as a detailed reference book.)

2.3 Field Measurements

2.3.1 Training/Quality Assurance-Quality Control/Field Manual

Multiple training sessions were conducted during the pre-fieldwork stage of the project. These training sessions included multiple reviews of HEAT by Caltrans staff, the research team, and Cal Poly. Detailed onsite field reviews were used to standardize field measurements. Examples of some of these field measurements that were standardized for the entire field team include:

- Channel measurements
- Slope degrees and lengths
- Percent vegetative cover
- Soil profile interpretations and nomenclature
- Site identification standards
- Soil sampling protocol

Field crews worked in teams of two within a single district. Approximately three to seven sites were evaluated for each district. Field data were entered into the HEAT program at each site. Once all sites within a district were finished, all HEAT sheets for that district were finalized. Field teams comprised different team members for each district. This served as an effective quality assurance/quality control tool by maintaining consistent sampling and interpretive methodologies throughout the entire six-person field team. An internally developed field manual and a field handbook for describing and sampling soils (USDA-NRCS, 1998) were used as field reference documents. Team members reviewed other authors' HEAT output sheets for completeness and accuracy.

2.3.1.1 Field Manual

A field manual was developed to provide consistent instructions for field personnel evaluating sites. The manual outlined the procedure followed for various field sections of HEAT, and provided guidelines for obtaining data and properly entering data into appropriate spaces in HEAT. Use of the manual resulted in greater consistency in the methodologies and terminologies used by field personnel. The manual referred field personnel to specific resources for field methodology and non-field data (e.g., non-field information). As a result, data such as climate and soil survey information were obtained from the same known sources and were consistent. Methods for field activities, such as

obtaining Global Positioning System (GPS) points, measuring channels, and assessing vegetative and non-vegetative soil cover were described. Additionally, the manual outlines site and sample naming criteria, which helped provide unique, informative identifications that could easily be associated with Caltrans districts. These measures helped to ensure complete data sets with minimal variability caused by human error or differences in field methodology.

2.4 Highway Erosion Assessment Tool

2.4.1 Methodology

The purpose of the following section is to describe the methodology and tools utilized to assess erosion at Caltrans highway sites throughout California. Specifically, the discussion highlights the HEAT program, a macro-driven spreadsheet designed to aid the research team in data collection and calculations. The field methodology included a number of qualitative and quantitative approaches to measure erosion losses or potential erodibility and assess the success of existing erosion control practices. This discussion outlines the systematic procedure that was followed in using the HEAT program during and after a site evaluation.

The principal challenge in erosion assessment is to determine the nature and magnitude of erosion with regard to the erosion prevention practice employed at the site. However, the abbreviated duration of the project only allowed one visit between January and April for each of the 57 sites, rather than continuous monitoring to determine changes to the site over time. Thus, observations of erosion losses after successive storm events, measurement of erosion losses with sediment traps, and other time-specific observations were not possible. Given these limitations, site evaluations had to be deductive, whereby the evaluator constructed a reasonable concept of site design, reasons for failure or success, and adherence to specified design.

2.4.1.1 Site Description Data

Site description data were collected before and during site visits, and included a variety of qualitative information such as design specifications, site practice, and condition observations.

Pre-visit Site Data. Pre-visit site data included climate information (e.g., high-intensity rainfall events, temperature, annual rainfall, and freeze-free days), available design specifications (e.g., seed mix, irrigation, and erosion control devices), and site evaluation identifiers (e.g., field personnel, Caltrans district, and soil type) (see Figure 1). Pre-visit site data provided the research team a context in which to evaluate conditions during the visit. This context included the potential for highly erosive conditions (e.g., high rainfall area or poorly developed soil) and the expected success of the erosion control practices. Pre-visit site data also provided a baseline against which existing conditions were compared. Problems observed on sites were evaluated in the context of the original design and site conditions since construction.

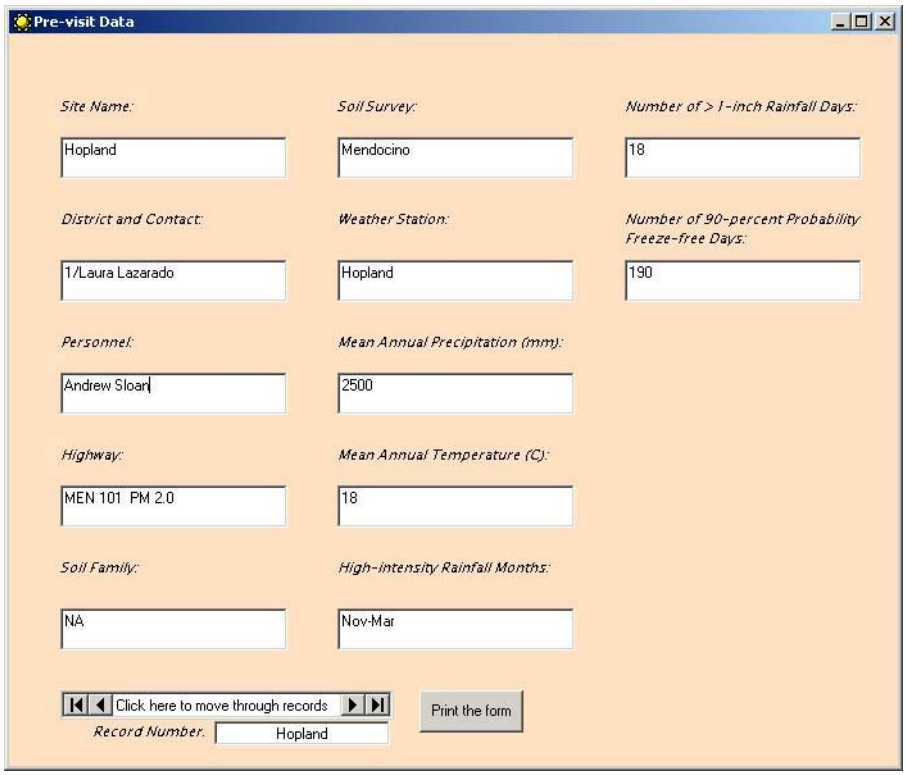


Figure 1. Pre-visit Data Entry Sheet

Visit-day Site Data. Visit-day site data were qualitative and quantitative data collected during the actual site visit day. These included observations of the condition of the site (e.g., the type of erosion observed, and erosion point sources), site design (e.g., the presence of slope benches, slope angle, and irrigation in use), and the size of the area (see Figure 2). Most importantly, these data provided valuable information regarding actual site design, particularly for comparisons to specifications.

2.4.1.2 Highway Erosion Assessment Tool—Global Positioning System Site Locations and Area Calculations

GPS locations were taken at each of the sites visited by field personnel. All GPS units were set up with the same coordinate system to ensure compatible data. Points were taken at corners of sites to calculate site areas and obtain coordinates for site location on state and district maps. In most cases, four points were entered into the HEAT program. Sites with inaccessible boundaries may have been estimated from fewer than four GPS points. All points were entered into a Geographic Information System (GIS) program for display on statewide and districtwide maps. Most points had three-dimension coordinates so that when they were linked to form polygons and a site surface, the area was obtained. Some GPS hand-held units were unable to record elevation information and resulted in polygons that represented a surface area that did not account for the slope. For these sites, the slope and slope lengths were used to assign elevations in GIS so that the surface area of the site could be calculated by the system. Site locations were overlaid onto precipitation information obtained from the Parameter-Elevation Regression on Independent Slopes Model

climate mapping program at Oregon State University. Roads and district boundaries were added for reference and graphic display of site locations.

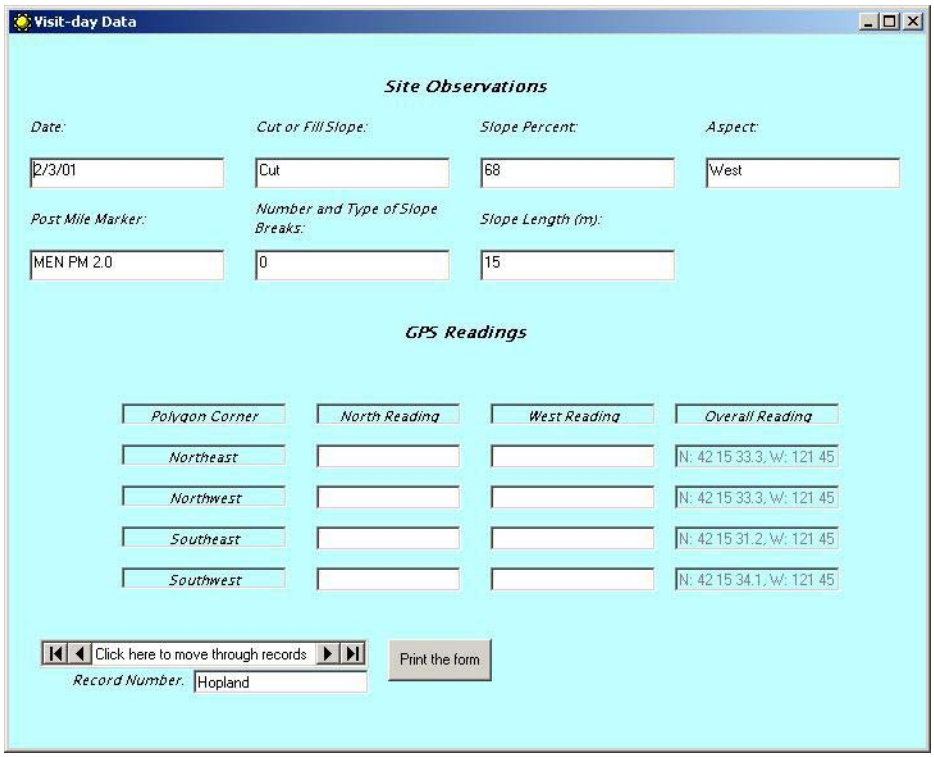


Figure 2. Visit-day Data Entry Sheet

2.4.2 Existing Practices

The evaluation of erosion control practices begun in the "Visit-day Site Information" form (Figure 2), continued on the "Existing Practices" form. In this record, the user reviewed a list of 38 erosion control technologies and determined whether they had been successfully or unsuccessfully implemented or not observed (see Figure 3). This evaluation was somewhat subjective regarding the determination of relative success or lack of success. Categorization in the "Implemented with Success" column required that the erosion control practice was successful on the majority of the site. In other words, an erosion control practice that appeared to be fulfilling its role over most locations where it was implemented (i.e., a given practice may not be used on the entire site) was considered successful.

2.4.3 Vegetation

The Statewide Erosion Control Review was, principally, an evaluation of vegetative erosion control approaches. Thus, utilization of a quantitative technique for determining vegetative, litter, and other forms of coverage was necessary to both evaluate the overall success of vegetative coverage, and to establish relationships with other quantitative factors (e.g., soil chemistry, climatic factors).

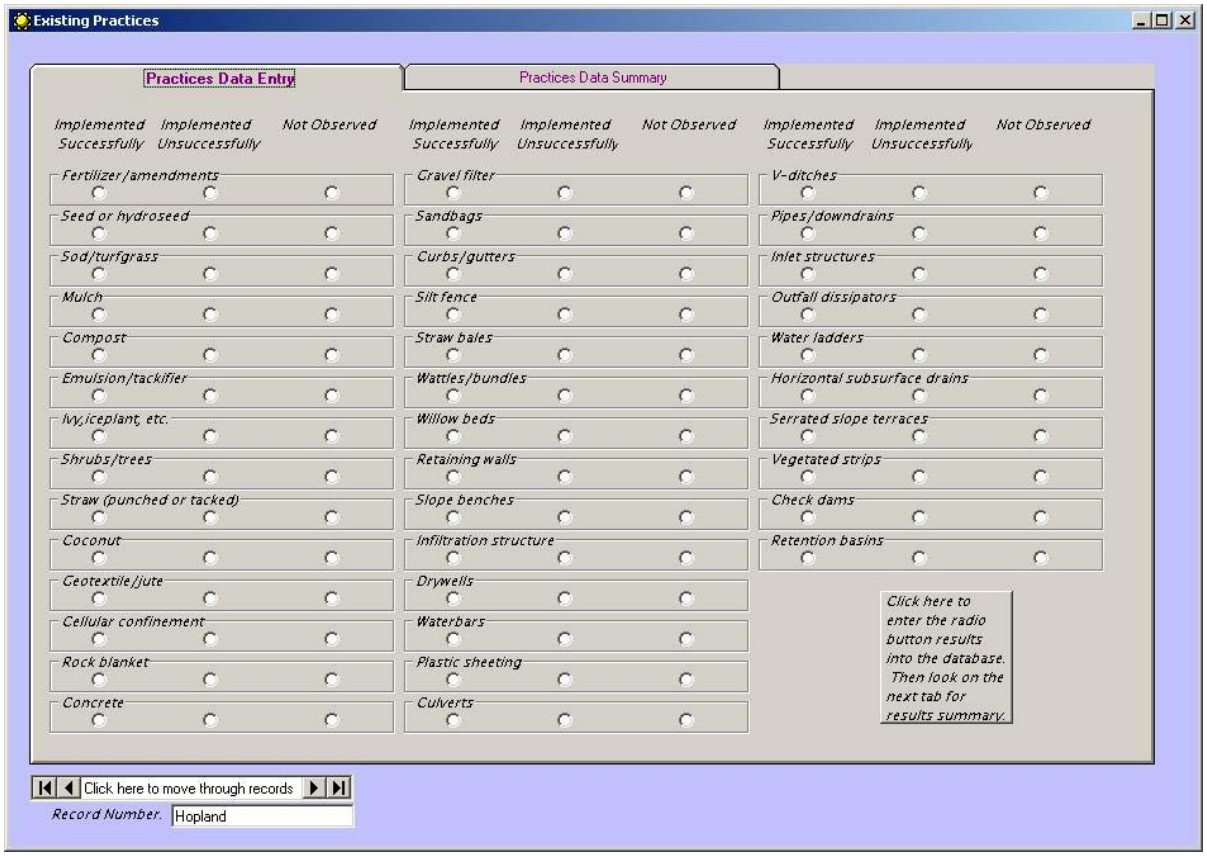


Figure 3. Existing Practices Checklist

This Statewide Erosion Control Review study used a modified version of the U.S. Bureau of Land Management Rangeland Monitoring Trend Studies Step Point Transect Method (Department of the Interior, 1985) to record vegetation coverage on the sites surveyed. Two primary modifications were made to the method to accommodate the scope of this project, including (1) using temporary transects instead of establishing permanent transects (for trend studies) and (2) determining one foliar level instead of multiple foliar levels, since most sites had been treated with grasses and herbaceous species. Table 1 lists the sites where vegetation samples were collected. The samples were sent to Mike Curto, Cal Poly, San Luis Obispo, for identification (see Table 1). The Step Point Transect Method and the methodology used in this study follow.

In practice, the Step Point Transect Method consisted of observing 100 points along a 50-foot transect at 6-inch intervals. The point was regarded as the smallest plot. The record monitored with this method was cover. Cover type corresponding to categories including foliar and basal cover was assessed (see Figure 4). This method had wide application and was suited for use with grasses, forbs, shrubs, and trees (U.S. Department of the Interior, 1985). It was also suitable for measuring major characteristics of the ground and vegetation cover in the area. Large areas could easily be sampled, particularly if the cover was reasonably uniform. It was possible to collect a large number of samples within a relatively short time.

TABLE 1
Identifications of Plant Samples Submitted by the Research Team during 2001 Field Season

District	Sample_ID	ID_Confidence	Species	Lifeform	Origin
3	BO	Not Possible	Unidentifiable/Bad Sample	Q	Q
3	FO	H	*Erodium cicutarium* (L.) L'Her.	Fa	Alien
3	FO	H	*Lupinus bicolor* Lindley	Fa	Native
3	FO	H	*Vicia sp.*	Fa	Q
3	FO	H	*Bromus rubens* L.	Ga	Alien
3	FO	H	*Festuca myuros* L.	Ga	Alien
3	FO	H	*Avena barbata* Pott ex Link	Ga	Alien
3	MF	H	*Achillea millefolium* L.	Fp	Native
3	PC	H	*Amsinckia sp.*	Fa	Native
3	PC	H	*Bromus rubens* L.	Ga	Alien
3	PC	H	*Lolium multiflorum* Lam.	Ga	Alien
4	AB	H	*Geranium sp.*	Q	Q
4	AB	H	*Lathyrus sp.*	Q	Q
4	AB	H	*Malva sp.*	Fa	Alien
4	AB	H	*Lupinus sp.*	Fa	Native
4	AB	H	*Erodium cicutarium* (L.) L'Her.	Fa	Alien
4	AB	H	*Tragopogon sp.*	Fp	Alien
4	AB	H	*Hordeum vulgare* L.	Ga	Alien
4	AB	H	*Polypogon monspeliensis* (L.) Desf.	Ga	Alien
4	AB	Q	*Amelanchier utahensis* Koehne	S	Q
4	AB	H	*Ceanothus sp.*	S	Native
4	AB	H	*Grevillea sp.*	S	Alien
4	CU	H	*Bromus diandrus* Roth	Ga	Alien
4	CU	H	*Taxus sp.*	S	Alien
4	DA	H	*Stellaria sp.*	Q	Q
4	DA	H	*Erodium cicutarium* (L.) L'Her.	Fa	Alien
4	DA	H	*Plantago major* L.	Fp	Alien
4	DA	H	*Bromus diandrus* Roth	Ga	Alien
4	DA	H	*Avena fatua* L.	Ga	Alien
4	DA	H	*Bromus rubens* L.	Ga	Alien
4	DA	H	*Festuca rubra* L.	Gp	Alien
4	DA	H	*Cortaderia jubata* (Lemoine) Stapf	Gp	Alien
4	DA	H	*Rhamnus californica* Eschsch.	S	Native
4	FH	H	*Erodium cicutarium* (L.) L'Her.	Fa	Alien
4	FH	H	*Lotus sp.*	Fa	Q
4	FH	H	*Vicia benghalensis* L.	Fa	Alien
4	FH	H	*Melilotus officinalis* (L.) Pall.	Fa	Alien
4	FH	H	*Avena fatua* L.	Ga	Alien
4	FH	H	*Avena barbata* Pott ex Link	Ga	Alien
4	FH	H	*Bromus rubens* L.	Ga	Alien
4	PM	H	*Erodium cicutarium* (L.) L'Her.	Fa	Alien
4	PM	H	*Medicago polymorpha* L.	Fa	Alien
4	PM	H	*Marah sp.*	Fp	Native
4	PM	H	*Festuca myuros* L.	Ga	Alien
4	PM	H	*Bromus rubens* L.	Ga	Alien
6	CA	H	*Castilleja sp.*	Fa	Native
6	CA	H	*Amsinckia sp.*	Fa	Native

TABLE 1
Identifications of Plant Samples Submitted by the Research Team during 2001 Field Season

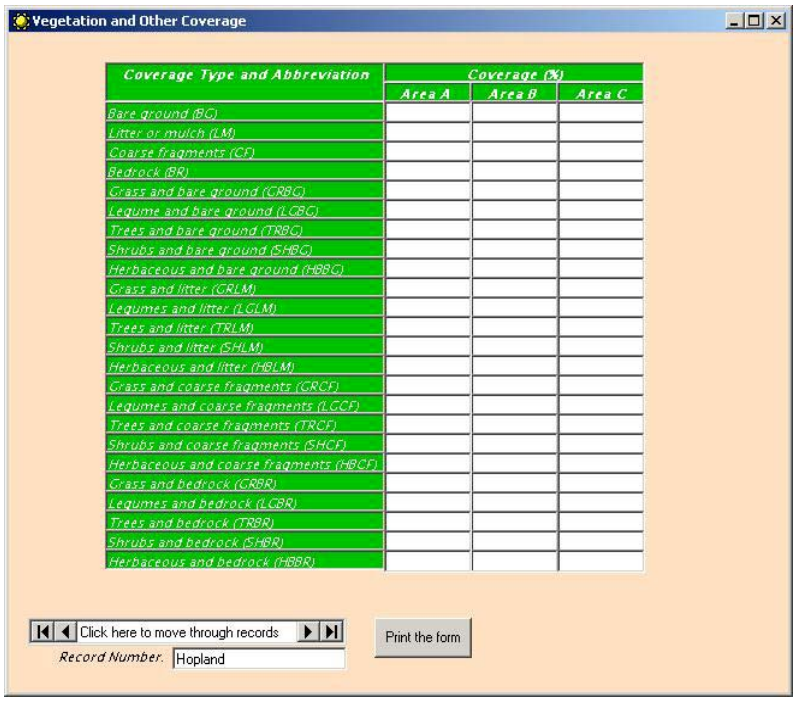
District	Sample_ID	ID_Confidence	Species	Lifeform	Origin
6	CA	H	*Lupinus sp.*	Fa	Native
6	CA	H	*Sisymbrium altissimum* L.	Fa	Alien
6	CA	H	*Phacelia sp.*	Fa	Native
6	CA	H	*Avena fatua* L.	Ga	Alien
6	CA	H	*Bromus diandrus* Roth	Ga	Alien
6	CA	H	*Dichelostemma pulchellum* (Salisb.) A. A. Heller	MHp	Native
6	EA	H	*Amsinckia sp.*	Fa	Native
6	EA	H	*Lupinus sp.*	Fa	Native
6	EA	H	*Bromus diandrus* Roth	Ga	Alien
6	EA	H	*Poa secunda* J. S. Presl	Gp	Native
6	EA	Q	*Adenostoma fasciculatum* Hook. & Arn.	S	Q
6	PC	H	*Amsinckia menziesii* (Lehm.) Nelson & J. F. Macbr.	Fa	Native
6	PC	H	*Erodium cicutarium* (L.) L'Her.	Fa	Alien
6	PC	H	*Hordeum murinum* L.	Ga	Alien
10	FH	H	*Vicia benghalensis* L.	Fa	Alien
10	FH	H	*Erodium botrys* (Cav.) Bertol.	Fa	Alien
10	FH	H	*Amsinckia sp.*	Fa	Native
10	FH	H	*Leymus triticoides* (Buckley) Pilger	Gp	Native
10	LD	H	*Geranium sp.*	Q	Q
10	LD	H	*Vicia benghalensis* L.	Fa	Alien
10	LD	H	*Bromus diandrus* Roth	Ga	Alien
10	VP	H	*Amsinckia sp.*	Fa	Native
10	VP	H	*Lupinus sp.*	Fa	Native
10	VP	H	*Festuca myuros* L.	Ga	Alien
10	WP	H	*Festuca sp.*	Gp	Q
10	WP	H	*Pinus sp.*	T	Q
10	WP	H	*Pseudotsuga menziesii*	T	Q
10	WP	H	*Platycladus sp.*	T	Alien
11	CA	Not Possible	Unidentifiable/Bad Sample		
11	DH	Not Possible	Unidentifiable/Bad Sample		
11	DM	Not Possible	Unidentifiable/Bad Sample		
11	MC	H	*Bromus diandrus* Roth	Ga	Alien
11	MC	H	*Avena barbata* Pott ex Link	Ga	Alien
11	MV	Not Possible	Unidentifiable/Bad Sample		
11	SP	Not Possible	Unidentifiable/Bad Sample		
11	TP	Not Possible	Unidentifiable/Bad Sample		

ID_Confidence, Lifeform, and Origin: H = high; Q = questionable
Lifeform: Fa = annual forb; Fp = perennial forb; Ga = annual grass;
Gp= perennial grass; Mp = perennial monocot; S = shrub; T = tree

2.4.4 Soils Data

Soils data provide critical information regarding the mechanical stability of the site, fertility, and consequent capacity to provide a substrate for vegetative cover. Soils data collection in the field included descriptions of auger borings or hand-dug pits for up to three locations, corresponding to distinct areas (see Figure 5). Data included soil texture, structure, color, and the depth of each horizon. Evaluators also determined the abundance and depth of root

penetration, as well as clay, sand, and gravel content. Overall soil permeability class and parent material were logged to provide information regarding the nature and stability of underlying strata, as well as the infiltration rate.



Vegetation and Other Coverage

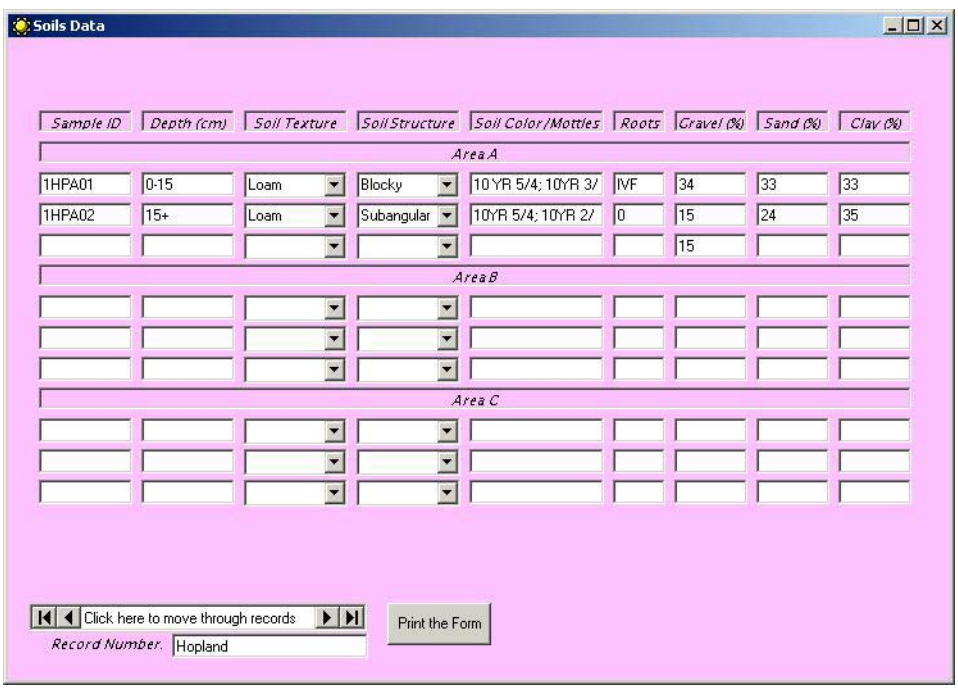
Coverage Type and Abbreviation	Coverage (%)		
	Area A	Area B	Area C
Bare ground (BG)			
Litter or mulch (LM)			
Coarse fragments (CF)			
Bedrock (BR)			
Grass and bare ground (GRBG)			
Legume and bare ground (LGBG)			
Trees and bare ground (TRBG)			
Shrubs and bare ground (SHBG)			
Herbaceous and bare ground (HBBG)			
Grass and litter (GRLM)			
Legumes and litter (LGLM)			
Trees and litter (TRLM)			
Shrubs and litter (SHLM)			
Herbaceous and litter (HBLM)			
Grass and coarse fragments (GRCF)			
Legumes and coarse fragments (LGCF)			
Trees and coarse fragments (TRCF)			
Shrubs and coarse fragments (SHCF)			
Herbaceous and coarse fragments (HBCF)			
Grass and bedrock (GRBR)			
Legumes and bedrock (LGBR)			
Trees and bedrock (TRBR)			
Shrubs and bedrock (SHBR)			
Herbaceous and bedrock (HBBR)			

Click here to move through records

Record Number: Hopland

Print the form

Figure 4. Vegetation and Other Coverage Data Entry Sheet



Soils Data

Sample ID	Depth (cm)	Soil Texture	Soil Structure	Soil Color/Mottles	Roots	Gravel (%)	Sand (%)	Clay (%)
Area A								
1HPA01	0-15	Loam	Blocky	10 YR 5/4; 10YR 3/	IVF	34	33	33
1HPA02	15+	Loam	Subangular	10YR 5/4; 10YR 2/	0	15	24	35
						15		
Area B								
Area C								

Click here to move through records

Record Number: Hopland

Print the Form

Figure 5. Soils Data Entry Sheet

Samples were collected from root zone horizons and sent for laboratory analysis to determine soil nutrients, organic matter content, texture, salts, pH, and other analytes potentially affecting plant growth. These data were ultimately important in determining if soil factors limited the growth of vegetative cover, and if the soil would remain mechanically stable if vegetative cover was not established or was lost.

2.4.5 Channel Calculations

The Channel Erosion Calculator was a volumetric method of estimating soil loss that was modified from the calculation of cross sections in a gully (Hudson, 1995). In an area exhibiting channel erosion, a representative channel was chosen. The average depth and width of the channel were measured at four points (see Figure 6). The four points were positioned along the channel to correspond to natural changes in channel size or dimension. This representative volume of soil lost per channel was calculated and multiplied by the total number of channels across the area for an overall estimation of soil loss caused by channel erosion. HEAT had the ability to calculate channel erosion for up to three areas within one site, which were chosen by field personnel to correspond to varying degrees of channel erosion (size or type of channels). This allowed HEAT to account for sites that were uniformly channeled as well as sites with varied degrees of channeling among different areas.

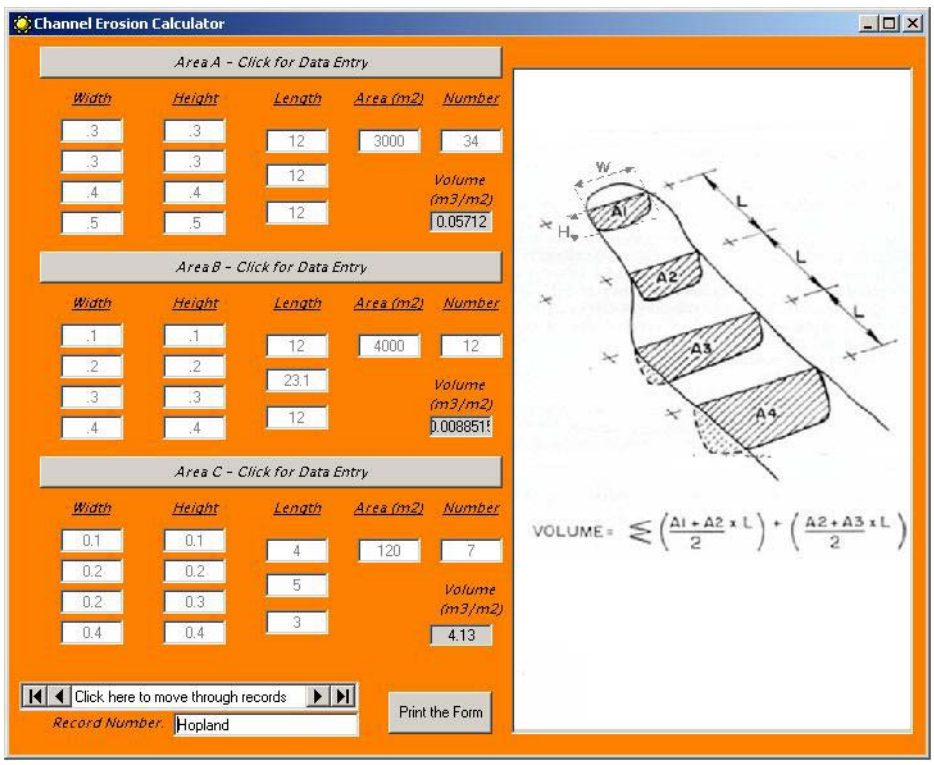


Figure 6. Channel Erosion Calculator Data Entry Sheet

2.4.6 Revised Universal Soil Loss Equation

RUSLE is an empirical model based on experimental data that uses a unique set of definitions to estimate average annual soil loss (tons/acre/year). RUSLE calculates average annual soil loss using five factors. Values for these factors were established from experimen

tal data and extrapolated to encompass a wide range of site conditions for use in RUSLE. Several sources discuss RUSLE, and information about RUSLE was obtained from Hudson (1995), Agriculture Handbook 703, (USDA-ARS, 1994), and Cal Poly. RUSLE is a revised version of the original Universal Soil Loss Equation (USLE) (see Figure 7). USLE was revised in the late 1980s to accommodate new research results and agricultural erosion control practices. This revision also increased the model's feasibility and applicability to non-agricultural situations such as rangeland.

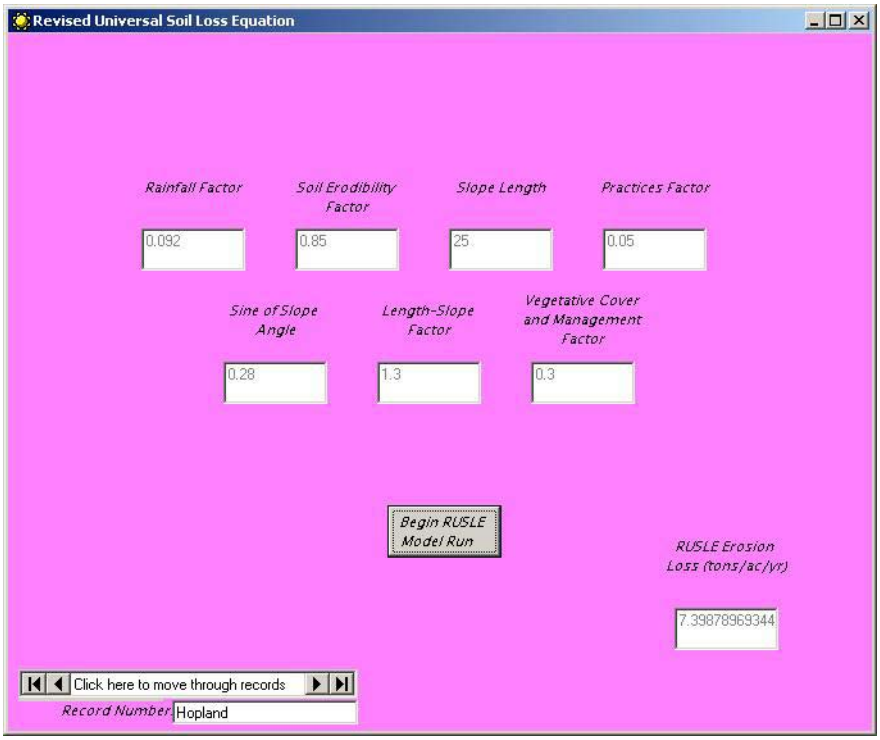


Figure 7. Revised Universal Soil Loss Equation Input Interface

For the sites observed, RUSLE was calculated using the following factors:

- The R factor (rainfall/runoff erosivity) was taken from the most recent isoerodent maps of California (USDA-ARS, 1994).
- K factors (soil erodibility) were computed using the nomograph function in the RUSLE 2 Windows-based program. Soil particle size information and organic matter percentage from laboratory analysis of site soils, field rock fragments, and soil structure estimations were used as inputs to retrieve K factors for each site. K values were corrected for rock fragments in the soil that otherwise affected permeability.
- LS factors (combined slope steepness and length) were calculated using the slopes and slope lengths estimated in the field. LS factors computing for steep slopes were somewhat reduced (although they still may have overestimated soil loss).
- P factors (support practice) were set at 1.0 because tillage and other management practices were not being applied to most sites.

- C factors (cover/management) were computed using the RUSLE 2 program by entering raw data into a default profile. C factors were calculated from subfactors rather than from the tables with common crop rotations and management practices. An average erosivity factor of 20 percent was used as suggested by the program for California. A canopy cover factor of 1.0 was used because tree and shrub canopies on most sites provided limited leaf vegetation during rainy seasons in California. Also, this allowed the sites observed during different periods and spring vegetation development to be compared.
- The prior use subfactor was set at 1.0 because most sites had been constructed recently and consisted of disturbed soils.
- An average surface roughness of 0.25 inch was used for bare ground, as suggested for California rangeland.
- The resulting C factor was obtained by adjusting the percent cover to equal total site cover (vegetative, rock fragment, and litter).

RUSLE has been designed primarily for agricultural use. Its application to recently constructed sites and steep slopes is somewhat questionable because data for these conditions have not been thoroughly reviewed or applied to RUSLE. Results are from the parameters used and are intended for comparison to other soil loss estimations.

2.4.7 Morgan, Morgan, and Finney

The HEAT program also includes an interface for erosion modeling using the Morgan, Morgan, and Finney model. This approach differs somewhat from RUSLE in that it allows entry of variable vegetative coverage throughout the year, as well as more soil physical data. As with RUSLE, input sheets included "Help" functions that provided typical values for soil physical properties, crop coverage and management, and climate factors. Figure 8 provides an illustration of one of the three Morgan, Morgan, and Finney input interfaces.

2.4.8 Field Notes

The Field Notes section of HEAT consisted of five categories under which research team members recorded their visual observations (see Figure 9). The following field note categories are included in the field notes interface in HEAT:

1. Surrounding Site Observations – Under this category, research team members described the vegetation and slopes that were in the vicinity of the evaluated site. Fieldworkers described how the vegetation and soil on the site compared and related to the area surrounding it.
2. Erosion Point Sources – This category included description of the possible areas/ watersheds that were contributing water to the evaluated site. These may have included housing developments, runoff from hills above the site, drainage from a freeway, and other possible scenarios.
3. Wildlife Observations – Included any erosive animal activity seen on or near the site such as burrowed tunnels. This category also included identification of sites designated as sensitive habitat areas.

4. Current Erosion Control Effectiveness – This was considered to be the most important of the five categories in the Field Notes section. Documentation under this category described erosion control practices seen in the field and their degree of success. This included details of specific failures and suggestions about how to remedy any problems. In this category, evaluators recorded any observations that were not covered in the rest of the HEAT program.

5. Photo Record – This category was used to describe any photos that the evaluation team may have taken of the overall site and erosion control practices.

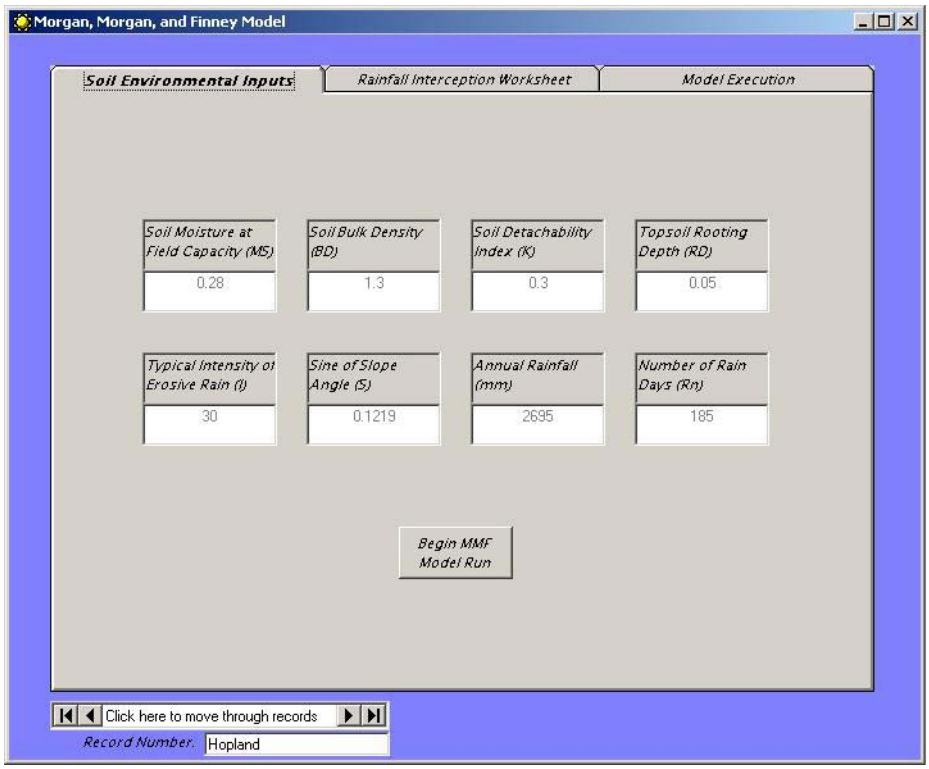


Figure 8. Morgan, Morgan, and Finney Input Interface

2.4.9 Help Menus

In a number of instances, the procedures for field measurements or calculations in HEAT were not obvious. This was particularly true in execution of the erosion models (e.g., Morgan, Morgan, and Finney and RUSLE) where a variety of decisions regarding input parameters was necessary. To provide assistance in these areas, as well as information regarding erosion control practices in general, HEAT included a series of help menus. These were accessible in the data entry macro on the sheets to which they provided support.

Help menus included soil and plant parameters for the Morgan, Morgan, and Finney model (Morgan, 1986), as well as rainfall factors and the Wischmeier soil detachability nomograph for RUSLE (Hallock, pers. comm., 2001; Hudson, 1995). Help menus also included a list of soil erosion control practices and their respective objectives. This list was designed to help assess successes or failures of erosion control practices observed during field evaluations.

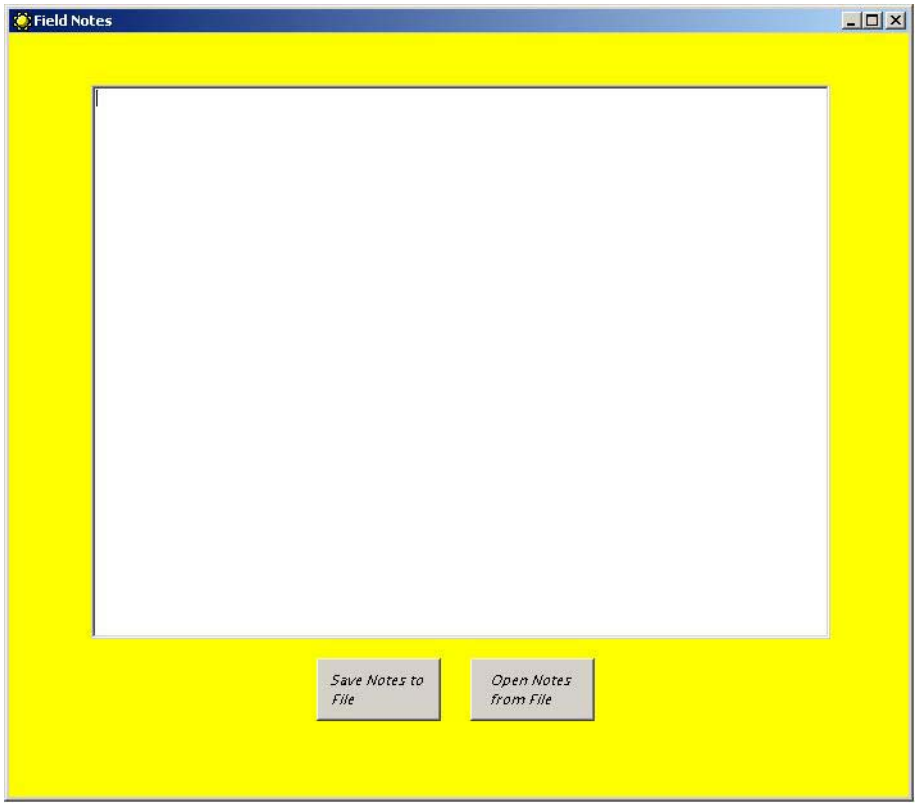


Figure 9. Field Notes Data Entry Sheet

2.5 Site Selection Criteria

The following list of site selection criteria was developed by the research team. The selection criteria were somewhat general to avoid exclusion of potential candidate sites because of a regionally or geographically non-applicable criterion. Flexibility in site selection was important to allow for selection of sites with varied characteristics, but still encompasses those that represented the soils and climatic zones within an individual district. The criteria for site selection included:

- Sites of 1 to 10 years in age since last significant construction activities
- Sites where some type of construction specifications and design drawings were potentially available
- Sites that had been experiencing some erosion control challenges
- Sites that had apparent erosion control measures currently being implemented or had been implemented as a part of construction
- Sites designated as a concern by district or headquarter Caltrans staff
- Sites with some successful erosion control, or sites with successful and unsuccessful erosion control practices to offer pair-wise comparisons

- Sites representing significant geographic, climatic, or soil conditions within a district; sites located in unique "pocket" areas within a district were mostly avoided
- Sites with diverse geographic, climatic, and/or soil characteristics to avoid repetitious evaluations

It was evident that not all sites would meet all of the criteria listed above, strictly because of the variability across the state. Every attempt was made to meet as many applicable and practical criteria as possible. Small groups of sites were approved, and evaluation work started while additional sites were being selected and approved. This approach allowed the research to be completed according to the project schedule (see Figure 10) and provided an opportunity for early and continuous review.

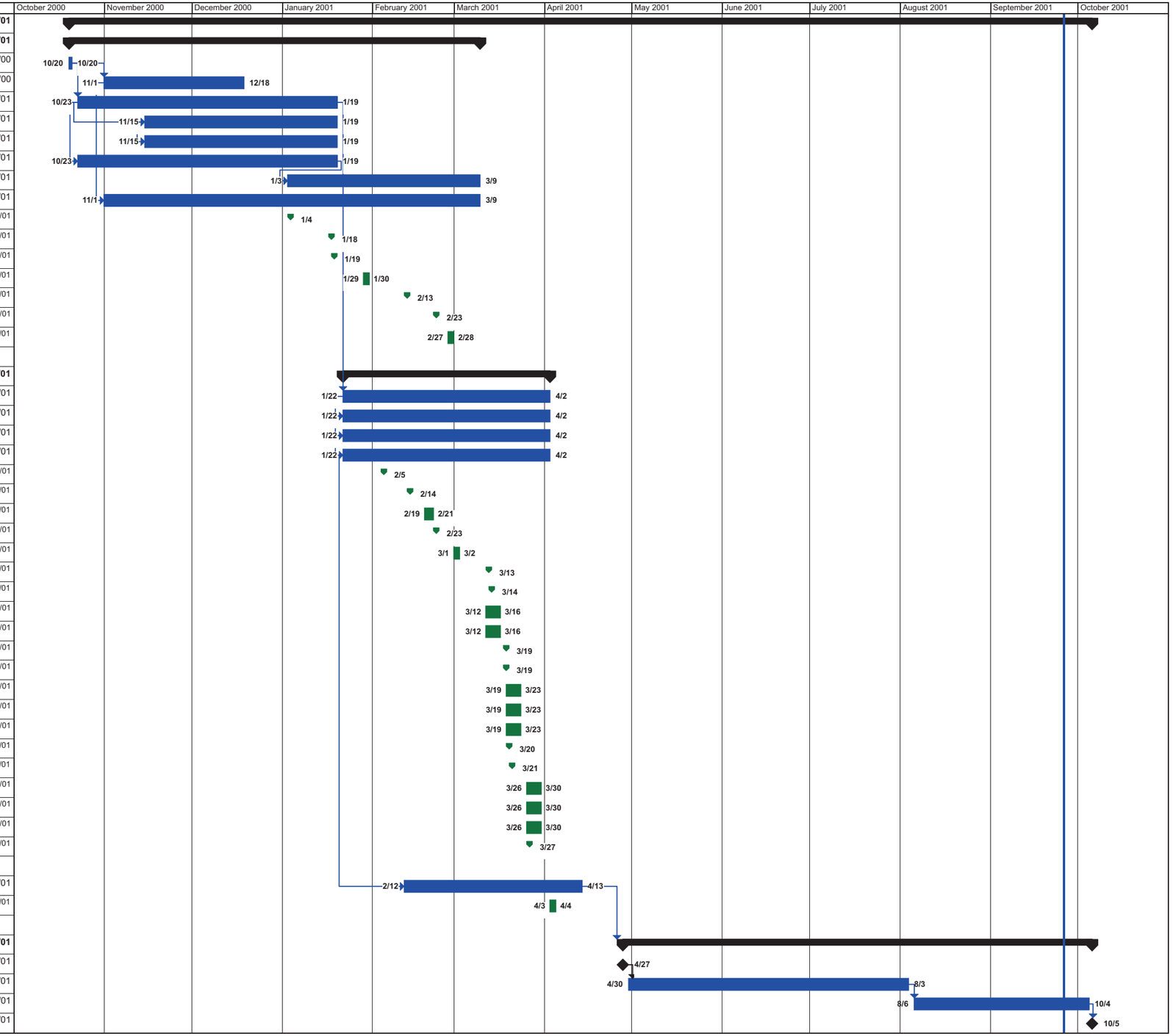
2.6 Site Evaluation Criteria

Criteria were developed as general guidance for site evaluations. These site evaluation criteria were intended to be comprehensive and were used as the basis for HEAT. The specific criteria were classified into the following overall categories:

- General erosion control criteria – The criteria encompassed documentation of any erosion control practices or products and their effectiveness. This included practices such as planting methods, slope breaks, terracing, track-walking, seed-bed preparation, surface and subsurface drainage, and any maintenance activities. A wide variety of erosion control products were used, depending on the site characteristics. Product criteria included the type of product used, the applicability of the product for the current use, whether the specified product was used or not, and the success of the product.
- Vegetative criteria – The criteria included evaluation and measurement (when possible) of rooting depth, percent cover, plant density, planting period, plant establishment, frequency, species diversity, native versus non-native species, and relative plant health.
- Soil and topographic criteria – Soil criteria that were evaluated/measured at each site included depth to restrictive horizon, soil moisture-holding capacity, texture, structure, color, field and/or laboratory analysis results, comparison to adjacent/native soil conditions, slope inclination, slope aspect, slope length, slope roughness, and depressions.
- Climatic criteria – The criteria that were evaluated included precipitation amounts, peak precipitation months, number of days with >1.0 inch of rain, mean annual temperatures, frost-free days, potential for soil freezing, and wind velocities (if possible).

Both quantitative and qualitative methods were used to evaluate the criteria listed above. Whenever possible, quantitative evaluations were conducted rather than qualitative assessments.

ID	Task Name	Duration	Start	Finish
1	**Caltrans Statewide Erosion Control Review**	**251 days**	**Fri 10/20/00**	**Fri 10/5/01**
2	**Pre-fieldwork Efforts**	**101 days**	**Fri 10/20/00**	**Fri 3/9/01**
3	Kick-off Meeting	1 day	Fri 10/20/00	Fri 10/20/00
4	Develop Work Plan	34 days	Wed 11/1/00	Mon 12/18/00
5	Review Existing Information	65 days	Mon 10/23/00	Fri 1/19/01
6	Develop Site Selection Criteria	48 days	Wed 11/15/00	Fri 1/19/01
7	Develop Site Evaluation Criteria	48 days	Wed 11/15/00	Fri 1/19/01
8	Develop Site Review Field Documentation Sheet	65 days	Mon 10/23/00	Fri 1/19/01
9	Contact and Interview District Personnel	48 days	Wed 1/3/01	Fri 3/9/01
10	Cooperation with Cal Poly	93 days	Wed 11/1/00	Fri 3/9/01
11	Caltrans Sacramento kickoff meeting	0 days	Thu 1/4/01	Thu 1/4/01
12	District 2 site tour in Redding with Caltrans and consultant	0 days	Thu 1/18/01	Thu 1/18/01
13	Caltrans field kickoff review meeting	0 days	Fri 1/19/01	Fri 1/19/01
14	Dry-run field review in District 2 with consultant	2 days	Mon 1/29/01	Tue 1/30/01
15	Consultant to Cal Poly to meet with Hallock	0 days	Tue 2/13/01	Tue 2/13/01
16	Consultant meeting in Santa Ana	0 days	Fri 2/23/01	Fri 2/23/01
17	Consultant trip with Caltrans to Cal Poly to coordinate Cal Poly	2 days	Tue 2/27/01	Wed 2/28/01
18				
19	**Statewide Site Evaluations**	**51 days**	**Mon 1/22/01**	**Mon 4/2/01**
20	Identification and Prioritization of Existing and P	51 days	Mon 1/22/01	Mon 4/2/01
21	Quantification of Erosion Characteristics	51 days	Mon 1/22/01	Mon 4/2/01
22	Addressing Site-specific Qualitative Erosion Co	51 days	Mon 1/22/01	Mon 4/2/01
23	Cooperation with Cal Poly	51 days	Mon 1/22/01	Mon 4/2/01
24	Statistical analysis meeting consultant	0 days	Mon 2/5/01	Mon 2/5/01
25	Meeting with District 3 reps Monica Finn, Vic, and Michael (S	0 days	Wed 2/14/01	Wed 2/14/01
26	District 2/consultant	3 days	Mon 2/19/01	Wed 2/21/01
27	District 3 site identification with Monica Finn (consultant)	0 days	Fri 2/23/01	Fri 2/23/01
28	District 3/consultant	2 days	Thu 3/1/01	Fri 3/2/01
29	Meeting with Jim von Dohlen District 10/consultant	0 days	Tue 3/13/01	Tue 3/13/01
30	Meeting with Jim Pittman District 9/consultant	0 days	Wed 3/14/01	Wed 3/14/01
31	District 12/consultant	5 days	Mon 3/12/01	Fri 3/16/01
32	District 6/consultant	5 days	Mon 3/12/01	Fri 3/16/01
33	Meeting with Allan Nakano District 8/consultant	0 days	Mon 3/19/01	Mon 3/19/01
34	Meeting with DBE subconsultants AEI-CASC Engineering	0 days	Mon 3/19/01	Mon 3/19/01
35	District 11/consultant	5 days	Mon 3/19/01	Fri 3/23/01
36	District 10/consultant	5 days	Mon 3/19/01	Fri 3/23/01
37	District 1/consultant	5 days	Mon 3/19/01	Fri 3/23/01
38	Meeting with Bob Schott District 4/consultant	0 days	Tue 3/20/01	Tue 3/20/01
39	Meeting with Jim voh Dohlen District 10/consultant	0 days	Wed 3/21/01	Wed 3/21/01
40	Districts 8 and 9/consultant	5 days	Mon 3/26/01	Fri 3/30/01
41	District 4/consultant	5 days	Mon 3/26/01	Fri 3/30/01
42	District 7/consultant	5 days	Mon 3/26/01	Fri 3/30/01
43	Meeting with AEI-CASC/consultant	0 days	Tue 3/27/01	Tue 3/27/01
44				
45	**Results Summarization**	45 days	Mon 2/12/01	Fri 4/13/01
46	Consultant meeting in Redding for report outline and writing	2 days	Tue 4/3/01	Wed 4/4/01
47				
48	**Draft and Final Report Preparation and Submitta**	**115 days**	**Fri 4/27/01**	**Fri 10/5/01**
49	Draft Report Submittal to Caltrans	0 days	Fri 4/27/01	Fri 4/27/01
50	Caltrans Review of Draft Document	70 days	Mon 4/30/01	Fri 8/3/01
51	Preparation of Final Report	44 days	Mon 8/6/01	Thu 10/4/01
52	Submittal of Final Report	0 days	Fri 10/5/01	Fri 10/5/01



Task | Milestone | Summary | Rolled Up Task | Meetings or site evaluations

FIGURE 10
CALTRANS STATEWIDE EROSION CONTROL REVIEW SCHEDULE
FINAL CALTRANS STATEWIDE EROSION CONTROL REVIEW

3317_50 (10/3/01)

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2.6.1 Interviewing District Personnel

Once the site selection criteria and site evaluation criteria were approved and finalized, staff from each district were contacted. The purpose of the contacts was to identify candidate sites for each district. This involved communication with individual district staff including:

- National Pollutant Discharge Elimination System coordinators
- District landscape architects
- District construction/stormwater staff

Initial contacts were made via telephone to introduce and discuss the project goals and scope and to set up an initial meeting. More detail was presented to district staff during a first meeting to further explain the goals of the Statewide Erosion Control Review. The main goal of meeting with district staff was to identify candidate sites that met many or all of the selection criteria outlined.

The interviews were also used to identify common needs or concerns by district staff. Discussion items included:

- Sites of general concern regarding erosion control within the district boundaries
- Successful sites within district boundaries and reasons for their success
- Rilling, gullying, or slope failures, and opinions from the district as to the cause of these failures
- Vegetative soil covers, plant species, successes, failures, and other related issues
- Site drainage
- Construction influence on erosion control
- Specifications and construction drawings
- Soil types commonly encountered
- Irrigation management
- Slope ratios for successful and unsuccessful erosion control practices
- District personnel opinions regarding erosion control practices that are successful and unsuccessful for the area

A general summary of district staff comments is included in the Results and Recommendations/Conclusions sections of this document.

2.6.2 Quantification of Erosion Characteristics

The research team evaluated methods of quantifying in-field observations of erosion characteristics. Through accurate quantification of erosion characteristics, it would be possible to objectively and statistically evaluate the data and develop trends or significant relationships between problem erosion sites and the potential causes. This resulted in a quantitative comparison of sites statewide. The research team utilized the following quantitative methods when evaluating a site for erosion severity:

- WEPP
- RUSLE predictive model
- Morgan, Morgan, and Finney predictive model
- Channel volume calculations
- Slope inclination, aspect, and length
- Climatic measurements
- Vegetative cover percentages
- Rooting depth
- Soil texture and depth to restrictive horizons
- Laboratory-measured soil chemical and physical analyses

2.6.3 Addressing Site-specific Qualitative Erosion Control Practices

The main goal of this task was to thoroughly evaluate each site for specific qualitative erosion control characteristics or problems, establish a trend of related causes, and provide detailed recommendations. Each site was evaluated for the following qualitative attributes:

- Accuracy, applicability, and clarity of specifications – Prior to site visits, as many specifications as possible were obtained from either district or headquarters staff. The specifications were thoroughly reviewed by the research team, evaluated to determine the applicability to the given site, and reviewed for their effectiveness. In many instances, it was found that the vegetative planting portion of the specifications were inconsistent with the vegetation onsite. This can be attributed to a variety of different factors including but not limited to the following: (1) the original seedlings did not germinate and either were not replanted or were planted with an available seed mix that was not specified in the specifications; (2) the original seeding application did not use species specified in the specifications because of unforeseen circumstances, i.e., seed mix was not available at the time of application; (3) the original planting consisted of a mix of native and non-native species of which one type or another did not germinate well and so was not replanted; and (4) the top priority was to plant something before the rainy season arrived, and specifications were not followed because of insufficient time. Specifications were obtained for 32 of the 57 sites evaluated; some of those specifications were collected after conducting site visits.

- Accuracy and usefulness of design documents – The plans and drawings related to erosion control for each site (when available to the research team) were evaluated prior to and during site evaluation to determine how accurately the contractor followed the documents, how well they served as guidance materials, and the completeness of the documents.

- Construction practices – Special attention was paid to construction practices related to or influencing erosion control measures. Some of these practices included track-walking, slope compaction and stability, seeding operation effectiveness, surface treatment effectiveness (e.g., mulches, tackifiers, and straw) for soil retention, soil type used for final cover, and site drainage.

- Initial and any ongoing maintenance practices not related to erosion control – The sites were evaluated to determine the effectiveness of any maintenance practices that were not directly related to erosion control that may have taken place since the completion of

construction. These maintenance practices may have influenced erosion control success. These were verified with district personnel during personal interviews and were evaluated in the field.

- Supplemental erosion control maintenance practices – Any and all supplemental erosion control practices that were employed following construction were verified with district personnel and evaluated for their effectiveness.
- Interrelationship of landscape architecture with the overall design of the site, erosion components, and functionality of the site – All landscape architecture components of design and specification documents were identified and evaluated according to their effectiveness for erosion control. This included specified types of plantings, structures, or topographic modifications for landscaping purposes that may have enhanced or degraded erosion control.
- Assessment of effectiveness of structural erosion control technology and products – Evaluation of any and all permanent or long-term temporary erosion control structures and products, whether as a part of the original construction or supplemental maintenance programs, were evaluated.
- Onsite recommendations from district staff – It was understood that some of the best knowledge about a specific site was local knowledge. District staff were encouraged to visit each site with the respective site evaluator to contribute additional knowledge about the construction, maintenance, and special circumstances of each site.

2.6.4 Cooperative Work Efforts with Cal Poly

A preliminary site visit to Cal Poly was conducted by the research team's project managers as a kickoff meeting to address cooperative efforts between Cal Poly and the research team through the duration of the project. Special attention was given to Dr. Hallock's work in Caltrans District 5 to avoid repeating work that might already have been performed.

2.7 Soil Analyses

Soils were sampled at each site evaluated by the research team. Soils were sampled from representative areas within the site and were taken at depths corresponding to soil profile descriptions. In most cases, soil samples were not taken below vegetation rooting depth. This was because the soil samples were taken to determine the present fertility status that could be influencing vegetative growth onsite. Soil profiles for each study site were described and sampled according to standard protocol (USDA-NCRS, 1998). Soil descriptions were entered into HEAT data sheets, and soil samples were sent to A&L Western Laboratories in Modesto, California, for analysis.

Samples were placed in thick-walled, re-sealable plastic bags and shipped to the laboratory in groups. Chain-of-custody sample forms were included with the samples sent to the laboratory, and a copy was kept for project records. The soil samples were analyzed for the following physical and chemical parameters:

- Organic matter
- Phosphorus (weak bray)

- Phosphorus (sodium bicarbonate)
- Extractable cations (potassium, magnesium, calcium, sodium)
- pH
- Cation exchange capacity
- Percent cation saturation (computed)
- Nitrate-nitrogen
- Electrical conductivity
- Sulfate sulfur
- Zinc
- Manganese
- Iron
- Copper
- Boron
- Sand, silt, and clay

2.8 Health and Safety

A Health and Safety Plan (HSP) was developed strictly applicable to the fieldwork associated with this project in various locations throughout California. The HSP described hazards associated with fieldwork, listed personal protective equipment to be used, and provided emergency response protocol. A copy of the HSP was carried with each field team at all times, in addition to a listing of all hospitals within the State of California.

Project-specific hazards included cold stress, heat stress, and exposure to vehicular traffic. Other hazards included manual lifting, hand augering, and biological hazards. As might be expected, the HSP specifically focused on the dangers and safety requirements associated with work along roadsides and in close proximity to passing traffic. Safety was stressed throughout the project. All team members that were a part of any fieldwork efforts were required to review and sign the HSP.

All team members were equipped with appropriate personal protective equipment before beginning field work. This included hard hats, safety glasses, high-visibility vests, and steel-toed boots. In addition, team members received high-visibility rain gear. Each team carried a cellular phone for emergencies. Each field vehicle was equipped with safety and emergency supplies. A flashing orange light was mounted on each vehicle and turned on when pulling off the roadway and parking within 40 feet of the roadway. Emergency equipment included a fire extinguisher, first aid kit, personal eye wash, potable water, and a blood-borne pathogen kit.

3.0 Results

3.1 Statistical Data Analysis

3.1.1 Introduction

Over the course of the 3-month evaluation, quantitative and qualitative data were collected for 57 sites representing widely varying environmental conditions across the state (see Table 2). This variation included larger-scale climatic factors such as rainfall (ranging from 5 to over 100 inches per year), temperature, prevailing wind direction and speed, geology and associated soil parent material, and even tectonic stability. Smaller-scale variations such as aspect, slope, soil materials, and site design and management added to a diverse statewide data set. The multitude of environmental and anthropogenic factors affecting measurable variables such as erosion and vegetative cover presented a considerable challenge in analysis and statistical interpretation of data.

Because data interpretation is most credible if statistically validated, data analysis for this evaluation employed several approaches to best highlight relationships and trends in the results. The most revealing and powerful approach to finding correlation or causal relationships among measured variables is the use of parametric statistical procedures. Parametric statistical analyses, such as simple linear regressions, are built upon the assumption that the population has a Gaussian, or normal distribution. Therefore, before selection of appropriate statistical procedures, normality was evaluated qualitatively using histogram plots, as well as quantitatively using skewness tests. Wilks-Shapiro, a more powerful quantitative test of normality, was not appropriate because of the sample size (number of sites evaluated).

Histogram plots of either the site data (e.g., precipitation, vegetative cover, and slope) or log-transformed data (base 10 logarithm of data values) indicated that most sample sets were derived from normally distributed populations (see Figures 11A through 11E). Some sample sets were skewed to one side of the mean or the other, while others had slight kurtosis, which is where the bell-shaped curve is slightly depressed in the center and pushed more towards the shoulders. Skewness tests were also conducted to numerically determine if samples were normally distributed. These tests revealed that all data sets except vegetative cover, vegetative and litter cover, and a number of high-intensity rainfall days were not normally or log-normally distributed. However, skewness test results, as well as kurtosis in the histogram plots, may simply suggest that the variance associated with the data still reflected a normal distribution, but merely disparate sample sets reflective of a highly variable population in an environmentally diverse area. This conclusion was supported by the normal distributions observed in histogram plots. Thus, it was deemed acceptable to conclude that the data were derived from normally distributed populations; and therefore, it was appropriate to use parametric statistical procedures.

Data analyses employing parametric statistical procedures, including linear regressions, are more powerful and precise than non-parametric procedures that generally rely upon ranking, and would aid in providing more definitive, quantitatively based data conclusions.

The linear regression evaluated relationships between factors, such as precipitation and plant growth or between sand content and channel erosion, whereby a significant effect implied causation. Coefficients of determination (R^2) were also calculated, where high values indicated that factors were correlated. Determination of a causal relationship (e.g., vegetative cover is significantly affected by soil organic matter) did not necessarily indicate correlation (e.g., vegetative cover increases linearly with organic matter).

Although it was beyond the scope of this evaluation to collect data from additional sites, the data distributions suggested that increasing the sample size may have better encompassed the wide variability measured across the state, and ultimately would have revealed normal distributions. Furthermore, a larger data set would have allowed grouping of variables, such as channel erosion or vegetative growth, by climate or other environmental factors that affect soil conditions, plant growth, and erosion. Given the variability encountered through the evaluation, significant effects in regressions were reported for α values of 0.01, 0.05, 0.10, and 0.15 (see Tables 3 and 4).

3.1.2 Linear Regressions: Vegetative and Litter Cover

Vegetation and litter were dependent variables, affected by such factors as soil fertility, slope, precipitation, and temperature. The following sections describe regressions of several vegetative cover factors to help understand how vegetative erosion control may have been influenced by the environment or site design and management.

3.1.2.1 Slope

Steeper slopes are more conducive to runoff and soil erosion, which degrade the soil for existing vegetation, as well as limit the foundation in which seeds may germinate. Increased runoff velocities from steeper slopes can also decrease infiltration of water into the soil and the depth of soil in which plants may establish roots.

Linear regressions were run for the effects of slope with vegetative cover using a reduced data set. Sites with other obvious reasons for depleted vegetation (e.g., recently planted sites, the landslide at Blue Slide, or non-irrigated desert environment at Barstow) were excluded from the analysis. Linear regressions of slope versus vegetative cover resulted in a significant, inversely proportional relationship ($\alpha = 0.05$). However, the coefficient of determination (R^2), the value indicating the amount of variability in vegetative cover explained by slope, was very low (<0.15), indicating that other factors also affected vegetative cover (Mahmood, 2002, pers. comm.).

As indicated by the above results, a slope corresponding to Caltrans' target minimum vegetative cover of 70 percent could not be identified. The results of this statistical analysis indicated that the data set established in this review was not appropriate for such a determination. The scope of this review included only a limited selection of problem sites. Therefore, it was concluded that a target slope would be best identified using a more focused study that would include a greater number of sites, perhaps generating regionally appropriate slope values.

Table 2
Summary Data Table for Statewide Erosion Evaluation Sites

Continuous Values

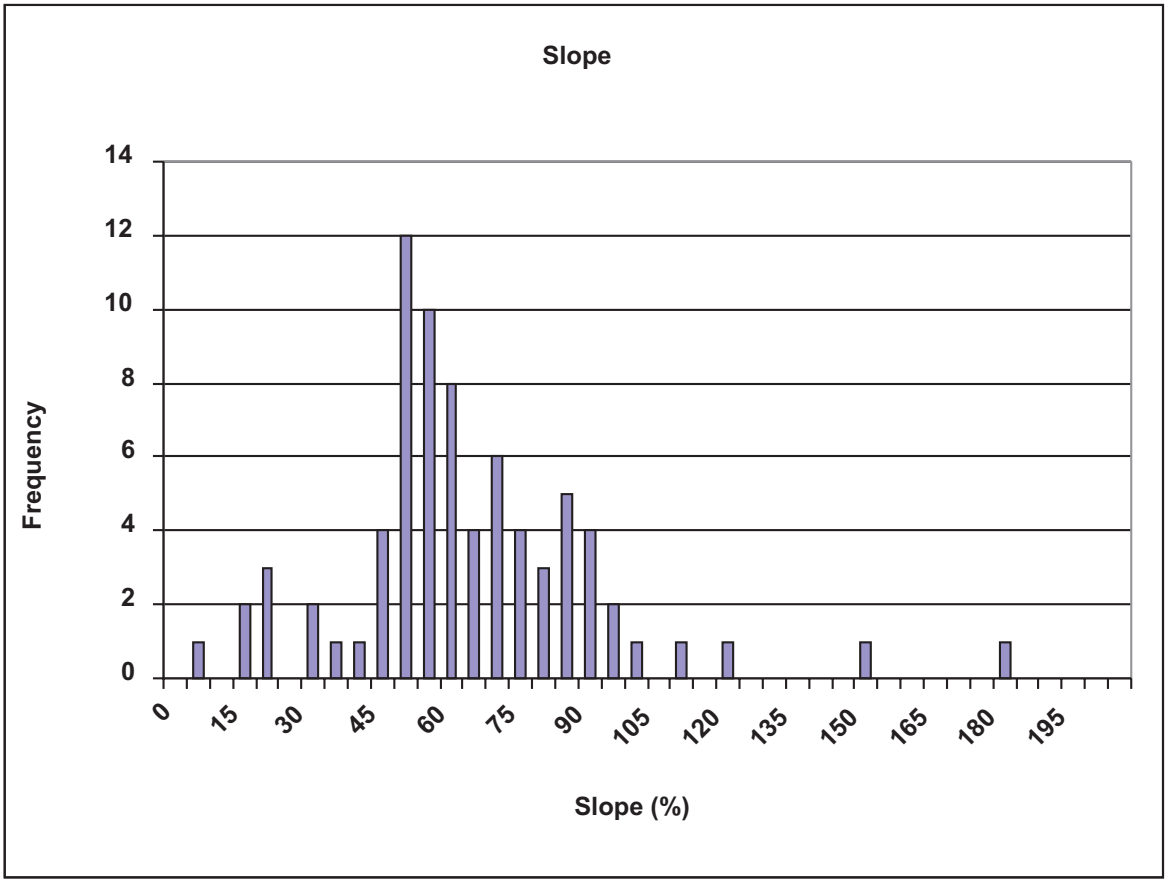
				Independent Environmental Parameters											Mixed Site Parameters			Dependent Site Parameters		
Site Name[a]	Code	Slope H:V/(%)	Slope Length (m)	>1" rainfall days (ct)	90% Freeze-free Days (ct)	Mean Temperature (°C)	Mean Precipitation (mm)	% Sand	% Clay	Nitrate (ppm)	pH	EC	CEC	OM	Vegetative Cover (%)	Vegetative and Litter Cover (%)	Litter Cover (%)	Channel Erosion (m^3/m^2)	MMF Erosion (kg/m^2)	RUSLE Erosion (tons/acre)
1BS (Blue Slide)	1BS	1.3:1 (80)	60	30	94	10.4	2,161	IS	IS	IS	IS	IS	IS	IS	0	0	0	NE	ID	ID
1GB (Garberville)	1GB	1.5:1 (67)	30	21	232	13.3	1,776	56	25	4.0	7.3	0.3	23.5	1.7	34	90	56	NE	0.00018	69.392
1 HP (Hopland)	1HP	1.6:1 (62)	25	14	245	15.8	1,588	50	30	2.0	8.0	0.2	20.9	1.1	86	96	10	NE	0.000039	34.227
1SR (Six Rivers)	1SR	1.1:1 (92)	20	17	135	13.9	1,394	64	15	4.0	7.0	0.3	20.2	1.9	0	0	0	NE	ID	ID
2CB (Canby)	2CB	1.2:1 (85)	25	2	254	8.2	388	IS	IS	IS	IS	IS	IS	IS	3	3	0	NE	ID	ID
2LH1 (Lakehead) 1	2LH1	1.5:1 (66)	28	21	250	16.7	1,599	82	6	17.0	7.5	0.6	12.6	1.7	6	6	0	NE	0.648	75.572
2LH2 (Lakehead 2)	2LH2	1.6:1 (62.5)	20	21	250	16.7	1,599	80	6	17.0	5.2	0.4	26.1	1.6	49	49	0	0.005254901	2.647	127.229
2OB (O'Brien) Area A	2OBA	1.2:1 (85)	13	6	250	16.7	1,599	IS	IS	IS	IS	IS	IS	IS	25	25	0	NE	0.01	65.839
2OB (O'Brien) Area B	2OBB	1.2:1 (85)	13	6	250	16.7	1,599	IS	IS	IS	IS	IS	IS	IS	25	25	0	NE	ID	ID
2OB (O'Brien) Area C	2OBC	1.6:1 (62)	13	6	250	16.7	1,599	60	17	13.0	5.7	0.2	11.2	2.0	90	90	0	NE	ID	ID
2WG (Weed Gap) Area A	2WGA	1.8:1 (56)	25	6	69	9.1	661	64	16	2.0	7.0	0.1	7.8	1.2	1	97	96	NE	1.276	1.57
2WG (Weed Gap) Area B	2WGB	1.8:1 (56)	25	6	69	9.1	661	64	16	9.0	6.4	1.5	13.6	2.4	1	97	96	NE	ID	ID
3BO (Blue Oaks)	3BO	2.2:1 (45)	10	6	187	15.4	577	65	14	1.0	6.9	0.2	8.4	0.8	45	84	39	0.00013104	2.228	4.87
3FO (Folsom)	3FO	2.2:1 (47)	50	6	237	16.5	959	69	14	9.8	5.9	0.2	16.6	1.6	45	55	10	NE	1.852	10.388
3MF (Missouri Flats)	3MF	1.2:1 (85)	33	13	173	13.8	981	56	23	3.0	5.8	0.1	20.1	2.7	53	58	5	NE	1.894	41.917
3PC (Prairie City)	3PC	1.8:1 (55)	8	6	237	16.5	608	62	22	79.0	5.4	0.8	19.9	13.7	18	48	30	NE	0.839	ID
4AB (Air Base Parkway)	4AB	1.3:1 (80)	13	5	196	15.7	559	44	23	5.0	7.7	0.3	32.0	2.3	12	36	24	0.000296748	0.839	ID
4CU (Cupertino)	4CU	5.6:1 (18)	22	2	236	15.6	369	49	25	3.0	7.6	0.2	28.0	1.8	0	65	65	NE	ID	ID
4DA (De Anza)	4DA	1.5:1 (68)	18	4	244	14.7	477	63	21	2.0	7.8	0.4	30.8	3.3	73	93	20	NE	ID	ID
4FH (Farm Hill) Area A	4FHA	1.8:1 (55)	30	2	205	14.4	392	58	21	3.0	8.0	0.4	33.0	2.0	54	78	24	0.014234356	ID	ID
4FH (Farm Hill) Area B	4FHB	1.8:1 (55)	30	2	205	14.4	392	78	5	5.0	8.3	0.6	8.2	1.9	54	78	24	NE	ID	ID
4PM (Point Molate)	4PM	1.6:1 (64)	10	6	264	14.7	582	57	21	4.3	2.3	0.1	7.0	0.9	31	93	62	NE	ID	ID
5AT (Atascadero) Area A	5ATA	2.4:1 (41)	16	3	159	16.2	178	45	37	1.6	5.2	0.2	27.9	1.1	92	96	4	NE	0.834	ID
5AT (Atascadero) Area B	5ATB	3.3:1 (30)	20	3	159	16.2	178	57	25	1.0	6.3	0.3	14.2	1.3	46	52	6	NE	1.37	ID
5LA (Los Alamos) Area A	5LAA	6.3:1 (16)	20	6	235	16.2	525	79	11	2.0	8.4	0.2	15.4	1.0	60	79	19	4.04567E-06	1.159	ID
5LA (Los Alamos) Area B	5LAB	1.7:1 (58)	7.5	6	235	16.2	525	40	41	2.0	6.8	0.2	33.1	1.7	26	78	52	NE	5.08	ID
5OR (Orcutt) Area A	5ORA	1.5:1 (68)	21	6	235	16.2	525	43	32	1.0	8.1	0.2	25.1	1.4	13	13	0	NE	0.119	ID
5OR (Orcutt) Area B	5ORB	1.4:1 (70)	21	6	235	16.2	525	37	22	3.0	7.8	0.2	27.5	1.1	54	54	0	NE	ID	ID
5PR (Prunedale)	5PR	1.4:1 (71)	33	2	170	14.7	343	33	21	8.0	5.5	0.2	20.6	2.5	96	96	0	NE	0.745	ID
6CA (Coalinga)	6CA	0.91:1 (110)	45	6	111	13.1	532	43	21	5.3	7.9	0.4	22.8	1.6	51	61	10	5.13552E-07	0.645	9.848
6EA (Easton)	6EAA	5.6:1 (18)	6	1	203	17.3	279	83	8	5.0	6.5	0.2	2.9	0.6	42	74	32	NE	ID	ID
6PC (Posos Creek)	6PC	1.9:1 (52)	8	0	276	18.4	158.8	74	11	52.0	7.7	5.2	23.8	1.4	26	26	0	2.86092E-05	0.202	7.364
7CA (Casitas Lake) Area A	7CA	1.7:1 (60)	20	7	228	16.5	545	58	15	2.0	7.8	0.3	23.2	0.8	20	20	0	2.56143E-05	1.126	ID
7CA (Casitas Lake) Area B	7CAB	1.7:1 (60)	20	7	228	16.5	545	54	15	2.0	7.8	0.3	23.2	0.8	68	68	0	NE	ID	ID
7MM (Magic Mountain)	7MMA	1.7:1 (60)	33	0	194	16.1	345	80	7	3.0	7.2	1.8	14.2	1.1	29	29	0	0.001588056	1.29	ID
7SH (Sierra Highway) Area A	7SHA	1.8:1 (55)	46	6	251	16.2	453	98	2	1.9	2.8	12.8	96.2	3.7	2	2	0	0.005095207	0.33	ID
7SH (Sierra Highway) Area B	7SHB	1.8:1 (55)	46	6	251	16.2	453	78	9	2.0	5.3	0.6	22.0	1.8	3	3	0	NE	0.33	19.6
7TH (Templin Highway)	7TH	1.2:1 (85)	35	2	186	16.6	200	66	13	2.0	8.3	0.3	11.6	0.4	54	56	2	0.000139074	0.167	7.27
8BM (Beaumont)	8BM	1.8:1 (55)	20	5	205	16.7	454	30	31	2.0	7.8	1.9	36.9	1.5	58	64	6	NE	0.782	ID
8BS (Barstow)	8BS	2.6:1 (38)	30	0	212	17.8	111.8	70	17	4.0	7.9	1.8	19.3	1.1	0	0	0	0.010971247	ID	ID
8CO (Corona) Area A	8COA	1.8:1 (55)	30	3	258	17.5	291.8	50	13	2.0	3.8	6.0	120.0	2.4	0	0	0	NE	0.623	ID
8CO (Corona) Area B	8COB	1.8:1 (55)	30	3	258	17.5	291.8	58	15	2.0	6.9	0.3	11.8	1.5	50	52	2	NE	ID	ID
8LE (Lake Elsinore)	8LE	0.56:1 (180)	22	3	205	17.8	281.7	IS	IS	IS	IS	IS	IS	IS	1	1	0	NE	ID	ID
9CS (Conway Summit)	9CS	1.9:1 (54)	30	3	84	8.6	355	59	19	2.0	8.2	0.1	11.7	1.2	6	12	6	NE	1.206	6.638
9ML (Mono Lake)	9ML	1.3:1 (80)	17	0	84	8.6	355	84	9	5.0	7.1	0.9	10.1	1.2	22	28	6	NE	0.924	7.808
9OL (Olancha)	9OL	3.3.1 (30)	6	0	189	15.2	170	86	7	4.0	8.2	0.4	10.1	0.9	26	46	20	NE	0.687	1.095
10BW (Barney Way)	10BW	1.2:1 (86)	18	16	169	13.8	1,176	61	16	3.0	6.6	0.1	27.5	2.1	25	41	16	0.000674201	1.947	36
10FH (Forest Home)	10FH	2.1:1 (48)	15	6	237	16.5	608	63	22	1.8	4.6	0.2	4.3	0.9	62	66	4	0.01766232	1.174	5.22
10LD (Lower Doran)	10LD	7.7:1 (13)	2	16	169	13.8	1,184	49	24	10.3	5.9	0.3	9.9	3.2	42	50	8	NE	2.615	18.422
10PG (Pine Grove)	10PG	1.1:1 (90)	20	9	171	15.8	751	IS	IS	IS	IS	IS	IS	IS	38	62	24	0.00051675	0.005	ID
10VP (Vista Point)	10VP	2.0:1 (51)	60	1	198	17.0	240	52	28	4.3	7.7	0.9	16.8	1.3	35	96	61	0.0000191	0.463	1.772
10WP (West Point) Area A	10WPA	1.1:1 (90)	16	16	169	13.8	1,176	71	16	1.0	6.6	0.1	8.7	1.3	19	72	53	0.00000462	1.947	29.407
10WP (West Point) Area B	10WPB	1.1:1 (90)	33	16	169	13.8	1,176	71	16	1.4	5.6	0.1	3.3	2.1	16	55	39	NE	ID	ID
11CA (College Avenue)	11CA	1.4:1 (70)	15.5	3	365	17.7	326	59	26	6.0	5.1	0.6	42.9	2.9	12	100	88	NE	0.396	4.753
11DH (Del Mar Heights) Area A	11DHA	2.0:1 (50)	18	2	349	16.0	261	93	3	2.0	5.6	0.2	3.6	0.6	90	100	10	NE	1.008	7.345
11DH (Del Mar Heights) Area B	11DHB	2.0:1 (50)	18	2	349	16.0	261	93	3	3.0	7.0	2.2	3.8	0.6	54	58	4	NE	ID	ID
11DM (Del Mar) Area A	11DMA	8.3:1 (12)	15	2	341	16.0	261	91	8	4.0	6.9	0.2	3.2	0.5	65	84	19	0.028136565	0.331	6.146
11DM (Del Mar) Area B	11DMB	2.0:1 (50)	35	2	341	16.0	261	85	8	2.0	6.4	0.5	6.3	0.6	55	55	0	NE	ID	ID
11DM (Del Mar) Area C	11DMC	20:1 (5)	10	2	341	16.0	261	49	21	71.0	7.5	50.0	45.4	1.8	6	6	0	NE	ID	ID
11MC (Maric College) Area A	11MCA	2.0:1 (50)	47	3	365	17.7	326	77	14	4.0	8.3	0.3	25.9	2.2	81	90	9	NE	0.248	3.287
11MC (Maric College) Area B	11MCB	20:1 (50)	47	3	365	17.7	326	41	22	3.0	7.2	0.5	18.1	3.1	70	100	30	NE	ID	ID
11MM (Miramar) Area A	11MM	1.3:1 (75)	25	3	365	17.7	326	77	14	16.0	7.8	1.0	14.1	1.7	50	70	20	NE	0.54	22.034
11MM (Miramar) Area B	11MMB	1.3:1 (75)	25	3	365	17.7	326	IS	IS	IS	IS	IS	IS	IS	50	50	0	NE	ID	ID
11MM (Miramar) Area C	11MMC	1.3:1 (75)	25	3	365	17.7	326	IS	IS	IS	IS	IS	IS	IS	80	80	0	NE	ID	ID
11MV (Mar Vista)	11MV	2.0:1 (50)	13	3	298	17.5	339	75	11	9.0	5.8	0.2	17.3	2.0	80	86	6	NE	0.561	5.378
11SP (San Pasqual) Area A	11SPA	1.1:1 (95)	20	3	273	18.2	372	93	4	3.0	7.0	0.1	11.4	1.2	60	65	5	NE	1.437	20.17
11SP (San Pasqual) Area B	11SPB	1.0:1 (100)	16	3	273	18.2	372	63	18	4.0	6.4	0.1	14.4	2.7	26	38	12	NE	ID	ID

Table 2
Summary Data Table for Statewide Erosion Evaluation Sites

Continuous Values

				Independent Environmental Parameters											Mixed Site Parameters			Dependent Site Parameters		
Site Name[a]	Code	Slope H:V/(%)	Slope Length (m)	>1" rainfall days (ct)	90% Freeze-free Days (ct)	Mean Temperature (°C)	Mean Precipitation (mm)	% Sand	% Clay	Nitrate (ppm)	pH	EC	CEC	OM	Vegetative Cover (%)	Vegetative and Litter Cover (%)	Litter Cover (%)	Channel Erosion (m^3/m^2)	MMF Erosion (kg/m^2)	RUSLE Erosion (tons/acre)
11TP (Teepee Road)	11TP	1.7:1 (60)	12.5	3	273	18.2	372	81	11	4.0	6.4	0.3	9.8	2.7	74	92	18	NE	0.472	5.423
12ET (El Toro) Area A	12ETA	2.1:1 (48)	50	3	241	12.0	327	63	18	2.0	8.3	0.2	13.3	1.0	60	65	5	0.019623606	0.451	5.468
12ET (El Toro) Area B	12ETB	2.1:1 (48)	50	3	241	12.0	327	63	16	2.0	8.1	0.2	12.7	1.2	30	45	15	NE	ID	ID
12LA (Los Alisos)	12LA	2.0:1 (50)	50	3	241	12.0	327	47	14	1.0	3.3	10.0	84.6	4.1	0	94	94	0.01026666	0.563	8.24
12LB (Laguna Beach) Area A	12LB	0.83:1 (120)	50	3	280	12.2	323	69	10	8.0	8.0	3.9	18.1	0.8	15	15	0	NE	0.191	245.8
12LB (Laguna Beach) Area B	12LBB	0.67:1 (150)	150	3	280	12.2	323	IS	IS	IS	IS	IS	IS	IS	15	15	0	NE	ID	ID
12LC (Laguna Canyon) Area A	12LCA	2.0:1 (50)	140	3	241	12.0	327	59	10	2.0	8.3	0.8	22.8	1.2	30	35	5	NE	0.563	12.585
12LC (Laguna Canyon) Area B	12LCB	2.0:1 (50)	140	3	241	12.0	327	69	16	3.0	7.8	0.6	15.5	1.4	68	76	8	NE	0.563	16.346
12TB (Toll Booth) Area A	12TBA	2.3:1 (43)	30	3	267	12.4	350	60	22	2.0	4.4	3.6	40.1	1.6	43	47	4	0.002674631	0.483	14.679
12TB (Toll Booth) Area B	12TBB	2.3:1 (43)	70	3	267	12.4	350	59	22	2.0	8.0	0.4	21.1	1.3	45	50	5	NE	ID	ID
12TB (Toll Booth) Area C	12TBC	2.9:1 (35)	30	3	267	12.4	350	72	14	4.0	7.1	1.2	40.3	1.0	77	85	8	NE	ID	ID

[a]Sites listed with multiple areas (e.g., Area A and Area B) are the same site, but were evaluated in sections to separate areas on a site with distinct differences that may have an effect on the vegetative erosion control achieved.
m = meters
ct = count
°C = degrees Celsius
mm = millimeters
ppm = parts per million
EC = electrical conductivity
CEC = cation exchange capacity
OM = organic matter
m^3/m^2 = cubic meters per square meters
MMF = Morgan, Morgan, and Finney
kg/m^2 = kilograms per square meter
IS = Insufficient sample
NE = Not evaluated
ID = Insufficient data



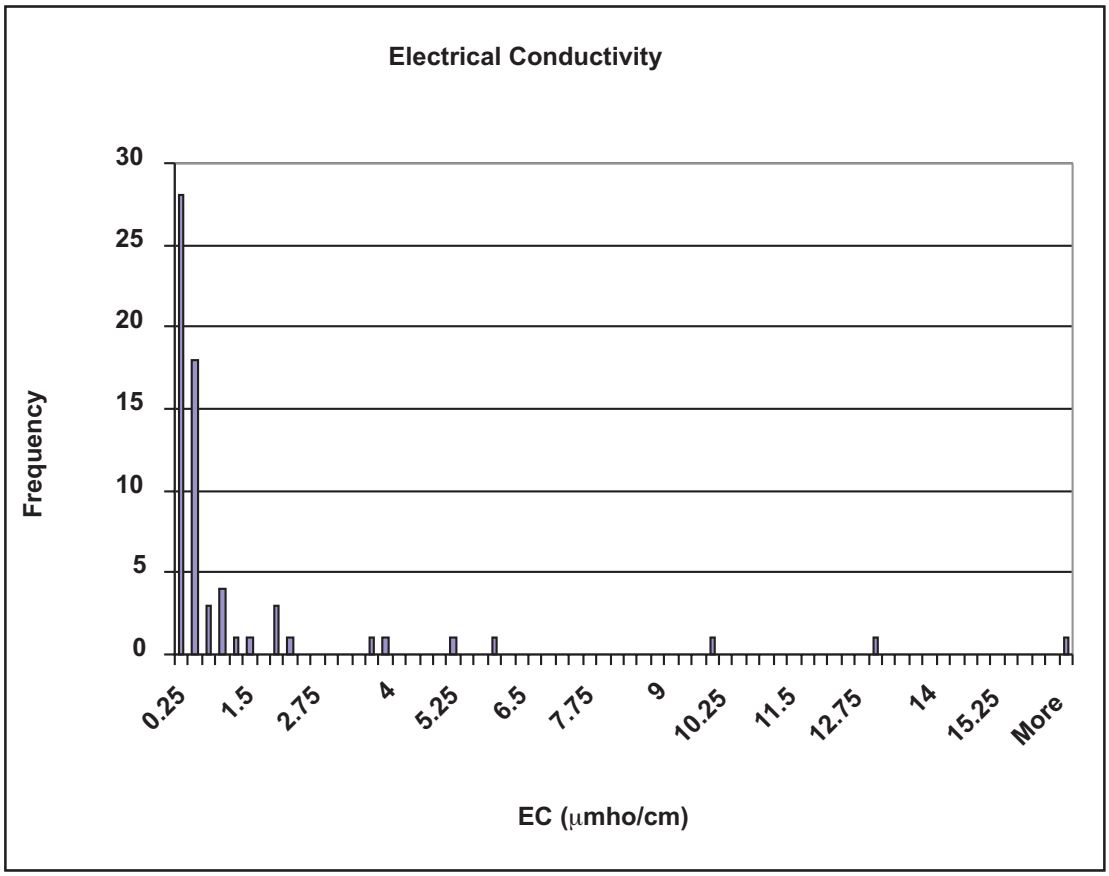
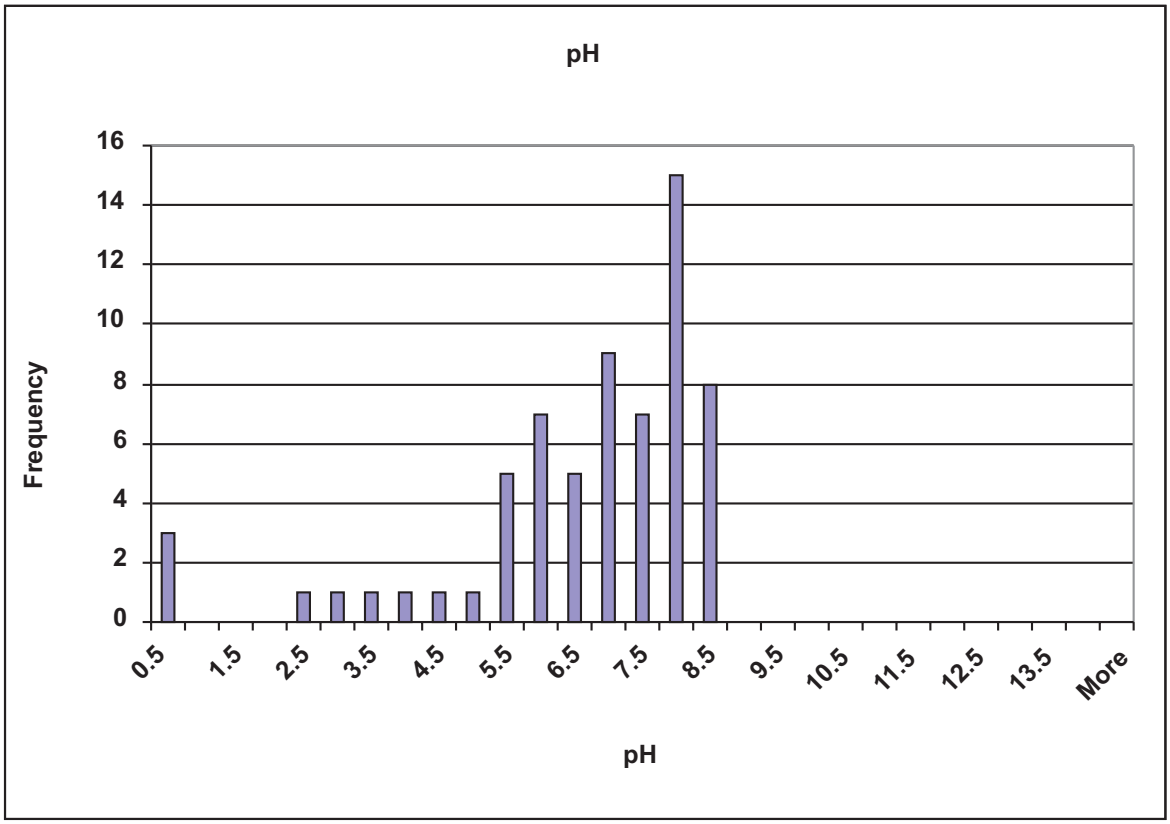


FIGURE 11A
HISTOGRAM RESULTS
FINAL CALTRANS STATEWIDE EROSION CONTROL REVIEW

3317_32 (9/28/01)



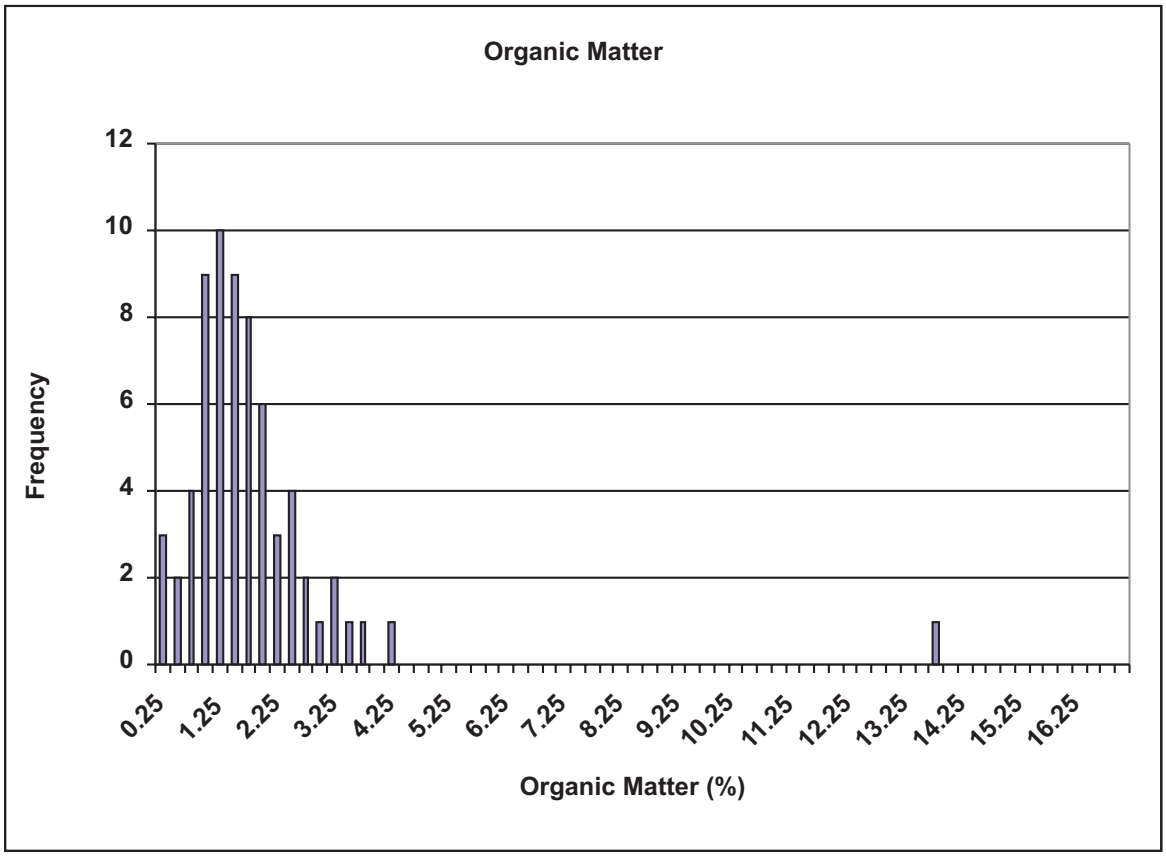
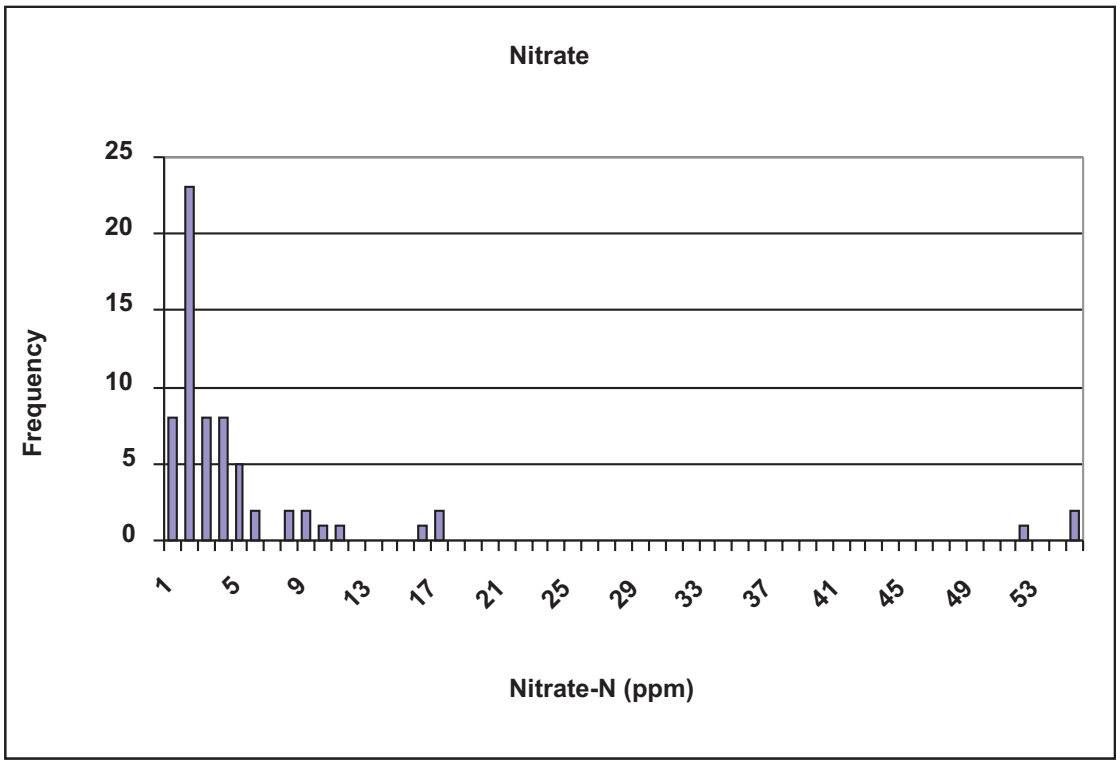


FIGURE 11B
HISTOGRAM RESULTS
FINAL CALTRANS STATEWIDE EROSION CONTROL REVIEW



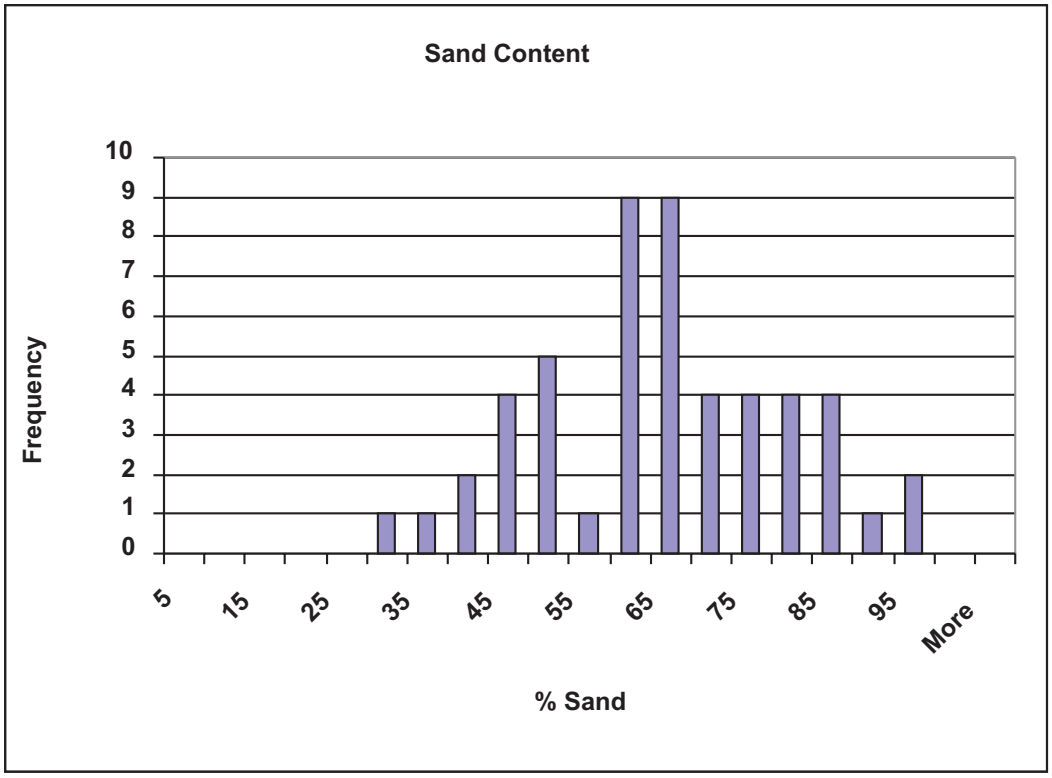


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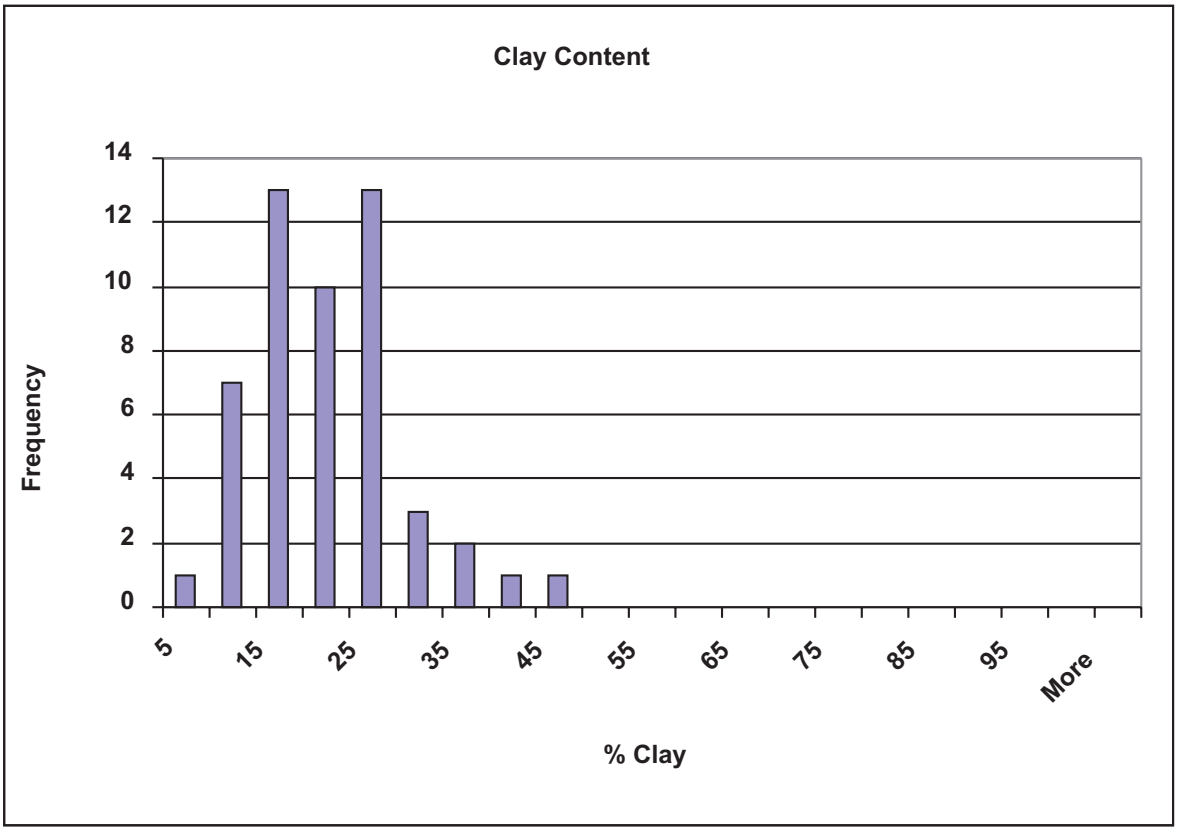
FIGURE 11C
HISTOGRAM RESULTS
FINAL CALTRANS STATEWIDE EROSION CONTROL REVIEW



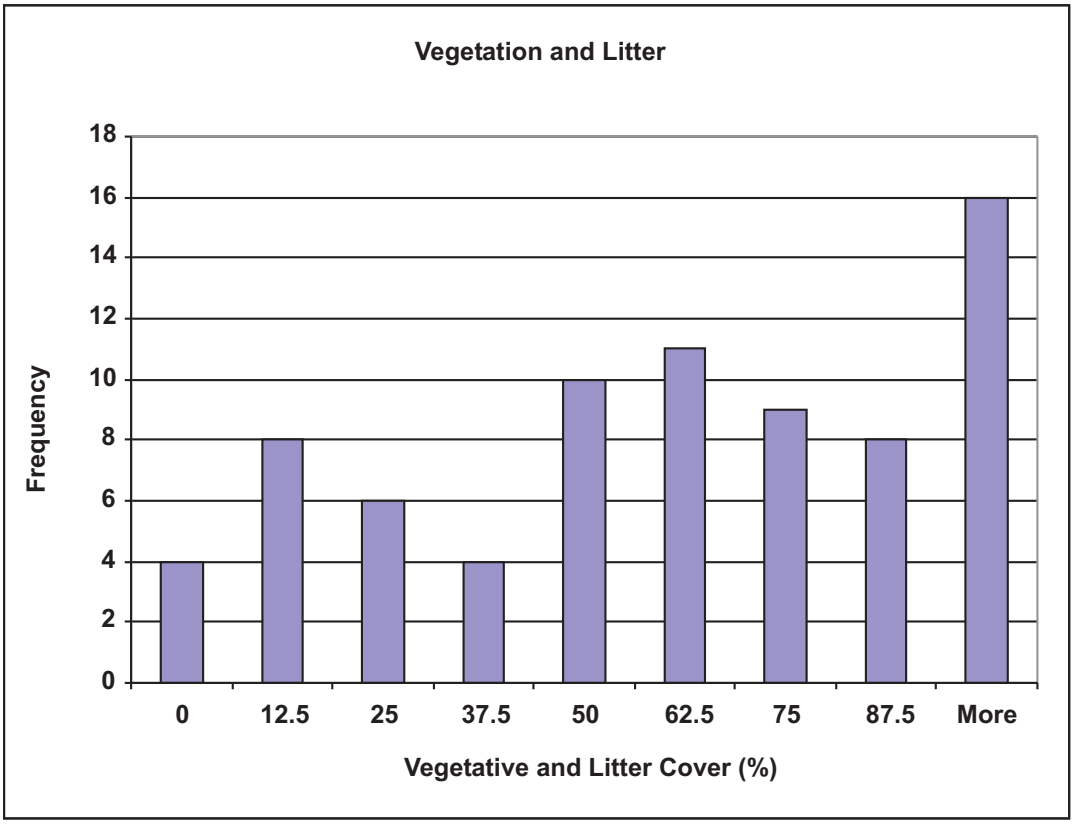
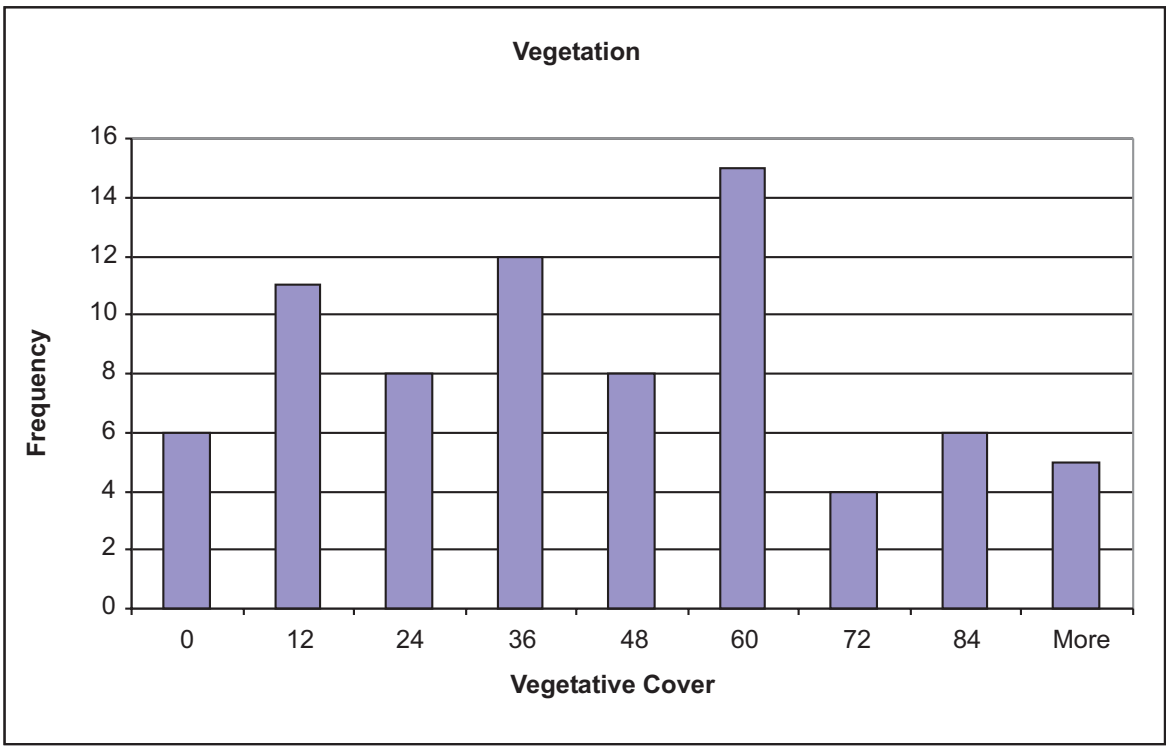
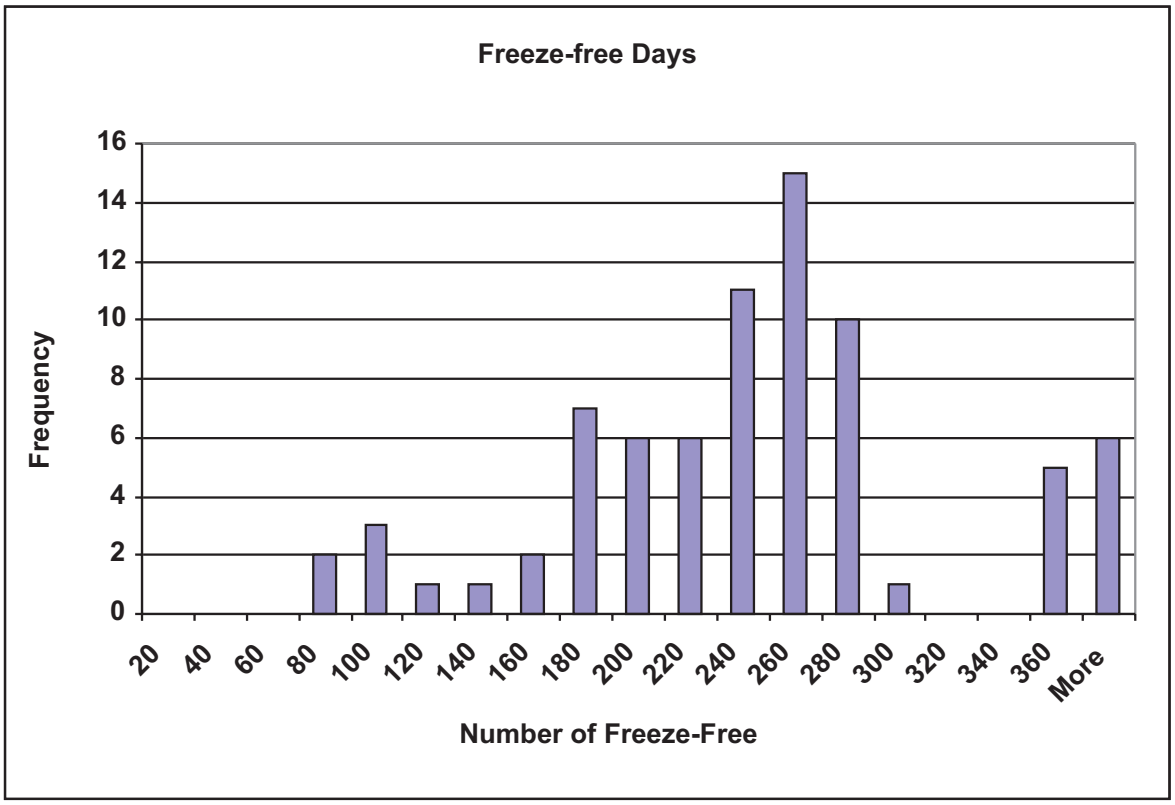


FIGURE 11D
HISTOGRAM RESULTS
FINAL CALTRANS STATEWIDE EROSION CONTROL REVIEW





3317_32 (9/28/01)

FIGURE 11E
HISTOGRAM RESULTS
FINAL CALTRANS STATEWIDE EROSION CONTROL REVIEW

TABLE 3
Linear Regression Results for Vegetative Coverage Measurements

Effect	Vegetative Cover[a]
Slope	**
Air Temperature	****
Mean Precipitation	*
Freeze-free Days	****
CEC	NS
pH	NS
Organic Matter	NS
Electrical Conductivity	**
Nitrate-N	NS
% Sand	NS

[a]Significance Levels: **** = 99%, *** = 95%, ** = 90%, * = 85%, NS = not significant.

TABLE 4
Linear Regression Results for Channel Erosion Measurements

Effect	Vegetative Cover[a]
Precipitation	NS
High Intensity Rainfall Events	NS
Slope	NS
CEC	NS
Organic Matter	NS
% Vegetative Cover	NS
% Litter Cover	NS
% Clay	NS
% Sand	NS

[a]Significance Levels: **** = 99%, *** = 95%, ** = 90%, * = 85%, NS = not significant.

3.1.2.2 Temperature, Freeze-free Days, and Precipitation

Climatic factors such as temperature and precipitation may have a number of indirect relationships or direct causal relationships. Regressions indicated that precipitation, mean air temperature, and the number of freeze-free days were significantly related to vegetative cover (α = 0.15, 0.01, and 0.01, respectively). Vegetative cover was decreased with greater precipitation levels, in spite of the fact that several sites were too dry to support good vegetative growth. Although this initially appears counterintuitive, it is supported by the significant relationship between slope and vegetative cover. These results indicate that sites receiving greater annual precipitation were more likely to exhibit erosion losses conducive to a poor environment for vegetative establishment, washout of seeds, and mass failure of slopes. Under these circumstances, the combination of excess water and an unstable, steeply sloped site contributed to sites where vegetation had either never been well established, or had been physically removed with excess runoff or slope failures.

Unlike the poor plant growth associated with precipitation, higher air temperature was found to be related to greater plant growth. A number of sites were located at elevations exceeding 5,000 feet. Cooler temperatures were likely related to vegetative cover in several

relationships. Aside from obvious effects of warmer environments on plant metabolism and growth, sites with greater numbers of freezing days may have also been compromised by freezing-thawing in soils. A number of higher-elevation sites exhibited freeze-expansion of soil particles, whereby erosion of soil related to freezing and thawing visibly occurred during site evaluations.

3.1.2.3 Soil Factors

A number of hypothesized relationships between soil factors, such as sand and clay content, macronutrients (e.g., nitrate), chemical parameters (e.g., pH), and organic matter were examined with regressions. The objective of this exercise was to determine causal relationships between poor vegetative coverage and poor soil fertility or the presence of adverse conditions that would compromise plant growth. With some soil parameters, identification of significant effects would coincide with relatively simple solutions, such as recommendations for additional fertilizer, liming to increase pH, or addition of mulch to increase organic-matter content.

Vegetative cover was regressed against nitrate concentration, organic matter, pH, EC, sand content, clay content, and CEC. However, a significant relationship was found only for EC ($\alpha = 0.10$), where higher EC resulted in diminished vegetative coverage. This indicated that a number of sites may have had salt levels that exceeded the range conducive to optimum plant growth. This was evident on at least one site where bare and covered areas exhibited high and low EC levels, respectively. In this case, the higher EC was attributed to different residual parent material.

Arid conditions in a number of districts were likely responsible for evaporation and consequent accumulation of salts in soils, particularly non-irrigated sites where agronomic practices of salt leaching were not possible. In some cases, the lack of significance observed with other factors, such as nitrate or organic matter, may have been from the masking effects of EC. Plants that are compromised in their growth by osmotic pressure caused by excess salts may not respond to improvements in other soil constituents.

3.1.2.4 Overall Conclusions on Vegetative Cover Results

On most sites, soil chemistry and fertility ranges were generally conducive to plant growth. Soil pH levels were not excessively basic or acidic, they were generally within one unit of neutrality; and nitrate levels were on average high enough to support vegetative growth. Site observations revealed that poor vegetative growth may have been as much a result of management as intrinsic soil properties. A number of sites exhibited poor grass emergence because of late planting dates, mass failures, and excess mulch coverage.

Many sites were too dry to support vegetative erosion control. Although precipitation was negatively related to vegetative cover because of its erosive effects, drought stress was still a likely cause of limited growth on a number of sites. On at least one location, soil chemical and physical conditions were similar on bare and well-covered areas, and grass growth was most prolific on a saturated seep area. This vigorous growth occurred at the beginning of the growing season, where both temperature and water conditions were ideal for the grass to end its winter dormancy. This scenario also illustrated that timing of water is as critical as quantity of available water.

3.1.3 Linear Regressions: Channel Erosion Calculations

On sites with considerable channel erosion, volume of soil lost from channels was quantified using the Channel Erosion Calculator in HEAT. Area-based calculations were performed for up to three areas on a site with different magnitudes of channeling. The channel calculation was performed for 21 of the 57 sites in the statewide evaluation. The remaining 36 sites did not have channel erosion substantial enough for measurement.

Volume of soil lost through channel erosion per unit area (expressed in m^3/m^2) was compared to soil, vegetation, and climate factors. The factors included mean annual rainfall, number of high-intensity (>1 inch) rainfall days, slope percent, percent vegetative cover, percent litter cover, percent sand, percent clay, percent soil organic matter, and soil CEC.

3.1.3.1 Statistical Evaluation

No statistically significant relationships were found (at $\alpha = 0.15$) between channel erosion and any of the evaluated factors. As with other statistical comparisons in this analysis, variability was likely the main contributor to non-significance (Table 3). Many direct (e.g., higher rainfall causing greater channel erosion) and indirect (e.g., lower CEC limiting plant growth that would otherwise minimize erosion) interactions between site conditions and environmental factors can contribute to soil erosion. Sites varied in climatic influence, soil composition, topography, and design. These and other factors likely played a large role in the rendering of insignificant results. In the absence of such extreme variation, it is likely that statistically significant relationships between several of these factors may have been observed.

3.1.3.2 Trend Evaluation

Some trends were observed in the comparison of channel erosion and some of the factors considered in the regression analysis. Slopes on most sites were steep, ranging from 38 to 110 percent (21 to 48 degrees). Although slope did have a statistically significant relationship with channel erosion, the relationship was negative, indicating that steeper slopes had less channel erosion. In most cases, the more steeply sloped sites had restrictive or non-erosive horizons (e.g., bedrock). Therefore, strictly on a total soil basis, less soil was available to erode. The sites that were generally less steep had deeper soils and much deeper channels, resulting in a larger volume of soil loss. If sites with similar soil depths and types had been repeatedly evaluated, it is possible that a positive relationship between slope and channel erosion would have been observed.

Percent sand and channel erosion were not significantly related, but exhibited some trends. Soils with increased sand content were observed to have more channel erosion. Soils high in sand are less cohesive and have lower soil water-holding capacities. Sandy soils also tend to have lower CEC and consequently a lower plant nutrient adsorption capacity. Statistically significant results may have been obtained if sites with varying textures and ages were grouped. This was not feasible because of the limited number of sites with channel erosion. Furthermore, some sites that had recently been constructed had logically lesser amounts of soil loss from channel erosion and may have skewed results.

3.1.3.3 Conclusions

No relationship was calculated between soil loss measured by the Channel Erosion Calculator and influencing parameters such as rainfall, vegetative cover, organic matter, soil cation exchange, and litter cover. The lack of significant relationships could have been due to interactions between and wide variation in soil, climate, and vegetation factors throughout the state. The small number of sites evaluated for channel erosion may also have restricted the detection of direct or indirect influences of these factors.

Channel erosion is likely caused by management and overall physical site characteristics more than climatic effects or soil chemical influences. Frequently, channel erosion was present because of concentrated runon, a result of problematic design or site maintenance. These design factors may have masked influences of slope, texture, and CEC. Design elements such as slope benches, subsurface drainage, and V-ditches for diversion of runoff were present on some sites. Channel erosion in a few locations appeared to be caused by broken irrigation systems, another example of the influence of site management.

3.2 Observational Results

Statewide, 13 factors contributing to soil loss from the sites surveyed were defined. These factors were identified through team consensus after all of the sites had been evaluated and include:

- Steep slopes
- Aspect (e.g., north-facing, shaded site)
- Adverse climatic conditions (e.g., intense rainfall, high winds, frost periods, or drought)
- Sparse, absent, or inappropriate vegetation for a particular climate or soil
- Inappropriate or non-functional site design (e.g., toe cutting)
- Poorly designed, maintained, or non-existent site drainage systems (surface and/or subsurface)
- Runon from adjacent watershed areas
- Insufficient irrigation and/or rainfall
- Excessive irrigation or broken systems
- Adverse soil chemical properties (e.g., pH, salts, and nutrient deficiencies/toxicities)
- Adverse soil physical properties (e.g., shallow soils, exposed parent material, high clay or sand contents, poor soil structure, and hard pans)
- Improper site maintenance (e.g., spraying, soil removal, and neglect)
- Improper installation and/or management of non-vegetative erosion control technologies (e.g., blankets, netting, and geogrids)

This list is likely not comprehensive with regard to all causes of erosion and the factors are not presented in order of significance. However, these are the main contributing factors associated with soil loss encountered on sites with vegetative erosion control systems in this study. Individual factors from this list were chosen and listed as contributing reasons for soil loss in a description of each individual site (see the Appendix). Some of these factors were determined as more prevalent causes than others over the 57 sites evaluated (Table 5).

TABLE 5
Occurrence of Factors Contributing to Soil Loss on Vegetatively Controlled Systems

Contributing Factor	Percent Occurrence on Sites Evaluated
Steep slopes	71
Aspect	11
Adverse climatic conditions	16
Sparse, absent, or inappropriate vegetation	75
Inappropriate or non-functional site design	32
Poorly designed, maintained, or non-existent site drainage systems	38
Runon from adjacent watershed areas	25
Insufficient irrigation and/or rainfall	14
Excessive irrigation or broken systems	9
Adverse soil chemical properties	30
Adverse soil physical properties	73
Improper site maintenance	14
Improper installation and/or management of non-vegetative erosion control technologies	9

No one contributing factor exclusively determined the success or lack of success on an individual site. Rather, multiple combinations of contributing factors were more typically the reason for soil loss. While contributing factors are discussed individually in the following sections, it is important to recall that relationships among factors are most critical.

These contributing factors were used to develop a generalized decision flow chart to initially assist site investigation, design, and construction staff in determining the suitability of vegetative control and/or non-vegetative control (see Figure 12).

3.2.1 Steep Slopes

Steep slopes were a significant contributor to soil loss on 71 percent of the sites evaluated. Ninety percent of these sites had slopes in excess of 50 percent. In many cases, excessively steep slopes were the result of limited right-of-ways or the overall topography of the surrounding area. In situations where slopes cannot be lessened during design, the stability and fertility of site soils need to be carefully assessed. Shallow soils commonly exist on the steeper slopes and can be unstable. Thin soils may limit plant growth through low soil moisture and fertility. Non-vegetative erosion control measures or a more aggressive combination of vegetative and non-vegetative measures should be considered on excessively steep slopes where re-vegetation may be challenging.

3.2.2 Aspect

Vegetative erosion control was influenced by aspect on only 11 percent of the sites evaluated. Aspect plays an important role in the success of vegetative erosion control measures, where north-facing slopes typically have limited sunlight available for plant growth and significantly cooler soil and ambient air temperatures. North-facing slopes also generally exhibit less soil development, because weathering reactions and plant growth are temperature-dependent. North-facing slopes or shaded sites experiencing limited vegetative growth predominantly because of aspect should likely be approached with non-vegetative control measures or, in some cases, special seed mixes/plant species suitable for shaded and cooler environments.

3.2.3 Adverse Climatic Conditions

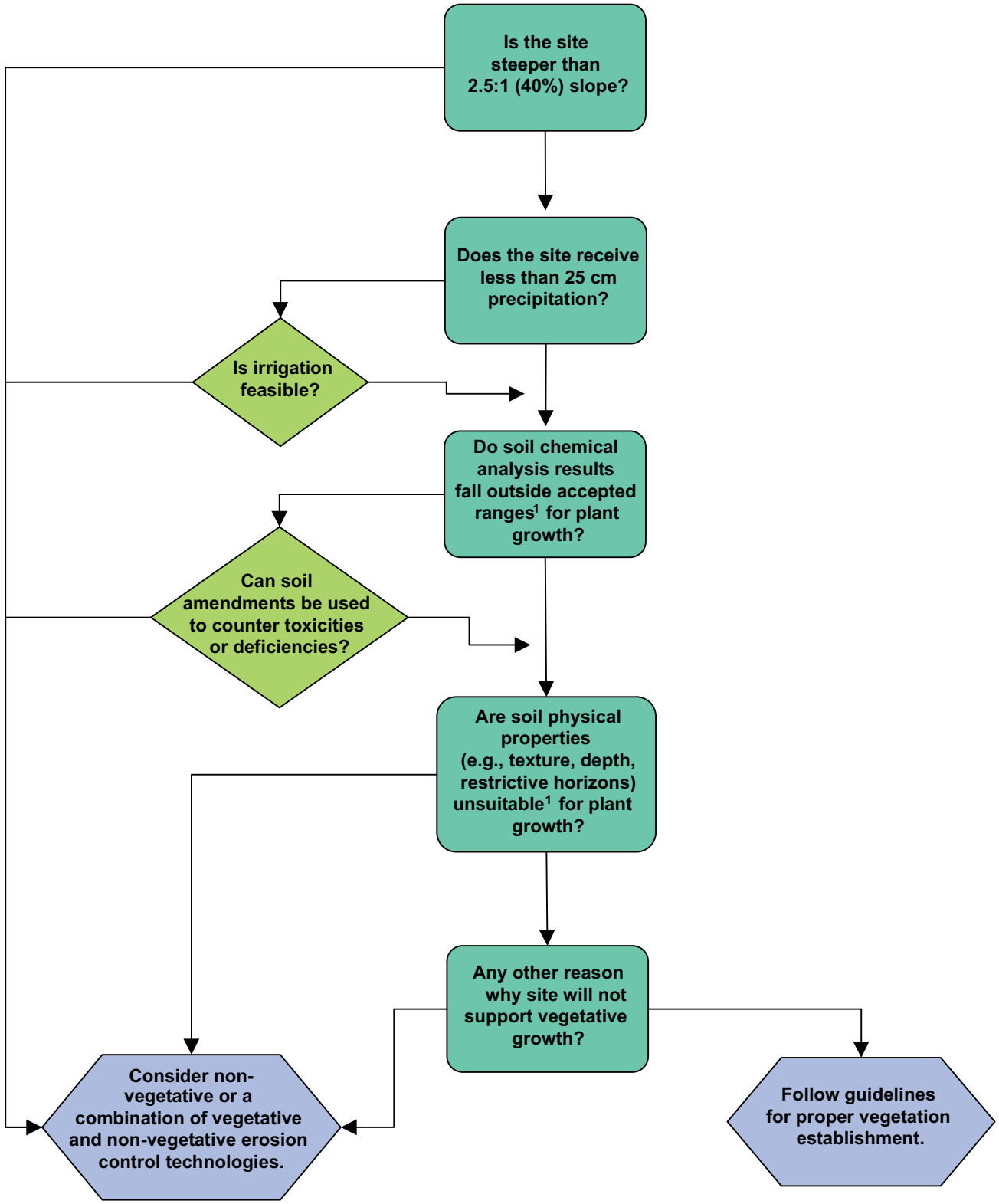
The State of California experiences extreme variations in climatic conditions (e.g., excessive rainfall, freeze-thaw conditions, excessive wind). This was determined as a significant influencing factor on 16 percent of the sites evaluated. Climate is likely more influential on more of the sites than indicated. However, this evaluation allowed only 1-day site visits that did not capture the range of climatic variation. With repeated site visits, it likely would have been easier to attribute soil loss to a weather event (e.g., site visits before and after a significant precipitation event). In most cases, however, district personnel were well aware of the extreme climatic conditions within their areas. Increased attention should be given to sites within districts that experience excessive rainfall or wind during the design and construction phases of work to ensure incorporation of adequate protection measures, whether vegetative, non-vegetative, or a combination of the two.

3.2.4 Sparse, Absent, or Inappropriate Vegetation

Approximately 75 percent of the time, sparse, absent, or inappropriate (not suitable on a particular site because of climate, soil, competition, or other factors) vegetation was listed as a reason for soil loss with vegetation control. A designation of sparse vegetation may include situations where site vegetative cover indicated the seed mix was applied at a lower than optimal rate or inappropriately applied (e.g., incorrect application technique). Seed viability may have played a role in sparse vegetative establishment. In some cases, sparse or absent vegetation was caused by excessively thick mulch or straw application limiting or restricting plant emergence.

Because this evaluation focused on vegetative erosion control, it was expected that the obvious cause of erosion would be poor vegetative coverage. In spite of this apparently simplistic explanation, vegetative cover was too often insufficient for erosion prevention. Simple changes in application methodologies (e.g., correct seeding timing, increasing seeding rates to account for anticipated losses, maintenance of seeded sites, and consultation with qualified technical staff to ensure correct seed mixture) will likely significantly improve vegetative cover on sites. Timing of seed application is significantly influenced by elevations and should correspond to appropriate time periods for the site location as determined by an erosion control specialist. Approximate seeding time periods indicated by elevation are:

- October 1 to November 15 (below 2,500 feet elevation)
- September 1 to October 15 (above 2,500 feet elevation)



[1] Consult the nursery or seed producer for acceptable ranges of soil chemical and physical properties.

FIGURE 12
GENERALIZED DECISION FLOWCHART FOR DETERMINATION OF VEGETATIVE OR NON-VEGETATIVE EROSION CONTROL TECHNOLOGIES

3.2.5 Inappropriate or Non-functional Site Design

Inappropriate or non-functional site design was determined to be a contributing factor to soil loss on nearly one-third of the sites evaluated. As stated previously, site design can be constrained by right-of-ways or the overall site topography. In some cases, site design could have been modified to divert water off the edges of the site or reduce flow lengths through the utilization of additional benches. A number of sites exhibiting mass failure showed evidence of large quantities of runon through upslope channels. In these cases, existing benches were insufficient to divert runoff, as the sites were destabilized from runon flow and saturation. In some areas, runon could have been attributed to adjacent developments established subsequent to site design and construction.

Appropriate routing of flow runoff was also not observed at all sites. In some of these cases, drainage outlets released water into offsite channels, where there were no measures to protect slope or dissipate flow energy. In these instances, large, eroded channels were formed at the outlets.

Cutting at the base of the slope (toeslope) was observed on sites exhibiting larger-scale mass failures (i.e., no vegetation, large slides, or slumps). In some of these instances, topography limited placement of the road deck, leaving a steep slope without the necessary toe support to prevent further failures. In these instances, vegetative control was likely not appropriate.

In some instances, it appeared as if seed-bed preparation could have been improved to result in better vegetative cover. Several sites were too heavily mulched to allow grass to properly develop. Other sites exhibited compacted and poorly aerated soils that likely contributed to minimal plant germination.

3.2.6 Poorly Designed, Maintained, or Non-existent Site Drainage Systems

The ability to effectively route water or control flow through a site (whether surface or subsurface) is a key factor in limiting soil loss. On nearly 40 percent of the sites evaluated, soil loss was attributed to poorly designed, constructed, or maintained drainage systems, or simply non-existent systems. Throughout the State of California, water-caused erosion was the predominant reason for soil loss. Management of this water through appropriate drainage engineering is an integral part of site design. Many times the drainage systems were likely initially successful, but lost effectiveness over time for a variety of reasons (e.g., clogging of outlets, development of preferential flow channels outside of designed channels, saturated areas caused by seasonal springs or other sub-surface flow, and broken culverts). Other systems were insufficient for site drainage needs.

The importance of saturation as a cause for mass failures or slumping, particularly on steeper sites, cannot be underestimated. Saturated soils, particularly on unstable bedrock, may easily result in a slide. Maintenance of these drainage systems is important to maintain vegetative cover. In some occasions, it appeared as if the drainage system was not designed to account for the full capacity of a significant rainfall event. It is likely that these were significant rainfall events because Caltrans designs for 25-year storm events.

3.2.7 Runon from Adjacent Watershed Areas

The ability to effectively route water around a site greatly limits soil loss. Diversion of runon was indicated as a significant contributor to soil loss on 25 percent of the vegetated sites evaluated. Some sites evaluated were at the terminus of the surrounding topography and received no runon. These were not considered to be part of the 25 percent. Other sites, however, received runon from much larger watersheds upgradient from the erosion control area.

During peak storm events, water runon to a site can be significant and concentrated. This was evident in the field; most of the sites that were designated as having runon problems were also sites with significant channelization or mass failures. Runon can be controlled during the design phase by understanding the overall watershed contribution and designing the site and diversion structures accordingly.

3.2.8 Insufficient Irrigation or Precipitation

Insufficient irrigation or precipitation was determined as a contributing factor to erosion on 14 percent of the sites evaluated. These sites were mostly located in southern California. On sites with irrigation (usually in urban areas), only a small number of sites appeared to have insufficient irrigation. This was usually noticed by spotty vegetative growth caused by poor irrigation coverage. Poor coverage could be attributed to plugged sprinklers, excessive sprinkler spacing, or low irrigation pressures.

Sheer lack of precipitation on sites evaluated in the desert areas of southeastern California resulted in sparse vegetation. Although a variety of plant species were seeded on many of these sites, the survivability in these dry environments was generally low. Plant species that are suited to limited precipitation environments (desert species) often provided less overall soil coverage and usually were not well suited for erosion control.

3.2.9 Excessive Irrigation or Broken Systems

Nine percent of the sites evaluated having excessive irrigation or broken irrigation systems resulted in soil loss. Both sheet and channel erosion were observed from flooded areas or pipe/sprinkler blowouts in permanent irrigation systems. These are typically uncomplicated modifications requiring more vigilant site monitoring and maintenance.

3.2.10 Adverse Soil Chemical Properties

Poor soil fertility, including low concentrations of plant nutrients or other characteristics (e.g., nitrate, phosphorus, organic matter), was determined as a contributing factor on about 30 percent of the sites evaluated. In most cases, the soil fertility on the sites evaluated was adequate for vegetative growth. In some cases, however, excessive salts, alkaline pH, or very low levels of nutrients resulted in sparse vegetative growth (see the Appendix). Many soil chemical properties can be easily remedied through sampling, inexpensive analysis, and amendment of site soils. Results, interpreted by a qualified technical expert, either will yield necessary soil amendments to promote increased vegetative growth or will indicate when onsite soils are not suitable as a plant-growth medium.

3.2.11 Improper Site Maintenance

In addition to maintenance problems related to drainage or irrigation equipment, other failures to maintain effective erosion control were observed. Improper site maintenance was observed on 14 percent of the sites evaluated. This included sites with failures in erosion control structures, including channeling between wattles; improperly secured geotextile or plastic netting; newly formed channels or slumps in need of repair; or toe cutting during road maintenance. Maintenance-related toe cutting, including the removal of eroded soil from road sides, successively depletes the slope of stabilizing material, thereby increasing slope. On sites where this was observed, vegetative erosion control may have been an inappropriate strategy.

3.2.12 Improper Installation and/or Management of Non-vegetative Erosion Control Technologies

Many times non-vegetative erosion control technologies were combined with vegetative erosion control methods. Approximately 9 percent of all sites evaluated had improper installation and/or management of these non-vegetative methods. Examples include: straw wattles with gaps between seams that channeled water downslope, wattles that were greater than 50 feet apart vertically up the slope, and geotextile material insufficiently fastened to slopes (staples pulled out). Non-vegetative erosion control technologies need to be prescribed by a qualified technical specialist and are likely to require increased management if not properly installed.

3.3 Specifications

Specifications directly related to re-vegetation or erosion control were available for approximately 70 percent of the sites evaluated. In some cases, specifications could not be found, although they were at one time developed. In other cases, no specifications were likely ever developed for the erosion control component of construction. At other sites, very comprehensive specifications and drawings with details specifically for erosion control were a component of the design drawings/specifications package. The wide range of specifications and drawings type and quality is likely a main contributor to successful, moderately successful, or unsuccessful erosion control on sites throughout the state.

Many of the erosion control requirements were derived from the Caltrans standard Type D specifications. These specifications are an adequate base for development of site-specific documents, but many times were only modified slightly from the standard for sites that required significant modification and likely had specific requirements. An improvement to the standard Type D specifications incorporating newer erosion control technologies and options should be considered.

3.4 Predictive Models

Morgan, Morgan, and Finney, RUSLE, and WEPP were three soil erosion loss predictive models that were used as tools to potentially establish statewide trends of vegetative erosion control. The models used a number of individual site parameters (e.g., slope, soil characteristics, percent vegetative cover, and precipitation) as inputs to predict soil loss on a site-

by-site basis. It is statistically inappropriate to evaluate model outputs versus input parameters. Therefore, the number of comparative parameters was limited to indirectly related factors, such as soil nutrients, EC, pH, as well as freeze-free days. Of the comparisons that were made, no statistical significance was discovered when compared to any of the predictive models. As with other data analyses in this study, it was likely that the extreme variability across the state resulted in these insignificant results. Individual site model results are informative on a site-by-site basis.

4.0 Recommendations/Conclusions

The approach of this Statewide Erosion Control Review was to measure and quantify as many field parameters and record as many observations on numerous sites as possible throughout the State of California. This research effort focused on problem slopes, and only a small sampling of the state's total roadway slopes was considered. This approach resulted in the development of statewide trends discussed in the Results section. Many of these results were fairly intuitive and were expected. Extreme variability across the state and between sites resulted in insignificant quantitative results for a number of parameters. A summation of individual site observations resulted in further scrutiny through repeated observations for causes of soil erosion at sites throughout the state.

These quantitative and qualitative results suggest and support the following recommendations:

- Regression analyses were performed on applicable data to determine if a statistical relationship existed between slope and vegetative coverage. The principal objective of this exercise was to identify, if possible, a critical slope where Caltrans' target minimum of 70-percent vegetative cover would be observed. Regressions indicated that while slope significantly affected vegetative coverage ($\alpha = 0.05$), the variability in vegetative coverage was only partly explained by slope (as indicated by a low coefficient of determination) (Mahmood, 2002, pers. comm.). Therefore, a slope corresponding to 70-percent coverage could not be identified. Based on these results, and because this review included only problem sites, it was concluded that a target slope would be best identified with a more focused study that would include a greater number of sites and regionally appropriate values.
- Soil sampling and chemical and physical analysis should be strongly encouraged in all vegetation establishment guidelines for re-vegetation erosion control efforts. A complete agronomic soil analysis performed by many soil and plant testing laboratories should provide the concentrations of all constituents of concern. Understanding site soil chemical and physical parameters through soil testing is a key factor in the successful vegetation of a site. Many times, soil chemical and physical analysis and correct interpretation will yield simple soil amendment or preparation remedies. It is important to relate the soil sampling results to the seed mix selected. This will ensure that the soil chemical and physical conditions are adequate for the specific species used.
- Seeding operations should be conducted during appropriate timing windows indicated by day length, frost danger, precipitation events, and elevation. Spring and especially early fall are preferred time periods for seeding without irrigation. However, this will vary according to the previously mentioned parameters. Construction delays often dictate timing of seeding. If construction termination occurs outside of the optimum seeding window, temporary non-vegetative erosion control measures should be implemented until seeding can take place. Timing of seeding can generally be based on elevation. Target seeding dates should be October 1 through November 15 for elevations below 2,500 feet, and September 1 through October 15 for elevations above 2,500 feet.

- Site drainage improvements and design should be implemented. Site observations indicated that surface and subsurface drainage design and implementation were many times insufficient to prevent erosion or mass failure or, in some cases, non-existent. Subsurface drainage, including the installation of perforated pipe laterally across hillsides or benches, or downdrains collecting drainage from slope benches, may effectively remove water stored in soil pore spaces. This is particularly critical on sites where soils are unstable and easily erodible. On several sites, cool wet seasons resulted in wet soils and dormant vegetation, where removal by vegetation using subsurface drainage is therefore recommended where appropriate. Although a number of other sites exhibited successful design and maintenance of slope benches and other approaches, other sites exhibited failure to prevent runon, accumulation of water and drainage over slope faces, and slope destabilization from toe cutting.
- If vegetative erosion control is the preferred alternative, species that have aggressive establishment characteristics should be used. It is important to note that it is imperative to avoid propagation of invasive species. As indicated by field observations, many times similar seed mixes were employed on sites with varying characteristics. It is recommended that minimization of sediment loss be tied to a more flexible strategy of selecting species for rapid establishment and not only for ecological integrity or aesthetic appeal. Determination of correct seed mixes/landscape plants should be selected according to areas of the state and site-specific conditions. It was evident that because of the extreme diversity of climatic conditions, soils, and elevation across the state, a generalized, statewide seed mix and application method is not applicable. The desirable colonization of native species on erosion control sites will only occur if the site is stable and supportive of plant growth from the outset.
- A number of sites exhibited mulch layers that were stable and well tacked to the slope, but too thick to allow successful emergence of grasses. Mulch provides beneficial organic matter to the soil, improving moisture retention, soil structure, and in some cases, nutrient holding capacity. However, when heavy applications cover seeds and prevent light penetration or retain excess moisture and cool temperatures, grass will not germinate or emerge. Mulch or straw must therefore be applied in amounts specified by the manufacturer to prevent surficial soil loss and not in amounts that restrict plant growth.
- The nature and soils of sites where freeze-thaw conditions are a concern should be understood. Sites at higher elevations frequently exhibited erosion from freezing and thawing. In this process, water-stored soil pores freeze and expand, thereby expanding the soil and degrading soil aggregates and overall structure. Soil particles suspended on ice crystals or otherwise destabilizing are then easily lost during melting. This phenomenon was observed as it occurred on several sites. If vegetative control is selected in these environments, cover must be established to aid in stabilizing the soil (e.g., through root development) before freezing and thawing conditions begin.
- Site observation on recently constructed sites revealed early stages of erosion, especially gully and slump. Severe advancement of these erosion types may be avoided with basic repair and maintenance. Site inspections and maintenance should be performed frequently during vegetative establishment and less frequently after vegetation is effectively controlling soil erosion.

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Attachment
Glossary of Terms

ATTACHMENT

Glossary of Terms

2:1 (H:V)	Indicates a slope ratio, i.e., units horizontal to unit vertical.
Accelerated Erosion	Erosion rates greater than the natural, undisturbed rates; sometimes caused by human disturbances.
Alluvial	Pertaining to processes or materials associated with transportation and deposition by running water.
Alluvium	Sediments deposited by running water of streams and rivers.
Backfill	The process of filling a cavity with soil, gravel rock, or other material of choice.
Barrier	A low dam or rack built to control flow of debris.
Basin	Space capable of retaining or detaining water or sediment. Usually a backup where erosion is imminent.
Bench	A horizontal surface or step in a slope used to intercept and divert flow.
Berm	Fill placed to divert flow or retain sediment.
Blanket	Material placed on a slope, streambank, or lakeshore to cover soil and protect it from raindrop impact.
Boulder	Largest rock transported by a stream or rolled in the surf; arbitrarily heavier than 12 kilograms and larger than 200 millimeters (8 inches) in diameter.
Cal Poly	California Polytechnic State University, San Luis Obispo
Caltrans	California Department of Transportation
Catch Basin	An area used to direct flow into a drainage inlet.
Caving	The collapse of a bank by undercutting caused by wearing away of the toe or an erodible soil layer above the toe.
CEC	cation exchange capacity
Channel	General term for a rill or gullly formed by the incision of water through soil.
Check Dam	A series of small dams used to slow flow. The dams are constructed of soil, rock, hay bales, logs, or other available materials.
Clay	Soil with a grain size fraction less than 0.002 millimeter in equivalent diameter.
cm	Centimeter.

Cobble	Rock smaller than a boulder and larger than gravel; arbitrarily 0.5 to 12 kilograms, or 75 to 200 millimeters in diameter.
Cohesive Soil	Microscopic soil particles that have natural resistance to being pulled apart at their point of contact.
Creek	A small stream, usually active.
Culvert	A pipe placed in a drainage channel to convey water under or around a structure. Highway designers use culverts to route water under roadways.
Cut Face	The open, steep face of an excavated slope.
Cutbank	The steep or overhanging slope on the outside of a meander curve, typically produced by lateral erosion of the stream.
Debris	Any material including floating woody materials and other trash, suspended sediment, or bedload moved by a flowing stream.
Deposit	An earth mass of particles settled or stranded from moving water or wind.
Deposition	The settlement of material out of the water column and onto the streambed or floodplain. Occurs when the flowing water is unable to transport the sediment load.
Ditch	Small artificial channel, usually unlined.
Discharge	A volume of water flowing out of a drainage structure or facility. Measured in cubic meters per second.
Dissipate	Expend or scatter harmlessly, such as energy of moving water.
Drain	Conduit intercepting and discharging surplus ground or surface water.
Drainage	The process of removing surplus ground or surface water by artificial means. The system by which the waters of an area are removed. The area from which waters are drained; a drainage basin.
Drainage Basin	A land surface collecting precipitation into one stream, sometimes referred to as a watershed.
EC	electrical conductivity
Embankment	Earth fill structure above natural ground.
Erodibility	A term used to describe how easily a soil can be eroded. “K” is the soil erodibility factor used in soil loss equations. Values range from 1.0 (most easily eroded) to 0.01 (almost nonerosive).
Erosion	The wearing away of natural (earth) and unnatural (embankment, slope protection, or structure) surfaces by the action of natural forces, particularly moving water and materials carried in moving water.
Face	The outer layer of slope.
Failure	Collapse or slippage of a large mass of soil/rock material.

Fill Material	Soil, rock, gravel, or other matter that is placed at a specified location to bring the ground surface up to a desired elevation.
Filter	A porous article or mass (such as fabric or even-graded mineral aggregate) through which water will freely pass but which will block the passage of soil particles.
Filter Fabric	An engineering fabric (geotextile) placed between the backfill and supporting or underlying soil through which water will pass and soil particles are retained.
Floodplain	The flat area adjacent to the bank-full channel, which is constructed by sediment deposition during flood stage.
Flow	A term used to define the movement of water, silt, or sand; discharge; total quantity carried by a stream.
Geogrid	A fabric with high-tensile strength and wide, frequent, apertures consisting of long-lasting plastic materials.
GIS	Geographic Information System – An organized collection of computer hardware, software, and geographic data designed to interpret, manipulate, and display geographically referenced information.
GPS	Global Positioning System – The GPS is a "constellation" of 24 well-spaced satellites that orbit Earth and make it possible for people with ground receivers to pinpoint geographically referenced information.
Grade	Elevation of bed or invert of a channel.
Gradient	The rate of ascent or descent expressed as a percent or as a decimal as determined by the ratio of the change in elevation to the length.
Gravel	Rock larger than sand and smaller than cobble, arbitrarily ranging in diameter from 2 millimeters to 7.5 centimeters (3 inches).
Gravel Filter	A berm or area of gravel used to retain sediment from storm water runoff.
Gully	A relatively young, well-defined and sharply cut erosional channel. Unlike rills, gullies cannot be obliterated by normal tillage.
Habitat	A place where a biological organism lives. The organic and non-organic surroundings that provide life requirements such as food and shelter.
HEAT	Highway Erosion Assessment Tool-A Comprehensive Microsoft Excel Visual Basic program for entry of field observations, measurements, and notes, as well as an interface for calculations using predictive models and field measurements of channel and sheet erosion.
HSP	Health and Safety Plan.
Hydrologic	Pertaining to the cyclic phenomena of waters of the earth; successively as precipitation, runoff, storage, and evaporation, and quantitatively as to distribution and concentration.
Impermeable	Properties that prevent the movement of water through the material.

Incised	Carved. Rills and gullies are carved (incised) into slopes.
Inlet	A drainage device that transitions surface flow into piping or other conduits.
Invert	The bottommost inside flowline of a pipe.
Kg	Kilogram.
Kg/ha	Kilogram per hectare.
km	Kilometer.
Linear regression	The process of fitting (minimizing the sum of the square of the deviations) a cloud of samples by a linear model.
m	Meter.
Microrelief	Local, slight irregularities in form and height of land surface superimposed upon a larger landform (e.g., small mounds and shallow pits).
mm	Millimeter.
Non-cohesive Soil	Soil particles that have no natural resistance to being pulled apart at their point of contact, for example, silt, sand, and gravel.
NPDES	National Pollutant Discharge Elimination System
Outwash	Debris transported from a restricted channel to an unrestricted area where it is deposited to form an alluvial or debris cone or fan.
Overflow	Discharge of piping or a stream outside its banks.
Permeable	Open to the passage of fluids, as for pervious soils.
PMM	Post mile marker.
Piping	Flow of water through subsurface conduits in the bank.
Precipitation	Discharge of atmospheric moisture such as rain, snow, or hail, measured in depth of fall or in terms of intensity of fall in unit time.
PRISM	Parameter-Elevation Regression on Independent Slopes Model
QA/QC	Quality assurance/quality control
Ravine	A valley larger than a gulch, smaller than a canyon, and less bold in relief than a gulch or arroyo.
Repose	The stable slope of a bank or embankment, expressed as an angle or the ratio of horizontal to vertical projection.
Rill	A small incised channel cut in the soil.
Riprap	A layer, facing, or protective mound of rubble or rock randomly placed to prevent erosion, scour, or sloughing of a structure or embankment; also, the stone used for this purpose.

Rock	Cobble, boulder, or quarry stone as a construction material.
	Hard natural mineral, in formation as in piles of talus.
Runoff	The surface waters that exceed the soil's infiltration rate and depression storage.
RUSLE	Revised Universal Soil Loss Equation (USLE) – An annual soil loss predication model that is based on a computation of factors including rainfall erosivity, soil erodibility, slope length, slope steepness, crop cover, and management practices.
Sand	Granular soil coarser than silt and finer than gravel, ranging in diameter from 0.05 to 5 millimeters.
Sediment	Eroded soil particles that have been transported and/or deposited by wind or water action.
Sedimentation	Gravitational deposit of transported material in flowing or standing water.
Seepage	Percolation of underground water through the slopes onto the ground surface.
Serpentinite	A rock group consisting of secondary minerals derived from magnesium-rich silicate minerals (e.g., antigorite ans chrysotile).
Sheet Flow	Overland flow of storm water that is relatively uniform in thickness and velocity.
Silt	Water-borne sediment. Detritus carried in suspension or deposited by flowing water, ranging in diameter from 0.005 to 0.05 millimeters. The term is generally confined to fine earth, sand, or mud, but is sometimes both suspended and bedload.
	Deposits of water-borne material. As in a reservoir, on a delta, or on floodplains.
Silt Fence	A fence constructed of geotextile fabric used to slow and filter storm water runoff.
Slide	Gravitational movement of an unstable mass of earth from its natural position.
Slope	Inclination of the face of an embankment, expressed as the ratio of horizontal to vertical projection.
	The face of an inclined embankment or cut slope. In hydraulics it is expressed as percent or in decimal form.
Slumping	The downward slipping of a mass of soil, moving as a unit usually with backward rotation, down a bank into the channel. Also called sloughing off.
Specifications	A detailed description of particulars, such as size of stone, quantity and quality of materials, contractor performance, terms, quality control, and equipment. Caltrans standard specifications.

Stone	Rock or rock-like material; a particle of such material, in any size from pebble to the largest quarried blocks.
Storm	A disturbance of the ordinary, average conditions of the atmosphere which, unless specifically qualified, may include any or all meteorological disturbances, such as wind, rain, snow, hail, or thunder.
Straw	Rice, wheat or barley. Used to intercept and filter flow as straw bales. Used as mulch when applied on slopes rolled, punched, or tracked.
Stream	Water flowing in a channel or conduit, ranging in size from small creeks to large rivers.
Surface Runoff	That portion of rainfall that moves over the ground toward a lower elevation and does not infiltrate the soil.
Swale	A natural or manmade drainage running between two ridges down a hillside slope. Swales are concave in shape (not incised).
Talus	Loose rocks and debris disintegrated from a steep hill or cliff standing at repose along the toe.
Terrace	Berm or bench-like earth embankment, with a nearly level plain bounded by rising and falling slopes.
Toe	The break in slope at the foot of the bank where the bank meets the bed.
Undercut	Erosion of the low part of a steep bank so as to compromise stability of the upper part.
Velocity	The rate of motion of objects or particles, or of a stream of particles.
Wash	Floodplain or active channel of an ephemeral stream, usually in recent alluvium.
Watershed	The area that contributes surface water runoff into a tributary system or watercourse.
Wattles	Tubes of straw or willow usually 8 to 9 inches in diameter and 25 feet long placed along the contour of a slope at 10- to 20-foot intervals to interrupt runoff flows and capture sediment and seeds.
Weathering	Physical disintegration or chemical decomposition of rock caused by wind, rain, heat, freezing, or thawing.
WEPP	Water Erosion Prediction Project.
Wetlands	Those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.