ORNAMENTAL ROADSIDE VEGETATED TREATMENT SITES (ORVTS) STUDY

FINAL REPORT

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15. Abstract

The California Department of Transportation (Caltrans) initiated a study to assess the treatment performance of roadside slopes planted with various ornamental vegetation in reducing runoff volumes, and constituent concentrations and load.

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Acronyms and Definitions

AADT	Average Annual Daily Traffic
AC	Asphalt Concrete
A-E	Architectural and Engineering
ANOVA	Analysis of Variance
BMP	Best Management Practice
C	Control Station
Caltrans	California Department of Transportation
CEQA	California Environmental Quality Act
CNDDB	California Natural Diversity Database
COC	Chain-of-Custody
CV	Coefficient of Variation
D	Dissolved
DAT	Data Analysis Tool
DOC	Dissolved Organic Carbon
DQO	Data Quality Objective
EDD	Electronic Data Deliverable
EOP	Edge-of-Pavement
EP	Encroachment Permits
ERVTS	Expanded Roadside Vegetated Treatment Sites
GRVTS	Groundcover Roadside Vegetated Treatment Sites
GSM	Gross Solid Removal
ID	Identification
ORTHO-P	Orthophosphate
ORVTS	Ornamental Roadside Vegetated Treatment Sites
MSDS	Material Safety Data Sheet
PM	Post Mile
PSTM	Post Storm Technical Memorandum
PVC	Polyvinyl Chloride
QA/QC	Quality Assurance/Quality Control
QPF	Quantity of Precipitation Forecast
ROS	Regression-on-Order Statistics
ROW	Right-of-Way
RVTS	Roadside Vegetated Treatment Sites
SR	State Route
SWMP	Caltrans Statewide Storm Water Management Plan
QPF	Quantitative Precipitation Forecast
T	Overlay Test Station or Total
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TMC	Traffic Management Control
TMDLs	Total Maximum Daily Loads
TOC	Total Organic Carbon
TP	Total Phosphorus
TS	Total Solids
TSS	Total Suspended Solids
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service

Units

ac	Acre
cm	Centimeter
ft	Feet
ft^2	Square feet
ft^3	Cubic feet
ft^3/ac	Cubic feet per acre
gal	Gallons
gpm	Gallons per minute
ha	Hectare
in	Inch
L	Liter
L/s	Liters per second
m	Meter
m^2	Square meter
mg	Milligram
mi	Miles
mL	Milliliter
mm	Millimeter
m^3	Cubic meter
m^3/ha	Cubic meters per hectare
NTU	Nephelometric turbidity units
µmhos/cm	Micromhos per centimeter
µg	Microgram

EXECUTIVE SUMMARY

Objectives

The Ornamental Roadside Vegetated Treatment Sites (ORVTS) Study was implemented to assess the stormwater treatment performance of roadside slopes planted with various ornamental vegetation in reducing runoff volume, and constituent concentration and load. The specific objectives of this study were to:

- Evaluate the effectiveness of strips and swales planted with ornamental vegetation in treating highway runoff in terms of constituent concentration, runoff volume, and constituent load reduction.
- Determine the impact of ornamental vegetation type on the treatment performance of strips planted with ornamental vegetation in terms of constituent concentration, runoff volume, and constituent load reduction.
- Determine the impact of strip width on the treatment performance of strips planted with ornamental vegetation in terms of constituent concentration, runoff volume, and constituent load reduction.
- Compare findings from the ORVTS Study to data from previous related studies such as the Roadside Vegetated Treatment Sites (RVTS) Study, the Caltrans Discharge Characterization Study, and the BMP Retrofit Pilot Program (BMP Program).

The long-term goal of the ORVTS Study is to offer designers more options for roadside landscapes while providing treatment of roadway runoff.

Background

The Roadside Vegetated Treatment Sites (RVTS) Study (Caltrans, 2008b) was a water quality monitoring project conducted by Caltrans from 2000 to 2008 to evaluate the constituent removal efficiency of roadside slopes planted with forbs and grass vegetation. The RVTS Study results showed that roadside slopes planted with standard grasses and forbs resulted in large concentration and load reductions for several constituents of concern for highway runoff. The ORVTS Study was implemented to assess the treatment performance of roadside slopes planted with ornamental (native and non-native) vegetation. The ORVTS Study was comprised of two types of locations: the Groundcover Roadside Vegetated Treatment Sites (GRVTS) at seven locations and the Expanded Roadside Vegetated Treatment Sites (ERVTS) adjacent to two previous RVTS study locations. The GRVTS locations were selected to assess the treatment performance (in terms of concentration, volume, and load reduction) of roadside slopes previously established with ornamental vegetation. The ERVTS locations were selected to provide a side-by-side comparison of the treatment potential from ornamental vegetation to the grasses and forbs evaluated in the RVTS Study. All locations are in California. The two ERVTS included vegetated strips located in Sacramento and Yorba Linda. Five of the seven GRVTS included vegetated strips in the following locations: Napa, San Mateo, Camarillo, Westminster, and San Diego. The other two GRVTS included vegetated swales in Newbury Park and Carlsbad (Palomar). The study covered three monitoring seasons including 2009-2010, 2010-2011, and

2011-2012; however, monitoring was completed by the end of 2011. A total of 432 storm events were monitored and/or sampled.

Study Findings

The fundamental conclusion from the Study's statistical analyses is that the incorporation of ornamental vegetation into highway drainage design provides effective treatment for constituent reduction by providing benefits via reduction of runoff volume and constituent loading.

Key findings of the Study are described below.

- Effectiveness of strips and swales planted with ornamental vegetation in treating highway runoff in terms of constituent concentration, runoff volume, and constituent load reduction:
    - Strips and swales planted with ornamental vegetation yields statistically mixed results for reduction of constituent concentrations in highway runoff.
    - Strips and swales planted with ornamental vegetation yields statistically mixed results for reduction in the volume of highway runoff.
    - Strips and swales planted with ornamental vegetation yields statistically significant reductions in constituent loadings in highway runoff.
- Impact of ornamental vegetation types (succulents, groundcover and low shrubs) on the treatment performance of strips planted with ornamental vegetation in terms of constituent concentration, runoff volume, and constituent load reduction:
    - Ornamental vegetation yields statistically mixed results for reduction of constituent concentrations in highway runoff.
    - Ornamental vegetation yields statistically significant reductions in the volume of highway runoff.
    - Ornamental vegetation yields statistically significant reductions in constituent loadings in highway runoff.
- Impact of strip width on the treatment performance of strips planted with ornamental vegetation in terms of constituent concentration, runoff volume, and constituent load reduction:
    - Long and short strip widths planted with ornamental vegetation yields statistically mixed results for reduction of constituent concentrations in highway runoff.
    - Long and short strip widths planted with ornamental vegetation yields statistically significant reductions in the volume of highway runoff
    - Long and short strip widths planted with ornamental vegetation yields statistically significant reductions in constituent loadings in highway runoff.
- Study Comparisons:
    - Ornamental vegetation's performance with respect to constituent reduction is comparable to that of grasses and forbs.

- Ornamental vegetation's performance with respect to volume reduction is better than that of grasses and forbs.
- Ornamental vegetation displayed improved water quality with respect to constituent concentration, than that of the 2003 Discharge Characterization Study.

SECTION 1 INTRODUCTION

1.1 PURPOSE

Between 2009 and 2012, Caltrans' Ornamental Roadside Vegetated Treatment Sites (ORVTS) Study (Study) was conducted to assess the treatment performance of roadside slopes planted with ornamental vegetation along California highways. The purpose was to increase stormwater treatment design options by determining whether strips planted with ornamental vegetation could be used for treatment of stormwater constituents.

1.2 BACKGROUND

Prior to this Study, the Roadside Erosion Control and Management Study (Caltrans, 2008a) and the RVTS Study (Caltrans, 2008b) evaluated vegetation for potential treatment of constituents. The RVTS Study (Caltrans, 2008b) was a water quality monitoring project conducted by the California Department of Transportation (Caltrans) from 2000 to 2008 and was designed to evaluate the constituent removal efficiency of roadside slopes planted with forbs and grass vegetation. Locations in Northern and Southern California were evaluated for width, slope, vegetation density, and hydraulic loading. The RVTS Study concluded that roadside slopes planted with standard forbs and grasses resulted in large reductions in concentration and load for several constituents in highway runoff. The RVTS Study results indicated that Caltrans roadside slopes, under certain vegetative conditions, can be considered functionally equivalent to buffer strips specifically engineered for reducing constituent concentrations. Concentration reductions frequently occurred for TSS & total metals. Nutrient concentrations were generally unchanged. These concentration trends were observed for sites with a minimum of 65 percent vegetation. Vegetative cover was less critical for obtaining positive load removal. A substantial load reduction was evident for all constituents, even at sites with less than 65 percent vegetation.

The Roadside Erosion Control and Management (RECM) Study (Caltrans 2008a) was a pilot *ex situ* study conducted at the Erosion Control Research Facility at the California Polytechnic State University in San Luis Obispo under the supervision of both Caltrans and the Office of Water Programs (OWP) at California State University, Sacramento. The RECM Study was conducted from 2005-2008 with the objective of determining the effects of different vegetation types and erosion control products on water quality in comparison to bare soil. The RECM Study concluded that, in comparison to bare soil, the erosion control products reduced runoff by 43 to 96 percent as well as sediment and turbidity by 96 to 99 percent. Another conclusion of the RECM Study was that ornamental vegetative box plots were 100-percent effective as treatment in controlling overland flow for all of the flows tested within the experiment. This was accomplished through losses (i.e. losses due to infiltration, interception, surface storage, and evapotranspiration). Differences among vegetation types and measured parameters of water quality were not observed; therefore, future studies were recommended. The RVTS and RECM studies served as learning experiences and established future study questions that led to the development of the ORVTS Study.

1.3 PROJECT OVERVIEW AND OBJECTIVES

The ORVTS Study was comprised of two types of study sites: the Expanded Roadside Vegetated Treatment Sites (ERVTS), and the Groundcover Roadside Vegetated Treatment Sites (GRVTS). The GRVTS locations were selected to assess the treatment performance of roadside slopes with existing ornamental vegetation. The ERVTS were selected to provide a side-by-side comparison of the treatment potential from ornamental vegetation to the grasses and forbs studied in the original RVTS Study. The goal of the ORVTS Study is to offer designers more options for roadside landscapes while providing treatment of roadway runoff. The objectives of this study were to:

- Evaluate the effectiveness of strips and swales planted with ornamental vegetation in treating highway runoff in terms of constituent concentration, runoff volume, and constituent load reduction.
- Determine the impact of ornamental vegetation type on the treatment performance of strips planted with ornamental vegetation in terms of constituent concentration, runoff volume, and constituent load reduction.
- Determine the impact of strip width on the treatment performance of strips planted with ornamental vegetation in terms of constituent concentration, runoff volume, and constituent load reduction.
- Compare findings from the ORVTS Study to data from previous related studies such as the Roadside Vegetated Treatment Sites (RVTS) Study, the Caltrans Discharge Characterization Study, and the BMP Retrofit Pilot Program (BMP Program).

The assessments presented in this report include comparisons of summary statistics between the stations (i.e. Test vs. Control) in terms of concentration and load reductions for the constituents analyzed for this Study. Constituents selected for analysis were divided into groups consisting of dissolved metals, total metals, sediment, nutrients, and conventionals. This report also includes comparisons of runoff volume reduction (losses) summary statistics.

1.4 REPORT ORGANIZATION

The report is organized as follows:

Section 1 – Introduction

- This section presents the study goal, objectives, project overview, and general information of the ORVTS Study. It also provides descriptions of general monitoring set-up information.

Section 2 – Study Approach

- This section presents the study plan, site characteristics, site locations, design features, and general information of the ORVTS Study. It also provides descriptions of monitoring locations and general set-up information.

Section 3 – Monitoring Methodology

- This section presents the methodology and approaches of the hydrologic and water quality monitoring performed under this Study. It provides detailed information on the

activities conducted, including hydrologic and water quality monitoring, vegetation assessments, data management and reporting, and operation and maintenance.

Section 4 – Monitoring Results

- This section presents monitoring results from the 2009-2010, 2010-2011, and 2011-2012 monitoring seasons. Results include visual observations made during monitoring events, hydrology and water quality results, and vegetation assessment results. It also addresses the results for Quality Assurance/Quality Control (QA/QC) purposes.

Section 5 – Data Assessments and Findings

- This section presents the methodology, results and discussions of data assessments, including Analysis of Variance (ANOVA) or equivalent non-parametric testing, when applicable, on concentration, runoff, and load data and applicable post-hoc comparisons, to address the various study objectives.
- This section presents Study findings drawn from analyses of data for the 2009-2012 monitoring seasons. It also addresses Study objectives, such as the effectiveness of roadside strips planted with ornamental vegetation in reducing constituent concentration, runoff volume, and constituent load.

Section 6 – Conclusions

- This section presents a summary of Study findings and a general comparison to various other Caltrans studies.

Section 7 – References

- This section consists of a bibliography of reference documentation.

SECTION 2 STUDY APPROACH

2.1 STUDY APPROACH

The ORVTS Study involved the installation of monitoring stations, runoff sampling, laboratory analysis of samples, collection of event rainfall and runoff data, evaluation of event hydrology, analysis of the monitored event, and operation and maintenance of the monitoring stations. Monitoring locations consisted of separate test stations with an adjacent control station due to the difficulty of monitoring the influent while maintaining the sheet flow to the effluent. Additionally, adjacent test and control locations ensured similar drainage area sizes and site characteristics.

Standardized monitoring protocols were used to provide consistency in sample collection methods, data collection, laboratory analysis, and general uniformity in monitoring setup. These protocols are defined in the ORVTS OM&M Plan (Caltrans, 2009).

2.2 SITE CHARACTERISTICS AND LOCATIONS (SITING)

After evaluating 50 potential locations for GRVTS, 13 locations were recommended at the start of the study. Further information on each recommended location is provided in Appendix B. A summary of the siting studies is included in the Scoping and Siting of Groundcovers and Low-Growing Shrub Vegetation Types in Biostrips and Bioswales for Storm Water Treatment Pilot Study Site Selection Technical Memorandum, Caltrans Document No. CTSW-TM-07-172.11.4 (Caltrans June 2007). Prior to the start of the 2009-2010 wet season, these locations were inspected for barriers or current construction activities. Seven locations from the 13 recommended locations were then selected for GRVTS application. However, ultimately five GRVTS locations remained for the entire duration of the study. As each monitoring year progressed additional sites were removed for various reasons:

- Monitoring at all three stations (11-328, 11-329, and 11-330) at the San Diego GRVTS location was discontinued following the first four monitored storm events of the 2009-2010 season due to substantial recurring bypass (i.e. stormwater flows were inadvertently diverted away from collection system) issues at both strip stations.
- Monitoring of one strip station (4-311) at the San Mateo GRVTS location was also discontinued after the first three monitored storm events of the 2009-2010 season due to substantial recurring bypass issues at this station.
- Finally, monitoring at the EOP station (4-307) at the Napa GRVTS location was discontinued after the first five monitored storm events of the 2010-2011 season due to the discovery of a rubberized, gap-graded hot mix asphalt (RHMA-G) porous overlay covering the highway. Refer to Appendix I.

In addition to the GRVTS locations, two ERVTS locations (Sacramento and Yorba Linda) were chosen for monitoring; one in each geographic region (Northern and Southern California). At each selected location, four new test plots were installed adjacent to the existing test plots from the RVTS Pilot Study. These test plots were newly vegetated with groundcover or low-growing shrub species and were monitored in sequence with the existing EOP RVTS.

By the end of all three monitoring seasons, only seven locations were completely monitored for the duration of the study. Therefore, study results summarized herein are based on the monitoring data from the five GRVTS locations and the two ERVTS locations.

2.3 SITE CHARACTERISTICS AND KEY DESIGN FEATURES

Detailed information of these ERVTS and GRVTS is described in the following sub-sections. Table 2-1 presents a visual guide to the vegetation utilized in the study and contains relevant information about the vegetation such as the binomial or scientific name, the abbreviation of the binomial name used throughout the text, the common name of the plant, and the plant type. Figure 2-1 shows the location of each selected ORVTS. Table 2-2 summarizes information such as the Caltrans Statewide ID, highway location, postmile, county, Caltrans District, Regional Board, drainage area, type of vegetation, average annual rainfall, and the Average Annual Daily Traffic (AADT) per lane of each location.

Table 2-1: ORVTS Vegetation Identification Guide

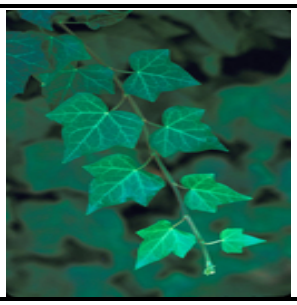
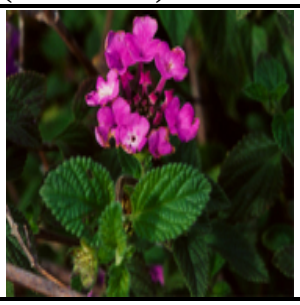
			
Binomial Name: *Baccharis pilularis* *'Twin Peaks'*	Binomial Name: *Carpobrotus edulis*	Binomial Name: *Hedera helix*	Binomial Name: *Iva hayesiana*
Text Abbreviation: *B. pilularis*	Text Abbreviation: *C. edulis*	Text Abbreviation: *H. helix*	Text Abbreviation: *I. hayesiana*
Common Name: Twin Peaks Coyote Brush	Common Name: Ice Plant	Common Name: Common or English Ivy	Common Name: San Diego Marsh Elder
Plant Type: Shrub (Low Shrub)	Plant Type: Perennial Herb (Succulent)	Plant Type: Vine/Shrub (Groundcover)	Plant Type: Perennial Herb (Low Shrub)
			References: *B. pilularis* *C. edulis* *H. helix* *I. hayesiana* *L. montevidensis* www.calflora.org *M. parvifolium* *S. mandraliscae* www.smgrowers.com
Binomial Name: *Lantana montevidensis*	Binomial Name: *Myoporum parvifolium*	Binomial Name: *Senecio mandraliscae*	
Text Abbreviation: *L. montevidensis*	Text Abbreviation: *M. parvifolium*	Text Abbreviation: *S. mandraliscae*	
Common Name: Purple Lantana	Common Name: Creeping Myoporum	Common Name: Blue Finger	
Plant Type: Vine/Shrub (Low Shrub)	Plant Type: Shrub (Low Shrub)	Plant Type: Succulent	

Figure 2-1: Statewide ORVTS Locations

Table 2-2: Locations of ORVTS

Location[a]	Biostrip/ Bioswale	Stations	Drainage Area[b] (ft^2)	Caltrans Statewide Station ID	Vegetation Type[g]	% Slope	Strip Width/ Swale Length (ft)	Highway Location	Postmile (approx.)	County	Caltrans District	Regional Board	Median Annual Rainfall[c] (inches)	Annual Average Daily Traffic per Lane[d] (AADT/Lane)
Sacramento I-5 ERVTS Strip	Biostrip	EOP Southern South-Central North-Central Northern	3,870 4,500 5,630 5,630 5,740	3-213 3-362 3-363 3-364 3-365	N/A *H. helix* *B. pilularis* *M. parvifolium* *H. helix*	N/A 10 33 33 33	0 9 24.5 23.5 24.5	NB I-5 between Pocket and Laguna Exits	13.5	Sacramento	3	5b	16.3	25,000
Yorba Linda SR 91 ERVTS Strip	Biostrip	EOP West West-Central East-Central East	9,800 12,200 13,000 13,900 13,200	12-225 12-346 12-347 12-348 12-349	*N/A* *I. hayesiana* *I. hayesiana* *S. mandraliscae* *L. montevidensis*	N/A 4 6 4 3	0 10 21 21 21	EB SR 91 between Weir Canyon Road and SR-241	15.0	Orange	12	8	13.5	39,330
Napa Hwy 29 GRVTS Strip	Biostrip	~~EOP~~ Southern Northern	~~3,550~~ 5,100 4,950	~~4-307~~ 4-308 4-309	~~N/A~~ *H. helix* *H. helix*	~~N/A~~ 35 35	~~0~~ 14 14	NB Hwy 29 off-ramp to Imola Ave.	10.4	Napa	4	2	24.6	47,000
San Mateo Hwy 380 GRVTS Strip	Biostrip	EOP ~~Western~~ Eastern	13, 150 ~~8,800~~ 9,750	4-310 ~~4-311~~ 4-312	N/A ~~*C. edulis*~~ *C. edulis*	N/A ~~9~~ 12	0 ~~16.5~~ 16.5	WB Hwy 380, just west of El Camino Real on-ramp	5.47	San Mateo	4	2	18.6	20,330
Camarillo Hwy 101 GRVTS Strip	Biostrip	EOP Southern Northern	9,000 10,575 18,990	7-340 7-341 7-342	N/A *C. edulis* *C. edulis*	N/A 25 25	0 15 15	NB Hwy 101 at Lewis Rd. exit	13.848	Ventura	7	4	12.6	27,800
Westminster I-405 GRVTS Strip	Biostrip	EOP Southern Northern	4,600 6,000 6,000	12-343 12-344 12-345	N/A *C. edulis* *C. edulis*	N/A 18 22	0 15 15	NB I-405 south of Goldenwest St./Bolsa Ave.	17.75	Orange	12	8	10.2	103,200
San Diego SR 52 GRVTS Strip	Biostrip	~~EOP~~ ~~Western~~ ~~Eastern~~	~~6,200~~ ~~1,500~~ ~~1,500~~	~~11-328~~ ~~11-329~~ ~~11-330~~	~~N/A~~ ~~*C. edulis*~~ ~~*C. edulis*~~	~~N/A~~ ~~9~~ ~~7~~	~~0~~ ~~15~~ ~~15~~	WB SR 52 at on ramp to NB I-5	0.2	San Diego	11	9	11.2	33,600
Newbury Park Hwy 101 GRVTS Swale	Bioswale	EOP Swale	44,740 49,800[f]	7-338 7-339	N/A *M. parvifolium*	N/A 1.4[e]	0 148	SB Hwy 101 at Rancho Conejo Blvd.	7.017	Ventura	7	4	12.6	51,670
Carlsbad (Palomar) I-5 GRVTS Swale	Bioswale	EOP Swale	185,300 207,200[f]	11-326 11-327	N/A *C. edulis*	N/A 0.6[e]	0 365	SB I-5 between Palomar Airport and Cannon	47	San Diego	11	9	9.2	48,250

(a) ERVTS locations have ornamental vegetation established in summer 2009 adjacent to previous RVTS Study stations. GRVTS locations have existing ornamental vegetation.
(b) Drainage area for the EOP was estimated using standard lane widths, shoulder widths, and the measurement of roadway contributing length. Drainage areas for strips were calculated just as the EOP, in addition to including strip width. All drainage areas were field checked during rain events.
(c) Available data since 1970 from Western Regional Climate Center (website: www.wrcc.dri.edu) are used. (d) Caltrans 2009. (e) Swale slope as opposed to strip slope.
(f) Drainage area includes EOP, the swale, the highway area alongside the swale for Carlsbad, but only minimal highway drainage for the swale at Newbury Park.
(g) Vegetation: *B. pilularis* = *Baccharis pilularis* (Twin Peaks), *C. edulis* = *Carpobrotus edulis* (Ice Plant), *H. helix* = *Hedera helix* (Common or English Ivy), *I. hayesiana* = *Iva hayesiana* (San Diego Marsh Elder), *L. montevidensis* = *Lantana montevidensis* (Purple Lantana), *M. parvifolium* = *Myoporum parvifolium* (Creeping Myoporum), *S. mandraliscae* = *Senecio mandraliscae* (Blue Finger)

Note: Crossed out entries indicate a lack of sample data or that monitoring was discontinued. These stations have been omitted from the overall Study and consequently will not be included in the statistical analyses presented herein.

2.3.1 Sacramento I-5 ERVTS Strip

Stations: 3-213, 3-362 (*H. helix*), 3-363 (*B. pilularis*), 3-364 (*M. parvifolium*) and 3-365 (*H. helix*)

The Sacramento ERVTS were located north of the existing RVTS Study plots along northbound Interstate 5 (I-5) between Laguna Boulevard and Pocket Road at postmile (PM) 13.5 in the City of Sacramento, Sacramento County, California (Caltrans District 3). Five stations, including the existing EOP station from the RVTS Study, were monitored for two monitoring seasons (i.e. 2009-2010 and 2010-2011) over the duration of the study.

One station was located at the EOP (Station 3-213) and had a drainage area of approximately 3,870 square feet (ft^2) and a 100-foot long concrete collection tray located at the edge of the shoulder. The other four stations (3-362, 3-363, 3-364, and 3-365) were vegetated strips with different characteristics. Prior to planting, the soil in the strips was amended with 1 inch layer of compost incorporated to a depth of 6 inches. Station 3-362 had an approximate strip width of 10 feet, a 9-percent slope, a drainage area of approximately 4,500 ft^2, and was planted with *H. helix* (Common or English Ivy). Stations 3-363, 3-364, and 3-365 each had an approximate strip width of 25 feet and a 33-percent slope. Station 3-363 had a drainage area of approximately 5,630 ft^2 and was vegetated with *B. pilularis* 'Twin Peaks' (Twin Peaks Coyote Bush). Station 3-364 had a drainage area of approximately 5,630 ft^2 and was vegetated with *M. parvifolium* (Creeping Myoporum). Station 3-365 had a drainage area of approximately 5,740 ft^2 and was vegetated with *H. helix*. After planting, bare soils in the strips were covered with a 3 inch layer of bark mulch. All four vegetated strip stations had collection trays approximately 100 feet long and slotted PVC pipes six inches in diameter. The drainage area for the EOP was estimated assuming three lanes each with an approximate width of 12 feet, one shoulder with an approximate width of 12 feet, and a length of 100 feet. The drainage area for each strip was estimated as the EOP drainage area described above plus the corresponding strip width. Figure 2-2 shows a plan view of the pilot facilities at the Sacramento ERVTS. Figure 2-3 shows a representative photograph of the location.

2.3.2 Yorba Linda SR 91 ERVTS Strip

Stations: 12-225, 12-346 (*I. hayesiana*), 12-347 (*I. hayesiana*), 12-348 (*S. mandraliscae*), and 12-349 (*L. montevidensis*)

The Yorba Linda ERVTS were located east of the existing RVTS Study plots along eastbound State Route 91 (SR 91) between the Weir Canyon and SR-241 exits at PM 15 in the City of Anaheim, Orange County, California (Caltrans District 12). Five stations, including the existing EOP station from the RVTS Study, were monitored for two monitoring seasons (i.e. 2009-2010 and 2010-2011) over the duration of the study.

One station was located at the EOP (Station 12-225) and had a drainage area of approximately 9,800 ft^2 and a 100-foot long concrete collection tray located at the edge of the shoulder. The other four stations (12-346, 12-347, 12-348, and 12-349) were vegetated strips with different characteristics. Prior to planting, the soil in the strips was amended with 1 inch layer of compost incorporated to a depth of 6 inches. Station 12-346 had an approximate strip width of 10 feet, a

4-percent slope, a drainage area of approximately 12,200 ft^2, and was vegetated with *I. hayesiana* (San Diego Marsh Elder). Stations 12-347, 12-348, and 12-349 each had an approximate strip width of 21 feet. Station 12-347 had a 6-percent slope, a drainage area of approximately 13,000 ft^2, and was vegetated with *I. hayesiana*. Station 12-348 had a 4-percent slope, a drainage area of approximately 13,900 ft^2, and was vegetated with *S. mandraliscae* (Blue Finger). Station 12-349 had a 3-percent slope, a drainage area of approximately 13,200 ft^2, and was vegetated with *L. montevidensis* (Purple Lantana). After planting, bare soils in the strips were covered with a 3 inch layer of bark mulch. All four vegetated strip stations had collection trays approximately 100 feet long and slotted PVC pipes six inches in diameter. The drainage area for the EOP was estimated assuming six lanes each with an approximate width of 12 feet, one shoulder with an approximate width of 12 feet, and a length of 100 feet. The drainage area for each strip was estimated as the EOP drainage area described above plus the corresponding strip width. Figure 2-4 shows a plan view of the pilot facilities at the Yorba Linda ERVTS. Figure 2-5 shows a representative photograph of the location.

2.3.3 Napa Hwy 29 GRVTS Strip

Stations: 4-307, 4-308 (*H. helix*), and 4-309 (*H. helix*)

The Napa GRVTS were located along northbound CA-29 adjacent to the Imola Avenue off-ramp at PM 10.4 in the City of Santa Rosa, Napa County, California (Caltrans District 4). Three stations were monitored for two monitoring seasons (i.e. 2009-2010 and 2010-2011) over the duration of the study. Monitoring was discontinued at the EOP (Station 4-307) after the first five events of the 2010-2011 season due to the RHMA-G porous overlay. Monitoring of the two strip stations (4-308 and 4-309) at Napa continued until the end of the 2010-2011 season.

One station was located at the EOP (Station 4-307) and had a drainage area of approximately 2,200 ft^2. The other two stations (4-308 and 4-309) were both vegetated strips with similar characteristics. Both stations had an approximate strip width of 15 feet, a 15-percent slope, a drainage area of approximately 3,700 ft^2, and were vegetated with *H. helix* (Common or English Ivy). All three stations had collection trays approximately 100 feet long and slotted PVC pipes six inches in diameter. The drainage area for the EOP was estimated assuming one lane with an approximate width of 12 feet, one shoulder with an approximate width of 12 feet, and a length of 100 feet. The drainage area for each strip was estimated as the EOP drainage area described above plus the corresponding strip width. Figure 2-6 shows a plan view of the pilot facilities at the Napa GRVTS. Figure 2-7 shows a representative photograph of the location.

2.3.4 San Mateo Hwy 380 GRVTS Strip

Stations: 4-310, 4-311 (*C. edulis*), and 4-312 (*C. edulis*)

The San Mateo GRVTS were located along westbound Highway 380 just west of the El Camino Real on-ramp at PM 5.47 in the City of San Bruno, San Mateo County, California (Caltrans District 4). Three stations were monitored for the duration of the study over three monitoring seasons (i.e. 2009-2010, 2010-2011, and 2011-2012). Monitoring of the third and final season at this site was completed on December 31, 2011.

One station was located at the EOP (Station 4-310) and had a drainage area of approximately 9,240 ft^2. The other two stations (4-311 and 4-312) were both vegetated strips with similar characteristics. Both stations had an approximate strip width of 16 feet, a drainage area of approximately 8,800 ft^2, and were vegetated with *C. edulis* (Ice Plant). Station 4-311 had a slope of 9 percent while station 4-312 had a slope of 12 percent. All three stations had collection trays approximately 100 feet long and slotted PVC pipes six inches in diameter. The drainage area for the EOP was estimated assuming five lanes each with an approximate width of 12 feet, one shoulder with an approximate width of 12 feet, one lane of the on-ramp with an approximate width of 12 feet, and a length of 100 feet. The drainage area for each strip was estimated as the EOP drainage area described above plus the corresponding strip width. Figure 2-8 shows a plan view of the pilot facilities at the San Mateo GRVTS. Figure 2-9 shows a representative photograph of the location.

2.3.5 Camarillo Hwy 101 GRVTS Strip

Stations: 7-340, 7-341 (*C. edulis*), and 7-342 (*C. edulis*)

The Camarillo GRVTS were located along northbound US-101 at the Lewis Road exit at PM 13.85 in the City of Camarillo, Ventura County, California (Caltrans District 7). Three stations were monitored for the duration of the study over three monitoring seasons (i.e. 2009-2010, 2010-2011, and 2011-2012). Monitoring of the third and final season at this site was completed on December 31, 2011.

One station was located at the EOP (Station 7-340) and had a drainage area of approximately 9,000 ft^2. The other two stations (7-341 and 7-342) were both vegetated strips with similar characteristics. Both stations had an approximate strip width of nine feet, a 25-percent slope, and were vegetated with *C. edulis* (Ice Plant). Station 7-341 had a drainage area of approximately 10,575 ft^2 and Station 7-342 had a drainage area of approximately 18,990 ft^2. All stations had collection trays approximately 100 feet long and slotted PVC pipes six inches in diameter. The drainage area for the EOP was estimated assuming five lanes each with an approximate width of 12 feet, one extra wide shoulder with an approximate width of 15 feet, and a length of 100 feet. The drainage area for each strip was estimated as the EOP drainage area described above plus the corresponding strip width. Figure 2-10 shows a plan view of the pilot facilities at the Camarillo GRVTS. Figure 2-11 shows a representative photograph of the location.

2.3.6 Westminster I-405 GRVTS Strip

Stations: 12-343, 12-344 (*C. edulis*), and 12-345 (*C. edulis*)

The biostrips were located along northbound I-405 south of the Golden West Street/Bolsa Avenue exit at PM 17.75 in the City of Westminster, Orange County, California (Caltrans District 12). Three stations were monitored for two monitoring seasons (i.e. 2009-2010 and 2010-2011) over the duration of the study.

One station was located at the EOP (Station 12-343) and had a drainage area of approximately 4,600 ft^2. The other two stations (12-344 and 12-345) were both vegetated strips with similar characteristics. Both stations had an approximate strip width of 15 feet, a drainage area of approximately 6,000 ft^2, and were vegetated with *C. edulis* (Ice Plant). Station 12-344 had a

slope of 18 percent while station 12-345 had a slope of 22 percent. All three stations had collection trays approximately 100 feet long and slotted PVC pipes 6 inches in diameter. The drainage areas were estimated assuming two-and-one-half lanes each with an approximate width of 12 feet, one shoulder with an approximate width of 12 feet, and length of 100 feet. The drainage area for each strip was estimated as the EOP drainage area described above plus the corresponding strip width. Figure 2-12 shows a plan view of the pilot facilities at the Westminster GRVTS. Figure 2-13 shows a representative photograph of the location.

2.3.7 San Diego SR 52 GRVTS Strip

Stations: 11-328, 11-329 (*C. edulis*), and 11-330 (*C. edulis*)

The biostrips were located along westbound State Route 52 (SR-52) just east of the interchange to northbound I-5 at PM 0.2 in the City of San Diego, San Diego County, California (Caltrans District 11). Monitoring was discontinued following the first four monitored storm events of the 2009-2010 season due to substantial recurring bypass issues at both strip stations.

One station was located at the EOP (Station 11-328) and had a drainage area of approximately 6,200 ft^2. The other two stations (11-329 and 11-330) were both vegetated strips with similar characteristics. Both stations had an approximate strip width of 15 feet, a drainage area of approximately 1,500 ft^2, and were vegetated with *C. edulis* (Ice Plant). Station 11-329 had a slope of 9 percent while station 11-330 had a slope of 7 percent. All three stations had collection trays approximately 100 feet long and slotted PVC pipes six inches in diameter. The drainage area for the EOP was estimated assuming two-and-one-half lanes each with an approximate width of 12 feet, one shoulder with an approximate width of 12 feet, and a length of 100 feet. The drainage area for each strip was estimated as the EOP drainage area described above plus the corresponding strip width. Figure 2-14 shows a plan view of the pilot facilities at the San Diego GRVTS. Figure 2-15 shows a representative photograph of the location.

2.3.8 Newbury Park Hwy 101 GRVTS Swale

Stations: 7-338 and 7-339 (*M. parvifolium*)

The bioswale was located along southbound US-101 at the off-ramp to Rancho Conejo Boulevard at PM 7 in the City of Newbury Park, Ventura County, California (Caltrans District 7). The location was between the highway and the off-ramp and could be accessed from the highway shoulder. Two stations were monitored for the duration of the study over three monitoring seasons (i.e. 2009-2010, 2010-2011, and 2011-2012). Monitoring of the third and final season at this site was completed on December 31, 2011.

One station was located at the EOP (Station 7-338) and had a drainage area of approximately 44,740 ft^2. The other station (7-339) was a vegetated swale with an approximate swale length of 148 feet, a width varying between two and 26 feet, a 1.4-percent slope, a drainage area of approximately 49,800 ft^2, and was vegetated primarily with *M. parvifolium* (Creeping Myoporum). A perimeter berm was not established by the curb within the traveled way of the freeway or along the off-ramp traveled way since both sides of the site drain away from the site due to the increased elevation at the off-ramp. It should be noted that minimal to no runoff from the freeway entered the swale along its entire length. The drainage area for the swale influent

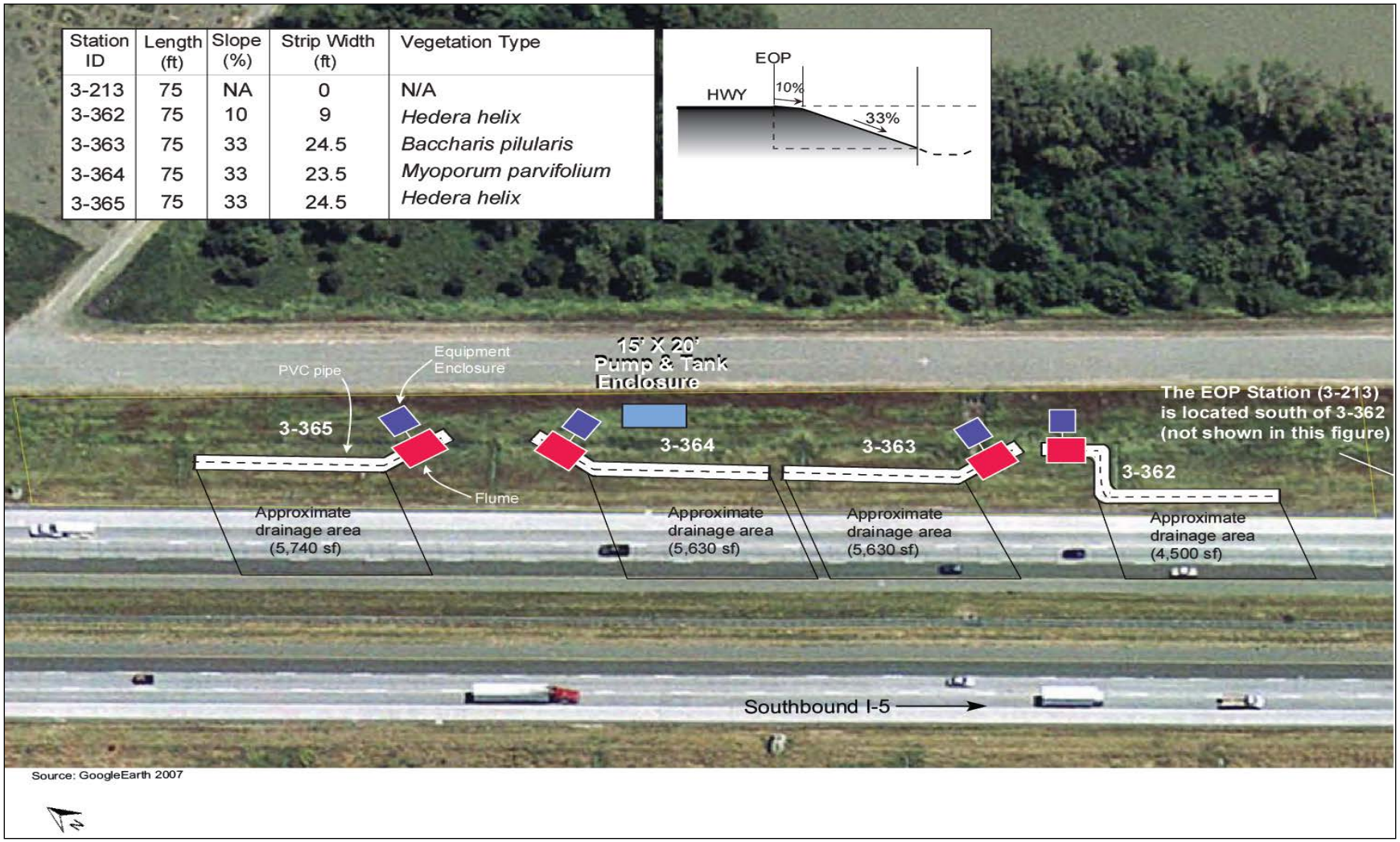
(EOP) was estimated assuming three lanes and one shoulder (at the center divider) each approximately 12-feet wide, and a drainage length of 617 feet. In addition, there was a triangular area that consists of the outside shoulder and gore area. This triangular area was approximately 48.5-feet wide at the base with a drainage length of 617 feet. The drainage area for the swale effluent was estimated as the EOP drainage area plus the vegetated area of the swale. Figure 2-16 shows a plan view of the pilot facilities at the Newbury GRVTS. Figure 2-17 shows a representative photograph of the location.

2.3.9 Carlsbad (Palomar) I-5 GRVTS Swale

Stations: 11-326 and 11-327 (*C. edulis*)

The bioswale was located along southbound I-5 between Cannon Road and Palomar Airport Road at PM 47 in the City of Carlsbad, San Diego County, California (Caltrans District 11). This location was designed as a bioswale for the Caltrans Best Management Practices (BMP) Retrofit Pilot Study (Caltrans 2004). Two stations were monitored for only two monitoring seasons (i.e. 2009-2010 and 2010-2011) over the duration of the study.

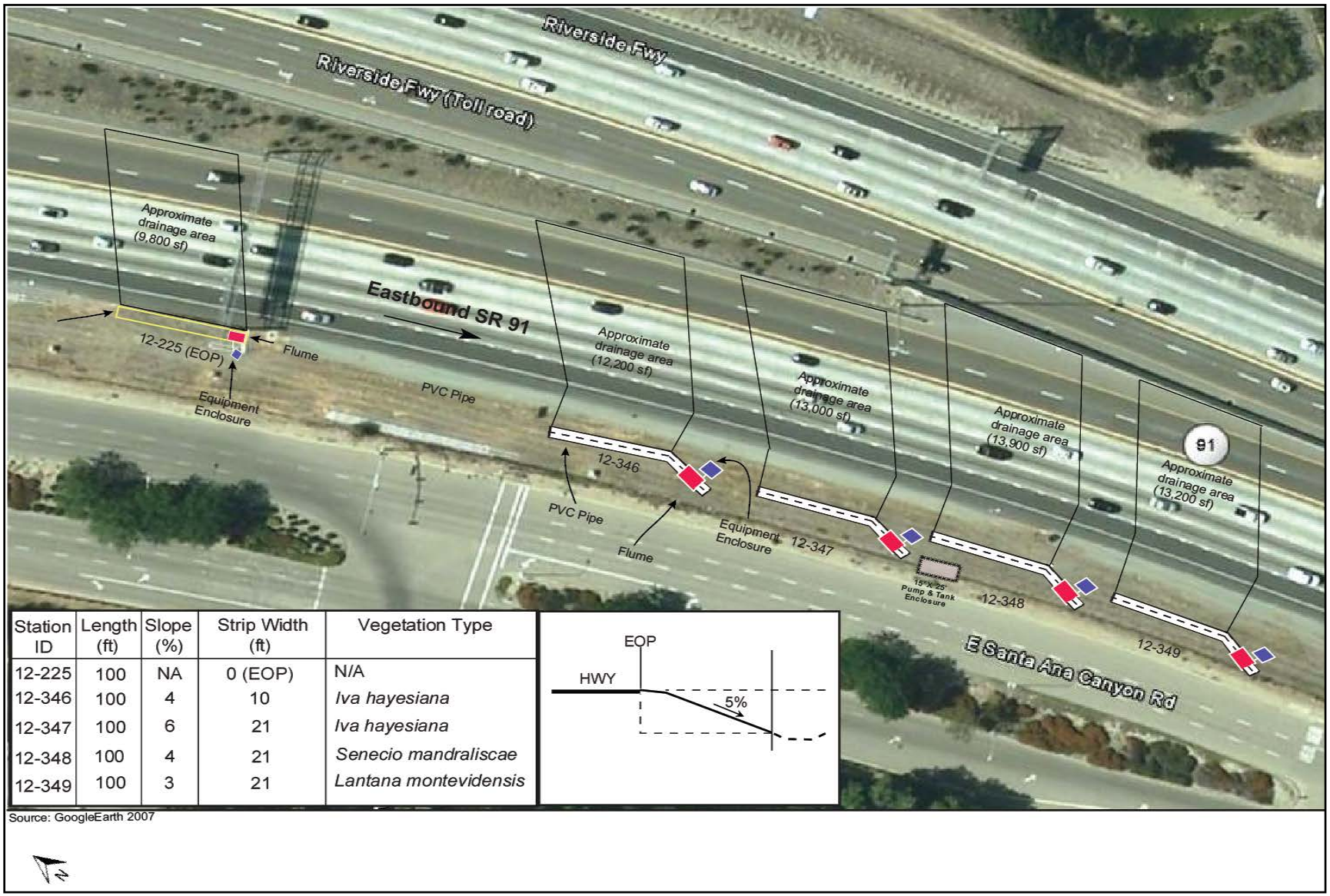
One station was located at the EOP (Station 11-326), where sheet flow from the freeway was directed into a concrete ditch approximately 60 feet long upstream of the concrete apron transition, followed by a monitoring flume. The drainage area for the EOP was approximately 185,300 ft^2. Station 11-327 was composed of three concrete approach channels interspersed by three bioswale segments. Runoff was directed through the first concrete approach channel that was 80 feet long and was followed by a 130-foot long bioswale segment. The flow then drained through the second concrete channel that was 45 feet long and was followed by a 75-foot long bioswale segment. Lastly, the flow was directed through the third concrete channel that was 50 feet long and was followed by a 160-foot long bioswale segment. Runoff was then monitored through a second monitoring flume and discharged into an existing drainage inlet. The existing storm drain discharged into an underground concrete box culvert that crossed I-5. All concrete channels ran north to south and had an approximate width of 2.2 feet. The swales also ran north to south and each had an approximate width of 6.5 feet, a slope of 0.6 percent, a drainage area of approximately 207,200 ft^2, and vegetation cover consisting of *C. edulis* (Ice Plant). A perimeter berm was not installed at this location in order for data to be compared to data from the BMP Retrofit Pilot Program (Caltrans, 2004), during which there was no berm. It should be noted that runoff from the freeway entered the swale along its entire length rather than just through the influent sampling location. The drainage area for the EOP was estimated assuming four lanes and two shoulders each with an approximate width of 12 feet, upstream of the concrete apron and influent monitoring flume. The drainage area for the effluent swale consists of the EOP drainage area described above plus all three vegetated swales, plus the two intermediate concrete approach channels, plus the highway and shoulder parallel to the swales or concrete channels. Figure 2-18 shows a plan view of the pilot facilities at the Carlsbad (Palomar) GRVTS swale. Figure 2-19 shows a representative photograph of the location.



Station ID	Length (ft)	Slope (%)	Strip Width (ft)	Vegetation Type
3-213	75	NA	0	N/A
3-362	75	10	9	*Hedera helix*
3-363	75	33	24.5	*Baccharis pilularis*
3-364	75	33	23.5	*Myoporum parvifolium*
3-365	75	33	24.5	*Hedera helix*

Figure 2-2: Conceptual Plan View of Sacramento I-5 ERVTS Strip
Vegetation: *B. pilularis* (Twin Peaks), *H. helix* (Common or English Ivy), and *M. parvifolium* (Creeping Myoporum)

Figure 2-3: Photograph of Sacramento I-5 ERVTS Strip

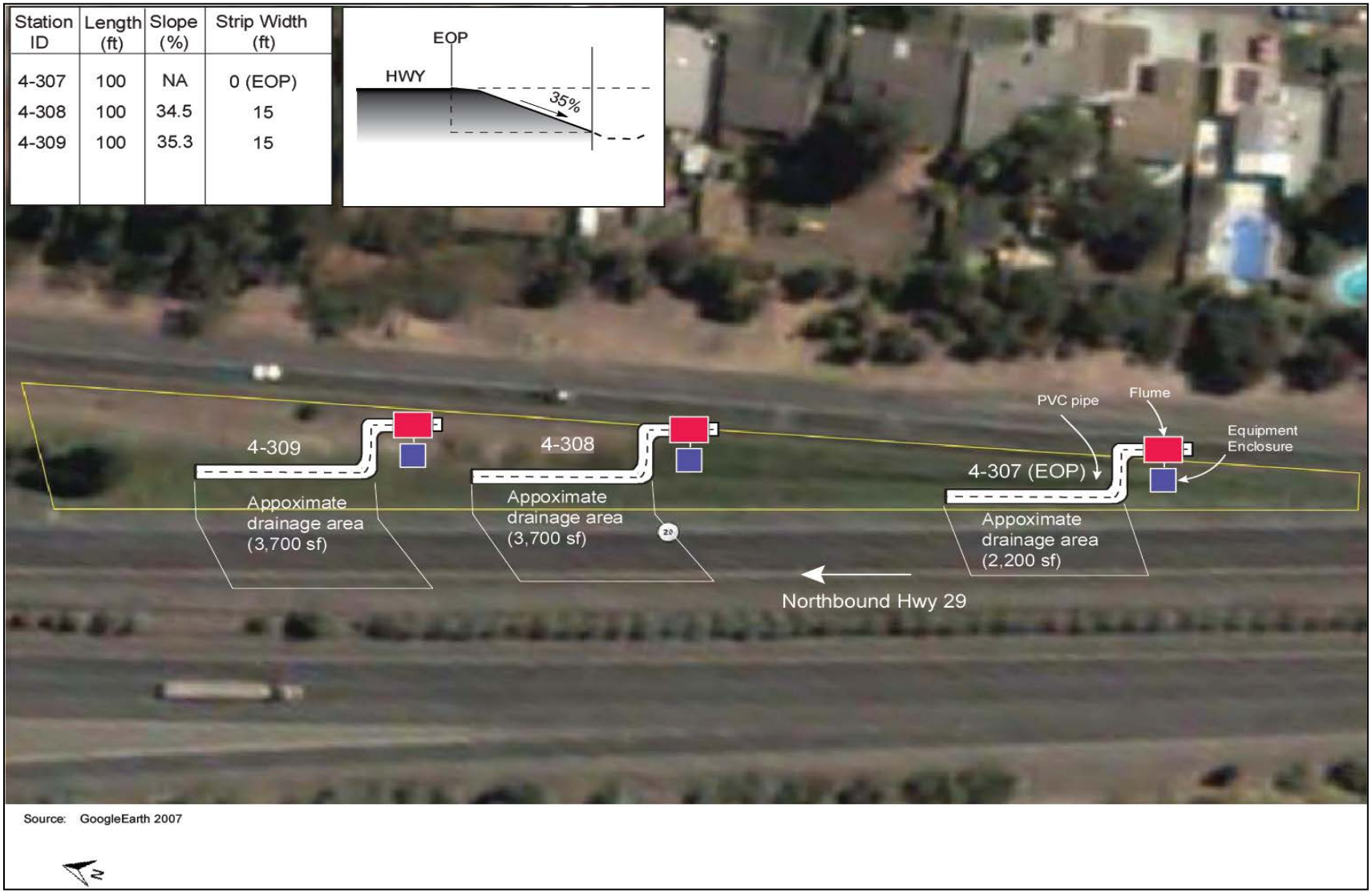


Station ID	Length (ft)	Slope (%)	Strip Width (ft)	Vegetation Type
12-225	100	NA	0 (EOP)	N/A
12-346	100	4	10	*Iva hayesiana*
12-347	100	6	21	*Iva hayesiana*
12-348	100	4	21	*Senecio mandraliscae*
12-349	100	3	21	*Lantana montevidensis*

Source: GoogleEarth 2007

Figure 2-4: Conceptual Plan View of Yorba Linda SR 91 ERVTS Strip
Vegetation: *I. hayesiana* (San Diego Marsh Elder), *L. montevidensis* (Purple Lantana), and *S. mandraliscae* (Blue Finger)

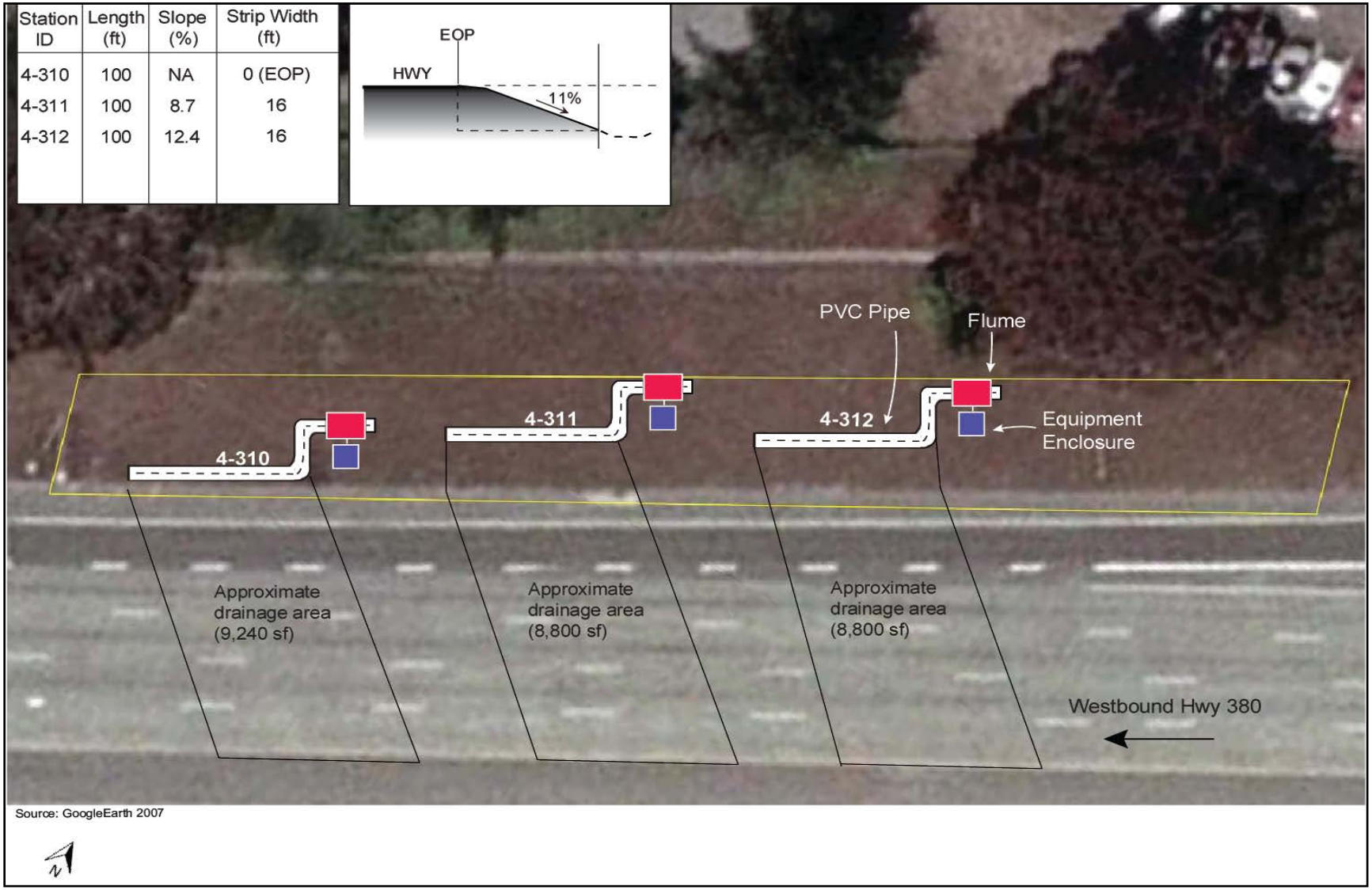
Figure 2-5: Photograph of Yorba Linda SR 91 ERVTS Strip



Station ID	Length (ft)	Slope (%)	Strip Width (ft)
4-307	100	NA	0 (EOP)
4-308	100	34.5	15
4-309	100	35.3	15

Figure 2-6: Conceptual Plan View of Napa Hwy 29 GRVTS Strip Vegetation: *C. edulis* (Ice Plant)

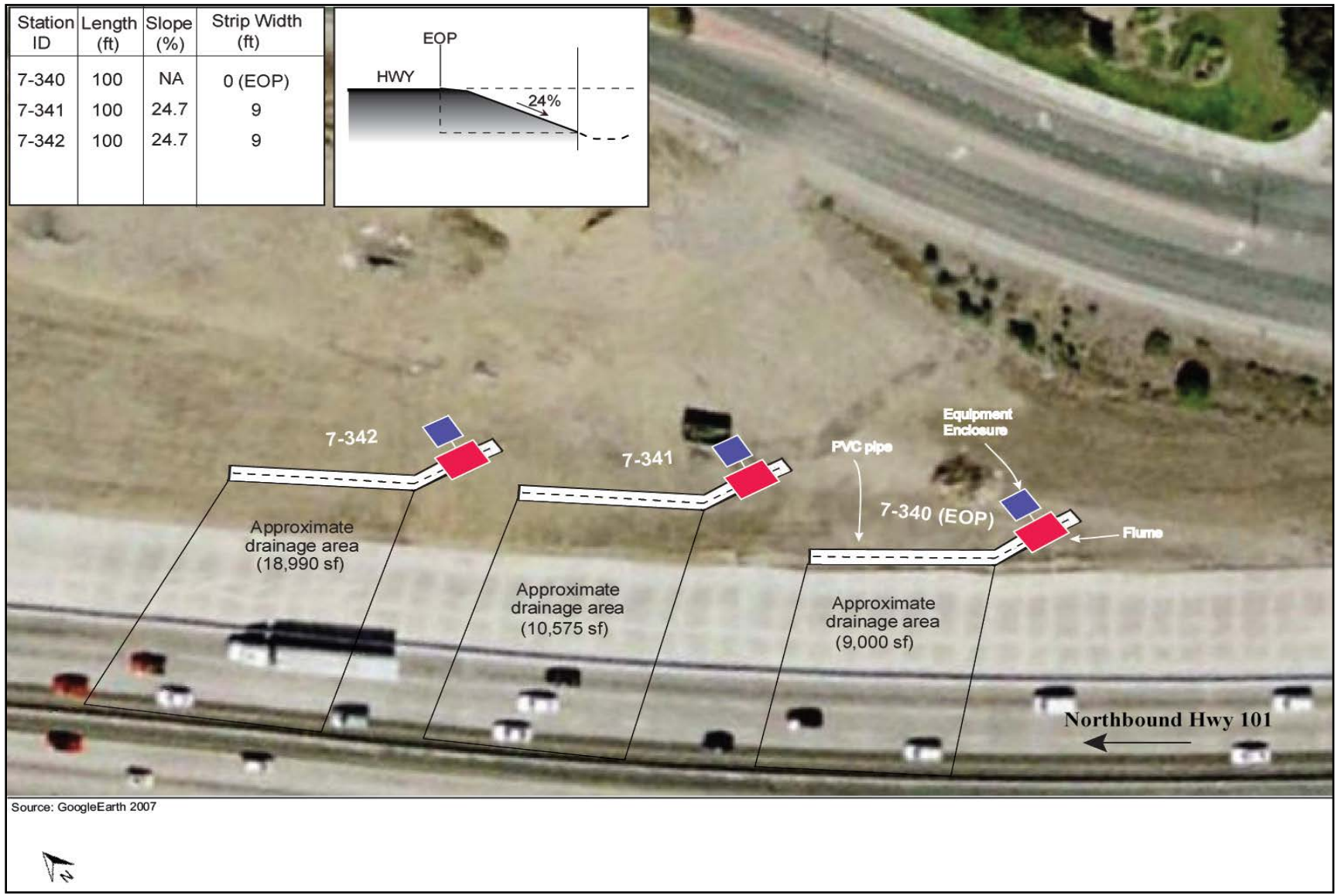
Figure 2-7: Photograph of Napa Hwy 29 GRVTS Strip



Station ID	Length (ft)	Slope (%)	Strip Width (ft)
4-310	100	NA	0 (EOP)
4-311	100	8.7	16
4-312	100	12.4	16

Figure 2-8: Conceptual Plan View of San Mateo Hwy 380 GRVTS Strip Vegetation: *C. edulis* (Ice Plant)

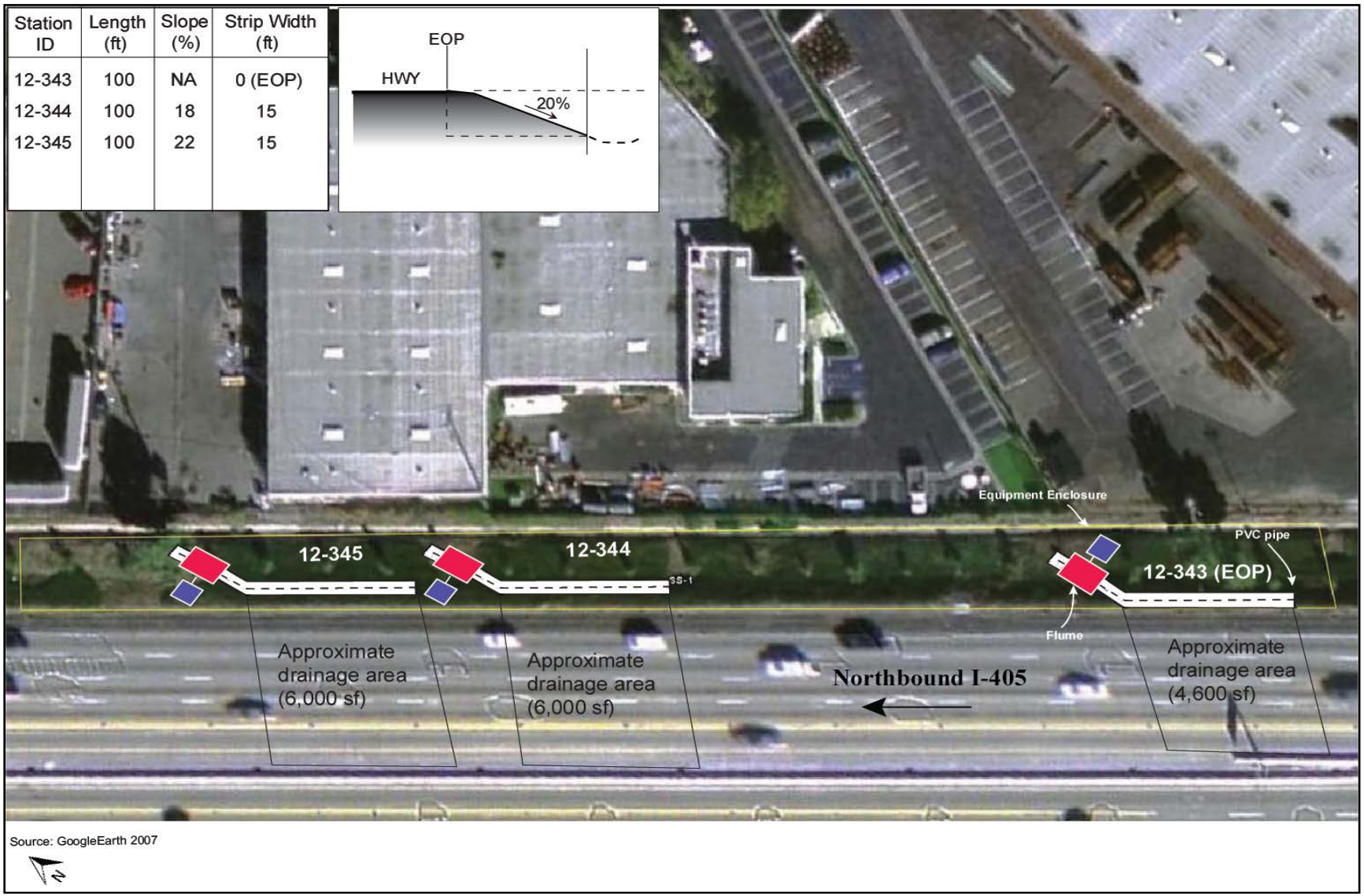
Figure 2-9: Photograph of San Mateo Hwy 380 GRVTS Strip



Station ID	Length (ft)	Slope (%)	Strip Width (ft)
7-340	100	NA	0 (EOP)
7-341	100	24.7	9
7-342	100	24.7	9

Figure 2-10: Conceptual Plan View of Camarillo Hwy 101 GRVTS Strip Vegetation: *C. edulis* (Ice Plant)

Figure 2-11: Photograph of Camarillo Hwy 101 GRVTS Strip



Station ID	Length (ft)	Slope (%)	Strip Width (ft)
12-343	100	NA	0 (EOP)
12-344	100	18	15
12-345	100	22	15

Figure 2-12: Conceptual Plan View of Westminster I-405 GRVTS Strip Vegetation: *C. edulis* (Ice Plant)

Figure 2-13: Photograph of Westminster I-405 GRVTS Strip

Figure 2-14: Conceptual Plan View of San Diego SR 52 GRVTS Strip Vegetation: *C. edulis* (Ice Plant)

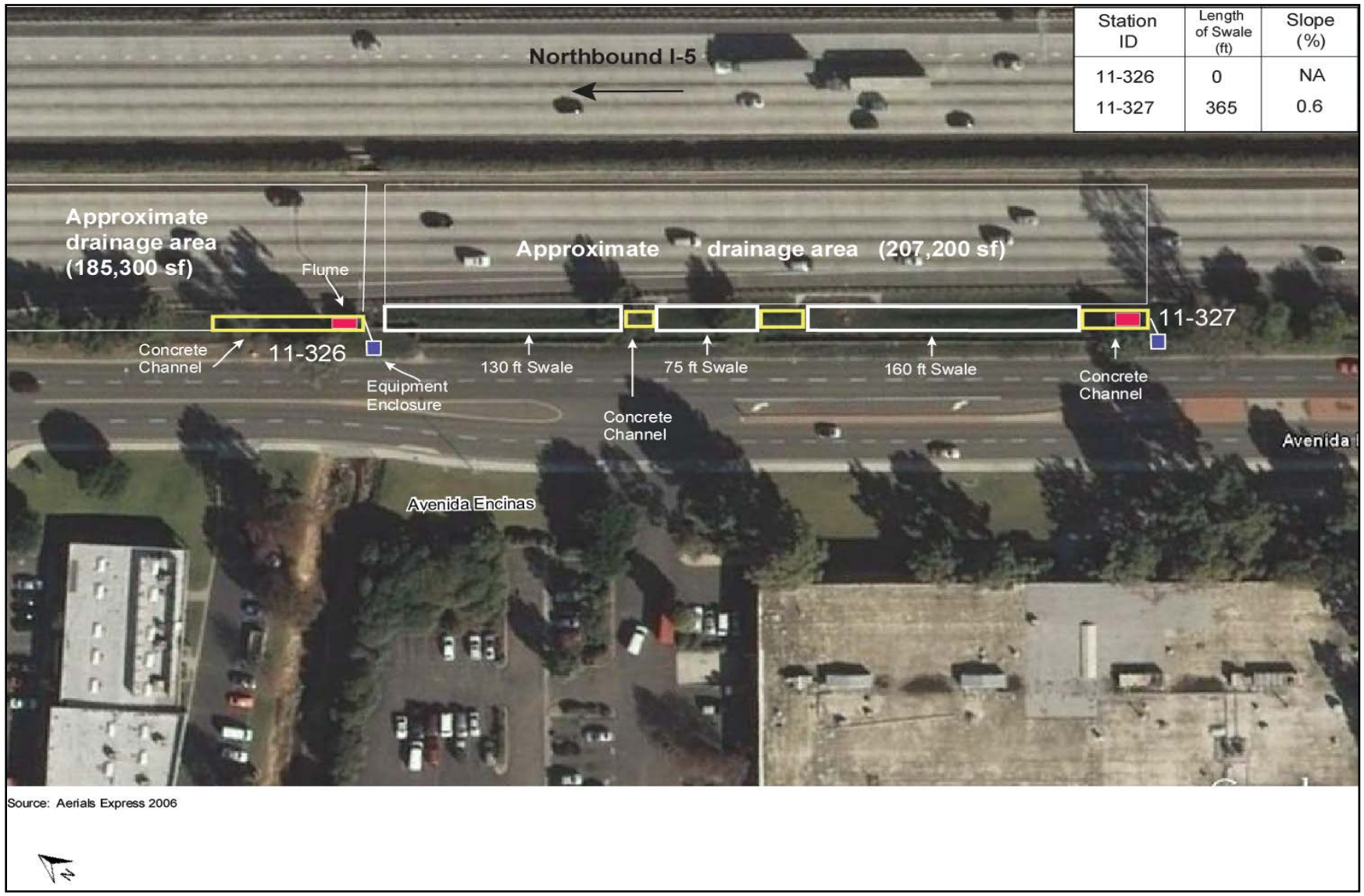
Figure 2-15: Photograph of San Diego SR 52 GRVTS Strip

Source: Aerials Express 2006

N

Figure 2-16: Conceptual Plan View of Newbury Park Hwy 101 GRVTS Swale
Vegetation: *M. parvifolium* (Creeping Myoporum)

Figure 2-17: Photograph of Newbury Park Hwy 101 GRVTS Swale



Station ID	Length of Swale (ft)	Slope (%)
11-326	0	NA
11-327	365	0.6

Source: Aerials Express 2006

Figure 2-18: Conceptual Plan View of Carlsbad (Palomar) I-5 GRVTS Swale Vegetation: *C. edulis* (Ice Plant)

Figure 2-19: Photograph of Carlsbad (Palomar) I-5 GRVTS Swale

SECTION 3 MONITORING METHODOLOGY

3.1 MONITORING

State-of-the-art monitoring protocols were used to provide consistency in sample collection methods, data collection, laboratory analysis, and general uniformity in monitoring setup. These protocols are defined in the ORVTS OM&M Plan (Caltrans, 2009). Monitoring included hydrologic and water quality monitoring, site inspections and maintenance, and vegetation assessments.

This study setup assumed that the EOP stations represented highway runoff or influent (i.e., control) and the strip and swale stations represented the ORVTS effluent (i.e., treatment) with the aim of comparing the runoff volume and constituent concentration and load of strip or swale runoff to that of the highway runoff. At each ERVTS location, there was one EOP station and four strip stations with various strip widths and/or ornamental vegetation types. Flow of runoff leaving the highway EOP was measured along with flow from highway runoff within the vegetated strips. Flow-weighted composite samples were collected and analyzed for specific constituents as listed in Table 3-1 at the EOP and the strip stations. At each GRVTS strip location, there was one EOP station and two strip stations with identical strip width and ornamental vegetation type. Flow was measured and flow-weighted composite samples were collected at both the EOP and the strip stations. At each GRVTS swale location, flow was measured and flow-weighted composite samples were collected at both the influent and effluent stations.

Flow monitoring was conducted during each monitored storm event and continually throughout the storm season at each of the ORVTS to measure annual flows and precipitation. Operational and calibration procedures for the flow measuring devices are presented in the ORVTS OM&M Plan (Caltrans, 2009). The collected flow and water quality data were used for data assessments to achieve the various study objectives as described in Section 1.1.

Each ORVTS location was configured with monitoring and sampling equipment primarily consisting of the following:

- A runoff collection channel or PVC pipe
- Rain covers that were applied only to ERVTS EOP stations
- Two rain gauges at each location, one primary and one backup
- A flume for flow measurements and a riprap flow dissipater at the flume discharge point
- A monitoring enclosure at each station containing a flow meter, automated sampler, telemetry equipment, power supply accessories (battery and cables), and sampling containers
- A solar panel erected on top of the enclosure

Figure 3-1 shows photographs of typical sample collection systems. Monitoring was performed from October 1st to April 30th during the 2009-2010 and 2010-2011 monitoring seasons. Three sites were chosen to be monitored from October 1st to December 31st during the 2011-2012 monitoring season (i.e. San Mateo, Newbury, and Camarillo). During the monitoring seasons, the

National Weather Service was the primary source for weather tracking. Storm selection and mobilization were performed in accordance with Caltrans approved logistics as described in the ORVTS OM&M Plan (Caltrans, 2009).

Photograph of Collection System at Station 7-340 Camarillo Biostrip

Photograph of Collection System at Station 7-338 Newbury Park Bioswale

Figure 3-1: Typical Collection Systems

Constituents selected for this program were based upon Table 4-1 of the *Caltrans Comprehensive Protocols Guidance Manual* (Caltrans, 2003b). The selected constituents, along with their analytical methods and target reporting limits, are listed in Table 3-1 of this report and in the ORVTS OM&M Plan (Caltrans, 2009), which also includes further details of the monitoring approach for this study. This list is consistent with the objectives of this program.

Table 3-1: Selected Analytical Constituents

Analyte	Analytical Procedure	Reporting Limits and Units
Conventional Constituents		
Hardness as $CaCO_3$ (hardness)	EPA 130.1	2 mg/L
Conductivity	EPA 120.1	1 μmhos/cm
Temperature	Field Meter	0.1 °C
pH	Field Meter	0.1 units
Total Organic Carbon (TOC)	EPA 415.1 (SM 5310)	1 mg/L
Dissolved Organic Carbon (DOC)	EPA 415.1 (SM 5310)	1 mg/L
Sediments		
Total Dissolved Solids (TDS)	EPA 160.1 (SM 2540C)	1 mg/L
Total Suspended Solids (TSS)	EPA 160.2 (SM 2540D)	1 mg/L
Turbidity	EPA 180.1	0.05 NTU
Nutrients		
Ammonia (NH_3-N)	EPA 350.1	0.1 mg/L
Nitrate as Nitrogen (NO_3-N)	EPA 300.0	0.1 mg/L
Nitrite as Nitrogen (NO_2-N)	EPA 300.0	0.1 mg/L
Total Kjeldahl Nitrogen (TKN)	EPA 351.1	0.1 mg/L
Total Phosphorus	EPA 365.1	0.03 mg/L
Dissolved Orthophosphate (Dissolved ortho-P)	EPA 365.1	0.03 mg/L
Metals (Total and Dissolved)		
Arsenic (As, total and dissolved)	EPA 200.8	1.0 μg/L
Cadmium (Cd, total and dissolved)	EPA 200.8	0.2 μg/L
Chromium (Cr, total and dissolved)	EPA 200.8	1 μg/L
Copper (Cu, total and dissolved)	EPA 200.8	1 μg/L
Lead (Pb, total and dissolved)	EPA 200.8	1 μg/L
Nickel (Ni, total and dissolved)	EPA 200.8	2 μg/L
Zinc (Zn, total and dissolved)	EPA 200.8	5 μg/L

Source: *Caltrans Comprehensive Protocols Guidance Manual* (Caltrans, 2003b).

3.2 HYDROLOGIC MONITORING

Hydrologic monitoring consisted of measuring runoff volume and precipitation during storm events. Instruments were calibrated and maintained in accordance with manufacturer specifications and Caltrans guidelines. Selected equipment has been used in previous Caltrans monitoring studies and as described in Section 3.1.

3.2.1 Flow Monitoring

Flow monitoring was performed using a combination of flumes and Sigma 950 flow meters. The bubbler tube from the Sigma 950 flow meter was mounted to the flume to measure the depth of flow. The flow meter then converted the instantaneous flow depth to calculate the runoff flow rates and volumes. Each time the runoff volume through the flume reached the pre-programmed pacing volume, the flow meter triggered the automated water quality sampler to initiate collection of a sample aliquot. Two-inch, 60-degree trapezoidal flumes were used at the Sacramento and Yorba Linda ERVTS EOP stations. At the Newbury Park GRVTS location, a 2-inch, 45-degree trapezoidal flume was used for the EOP station. At the Carlsbad (Palomar) GRVTS swale location, two 12-inch H-type flumes were used for both the EOP and swale stations. All other stations used 60-degree trapezoidal flumes.

3.2.2 Precipitation Monitoring

Tipping bucket rain gauges were installed at monitoring stations to measure the amount of precipitation over a period of time. The tipping bucket rain gauge consists of a cylinder with a funnel at the top that collects and channels the precipitation into a small bucket balanced in the same manner as a scale. After an amount of 0.01 inches (0.25 mm) of precipitation falls into the bucket it tips like a lever and a signal is sent to the flow meter, which records the amount of rainfall. Two rain gauges were installed at each location on a pole above the enclosures. One rain gauge served as the primary while the other served as a backup. The rain gauges were connected to the flow meter, which logged the rainfall data.

3.3 WATER QUALITY MONITORING

Water quality monitoring included collection of automated, flow-weighted composite samples and grab samples as required for the specific constituents listed in Table 3-1 following methods prescribed in the Guidance Manual (Caltrans, 2003b). Temperature and pH were measured in the field by taking grab samples and the rest of the constituents were analyzed by the laboratory. The analyses performed as part of this study are described in the ORVTS OM&M Plan (Caltrans, 2009).

3.3.1 Sampling Methods

The stormwater sampling equipment described below was designed to collect composite samples of stormwater runoff in a flow-weighted manner. Components installed for sampling purposes included a flow meter, an automated water quality sampler with a peristaltic pump, tubing, a 20-liter sample bottle, a GSM cellular modem at all stations except for stations at the Sacramento ERVTS, and a power supply including 30-watt solar panels and 12-volt batteries.

The 20-liter sample collection bottles were made of either borosilicate glass or Polyethylene. Polyethylene bottles were a viable alternative to the borosilicate glass bottles for this project as

organic parameters (e.g., pesticides and polynuclear aromatic hydrocarbons) were not a part of the Project's sampling constituent list. Prior to each monitoring event, field personnel placed a sample bottle in a large container and surrounded the bottle with ice to prevent degradation of the analytical constituents and to aid in safe transport of the samples.

Once the equipment was installed and powered up, a field team member ran through the set-up program and input the sample pacing information specific to each station and storm event based on the expected quantitative precipitation forecast (QPF). During storm events, the flow meter triggered the sampler to collect sample aliquots as described in the ORVTS OM&M Plan (Caltrans, 2009). The automated sampler retrieved the aliquots via a peristaltic pump and directed them through the sample tubing to the sample bottle.

3.3.2 Constituents and Analytical Methods

As shown in Table 3-1, a total of 29 constituents were selected for sampling and analysis for this study. Two constituents (pH and temperature) were measured in the field during storm monitoring due to their holding time and sample preservation constraints. Five other constituents (turbidity, conductivity, dissolved ortho-P, nitrite, and nitrate) required expedited laboratory analyses due to hold time constraints.

3.4 DATA MANAGEMENT AND REPORTING

Following storm events, the monitoring teams performed a series of tasks involving data management and reporting. Overall management of the data was consistent with established Caltrans procedures for stormwater monitoring projects. Each activity is discussed below.

3.4.1 Event Data Downloading and Summaries

For each monitoring station, rainfall, flow, and sampling data were downloaded after every storm event. Data were then summarized as described below.

- Produced event summaries and hydrographs using the Caltrans Hydrologic Utility Tool (Caltrans, 2003c).
- Checked representativeness of the sample volume and percent capture against Data Quality Objectives (DQOs), which are discussed in the ORVTS OM&M Plan (Caltrans, 2009).

3.4.2 Data Validation and Reporting

For each event, Post Storm Technical Memorandums (PSTMs) were prepared and submitted following QA/QC checks as described below.

- Performed QA/QC checks of electronic data deliverables (EDDs) received from the laboratories for input errors, and validated the data using the Caltrans Automated Data Validation Software, as described in Appendix G.

3.5 VEGETATION ASSESSMENTS

Quarterly vegetation assessments were conducted according to the following schedule: summer (July to August); fall (October to November); winter (January to February); spring (April to May) of each monitoring season.

The assessments were conducted using a typical stratified random sampling design. A transect tape was placed along the entire length of the collection pipe/channel for each biostrip test plot, and along the top of one of the swale banks for the bioswales. The tape started on the end of the pipe/channel or swale bank (depending on the orientation of the roadway), and was pulled taut and staked in place. The orientation of the tape was kept consistent regardless of the direction of flow in the pipes/channels/swales. A second tape was then placed perpendicular to the first tape and extended from the collection pipe/channel toward the end of vegetation at the roadway edge for strips, and from the top of one of the swale banks to the top of the other swale bank for swales. A flagged metal rod was placed every four meters along this second tape, as the width of each strip/swale allowed. This process with the second tape was repeated every ten meters and vegetation was estimated visually using the quarter-square-meter quadrants (0.5-meter by 0.5-meter) at each flag within each four-meter-by-ten-meter cell of the resulting grid pattern.

For each quadrant, the following characteristics were estimated visually:

- Percent vegetated cover (including detail on type of plants)
- Percent bark mulch cover
- Percent bare soil cover
- The tallest plant height and type
- Average height of all plants in the quadrant

The results of the 2009-2012 vegetation assessments are discussed in Section 4.5. Table 4-1 presents the dates of the vegetation assessments. Detailed results are presented in Appendix A.

3.6 OPERATION AND MAINTENANCE

The field teams conducted complete maintenance inspection procedures for each monitoring location before and after each storm event during the monitoring period, or at least monthly in the absence of rain. Equipment maintenance procedures included checking the performance of all equipment and power supplies, inspecting and clearing intake structures, checking rain covers, decontaminating equipment containers, and conducting instrument calibrations in accordance with manufacturer specifications.

Site maintenance procedures included the collection of trash, implementation of preventative measures to deter burrowing animals and repair of damage caused by burrowing animals when necessary, and weeding and cutting vegetation if and when roots disturbed the equipment or when required by Caltrans district personnel. No herbicides or fertilizers were applied at the sites during the Study. Site-specific maintenance requirements are presented in Appendix E of the ORVTS OM&M Plan (Caltrans, 2009).

SECTION 4 MONITORING RESULTS

4.1 SUMMARY OF DATA COLLECTION

During the 2009-2010 season, monitoring and sampling activities were conducted at all nine ORVTS sites. During the 2010-2011 season, monitoring and sampling activities were conducted at only eight ORVTS sites, excluding the San Diego site. Monitoring was completed for various site specific reasons after the 2010-2011 monitoring seasons for all remaining sites with the exception of the Camarillo, Newbury Park, and San Mateo sites. These three sites continued monitoring until December of the 2011-2012 season, which concluded all monitoring activities for this Study.

As each monitoring year progressed, sites were removed from further monitoring for various reasons. Sampling at all three stations (11-328, 11-329, and 11-330) at the San Diego site was discontinued after the first four monitored storm events of the 2009-2010 season due to substantial recurring bypass issues at both strip stations. No data for the San Diego sites was included in the analysis presented herein. One strip station (4-311) at the San Mateo site was also discontinued after the first three monitored storm events of the 2009-2010 season due to substantial recurring bypass issues. Sampling at the EOP station (4-307) at the Napa site was discontinued after the first five monitored storm events of the 2010-2011 season due to the discovery of a rubberized, gap-graded hot mix asphalt (RHMA-G) porous overlay covering the highway. The assessments and conclusions of the RHMA-G water quality comparison are included in Appendix I.

Most monitored sites performed as expected and were monitored according to the ORVTS OM&M Plan (Caltrans, 2009). Table 4-1 summarizes the monitoring activities at each station.

Table 4-1: ORVTS Monitoring Summary

Station Name	Station ID	Number of Storm Events Monitored	Number of Events with Representative Samples[(a)]	Vegetation Assessment Conducted
Sacramento EOP	3-213	22	21	NA
Sacramento 9-ft Strip	3-362	22	18	8/2009, 11/2009, 2/2010, 5/2010, 8/2010, 2/2011, 5/2011
Sacramento 25-ft Strip	3-363	22	20	8/2009, 11/2009, 2/2010, 5/2010, 8/2010, 2/2011, 5/2011
Sacramento 24-ft Strip	3-364	22	19	8/2009, 11/2009, 2/2010, 5/2010, 8/2010, 2/2011, 5/2011
Sacramento 25-ft Strip	3-365	22	18	8/2009, 11/2009, 2/2010, 5/2010, 8/2010, 2/2011, 5/2011
Yorba Linda EOP	12-225	20	20	NA
Yorba Linda 10-ft Strip	12-346	20	17	8/2009, 11/2009, 3/2010, 5/2010, 8/2010, 11/2010, 2/2011, 5/2011
Yorba Linda 21-ft Strip	12-347	20	16	8/2009, 11/2009, 3/2010, 5/2010, 8/2010, 11/2010, 2/2011, 5/2011

Table 4-1: ORVTS Monitoring Summary

Station Name	Station ID	Number of Storm Events Monitored	Number of Events with Representative Samples[(a)]	Vegetation Assessment Conducted
Yorba Linda 21-ft Strip	12-348	20	13	8/2009, 11/2009, 3/2010, 5/2010, 8/2010, 11/2010, 2/2011, 5/2011
Yorba Linda 21-ft Strip	12-349	20	12	8/2009, 11/2009, 3/2010, 5/2010, 8/2010, 11/2010, 2/2011, 5/2011
San Mateo EOP	4-310	21	21	NA
San Mateo 16-ft Strip	4-312	21	21	8/2009, 11/2009, 1/2010, 4/2010, 7/2010, 11/2010, 3/2011, 5/2011, 8/2011, 10/2011
Camarillo EOP	7-340	12	9	NA
Camarillo 9-ft Strip	7-341	12	7	11/2009, 1/2010, 5/2010, 7/2010, 11/2010, 4/2011, 7/2011, 10/2011
Camarillo 9-ft Strip	7-342	12	10	11/2009, 1/2010, 5/2010, 7/2010, 11/2010, 4/2011, 7/2011, 10/2011
Westminster EOP	12-343	20	18	NA
Westminster 15-ft Strip	12-344	20	4	8/2009, 11/2009, 3/2010, 5/2010, 8/2010, 11/2010, 2/2011, 5/2011
Westminster 15-ft Strip	12-345	20	5	8/2009, 11/2009, 3/2010, 5/2010, 8/2010, 11/2010, 2/2011, 5/2011
Newbury Park Swale Influent	7-338	12	11	NA
Newbury Park Swale Effluent	7-339	12	11	11/2009, 1/2010, 5/2010, 7/2010, 11/2010, 3/2011, 4/2011, 7/2011, 10/2011
Carlsbad (Palomar) Swale Influent	11-326	20	12	NA
Carlsbad (Palomar) Swale Effluent	11-327	20	13	8/2009, 11/2009, 3/2010, 5/2010, 8/2010, 11/2010, 2/2011, 5/2011

(a) Representative samples are those deemed as representing an entire storm event based on review of all available information (e.g., achieving minimum required aliquots and percent capture, and not issues or the resolution of any observed issues). See Sections 4.2 and 4.3.

Detailed discussions on the results from the monitoring activities are presented in the following sub-sections.

4.2 DATA REVIEW

Despite a state-of-the-art monitoring effort, a comprehensive data review was performed to reject obviously erroneous measurements and thus increase the quality of data used in the analysis. Data review was performed on a storm-by-storm and station-by-station basis. A comprehensive data review was performed on the hydrologic (flow and rainfall) data, as well as the analytical data by the responsible consultant. The data were reviewed for any issues that could make the data not representative (e.g., erroneous water level readings, equipment error during data collection, low percent capture, peak flow not captured, etc.). All available information including finalized PSTMs, field notes, photographs, and laboratory reports were used for the data review process. Based on the review, a decision was made for each monitored storm event at each

station on whether the collected hydrologic data and the corresponding analytical data were representative. Specific data review results for each monitored station are presented in the data review summary included as Appendix F.

4.2.1 Observations and Issues during Monitoring

For each monitored storm event at each station, field forms were completed to document activities and observations before, during, and after the storm. Overall, during the course of the Study, sampling operations generally went well with each station able to successfully capture multiple storm events across several monitoring seasons. Sampling equipment functioned properly and successful samples were taken. However, some operational issues occurred during the Study, some of which were recurring. In cases of substantial recurring or permanent operational issues, sampling at the affected stations was terminated as described in Section 4.1. The PSTMs (included as Appendix E) document the detailed observations and operational issues for each monitored storm event at each station. Commonly encountered issues at the project locations during the Study are listed below in Table 4-2 and are described in Appendix A.1.

Collected flow, rain, and analytical data were assessed to determine if the commonly encountered issues reflected in Appendix A.1 and Appendix F (Data Review Summary) impacted the sample representativeness of the data. All data were evaluated on a case-by-case, station-by-station, and event-by-event basis. Commonly encountered issues were grouped based on the type of issue encountered: diversion of flow, flow measurements, equipment malfunction, and sample representativeness. A summary of commonly encountered flow and water quality data issues is presented in Table 4-2.

Table 4-2: Summary of Observation and Monitoring Issues

Flow Data Issues	**Criteria**
Diversion of Flow	
Interface at the vegetation/collection pipe flashing allowed runoff to infiltrate beneath collection system, but the amount was considered to be minimal.	A
Mulch at beginning of strip absorbed runoff or promoted losses, until saturation was reached, but this was considered part of the strip treatment system.	A
Rodent burrows caused channeling within strip or at collection pipe/vegetation interface, but this was considered a typical occurrence for highway runoff.	A
Upstream drain inlet clogged causing excess flow to enter typical drainage area.	R
Gap at highway shoulder/EOP flashing interface resulted in bypassing. Sometimes most runoff from highway did not enter the strip, but in other times it was considered a typical occurrence.	A/R
Elevated gravel shoulder, vegetation, or soil caused runoff from highway to bypass the strip. Sometimes the bypass was substantial, but other times it was minimal.	A/R
Parked vehicles caused depressions that diverted flow away from the collection stations or allowed losses. Sometimes this was substantial, but other times it was minimal.	A/R

Table 4-2: Summary of Observation and Monitoring Issues (continued)

Flow Data Issues	**Criteria**
Flow Measurements	
Abundant vegetation at the entrance of swales caused ponding in the flume, but ponding was minimal.	A
The bubbler clogged.	R
Trash or large amounts of debris caused ponding of water, resulting in a significant degree of elevated flow measurements.	R
Electronic background noise reflected in flow data.	A
Flow and rainfall measurements were not synchronized. Sometimes flow data were inconsistent in comparison to rain data, but when compared to other adjacent stations, the behavior was found to be similar. In other cases the similar behavior between rainfall and flow data were not found.	A/R
Equipment Malfunction	
Flow meter did not register flow correctly or failed.	R
Low battery interrupted flow meter operation.	A
Sample inlet tubing displaced.	R
Automated sampler failed.	R
Flow meter failed and the recreation of a hydrograph could not be done based on adjacent stations, event, or historical data.	R
Flow meter did not register zero flow correctly (i.e., low bubbler pressure) during dry periods, and could not be corrected on the hydrograph.	R
Bubbler line clogged or froze.	R
Downloaded data were corrupted.	R
Water Quality Data Issues	
Sample Representativeness	
Insufficient sample volume was collected to sample all constituents.	A
Aliquots missed at the beginning of event, but minimum percent capture and number of aliquots still met.	A
No samples collected due to insufficient sample volume or automated sampler malfunction.	R
Hold time was exceeded due to incorrect shipping label.	R
Insufficient number of aliquots, sample volume, or majority of event flow was not collected for laboratory analysis.	R
Aliquots taken from flooded sample tray.	R

Notes: A = Accept data, R = Reject data, A/R = Accept or Reject data on a case-by-case basis.

4.2.1.1 Flow Data Issues

As is typical with stormwater monitoring of very small catchments, flow data issues commonly occurred during the study. These issues were associated with diversion of flow, irregularity in flow measurements, and equipment malfunction. These issues and the resolution for each are described below.

Diversion of Flow

Certain stations had significant sheet flow diversion from stations, while others had minimal to none. Figure 4-1a through 4-1d show photographs of both minimal and significant bypass. Figure 4-1e shows flow diversion during an event.

Each case of flow diversion was evaluated individually in conjunction with PSTMs, field notes, and photographs to determine the acceptability of the data for analysis. Examples of flow diversion issues evaluated on a case-by-case basis include:

- When runoff infiltrated beneath the collection system at the vegetation/collection pipe flashing, this was considered to be a minimal amount of runoff and data were accepted in all cases.
- When mulch located at the beginning of the strip absorbed runoff or promoted losses (i.e. losses due to infiltration, interception, surface storage, and evapotranspiration) until saturation was reached, this was considered part of the strip treatment system and data were accepted in all cases.
- When runoff infiltrated into the highway asphalt shoulder, the runoff was considered to be treated within the EOP and data were accepted in all cases.
- When rodent burrows caused channeling within strips or at the collection pipe/vegetation interface, these were considered a typical occurrence and data were accepted in all cases.
- When upstream drain inlets clogged, causing excess flow to enter the typical drainage area, data were rejected in all cases.
- When gaps at the highway shoulder/EOP flashing interface diverted flow, data were accepted if losses appeared to occur at the gap until saturation was reached and runoff was directed into the strip. If saturation was not reached, however, due to low flow velocity and/or rainfall intensity, and flow did not enter the strip to produce sufficient runoff volume, data were rejected.
- When the elevated gravel shoulder, vegetation, or soil caused diversion of flow from the highway, all data from the station was rejected if the diversion was excessive. The data were accepted if the diversion was limited.
- When parked vehicles caused depressions in the ground that diverted flow away from the collection station, data were accepted as this is considered an occasional occurrence within strips. All data from the stations were rejected if the depression was excessive.

Flow Measurements

Flow measurements depend on the volume of rain and flow generated during an event. Flow measurements that were considered to be in error, but that could be corrected accurately with confidence, were accepted. In certain instances, flow measurements were significantly impacted, and these data were rejected. Figure 4-1f shows sediment accumulation in a flume, which can affect the accuracy of level readings.

Each instance of inaccurately measured flow was evaluated individually in conjunction with PSTMs, field notes, and photographs to determine the acceptability of the data for analysis. Examples of inaccurate flow measurements evaluated on a case-by-case basis include:

- When elevated vegetation at the entrance of a swale caused ponding, data were corrected based on a flume calibration project. See Appendix J.

- If the bubbler clogged the data was rejected.
- When trash or large amounts of debris caused water to pond within a flume, resulting in elevated flow measurements that could not be corrected accurately, data were rejected in all cases.
- When background noise (electrical and process) caused fluctuations in recorded flow data, the data were accepted.
- When flow and rainfall measurements were not synchronized or did not appear to reflect accurately the intensity of an entire storm event, data were rejected. Sometimes, flow data were considered to be inconsistent in comparison to rain data at the beginning of a storm, but were seen to synchronize as the storm progressed. In these cases, data were accepted. If the flow and rainfall measurements, when compared against each other and to measurements from adjacent stations, were not considered to be in synchronization for more than half a storm event, however, data were rejected.

Equipment Malfunction

Prior to the start of the Study, all monitoring equipment was evaluated to help improve the performance of the equipment throughout the Study. Some equipment malfunctions had a significant impact on flow data, while other equipment malfunctions had minimal to no impact on flow data.

Each case of equipment malfunction was evaluated individually in conjunction with PSTMs, field notes, and photographs to determine the acceptability of the data for analysis. Examples of equipment malfunction issues evaluated on a case-by-case basis include:

- When a flow meter did not register flow correctly during dry periods, data were corrected on hydrographs and were accepted in all cases.
- When flow meter operation was interrupted due to a battery needing to be replaced, and causing only a minimal loss of information, data were accepted in all cases.
- When the automated sampler inlet tubing was displaced, data were rejected in all cases.
- When an automated sampler failed, data were rejected in all cases.
- When a flow meter failed, data were rejected in all cases.
- When a flow meter did not register zero flow correctly (i.e., low bubbler pressure) during dry periods, and the hydrograph could not be corrected accurately, data were rejected in all cases.
- When a bubbler line clogged or froze, data were rejected in all cases.
- When downloaded data files were corrupted, data were rejected in all cases.

4.2.1.2 Water Quality Data Issues

Water quality data issues did not commonly occur during the monitoring season and were only associated with sample representativeness of a storm event. This issue is described below.

Sample Representativeness

Automated samplers were programmed prior to each event to capture a representative volume of water from each storm. Collected samples that met the sample representativeness criteria in the ORVTS OM&M Plan were accepted, otherwise, data were rejected.

Each case of failure to meet the criteria for sample representativeness was evaluated individually in conjunction with PSTMs, field notes, and photographs to determine the acceptability of the data for analysis. Examples of sample representativeness issues evaluated on a case-by-case basis include:

- When insufficient volume was collected for laboratory analysis of all constituents, but the requisite number of aliquots was collected, data were accepted for all cases for the constituents that were able to be analyzed with the sample volume provided.
- When aliquots were missed at the beginning of an event, but the criteria for both minimum percent capture and the requisite number of aliquots were met, data were accepted for all cases.
- When no samples were collected due to insufficient sample volume or automated sampler malfunction, data were rejected in all cases.
- When hold times were exceeded due to incorrect shipping labels, data were rejected in all cases.
- When an insufficient number of aliquots, sample volume, or when the majority of event flow data were not collected for laboratory analysis, data were rejected in all cases.
- When aliquots were collected from a flooded sample tray, data were rejected in all cases.

Figure 4-1: Examples of Commonly Observed Issues

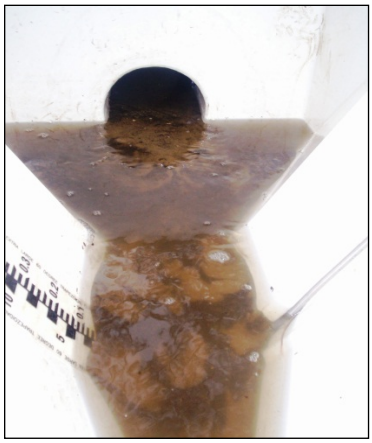
(a) Vegetation and soil elevations higher than the road caused minimal flow to bypass the strip.

(b) Flow bypassing the collection pipe at the EOP due to an excessive volume of runoff exceeding the capacity of the pipe, following the clogging of an adjacent drain.

(c) Rodent burrows caused channeling within the strip and at the collection pipe/vegetation interface, sometimes leading to bypass underneath the pipe.

(d) The highway asphalt shoulder allowed runoff to infiltrate, but this was considered treatment within the EOP.

(e) Parked vehicles caused depressions that diverted flow away from the collection stations or allowed losses. Sometimes this was significant, but other times it was minimal.



(f) Sediment from soil erosion within the strip accumulated in the flume during rain events causing temporarily inflated level readings. Sediment was cleared throughout storm events, when necessary, and impacts were minimized with a few exceptions.

4.2.2 Hydrograph Reviews

For each monitored storm event at each station, the Caltrans Hydrologic Utility was used to create hydrographs based on collected flow and rainfall data. These hydrographs show flow and rainfall information throughout a storm, as well as when the individual aliquots of each composite sample were collected. It should be noted that the drainage area for each station on these hydrographs was re-estimated multiple times during the season by field crews, and the re-estimated drainage areas may differ from those presented in the ORVTS OM&M Plan (Caltrans, 2009). The re-estimated drainage areas are presented in Table 2-2 of this report and data assessments presented in this report assume these values. Nevertheless, these re-estimated drainage areas may still deviate from the actual drainage area due to difficulties in accurately estimating drainage areas in general.

All hydrographs were reviewed to identify the possible flow data issues presented in Table 4-2. Review of these hydrographs is discussed in Section 4.2. Criteria to accept or reject data for hydrograph issues are described in Section 4.2.1.1 and in Appendix F. Finalized hydrographs are included as part of the PSTMs presented in Appendix E.

4.2.3 Water Quality Data Quality Assurance/Quality Control Results

Water quality data validation was performed in accordance with the US Environmental Protection Agency (USEPA) *National Functional Guidelines for Superfund Organic Methods Data Review* (USEPA 2008), the *National Functional Guidelines for Superfund Inorganic Methods Data Review* (USEPA 2004), and the *Guidance on the Documentation and Evaluation of Trace Metals Data Collected for Clean Water Act Compliance Monitoring* (USEPA 1995). All laboratory and field data generated under this program were reviewed for accuracy, precision, and completeness as specified in the *Caltrans Comprehensive Protocols Guidance Manual* (Caltrans, 2003b). The types of results reviewed (such as holding times, field and laboratory QA/QC sample results, etc.) to assess data quality are listed in full in Appendix G. Following the review, data points were assigned data qualifiers, as appropriate:

- U – The target analyte is not detected above the Method Detection Limit (MDL) for that analyte and all laboratory quality control criteria have been met. For example:
    - A target analyte is detected in the sample at 0.47 ug/L and the MDL is 0.53. The analytical result is reported as “less than” the MDL (< 0.53 mg/L), and assigned a “U” qualifier.
- UJ – The target analyte is not detected above the MDL for that analyte and some element of the associated laboratory quality control did not meet acceptance criteria.

  Laboratory blank contamination is a common basis for assigning “UJ” qualifiers. If the target analyte is detected in a laboratory method blank at a concentration above the Reporting Limit (RL) for that analyte, the analyte concentration in the blank is compared to the concentrations detected in all associated field samples. If the concentration in a sample is ten times or greater the concentration in the blank, no action is taken. If the concentration in a sample is less than ten times the concentration in the blank, the sample result should be reported as “less than” the concentration detected in the sample and assigned a “UJ” qualifier. Examples include:

- A target analyte is detected at 14.3 ug/L in the sample and at 1.2 ug/L in the laboratory blank, with an RL of 1.0 ug/L. The concentration in the sample is greater than 10x the concentration in the blank, so no action is taken.
- A target analyte is detected at 7.1 ug/L in the sample and at 1.2 ug/L in the laboratory blank, with an RL of 1.0 ug/L. The sample result is less than 10x the concentration in the blank, so the sample result is reported as "less than" 7.1 (<7.1 ug/L) and assigned a "UJ" qualifier.
- A target analyte is detected at 0.63 ug/L in the laboratory blank, with an RL of 1.0 ug/L and an MDL of 0.53 mg/L. Even though the concentration in the blank is above the MDL, it is below the RL, and so no action is taken.

- J – The target analyte is detected in the sample, but the associated numeric value is the approximate concentration of the analyte in the sample and may not be accurate. The data are estimated due to laboratory QA/QC not meeting acceptance criteria, signifying that a bias was present within the analytical procedures while the samples were being analyzed. Examples of when 'J' data qualifiers are applied include:
  - An analytical result is less than the RL but equal to or greater than the MDL.
  - An analytical result is greater than the MDL but the associated Laboratory Control Spike (LCS) percent recovery is 65 percent for the target analyte, and the acceptance criteria are 70-130 percent recovery for that analyte.
  - An analytical result is greater than the MDL but an associated Matrix Spike (MS) percent recovery is 65 percent for the target analyte, and the acceptance criteria are 70-130 percent recovery for that analyte.
- R – The analytical result is rejected due to serious deficiencies in the ability to analyze the sample and meet quality control criteria. The presence or absence of the analyte cannot be verified.

In general, data are qualified with a U, UJ, J, or R when any of the reviewed QA/QC parameters (such as holding times, percent recovery, relative percent difference, etc.) are exceeded, as described above and in Appendix G. For the 2009-2012 monitoring effort at the nine monitored project locations, 173 values were rejected based on QA/QC exceedances. This monitoring season resulted in 10,695 chemical measurements. Of these; 552 values (5.16%) required data qualification of U, 1193 values (11.15%) required data qualification of J, and 371 values (3.47%) required data qualification of UJ.

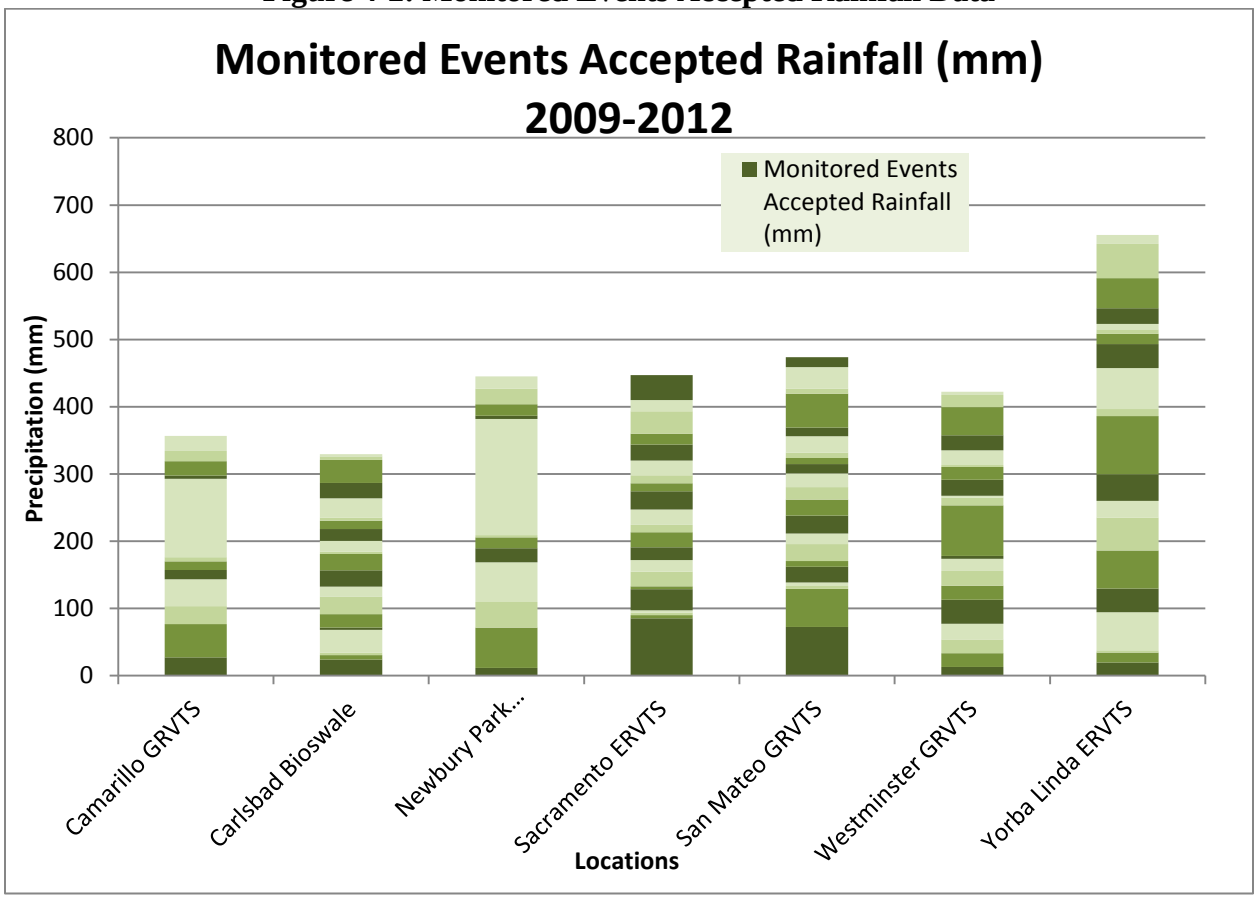
4.3 HYDROLOGY RESULTS

During the Study, the total number of sampling events ranged from 12 at Camarillo and Newbury Park, to twenty-two at Sacramento. During each monitored storm event, flow and rainfall data were recorded at one-minute intervals as discussed in Section 3.2. Discussions on the hydrology results are presented in the following sub-sections.

4.3.1 Precipitation Results

Figure 4-2 shows the total rainfall measured by rain gauges at each location for monitored storm events with accepted rain data.

Figure 4-2: Monitored Events Accepted Rainfall Data



*Different shades indicate precipitation from individual monitored events

4.3.2 Flow Data

As described in Section 4.2, flow data were collected at one-minute intervals for each monitored storm at each station using a combination of flumes and Sigma 950 flow meters. A summary of the flow and runoff data for each monitored storm is presented in Appendix C. Flow data for sampled events at each station are included in Appendix K.

4.3.3 Volumetric Runoff Coefficients

Following the hydrograph review, the volumetric runoff coefficient (R_V) was calculated for each storm event at each station with the accepted flow and rainfall data. The R_V is calculated as the recorded runoff volume during the entire storm event divided by the drainage area and divided by the rainfall depth. As described in Section 4.2.2, the re-estimated drainage areas were used for the calculations; therefore, the drainage areas and resulting R_V's may differ from those listed on the PSTM hydrographs. Two types of R_V's are presented in Table 4-3. One is a range of event R_V's and the other is a single overall estimate of the R_V (the overall R_V for a station through the seasons as determined by a linear regression of the volumetric runoff coefficients (i.e. runoff

volume divided by rainfall volume) data from all events). Various plots (runoff vs. rainfall and R_V over time) are presented in Appendix C.

Table 4-3: Summary Volumetric Runoff Coefficient

Station Description	Station ID	Ornamental Vegetation Type	Number of Data Points	Range of Volumetric Runoff Coefficient (R_V)		Overall R_V[(a)]	R^2
				Min.	Max.		
Sacramento EOP	3-213	-	16	0.86	2.41	1.59	0.90
Sacramento 9-ft Strip	3-362	*H. helix*	17	.050	0.15	0.09	0.70
Sacramento 24.5-ft Strip	3-363	*B. pilularis*	20	0.00	.05	0.02	0.39
Sacramento 23.5-ft Strip	3-364	*M. parvifolium*	18	0.00	.27	0.07	0.20
Sacramento 24.5-ft Strip	3-365	*H. helix*	18	0.00	0.11	0.03	0.31
Yorba Linda EOP	12-225	-	18	0.88	1.45	1.09	0.95
Yorba Linda 10-ft Strip	12-346	*I. hayesiana*	17	0.08	0.52	0.37	0.80
Yorba Linda 21-ft Strip	12-347	*I. hayesiana*	15	0.02	0.70	0.35	0.31
Yorba Linda 21-ft Strip	12-348	*S. mandraliscae*	13	0.00	0.13	0.06	0.44
Yorba Linda 21-ft Strip	12-349	*L. montevidensis*	12	0.01	0.17	0.12	0.65
San Mateo EOP	4-310	-	18	0.65	1.48	1.08	0.88
San Mateo 16-ft Strip	4-312	*C. edulis*	19	0.02	1.07	0.58	0.67
Camarillo EOP	7-340	-	5	1.21	1.53	1.35	0.96
Camarillo 9-ft Strip	7-341	*C. edulis*	6	0.04	0.22	0.18	0.87
Camarillo 9-ft Strip	7-342	*C. edulis*	7	0.04	0.73	0.40	0.94
Westminster EOP	12-343	-	16	0.03	0.76	0.51	0.83
Westminster 15-ft Strip	12-344	*C. edulis*	4	0.01	0.11	0.06	0.62
Westminster 15-ft Strip	12-345	*C. edulis*	3	0.03	0.10	0.05	0.63
Newbury Park Swale Influent	7-338	-	9	0.28	0.98	0.91	0.11
Newbury Park Swale Effluent	7-339	*M. parvifolium*	7	0.13	0.57	0.53	1.00

NA = Not available.

(a) The overall R_V is based on linear regression of the volumetric runoff coefficients rainfall data from all events at each station.

As shown in Table 4-3 and the associated plots in Appendix C, the overall volumetric runoff coefficients (R_V's) range from 0.00, at Sacramento and Yorba Linda strips, to 2.41 at Sacramento's EOP. The range of R_V values may be the result of variations on a station's drainage area due to site and storm event conditions, such as wind velocities, traffic, storm size, storm intensity, etc.

Sacramento I-5 ERVTS Strip

Stations: 3-213, 3-362 (*H. helix*), 3-363 (*B. pilularis*), 3-364 (*M. parvifolium*), and 3-365 (*H. helix*)

For the Sacramento location, the overall R_V for the EOP station (3-213) is 1.59, and the event R_V's range from 0.86 to 2.41 with an R^2 of 0.90. The variation of event R_V's may be caused by

flow noise. It should be noted, as described in Section 1.3, that this station was one of the original RVTS monitoring stations and has been monitored since 2000. Historical data from this station indicated that the R_V values at this station during the RVTS Study had a bigger range (0.2 to 2.1). The strip Station 3-362 has an overall R_V of 0.09, and the event R_V's range from 0.05 to 0.15 with an R^2 of 0.70. The strip Station 3-363 has an overall R_V of 0.02, and the event R_V's range from 0.00 to 0.05 with an R^2 of 0.39. The strip Station 3-364 has an overall R_V of 0.07, and the event R_V's range from 0.00 to 0.27 with an R^2 of 0.20. The strip Station 3-365 has an overall R_V of 0.03, and the event R_V's range from 0.00 to 0.11 with an R^2 of 0.31.

The large overall R_V for the EOP station 3-213 may be a result from the contribution of additional drainage area due to variations of wind, traffic, storm size, and/or storm intensity. Based on field observations, the low R_V values of all four strips are most likely due to runoff losses (i.e. losses due to infiltration, interception, surface storage, and evapotranspiration) occurring within the vegetated strip areas. The larger EOP R_V value, may impact infiltration and load reduction results when comparing to the lower R_V value of the strips.

Yorba Linda SR 91 ERVTS Strips

Stations: 12-225, 12-346 (*I. hayesiana*), 12-347 (*I. hayesiana*), 12-348 (*S. mandraliscae*), and 12-349 (*L. montevidensis*)

For the Yorba Linda location, the overall R_V for the EOP station (12-225) is 1.09, and the event R_V's range from 0.88 to 1.45 with an R^2 of 0.95. The strip Station 12-346 has an overall R_V of 0.37, and the event R_V's range from 0.08 to 0.52 with an R^2 of 0.80. The strip Station 12-347 has an overall R_V of 0.35, and the event R_V's range from 0.02 to 0.70 with an R^2 of 0.31. The strip Station 12-348 has an overall R_V is 0.06, and the event R_V's range from 0.00 to 0.13 with an R^2 of 0.44. The strip Station 12-349 has an overall R_V of 0.12, and the event R_V's range from 0.01 to 0.17 with an R^2 of 0.65.

The low average R_V at station 12-348 is possibly due to a combination of factors, such as losses within vegetated strip area and gravel shoulder.

San Mateo Hwy 380 GRVTS Strip

Stations: 4-310 (EOP) and 4-312 (*C. edulis*)

For the San Mateo location, the overall R_V for the EOP station (4-310) is 1.08, and the event R_V's range from 0.65 to 1.48 with an R^2 of 0.88. The strip Station 4-312 has an overall R_V of 0.58, and the event R_V's range from 0.02 to 1.07 with an R^2 of 0.67.

Camarillo Hwy 101 GRVTS Strip

Stations: 7-340, 7-341 (*C. edulis*), and 7-342 (*C. edulis*)

For the Camarillo location, the overall R_V for the EOP station (7-340) is 1.35, and the event R_V's range from 1.21 to 1.53 with an R^2 of 0.96. The strip Station 7-341 has an overall R_V of 0.18, and the event R_V's range from 0.04 to 0.22 with an R^2 of 0.87. The strip Station 7-342 has an overall R_V of 0.40, and the event R_V's range from 0.04 to 0.73 with an R^2 of 0.94.

Historically at this site, the strip Stations 7-341 and 7-342 have been subject to low observed volumetric runoff coefficients values during storm events. This is due to the roadway geometrics. The existing longitudinal grade of the freeway is greater than the cross slope of the mulch area which conveys flows to the 5m stations. This causes runoff to partially bypass the 5m stations

and flow downstream to the EOP station (7-340). Also, mulch was reapplied on September 20, 2011, possibly causing additional bypass issues. The lower R_V values at the strips, may impact infiltration and load reduction results when comparing to the EOP R_V value.

Westminster I-405 GRVTS Strip

Stations: 12-343, 12-344 (*C. edulis*), and 12-345 (*C. edulis*)

For the Westminster location, the overall R_V for the EOP station (12-343) is 0.51, and the event R_V's range from 0.03 to 0.76 with an R^2 of 0.83. The strip Station 12-344 has an overall R_V of 0.06, and the event R_V's range from 0.01 to 0.11 with an R^2 of 0.62. The strip Station 12-345 has an overall R_V of 0.05, and the event R_V's range from 0.03 to 0.10 with an R^2 of 0.63. Based on field observations, the overall R_V for the EOP station appears to be low, possibly due to the drainage area being lower than estimated and/or minor runoff entering the drainage area of this station for some of the storm events. For both strip stations, the overall R_V values are also low, mostly due to losses beneath the collection pipe.

Newbury Park Hwy 101 GRVTS Swale

Stations: 7-338 and 7-339 (*M. parvifolium*)

For the Newbury Park location, the overall R_V for the swale influent station is 0.91, and the event R_V's range from 0.28 to 0.98 with an R^2 of 0.11. Based on information collected during the season, possible causes of the high R_V include the estimated drainage area being higher than the actual drainage area, and ponding in the influent flume due to the presence of an existing earthen weir downstream of the flume. Various attempts were made to correct the flow data for ponding over the course of the study. Several analytical adjustments were developed and subsequently withdrawn due to each method's inability to accurately adjust the results generated by the ponded condition. Finally, on September 20, 2011 field crews conducted a Flume Calibration Test during which water was discharged into the Influent flume at various uniform rates and respective depth measurements were taken. These data points were then plotted and a best fit equation was applied, generating a polynomial equation which was then used to adjust all flow data throughout the Study. A complete discussion of this process is included in the *Ornamental Roadside Vegetated Treatment Sites (ORVTS) Study; Controlled Flow Versus Head Flume Calibration Test Technical Memorandum* (CTSW-TM-12-290.02.1). The overall RV for the swale effluent station is 0.53. The event R_V's range from 0.13 to 0.57, with an R^2 of 1.00. The reduction of runoff at this station is mostly due to losses occurring within the swale.

4.4 WATER QUALITY DATA

As shown in Table 4-1, during the Study, a total of eight to twenty-two storm events were monitored at the various monitoring locations. For some storms, no representative samples were generated for laboratory analysis. Detailed analytical results are presented in Appendix H.

For each monitored station, validated analytical results were compiled for statistical analysis based on results from the data review process. Summary statistics were generated using the Caltrans Data Analysis Tool (DAT). Detailed results of the DAT runs are presented in Appendix G. The summary statistics include the number of data points (n), percent detection, range of values, mean, median, and standard deviation.

4.5 VEGETATION ASSESSMENT

Quarterly vegetation assessments were conducted for all strips and swales during the study. A standard procedure was used for each assessment as described in the ORVTS OM&M Plan (Caltrans, 2009). Vegetation was estimated visually using a quarter-square-meter quadrant for percent vegetated cover specific to vegetation type, percent bark mulch cover, percent bare soil cover, tallest plant height and type, and the average height of all plants within the quadrant. Table 4-1 presents the dates of the vegetation assessments. Detailed results are presented in Appendix A. The impact on concentration, losses (i.e. losses due to infiltration, interception, surface storage, and evapotranspiration), and load due to various ornamental vegetation types is further discussed in Section 5.

Overall, during the course of this study, the vegetation coverage at the sites was considered generally good, as most sites provided over 70% vegetative cover. However, at the Yorba Linda site, vegetation at stations 12-346 and 12-349 was observed to be consistently low, less or equal to 50% vegetative cover. The reason for low coverage at these stations, based on the vegetation assessments and observations at these sites, was due to an irrigation system that did not function as intended. Attempts were made to develop higher vegetation coverage but coverage remained at less or equal to 50%.

It should be noted that statistical analyses results do not suggest that percent of vegetative coverage effected treatment performance provided by ornamental vegetation in this Study. For example, in comparing Yorba Linda's test stations to its corresponding EOP station, the site's station with the lowest observed vegetation (station 12-346 at less than 50% coverage) provided statistical decreases for a greater number of constituent concentrations than the adjacent test stations. See Appendix H for analysis results.

SECTION 5 DATA ASSESSMENTS AND FINDINGS

5.1 ANALYSES PHASING

In order to adequately analyze each contributing factor of reduction of constituent concentration, runoff volume, and constituent loading on an isolated basis, a tiered analysis structure was developed. The desired correlations were derived from the Study's objectives (Section 1) and placed into respective phases of analysis, with Phase I – Primary Analysis being the first to be analyzed, followed by Phase II – Secondary Analysis.

Phase I – Primary Analyses

1. **Grouped Swales and Strips vs. Grouped Controls**
    a. Grouped Strips vs. Grouped Controls
        i. Constituent Concentration
        ii. Runoff Volume
        iii. Constituent Loading
    b. Grouped Swales vs. Grouped Controls
        i. Constituent Concentration
        ii. Runoff Volume
        iii. Constituent Loading

Phase II – Secondary Analyses

1. **Vegetation Type**[1]
    a. Grouped Succulents vs. Grouped Control
        i. Constituent Concentration
        ii. Runoff Volume
        iii. Constituent Loading
    b. Grouped Groundcovers vs. Grouped Control
        i. Constituent Concentration
        ii. Runoff Volume
        iii. Constituent Loading
    c. Grouped Low Shrubs vs. Grouped Control
        i. Constituent Concentration
        ii. Runoff Volume
        iii. Constituent Loading
2. **Strip Width**
    a. Grouped Short Strips (≤10ft) vs. Grouped Control
        i. Constituent Concentration
        ii. Runoff Volume

[1] Succulents: 12-348, 4-312, 7-341, 7-342, 12-344, 12-345, 11-327; Ground covers: 3-362, 3-364, 3-365, 7-339; Low shrubs: 3-363, 12-346, 12-347, 12-349.

iii. Constituent Loading

b. Grouped Long Strips (>10ft) vs. Grouped Control

i. Constituent Concentration

ii. Runoff Volume

iii. Constituent Loading

Phase I – Primary Analysis is centered on overall grouped test stations compared to overall grouped control station (EOP) results. This Phase does not take into account specific factors such as treatment BMP size, vegetation type, etc. This Phase was conducted to assess state-wide BMP performance, regardless of location, vegetation type, or width. It is comprised of two analyses, each of which addresses reduction of constituent concentration, runoff volume, and constituent loading.

(a) Grouped Strips vs. Grouped Controls – This analysis was designed to determine the impact of this ORVTS treatment BMP type on constituent concentration, runoff volume and constituent loading.

(b) Grouped Swales vs. Grouped Controls – This analysis was designed to determine the impact of this ORVTS treatment BMP type on constituent concentration, runoff volume and constituent loading.

Phase II – Secondary Analysis is based on a more specialized group of factors impacting constituent concentration, runoff volume and constituent loading. It consists of two analyses, both of which are comprised of multiple sub-analyses that address the characteristics of each ORVTS Treatment BMP type. Similar to Phase I, each Phase II analysis will address reduction of constituent concentration, runoff volume and constituent loading.

(a) Vegetation Type – This analysis compared the treatment qualities of each vegetation type tested throughout the Study by grouping each species into one of three overall groups: Groundcovers, Succulents or Low Shrubs. Each of these groups were then compared to the grouped results of its respective control stations.

(b) Strip Width – This analysis compares the treatment qualities of various strip widths by grouping each strip station into one of two overall groups and then comparing the two. Stations were considered to either have Long Strips (>10 ft) or Short Strips (≤10 ft). Each of these two groups was then compared to the grouped results of its respective control stations.

See Appendix L for Table 1-2 highlights of corresponding stations included in statistical analyses groupings per BMP classification and vegetation type.

5.2 DATA ASSESSMENT METHODOLOGY

For this Study, there were twenty nine (29) constituents monitored, out of which only twenty six (26) were analyzed. Temperature, pH and conductivity were excluded from statistical analysis. The measured runoff volume for each storm event was normalized by drainage area for comparison purposes and the normalized load of a water quality constituent was derived for each

storm event, per ***Equation 1***. Normalized loads were calculated based on the volume, drainage area and concentration for each site specific sample.

Equation 1:

$$Load_{i,n} = \frac{\mathrm{Vol_n}}{\mathrm{DA}} \ \mathbf{x} \ C_{i,n}$$

Where:

- $\mathrm{Load}_{i,n}$ is the normalized load of constituent i during storm event n
- Vol_n is the recorded runoff volume at the monitored station during storm event n
- DA is the drainage area of the monitored reference or test station
- $C_{i,n}$ is the event mean concentration of constituent i during storm event n

Statistical tests were performed using the statistical software Minitab® 16. Event Mean Concentrations (EMC) derived from composite samples for each of the 26 constituents were identified during the data sorting process. When multiple discrete samples were taken over the duration of a single storm event, a flow-weighted average concentration was considered as the equivalent EMC. These EMCs were later used to calculate the concentration reductions. Load reduction estimates were conducted on 25 of the 29 constituents, as turbidity, temperature, pH and conductivity were not included in the analysis.

ORVTS Statistical Methodology

The ORVTS monitoring data for concentration, normalized runoff volume, and normalized load was analyzed and statistical comparisons were performed between groups of different characteristics to address the different study questions. This section summarizes the methodologies of the statistical analyses performed in Phase I – Primary Analyses and Phase II – Secondary Analyses, respectively.

A significance level (alpha) of 0.10 was used to perform statistical testing, which is consistent with the value recommended in the BMP Pilot Study Guidance Manual (CTSW-RT-06-171.02.1). The significance level corresponds to the probability of falsely rejecting the null hypothesis. Statistical tests assume that the compared datasets have populations that are not significantly different in concentration, normalized runoff, or normalized load. A p-value resulting from a statistical test that is lower than 0.10 would reject the null hypothesis, and thus the observed difference would be considered statistically significant.

For each comparison, an Analysis of Variance (ANOVA) or the equivalent non-parametric test (Kruskal-Wallis) served as the primary statistical test since multiple populations were compared. Assumptions were tested prior to performing the primary statistical test. The results from assumption testing helped indicate what statistical test and post-hoc testing would provide the most powerful statistics. ANOVA's assumptions include:

- Normality of residuals: the normality of residuals was evaluated based on the results of an Anderson-Darling test over the residuals of compared samples. Graphical distributions

were considered when determining the normality of residual distributions. Where the normality of residuals was not established from the original samples, stabilizing transformations such as natural logarithmic transformations were also considered.

- Homoscedasticity or common variance among compared samples: F-test or Levene's test were performed over the compared populations. Equal variance was established upon non-rejection of the assumption that variances of the compared distributions are equal. Non-rejection occurs when individual p-values are greater or equal to 0.10 and test F-values are lower than the associated critical F. Outliers were not identified nor removed from the samples because of the small number of samples, thus increasing the estimate for sample variance.
- Independence: The samples were taken independently at separate stations and different storm events.

Results from the ANOVA were subsequently analyzed with appropriate post-hoc testing, which identified amongst the compared groups those individual stations that returned significantly different results than others. The overall approaches selected to perform the statistical comparisons.

The compared test and control samples were relatively of unequal sizes, hence statistical tests for unpaired distributions applied. Non-parametric tests do not return powerful results from a statistical standpoint if the hypothesis of equal sample sizes is not met, therefore non-parametric tests were not considered for grouped comparisons. For each comparison, the selection of the most powerful statistical test was determined based on two factors: the scedasticity and the ratio between sample sizes of grouped test and grouped control distributions.

- When comparing two grouped test and control distributions of equal variances, or two grouped test and control distributions of unequal variances but exhibiting sample sizes that are not different by more than a factor of 2, an ANOVA along with a Tukey-Kramer's post-hoc testing were performed to determine the statistical significance, if any, of the difference. A family error rate or type I error of 0.10 was used for post-hoc testing.
- When comparing two grouped test and control distributions of unequal variances and whose sample sizes differ by more than a factor of 2, an ANOVA along with a Dunnett's post-hoc testing were performed to determine the statistical significance, if any, of the difference. A family error rate or type I error of 0.10 was used for post-hoc testing.

Statistical results reported in Section 5.4, Section 5.5, or Section 5.6 highlight the expected concentration, normalized volume, or normalized load that is the most relevant from a statistical standpoint for each distribution, respectively. The expected concentration, normalized volume, or normalized load will either be an arithmetic mean, a geometric mean, or a median depending on the most powerful statistical test performed over the compared test and control distributions. The arithmetic mean is reported for those comparisons for which an ANOVA was performed on natural distributions, i.e. for distributions exhibiting a normality of residuals and equal variances. A geometric mean is reported for those comparisons for which the ANOVA was performed on log-normal distributions, i.e. for log-transformed distributions exhibiting a normality of residuals. One may note that the arithmetic mean of a log-transformed distribution will be identified as a geometric mean, when back-transformed to the natural scale. A median is reported for those comparisons for which a non-parametric Kruskal-Wallis test was performed on natural

distributions, i.e. for natural distributions exhibiting a nonnormality of residuals and an inequality of variances. The statistical results derived in this ORVTS study may be used in the future. In this instance, the usage of statistical means should be limited to those reported in this Section.

5.3 OUTSTANDING DATA AND POTENTIAL EFFECTS

The ORVTS Study collected data for the 2009-2010, 2010-2011, and the 2011-2012 monitoring seasons. For the 2011-2012 monitoring season, monitoring continued at the Newbury Park, Camarillo and San Mateo sites until December of 2011. However, data for this partial 2011-2012 monitoring season were not incorporated into the statistical analysis comparisons that were conducted.

Data regarding events where the EOP registered flow but the test strips or swale stations did not (due to complete losses within the BMP), were included in the statistical comparisons for the EOP data set, but were not included for the corresponding strip or swale data set as zero or undetected flow. It should be noted that inclusion of these additional data points may affect the statistical results causing some of the reductions and/or increases in concentrations, volume and runoff to be statistically significant where they currently may not be exhibited as such. Specific effects for each comparison are discussed below.

5.4 CONCENTRATION ASSESSMENTS

To assess the water quality changes between the EOP and the vegetation strips and swales, event mean concentrations (EMC) were compared to determine whether a reduction or increase between concentration levels was exhibited.

Tables providing summary statistics (number of data points, arithmetic mean, percent change from the EOP, range, and standard deviation) of the data sets are provided in the subsections below. The summaries highlighted in grey, green, or red are either normally distributed or log-normally distributed based on the distribution tests as described in Section 5.2. Statistical summaries highlighted in green exhibit statistically significant decreases in concentration from EOP data, in red exhibit statistically significant increases in concentration from EOP data, and in grey exhibit no statistical change. A summary with no color coding means the data set is from the EOP. The output from the Minitab® ANOVA analyses is included in Appendix H.

For the following statistical summary tables, the following legend of coloring shall apply to all tables:

Standard Table Legend:

Red = Statistically significant increase at a 90-percent confidence level

Green = Statistically significant reduction at a 90-percent confidence level

Gray = Results not statistically significant at a 90-percent confidence level

White = EOP Station data

5.4.1 Phase I – Primary Analysis

5.4.1.1 Grouped Strips

The results presented below for grouped strips should be considered conservative. Although a portion of the available data was omitted from the statistical analyses presented below (see Section 5.3), the majority of the data were from complete infiltration events. Assigning the runoff volumes and resulting loads a value of zero (or even half of the reporting limit for concentration) would increase the already observed percent reductions or decrease the percent increases.

Conventional Constituents

Statistically significant increases in concentrations were observed for all conventional constituents analyzed. See Table 5-1 below.

Table 5-1: Grouped Strips – Statistical Analysis of Conventionals Concentrations

Grouped Strips Concentration		
Constituent	**Control (Grouped Strips)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Test (Grouped Strips)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
DOC (mg/L)	82 - 4.7 0% 1.1 - 36.0 N/A	163 - 10.5 -125% 1.6 - 73.1 N/A
Hardness as $CaCO_3$ (mg/L)	84 36 - 0% 10 - 100 15	167 63 - -75% 12 - 388 52
TOC (mg/L)	83 - 6.5 0% 1.6 - 45.5 N/A	167 - 14.5 -124% 1.9 - 370.0 N/A

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

Sediments

A statistically significant increase in sediment concentration was observed for TDS. No statistically significant changes were observed for TSS and turbidity. See Table 5-2 below.

Table 5-2: Grouped Strips – Statistical Analysis of Sediments Concentrations

Grouped Strips Concentration		
Constituent	**Control (Grouped Strips)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Test (Grouped Strips)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
TDS (mg/L)	85 45.1 - 0% 0.2 - 154.0 27.7	169 98.0 - -117% 0.2 - 500.0 82.2
TSS (mg/L)	85 56 - 0% 6 - 238 42	171 62 - -10% 1 - 426 81
Turbidity (NTU)	72 37.8 - 0% 7.6 - 113.0 22.3	162 43.3 - -15% 0.1 - 641.0 62.5

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

Nutrients

A statistically significant reduction in concentration was observed for nitrite. Statistically significant increases in concentration were observed for nitrate, ortho-p, and total phosphorous. No statistically significant changes in concentration were observed for ammonia, nitrate, and TKN. See Table 5-3 below.

Table 5-3: Grouped Strips – Statistical Analysis of Nutrients Concentrations

Grouped Strips Concentration		
Constituent	**Control (Grouped Strips)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Test (Grouped Strips)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
Ammonia NH_3-N (mg/L)	84 0.379 - 0% 0.005 - 1.530 0.272	168 0.515 - -36% 0.005 - 8.640 0.971
Nitrite NO_2-N (mg/L)	71 0.050 - 0% 0.010 - 0.230 0.038	161 0.036 - 29% 0.004 - 0.730 0.062
Nitrate NO_3-N (mg/L)	72 0.494 - 0% 0.100 - 2.220 0.429	162 0.785 - -59% 0.005 - 15.800 1.610
Ortho-P, diss (mg/L)	68 0.051 - 0% 0.003 - 0.240 0.044	157 0.465 - -812% 0.003 - 5.270 0.648
Total Phosphorus (mg/L)	85 - 0.131 0% 0.008 - 1.220 N/A	168 - 0.434 -230% 0.030 - 5.400 N/A
TKN (mg/L)	85 1.57 - 0% 0.23 - 10.20 1.52	169 4.59 - -192% 0.10 - 284.00 21.82

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

Metals

Statistically significant decreases in concentrations were observed for dissolved and total chromium, dissolved and total copper, dissolved and total zinc, and total lead. Statistically significant increases in concentration were observed for dissolved and total arsenic. No statistically significant changes in concentrations were observed for dissolved and total cadmium, dissolved and total nickel, and dissolved lead. See Table 5-4 below.

Table 5-4: Grouped Strips –
Statistical Analysis of Metal Concentrations

Grouped Strips Concentration		
Constituent	**Control (Grouped Strips)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Test (Grouped Strips)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
Dissolved Metals		
As, diss (ug/L)	85 - 0.53 0% 0.16 - 2.80 N/A	171 - 1.44 -173% 0.20 - 10.00 N/A
Cd, diss (ug/L)	85 0.12 - 0% 0.02 - 0.50 0.08	171 0.16 - -34% 0.01 - 3.00 0.29
Cr, diss (ug/L)	85 2.7 - 0% 0.5 - 14.0 2.3	171 1.4 - 48% 0.2 - 8.0 1.3
Cu, diss (ug/L)	85 15.10 - 0% 2.90 - 64.00 13.16	171 10.13 - 33% 2.70 - 120.00 10.07
Ni, diss (ug/L)	85 1.9 - 0% 0.4 - 12.0 2.0	171 1.7 - 10% 0.2 - 7.1 1.2
Pb, diss (ug/L)	85 0.43 - 0% 0.07 - 4.80 0.75	171 0.43 - -2% 0.08 - 8.60 0.89

Grouped Strips Concentration		
Constituent	**Control (Grouped Strips)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Test (Grouped Strips)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
Zn, diss (ug/L)	85 55.9 - 0% 2.8 - 1100.0 134.6	171 14.6 - 74% 3.0 - 73.0 10.9
Total Metals		
As, total (ug/L)	85 - 1.1 0% 0.4 - 6.9 N/A	171 - 2.3 -106% 0.3 - 12.0 N/A
Cd, total (ug/L)	85 0.5 - 0% 0.1 - 6.1 0.7	171 0.7 - -37% 0.1 - 52.0 4.0
Cr, total (ug/L)	85 8.7 - 0% 2.4 - 34.0 5.1	171 6.2 - 28% 0.5 - 36.0 6.4
Cu, total (ug/L)	85 50.1 - 0% 9.6 - 160.0 26.3	171 20.3 - 59% 5.6 - 170.0 16.9
Ni, total (ug/L)	85 7.4 - 0% 1.6 - 33.0 4.9	171 6.3 - 14% 0.6 - 35.0 6.0
Pb, total (ug/L)	85 16.4 - 0% 1.9 - 93.0 13.0	171 10.9 - 33% 0.2 - 240.0 27.9
Zn, total (ug/L)	85 245.0 - 0% 23.0 - 5700.0 611.1	171 49.6 - 80% 7.4 - 470.0 55.6

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

5.4.1.2 Grouped Swales

The results presented below for grouped swales should be considered conservative. Although a portion of the available data was omitted from the statistical analyses presented below (see Section 5.3), comparisons indicate that had all data been included, there would be no substantial change in the results for constituents already showing a statistically significant difference between the EOP and swale effluent. For three of the four constituents currently having a lack of a statistically significant difference (phosphorous, TDS, and turbidity) the concentrations of the omitted data were comparable to the existing dataset, and their inclusion would likely increase the confidence of the currently observed results. It is unknown however, if these additional data points would be enough to shift the results from a lack of statistical significance to a confirmation of one. For dissolved cadmium, which also had a lack of a statistically significant difference, the omitted data showed a concentration increase between the EOP and swale effluent, and this is contrary to the current dataset which showed a concentration decrease. However, this difference could be a result of the data being reported below the Reporting Limit (down to the Method Detection Limit). Data below the Reporting Limit is considered an estimate and no definitive conclusion should be made based on such data.

Conventional Constituents

No statistically significant changes were observed in conventional constituent concentrations for all constituents analyzed. See Table 5-5 below.

Table 5-5: Grouped Swales –
Statistical Analysis of Conventionals Concentrations

Grouped Swales Concentration		
Constituent	**Control (Grouped Swales)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Test (Grouped Swales)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
DOC (mg/L)	26 - 5.41 0% 1.00 - 19.50 N/A	20 - 6.01 -11% 2.00 - 23.50 N/A
Hardness as $CaCO_3$ (mg/L)	26 - 35.21 0% 18.00 - 74.00 N/A	20 - 39.50 -12% 20.00 - 94.00 N/A
TOC (mg/L)	26 9.66 - 0% 3.00 - 26.90 6.92	20 10.78 - -12% 3.00 - 52.30 11.23

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

Sediments

A statistically significant reduction in TSS was observed. No statistically significant changes were observed for TDS and turbidity. See Table 5-6 below.

Table 5-6: Grouped Swales – Statistical Analysis of Conventionals Concentrations

Grouped Swales Concentration		
Constituent	**Control (Grouped Swales)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Test (Grouped Swales)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
TDS (mg/L)	27 - 47.01 0% 14.00 - 192.00 N/A	20 - 58.38 -24% 18.00 - 300.00 N/A
TSS (mg/L)	27 - 29.17 0% 1.00 - 215.00 N/A	21 - 7.68 74% 1.00 - 39.00 N/A
Turbidity (NTU)	9 20.67 - 0% 8.80 - 44.80 10.57	7 16.98 - 18% 7.58 - 29.50 9.26

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

Nutrients

Statistically significant decreases in concentration were observed for ammonia and TKN. Statistically significant increases in concentration were observed for ortho-p. No statistically significant changes in concentration were observed for nitrite, nitrate, and total phosphorous. See Table 5-7 below.

Table 5-7: Grouped Swales – Statistical Analysis of Nutrients Concentrations

Grouped Swales Concentration		
Constituent	**Control (Grouped Swales)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Test (Grouped Swales)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
Ammonia NH_3-N (mg/L)	26 0.345 - 0% 0.040 - 1.170 0.252	20 0.094 - 73% 0.005 - 0.480 0.121
Nitrite NO_2-N (mg/L)	9 - 0.04 0% 0.01 - 0.15 N/A	7 - 0.03 42% 0.01 - 0.15 N/A
Nitrate NO_3-N (mg/L)	9 - 0.31 0% 0.10 - 1.13 N/A	7 - 0.19 38% 0.04 - 1.50 N/A
Ortho-P, diss (mg/L)	9 0.05 - 0% 0.02 - 0.07 0.02	7 0.13 - -153% 0.07 - 0.18 0.05
Total Phosphorus (mg/L)	26 0.194 - 0% 0.008 - 1.120 0.218	20 0.250 - -29% 0.100 - 0.930 0.185
TKN (mg/L)	26 - 1.09 0% 0.17 - 7.55 N/A	20 - 0.66 39% 0.17 - 2.31 N/A

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

Metals

Statistically significant decreases in concentration were observed for dissolved chromium, nickel, copper, lead, and zinc. No statistically significant changes in concentration were observed for dissolved arsenic and dissolved cadmium. Statistically significant decreases were observed for total arsenic, cadmium, chromium, copper, nickel, lead, and zinc. See Table 5-8 below.

Table 5-8: Grouped Swales – Statistical Analysis of Metals Concentrations

Grouped Swales Concentration		
Constituent	Control (Grouped Swales) N Arith. Mean Geom. Mean % Δ btwn Means[1] Range[2] Std. Dev.	Test (Grouped Swales) N Arith. Mean Geom. Mean % Δ btwn Means[1] Range[2] Std. Dev.
Dissolved Metals		
As, diss (ug/L)	27 - 0.587 0.00% 0.200 - 1.400 N/A	21 - 0.588 -0.03% 0.200 - 1.300 N/A
Cd, diss (ug/L)	27 0.14 - 0% 0.10 - 0.60 0.11	21 0.12 - 13% 0.10 - 0.30 0.06
Cr, diss (ug/L)	27 - 3.90 0% 0.90 - 12.00 N/A	21 - 2.77 29% 0.80 - 8.50 N/A
Cu, diss (ug/L)	27 - 12.34 0% 4.10 - 44.00 N/A	21 - 7.06 43% 2.60 - 19.00 N/A
Ni, diss (ug/L)	27 2.44 - 0% 0.80 - 8.10 1.92	21 1.12 - 54% 0.50 - 2.70 0.58
Pb, diss (ug/L)	27 0.36 - 0% 0.08 - 1.10 0.30	21 0.23 - 35% 0.08 - 0.60 0.17
Zn, diss (ug/L)	27 - 30.79 0% 12.00 - 99.00 N/A	21 - 12.79 58% 4.90 - 34.00 N/A

Grouped Swales Concentration		
Constituent	**Control (Grouped Swales)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Test (Grouped Swales)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
Total Metals		
As, total (ug/L)	27 - 1.18 0% 0.50 - 3.00 N/A	21 - 0.77 35% 0.30 - 1.90 N/A
Cd, total (ug/L)	27 0.45 - 0% 0.10 - 2.20 0.45	21 0.17 - 62% 0.10 - 0.40 0.08
Cr, total (ug/L)	27 - 8.06 0% 1.99 - 34.00 N/A	21 - 4.82 40% 2.00 - 10.00 N/A
Cu, total (ug/L)	27 - 39.47 0% 7.20 - 240.00 N/A	21 - 11.80 70% 5.70 - 30.00 N/A
Ni, total (ug/L)	27 - 5.35 0% 1.40 - 25.00 N/A	21 - 1.97 63% 0.80 - 6.60 N/A
Pb, total (ug/L)	27 - 12.03 0% 1.60 - 180.00 N/A	21 - 2.87 76% 0.80 - 25.00 N/A
Zn, total (ug/L)	27 - 123.29 0% 17.00 - 1200.00 N/A	21 - 29.32 76% 12.00 - 98.00 N/A

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

5.4.2 Phase II – Secondary Analysis

5.4.2.1 Grouped Succulents

The results presented below for grouped succulents should be considered conservative. Although a portion of the available data was omitted from the statistical analyses presented below (see Section 5.3), the majority of the data were from complete losses (i.e. losses due to infiltration, interception, surface storage, and evapotranspiration). Assigning the runoff volumes and resulting loads a value of zero (or even half of the reporting limit for concentration) would increase the already observed percent reductions or decrease the percent increases.

Conventional Constituents

Statistically significant increases in concentrations were observed for all conventional constituents analyzed. See Table 5-9 below.

Table 5-9: Grouped Succulents – Statistical Analysis of Conventionals Concentrations

Grouped Succulents Concentration		
Constituent	**Control (Grouped Succulents)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Test (Grouped Succulents)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
DOC (mg/L)	80 - 5.12 0% 1.0 - 36.0 N/A	61 - 7.02 -37% 1.8 - 37.0 N/A
Hardness as $CaCO_3$ (mg/L)	81 35.2 - 0% 10.0 - 100.0 15.2	61 53.2 - -51% 16.0 - 274.0 43.2
TOC (mg/L)	80 - 7.1 0% 1.6 - 45.5 N/A	61 - 9.6 -34% 2.7 - 53.0 N/A

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

Sediments

A statistically significant increase in concentration was observed for TDS. No statistically significant changes were observed for TSS and Turbidity. See Table 5-10 below.

Table 5-10: Grouped Succulents – Statistical Analysis of Sediments Concentrations

Grouped Succulents Concentration		
Constituent	**Control (Grouped Succulents)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Test (Grouped Succulents)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
TDS (mg/L)	83 47.8 - 0% 0.2 - 192.0 34.0	62 96.3 - -102% 0.2 - 500.0 82.9
TSS (mg/L)	83 49.0 - 0% 1.0 - 215.0 38.0	63 53.5 - -9% 1.0 - 380.0 70.7
Turbidity (NTU)	57 - 27.69 0% 7.6 - 80.3 N/A	52 - 30.97 -12% 5.2 - 160.0 N/A

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

Nutrients

Statistically significant decreases in concentrations were observed for ammonia and nitrite. Statistically significant increases were observed for ortho-p and total phosphorus. No statistically significant changes in concentrations were observed for nitrate and TKN. See Table 5-11 below.

Table 5-11: Grouped Succulents – Statistical Analysis of Nutrients Concentrations

Grouped Succulents Concentration		
Constituent	**Control (Grouped Succulents)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Test (Grouped Succulents)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
Ammonia NH_3-N (mg/L)	81 0.361 - 0% 0.005 - 1.530 0.274	62 0.204 - 44% 0.005 - 3.800 0.488
Nitrite NO_2-N (mg/L)	56 0.049 - 0% 0.010 - 0.230 0.040	52 0.027 - 44% 0.004 - 0.090 0.022
Nitrate NO_3-N (mg/L)	57 - 0.35 0% 0.10 - 2.22 N/A	52 - 0.33 8% 0.03 - 4.33 N/A
Ortho-P, diss (mg/L)	53 0.036 - 0% 0.003 - 0.160 0.030	47 0.352 - -873% 0.014 - 4.070 0.587
Total Phosphorus (mg/L)	82 - 0.11 0% 0.008 - 1.120 N/A	61 - 0.30 -170% 0.070 - 1.000 N/A
TKN (mg/L)	82 1.55 - 0% 0.23 - 10.20 1.58	62 1.68 - -9% 0.10 - 16.00 2.16

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

Metals

Statistically significant decreases in concentrations were observed for dissolved and total chromium, dissolved and total copper, dissolved and total nickel, and dissolved and total zinc. Statistically significant increases in concentrations were observed for dissolved and total arsenic, and dissolved lead. No statistically significant changes in concentrations were observed for dissolved and total cadmium, and total lead. See Table 5-12 below.

Table 5-12: Grouped Succulents – Statistical Analysis of Metals Concentrations

Grouped Succulents Concentration		
Constituent	Control (Grouped Succulents) N Arith. Mean Geom. Mean % Δ btwn Means[1] Range[2] Std. Dev.	Test (Grouped Succulents) N Arith. Mean Geom. Mean % Δ btwn Means[1] Range[2] Std. Dev.
Dissolved Metals		
As, diss (ug/L)	83 0.47 - 0% 0.16 - 1.40 0.24	63 1.06 - -124% 0.20 - 3.80 0.84
Cd, diss (ug/L)	83 0.13 - 0% 0.02 - 0.60 0.10	63 0.16 - -23% 0.01 - 3.00 0.37
Cr, diss (ug/L)	83 3.82 - 0% 0.8 - 14.0 2.84	63 2.84 - 26% 0.5 - 8.5 2.11
Cu, diss (ug/L)	83 16.7 - 0% 2.9 - 64.0 13.4	63 9.0 - 46% 2.9 - 32.0 5.1
Ni, diss (ug/L)	83 2.3 - 0% 0.4 - 12.0 2.2	63 1.4 - 36% 0.4 - 4.7 1.0
Pb, diss (ug/L)	83 0.47 - 0% 0.08 - 4.80 0.69	63 0.78 - -67% 0.10 - 8.60 1.35

Grouped Succulents Concentration		
Constituent	**Control (Grouped Succulents)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Test (Grouped Succulents)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
Zn, diss (ug/L)	83 64.9 - 0% 2.8 - 1100.0 134.6	63 12.8 - 80% 3.0 - 68.0 9.6
Total Metals		
As, total (ug/L)	83 - 0.94 0% 0.4 - 3.0 N/A	63 - 1.42 -52% 0.3 - 4.6 N/A
Cd, total (ug/L)	83 0.40 - 0% 0.1 - 2.2 0.32	63 0.32 - 21% 0.1 - 4.9 0.63
Cr, total (ug/L)	83 - 7.5 0% 2.4 - 34.0 N/A	63 - 5.6 25% 0.9 - 36.0 N/A
Cu, total (ug/L)	83 - 47.7 0% 7.2 - 240.0 N/A	63 - 17.5 63% 5.7 - 82.0 N/A
Ni, total (ug/L)	83 - 5.6 0% 1.4 - 25.0 N/A	63 - 4.2 26% 0.8 - 35.0 N/A
Pb, total (ug/L)	83 23.2 - 0% 2.0 - 180.0 25.9	63 22.5 - 3% 0.7 - 240.0 43.0
Zn, total (ug/L)	83 266.60 - 0% 17.0 - 5700.0 629.2	63 54.00 - 80% 12.0 - 370.0 58.5

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

5.4.2.2 Grouped Groundcovers

The results presented below for grouped groundcovers should be considered conservative. Although a portion of the available data was omitted from the statistical analyses presented below (see Section 5.3), the majority of the data were from complete losses. Assigning the runoff volumes and resulting loads a value of zero (or even half of the reporting limit for concentration) would increase the already observed percent reductions or decrease the percent increases.

Conventional Constituents

Statistically significant increases in concentrations were observed for all conventional constituents analyzed. See Table 5-13 below.

Table 5-13: Grouped Groundcovers – Statistical Analysis of Conventionals Concentrations

Grouped Groundcover Concentration		
Constituent	**Associated EOP Control** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Groundcover** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
DOC (mg/L)	28 - 4.179 0% 2.09 - 14.20 N/A	59 - 13.192 -216% 2.00 - 73.10 N/A
Hardness as $CaCO_3$ (mg/L)	29 38.830 - 0.0% 18.00 - 80.00 14.360	62 66.250 - -70.6% 20.00 - 186.00 42.070
TOC (mg/L)	29 - 5.8 0% 2.80 - 37.90 N/A	62 - 18.6 -222% 3.00 - 270.00 N/A

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

Sediments

A statistically significant increase in concentration was observed for TDS. A statistically significant decrease was observed for TSS. No statistically significant change was observed for turbidity. See Table 5-14 below.

Table 5-14: Grouped Groundcovers – Statistical Analysis of Sediments Concentrations

Grouped Groundcover Concentration		
Constituent	**Associated EOP Control** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Groundcover** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
TDS (mg/L)	29 - 42.7 0% 14.00 - 114.00 N/A	62 - 84.6 -98% 18.00 - 322.00 N/A
TSS (mg/L)	29 - 50.8 0% 5.0 - 238.0 N/A	63 - 34.2 33% 4.0 - 426.0 N/A
Turbidity (NTU)	24 - 36.7 0% 8.80 - 113.00 N/A	55 - 28.9 21% 5.20 - 272.00 N/A

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

Nutrients

Statistically significant increases in concentration were observed for ammonia, ortho-p, total phosphorous, and TKN. No statistically significant changes in concentrations were observed for nitrite and nitrate. See Table 5-15 below.

Table 5-15: Grouped Groundcovers – Statistical Analysis of Nutrients Concentrations

Grouped Groundcover Concentration		
Constituent	**Associated EOP Control** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Groundcover** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
Ammonia NH_3-N (mg/L)	29 0.398 - 0.0% 0.07 - 1.16 0.246	62 0.754 - -89.5% 0.005 - 4.180 0.880
Nitrite NO_2-N (mg/L)	24 0.06 - 0% 0.01 - 0.16 0.04	55 0.06 - 2% 0.01 - 0.73 0.10
Nitrate NO_3-N (mg/L)	24 - 0.428 0% 0.100 - 1.740 N/A	55 - 0.360 16% 0.005 - 4.290 N/A
Ortho-P, diss (mg/L)	24 - 0.073 0% 0.02 - 0.24 N/A	55 - 0.485 -564% 0.07 - 5.27 N/A
Total Phosphorus (mg/L)	29 0.28 - 0% 0.008 - 1.220 0.25	62 1.04 - -267% 0.10 - 5.40 0.90
TKN (mg/L)	29 1.63 - 0% 0.17 - 6.08 1.36	62 4.32 - -165% 0.17 - 14.20 3.37

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

Metals

Statistically significant decreases in metal concentrations were observed for dissolved and total chromium, total copper, total nickel, total lead, and total zinc. Statistically significant increases in metal concentrations were observed for dissolved and total arsenic. No statistically significant changes in concentrations were observed for dissolved and total cadmium, dissolved copper, dissolved nickel, dissolved lead, and dissolved zinc. See Table 5-16 below.

Table 5-16: Grouped Groundcovers – Statistical Analysis of Metals Concentrations

Grouped Groundcover Concentration		
Constituent	Associated EOP Control N Arith. Mean Geom. Mean % Δ btwn Means[1] Range[2] Std. Dev.	Grouped Groundcover N Arith. Mean Geom. Mean % Δ btwn Means[1] Range[2] Std. Dev.
Dissolved Metals		
As, diss (ug/L)	29 1.16 - 0% 0.50 - 2.80 0.51	63 2.86 - -146% 0.70 - 10.00 2.01
Cd, diss (ug/L)	29 0.10 - 0% 0.07 - 0.20 0.02	63 0.12 - -18% 0.10 - 0.50 0.06
Cr, diss (ug/L)	29 1.49 - 0% 0.50 - 2.89 0.55	63 0.75 - 49% 0.20 - 3.00 0.51
Cu, diss (ug/L)	29 10.24 - 0% 3.20 - 42.00 7.78	63 11.92 - -16% 2.60 - 120.00 15.42
Ni, diss (ug/L)	29 1.29 - 0% 0.40 - 3.50 0.74	63 1.59 - -23% 0.40 - 6.50 1.15
Pb, diss (ug/L)	29 0.25 - 0% 0.07 - 3.10 0.56	63 0.18 - 25% 0.08 - 1.10 0.19

Grouped Groundcover Concentration		
Constituent	**Associated EOP Control** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Groundcover** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
Zn, diss (ug/L)	29 - 11.1 0% 4.60 - 35.00 N/A	63 - 11.7 -6% 3.30 - 73.00 N/A
Total Metals		
As, total (ug/L)	29 - 2.0 0% 0.80 - 6.90 N/A	63 - 3.1 -58% 0.80 - 12.00 N/A
Cd, total (ug/L)	29 0.70 - 0% 0.10 - 6.10 1.10	63 1.13 - -60% 0.10 - 52.00 6.56
Cr, total (ug/L)	29 - 8.3 0% 1.99 - 34.00 N/A	63 - 3.6 56% 0.50 - 30.00 N/A
Cu, total (ug/L)	29 - 31.8 0% 3.20 - 42.00 N/A	63 - 15.8 50% 2.60 - 120.00 N/A
Ni, total (ug/L)	29 - 7.265 0% 1.90 - 33.00 N/A	63 - 4.536 38% 1.10 - 31.00 N/A
Pb, total (ug/L)	29 - 5.8 0% 0.07 - 3.10 N/A	63 - 1.3 77% 0.08 - 1.10 N/A
Zn, total (ug/L)	29 - 115.8 0% 34.0 - 380.0 N/A	63 - 32.1 72% 9.7 - 470.0 N/A

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

5.4.2.3 Grouped Low Shrubs

The results presented below for grouped low growing shrubs should be considered conservative. Although a portion of the available data was omitted from the statistical analyses presented below (see Section 5.3), the majority of the data were from complete loss events. Assigning the runoff volumes and resulting loads a value of zero (or even half of the reporting limit for concentration) would increase the already observed percent reductions or decrease the percent increases.

Conventional Constituents

Statistically significant increases in concentrations were observed for all conventional constituents analyzed. See Table 5-17 below.

Table 5-17: Grouped Low Shrubs – Statistical Analysis of Conventionals Concentrations

Grouped Low Shrubs Concentration		
Constituent	**Control (Grouped Low Shrubs)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Test (Grouped Low Shrubs)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
DOC (mg/L)	40 - 5.5 0% 1.5 - 36.0 N/A	63 - 10.6 -92% 1.6 - 48.8 N/A
Hardness as $CaCO_3$ (mg/L)	41 39.8 - 0% 18.0 - 100.0 17.6	64 61.7 - -55% 12.0 - 388.0 60.5
TOC (mg/L)	41 - 7.6 0% 2.8 - 45.5 N/A	64 - 14.1 -86% 1.9 - 55.8 N/A

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

Sediments

A statistically significant increase in concentration was observed for TDS. No statistically significant changes were observed for TSS and Turbidity. See Table 5-18 below.

Table 5-18: Grouped Low Shrubs – Statistical Analysis of Sediments Concentrations

Grouped Low Shrubs Concentration		
Constituent	**Control (Grouped Low Shrubs)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Test (Grouped Low Shrubs)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
TDS (mg/L)	41 - 42.4 0% 14.0 - 154.0 N/A	65 - 56.5 -33% 8.0 - 422.0 N/A
TSS (mg/L)	41 70.66 - 0% 7.00 - 238.00 48.42	66 53.98 - 24% 1.00 - 367.00 78.27
Turbidity (NTU)	33 45.6 - 0% 12.3 - 113.0 24.0	62 42.9 - 6% 0.1 - 641.0 85.0

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

Nutrients

A statistically significant decrease in concentration was observed for nitrite. Statistically significant increases in concentrations were observed for ortho-p and total phosphate. No statistically significant changes in concentrations were observed for ammonia, nitrate, and TKN. See Table 5-19 below.

Table 5-19: Grouped Low Shrubs – Statistical Analysis of Nutrients Concentrations

Grouped Low Shrubs Concentration		
Constituent	**Control (Grouped Low Shrubs)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Test (Grouped Low Shrubs)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
Ammonia NH_3-N (mg/L)	40 0.451 - 0.0% 0.005 - 1.530 0.315	64 0.452 - -0.2% 0.005 - 8.640 1.193
Nitrite NO_2-N (mg/L)	32 0.06 - 0% 0.02 - 0.23 0.05	61 0.02 - 60.363% 0.01 - 0.10 0.02
Nitrate NO_3-N (mg/L)	33 0.68 - 0% 0.19 - 2.22 0.54	62 0.96 - -42% 0.03 - 15.80 2.39
Ortho-P, diss (mg/L)	33 0.072 - 0% 0.003 - 0.240 0.053	62 0.277 - -282% 0.003 - 2.100 0.320
Total Phosphorus (mg/L)	41 - 0.177 0% 0.008 - 1.220 N/A	65 - 0.288 -63% 0.030 - 2.590 N/A
TKN (mg/L)	41 1.87 - 0% 0.42 - 6.91 1.50	65 6.45 - -245% 0.32 - 284.00 35.03

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

Metals

Statistically significant decreases in metals concentrations were observed for dissolved and total chromium, dissolved and total copper, dissolved and total zinc, total nickel, and total lead. A statistically significant increase in concentration was observed for dissolved arsenic. No statistically significant changes were observed for total arsenic, dissolved and total cadmium, dissolved nickel, and dissolved lead. See Table 5-20 below.

Table 5-20: Grouped Low Shrubs – Statistical Analysis of Metals Concentrations

Grouped Low Shrubs Concentration		
Constituent	**Control (Grouped Low Shrubs)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Test (Grouped Low Shrubs)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
Dissolved Metals		
As, diss (ug/L)	41 0.88 - 0% 0.20 - 2.80 0.58	66 2.04 - -132% 0.20 - 9.00 2.25
Cd, diss (ug/L)	41 0.14 - 0% 0.07 - 0.50 0.11	66 0.18 - -27% 0.10 - 2.30 0.29
Cr, diss (ug/L)	41 - 1.7 0% 0.5 - 7.6 N/A	66 - 1.1 34% 0.2 - 4.8 N/A
Cu, diss (ug/L)	41 15.26 - 0% 3.20 - 64.00 14.65	66 8.72 - 43% 3.90 - 21.00 3.68
Ni, diss (ug/L)	41 2.33 - 0% 0.40 - 12.00 2.68	66 1.82 - 22% 0.20 - 7.10 1.29
Pb, diss (ug/L)	41 0.25 - 0% 0.07 - 3.10 0.49	66 0.28 - -12% 0.08 - 2.80 0.37

Grouped Low Shrubs Concentration		
Constituent	**Control (Grouped Low Shrubs)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Test (Grouped Low Shrubs)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
Zn, diss (ug/L)	41 - 31.0 0% 4.6 - 1100.0 N/A	66 - 13.5 56% 4.6 - 46.0 N/A
Total Metals		
As, total (ug/L)	41 - 1.6 0% 0.5 - 6.9 N/A	66 - 1.9 -24% 0.3 - 11.0 N/A
Cd, total (ug/L)	41 0.66 - 0% 0.10 - 6.10 0.92	66 0.42 - 37% 0.10 - 4.20 0.61
Cr, total (ug/L)	41 - 8.2 0% 3.0 - 34.0 N/A	66 - 3.8 54% 0.6 - 25.0 N/A
Cu, total (ug/L)	41 - 43.8 0% 14.0 - 120.0 N/A	66 - 15.4 65% 5.6 - 44.0 N/A
Ni, total (ug/L)	41 9.29 - 0% 2.70 - 33.00 5.82	66 5.19 - 44% 0.60 - 25.00 4.68
Pb, total (ug/L)	41 12.36 - 0% 1.90 - 31.00 6.63	66 6.42 - 48% 0.20 - 49.00 7.83
Zn, total (ug/L)	41 355.3 - 0% 45.0 - 5700.0 866.6	66 46.0 - 87% 7.4 - 250.0 37.3

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

5.4.2.4 Grouped Strips – Short Width

The results presented below for grouped short width strips should be considered conservative. Although a portion of the available data was omitted from the statistical analyses presented below (see Section 5.3), comparisons indicate that had all data been included, there would be no substantial change in the results for constituents already showing a statistically significant difference between the EOP and swale effluent, For five of the ten constituents currently having a lack of a statistically significant difference (dissolved arsenic, nitrate-nitrogen, total phosphorous, TDS, and turbidity) the concentrations of the omitted data were comparable to the existing dataset, and their inclusion would likely increase the confidence of the currently observed results. It is unknown however, if these additional data points would be enough to shift the results from a lack of statistical significance to a confirmation of one. For hardness, TKN, TOC, TSS, and dissolved zinc, which also lacked statistically significant differences, the omitted data showed a concentration increase between the EOP and strip effluent, and these results are contrary to the current dataset which showed concentration decreases. However, this differences could be a result of the data being reported below the Reporting Limit (down to the Method Detection Limit) Data below the Reporting Limit is considered an estimate and no definitive conclusion should be made based on such data.

Conventional Constituents

A statistically significant increase in concentration was observed for DOC. No statistically significant changes in concentration were observed for hardness and TOC. See Table 5-21 below.

Table 5-21: Grouped Short Strips – Statistical Analysis of Conventionals Concentrations

Grouped Short Strips Concentration		
Constituent	**Associated EOP Control** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Short Strips** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
DOC (mg/L)	40 7.2 - 0% 1.50 - 36.00 6.5	34 10.9 - -52% 1.90 - 49.70 11.7
Hardness as $CaCO_3$ (mg/L)	41 - 36.760 0% 18.00 - 100.00 N/A	34 - 36.551 1% 12.00 - 186.00 N/A
TOC (mg/L)	41 10.35 - 0% 2.80 - 45.50 10.02	35 23.03 - -123% 2.30 - 370.00 61.44

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

Sediments

No statistically significant changes in concentrations were observed for all sediments analyzed. See Table 5-22 below.

Table 5-22: Grouped Short Strips – Statistical Analysis of Sediments Concentrations

Grouped Short Strips Concentration		
Constituent	**Associated EOP Control** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Short Strips** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
TDS (mg/L)	41 - 42.4 0% 14.0 - 154.0 N/A	35 - 43.3 -2% 8.0 - 252.0 N/A
TSS (mg/L)	41 70.66 - 0% 7.00 - 238.00 48.42	35 77.71 - -10% 2.00 - 426.00 105.33
Turbidity (NTU)	41 - 39.7 0% 12.30 - 113.00 N/A	35 - 29.8 25% 4.40 - 272.00 N/A

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

Nutrients

A statistically significant decrease in concentration was observed for nitrite. A statistically significant increase in concentration was observed for ortho-p. No statistically significant changes in concentrations were observed for ammonia, nitrate, total phosphorous, and TKN. See Table 5-23 below.

Table 5-23: Grouped Short Strips – Statistical Analysis of Nutrients Concentrations

Grouped Short Strips Concentration		
Constituent	**Associated EOP Control N Arith. Mean Geom. Mean % Δ btwn Means[1] Range[2] Std. Dev.**	**Grouped Short Strips N Arith. Mean Geom. Mean % Δ btwn Means[1] Range[2] Std. Dev.**
Ammonia NH_3-N (mg/L)	40 0.451 - 0.0% 0.005 - 1.530 0.315	34 0.538 - -19.2% 0.01 - 2.90 0.716
Nitrite NO_2-N (mg/L)	32 0.06 - 0% 0.02 - 0.23 0.05	31 0.04 - 41% 0.01 - 0.13 0.03
Nitrate NO_3-N (mg/L)	33 0.67 - 0% 0.19 - 2.22 0.54	32 0.61 - 10% 0.137 - 2.900 0.62
Ortho-P, diss (mg/L)	33 - 0.053 0% 0.003 - 0.240 N/A	32 - 0.110 -108% 0.003 - 1.230 N/A
Total Phosphorus (mg/L)	41 - 0.177 0% 0.008 - 1.220 N/A	35 - 0.252 -42% 0.03 - 1.73 N/A
TKN (mg/L)	41 - 1.5 0% 0.42 - 6.91 N/A	35 - 1.5 -3% 0.32 - 10.60 N/A

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

Metals

Statistically significant decreases in concentrations were observed for dissolved chromium, dissolved and total copper, dissolved and total nickel, dissolved and total zinc, and total lead. No statistically significant changes in concentrations were observed for dissolved and total arsenic, dissolved cadmium, and dissolved lead. See Table 5-24 below.

Table 5-24: Grouped Short Strips – Statistical Analysis of Metals Concentrations

Grouped Short Strips Concentration		
Constituent	Associated EOP Control N Arith. Mean Geom. Mean % Δ btwn Means[1] Range[2] Std. Dev.	Grouped Short Strips N Arith. Mean Geom. Mean % Δ btwn Means[1] Range[2] Std. Dev.
Dissolved Metals		
As, diss (ug/L)	41 0.88 - 0% 0.20 - 2.80 0.58	35 1.19 - -36% 0.20 - 6.20 1.19
Cd, diss (ug/L)	41 0.14 - 0% 0.07 - 0.50 0.11	35 0.14 - 4% 0.10 - 0.80 0.14
Cr, diss (ug/L)	41 - 1.7 0% 0.50 - 7.60 N/A	35 - 1.0 43% 0.30 - 3.40 N/A
Cu, diss (ug/L)	41 15.26 - 0% 3.20 - 64.00 14.65	35 9.34 - 39% 2.70 - 28.00 6.29
Ni, diss (ug/L)	41 2.33 - 0% 0.40 - 12.00 2.68	35 1.37 - 41% 0.40 - 5.50 1.07
Pb, diss (ug/L)	41 0.25 - 0% 0.07 - 3.10 0.49	35 0.18 - 28% 0.08 - 0.80 0.15

Grouped Short Strips Concentration		
Constituent	**Associated EOP Control N Arith. Mean Geom. Mean % Δ btwn Means[1] Range[2] Std. Dev.**	**Grouped Short Strips N Arith. Mean Geom. Mean % Δ btwn Means[1] Range[2] Std. Dev.**
Zn, diss (ug/L)	41 - 31.0 0% 4.6 - 1100.0 N/A	35 - 13.1 58% 4.2 - 54.0 N/A
Total Metals		
As, total (ug/L)	41 - 1.6 0% 0.50 - 6.90 N/A	35 - 1.5 8% 0.30 - 8.70 N/A
Cd, total (ug/L)	41 0.66 - 0% 0.10 - 6.10 0.92	35 0.24 - 64% 0.10 - 1.40 0.23
Cr, total (ug/L)	41 9.33 - 0% 3.00 - 34.00 5.66	35 6.22 - 33% 1.80 - 30.00 5.86
Cu, total (ug/L)	41 - 43.8 0% 14.00 - 120.00 N/A	35 - 18.9 57% 5.90 - 49.00 N/A
Ni, total (ug/L)	41 9.29 - 0% 2.70 - 33.00 5.82	35 5.97 - 36% 0.60 - 31.00 6.35
Pb, total (ug/L)	41 - 10.7 0% 1.90 - 31.00 N/A	35 - 3.3 69% 0.60 - 15.00 N/A
Zn, total (ug/L)	41 355.3 - 0% 45.0 - 5700.0 866.6	35 64.6 - 82% 9.7 - 470.0 75.7

[1]The most appropriate statistic (arithmetic mean,

Grouped Short Strips Concentration		
Constituent	**Associated EOP Control** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Short Strips** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
geometric mean, or median) was used to calculate the percent difference. [2]Caltrans practice is to report values between the method detection level and the reporting limit.		

5.4.2.5 Grouped Strips – Long Width

The results presented below for grouped long width strips should be considered conservative. Although a portion of the available data was omitted from the statistical analyses presented below (see Section 5.3), the majority of the data were from complete losses. Assigning the runoff volumes and resulting loads a value of zero (or even half of the reporting limit for concentration) would increase the already observed percent reductions or decrease the percent increases.

Conventional Constituents

Statistically significant increases in concentrations were observed for all conventional constituents analyzed. See Table 5-25 below.

Table 5-25: Grouped Long Width Strips – Statistical Analysis of Conventionals Concentrations

Grouped Long Strips Concentration		
Constituent	**Grouped Control** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Long Strips (>10ft)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
DOC (mg/L)	82 - 4.7 0% 1.1 - 36.0 N/A	129 - 11.6 -148% 1.6 - 73.1 N/A
Hardness as $CaCO_3$ (mg/L)	84 36 - 0% 10 - 100 15	132 68 - -89% 16 - 388 55
TOC (mg/L)	83 - 6.5 0% 1.6 - 45.5 N/A	132 - 15.7 -144% 1.9 - 80.1 N/A

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

Sediments

A Statistically significant increase in concentration was observed for TDS. No statistically significant changes were observed for TSS and turbidity. See Table 5-26 below.

Table 5-26: Grouped Long Width Strips – Statistical Analysis of Conventionals Concentrations

Grouped Long Strips Concentration		
Constituent	**Grouped Control** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Long Strips (>10ft)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
TDS (mg/L)	85 45.1 - 0% 0.2 - 154.0 27.7	134 107.6 - -138% 0.2 - 500.0 85.3
TSS (mg/L)	85 56 - 0% 6 - 238 42	136 57 - -2% 1 - 380 74
Turbidity (NTU)	72 37.8 - 0% 7.6 - 113.0 22.3	130 42.6 - -13% 0.1 - 641.0 64.3

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

Nutrients

A Statistically significant decrease in concentration was observed for nitrite. Statistically significant increases in concentrations were observed for ortho-p and total phosphorous. No statistically significant changes were observed for ammonia, nitrate, and TKN. See Table 5-27 below.

Table 5-27: Grouped Long Strips – Statistical Analysis of Nutrients Concentrations

Grouped Long Strips Concentration		
Constituent	**Grouped Control** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Long Strips (>10ft)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
Ammonia NH_3-N (mg/L)	84 0.379 - 0% 0.005 - 1.530 0.272	134 0.509 - -34% 0.005 - 8.640 1.027
Nitrite NO_2-N (mg/L)	71 0.050 - 0% 0.010 - 0.230 0.038	130 0.035 - 30% 0.004 - 0.730 0.067
Nitrate NO_3-N (mg/L)	72 0.494 - 0% 0.100 - 2.220 0.429	130 0.829 - -68% 0.005 - 15.800 1.769
Ortho-P, diss (mg/L)	68 0.051 - 0% 0.003 - 0.240 0.044	125 0.528 - -935% 0.014 - 5.270 0.700
Total Phosphorus (mg/L)	85 - 0.131 0% 0.008 - 1.220 N/A	133 - 0.501 -281% 0.070 - 5.400 N/A
TKN (mg/L)	85 1.57 - 0% 0.23 - 10.20 1.52	134 5.08 - -224% 0.10 - 284.0 24.45

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

Metals

Statistically significant decreases were observed in metal loads for dissolved and total chromium, dissolved and total copper, and dissolved and total zinc. Statistically significant increases in loads were observed for dissolved and total arsenic. No statistically significant changes in loads were observed for dissolved and total cadmium, dissolved and total nickel, and dissolved and total lead. See Table 5-28 below.

Table 5-28: Grouped Long Strips – Statistical Analysis of Metals Concentrations

Grouped Long Strips Concentration		
Constituent	**Grouped Control** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Long Strips (>10ft)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
Dissolved Metals		
As, diss (ug/L)	85 - 0.53 0% 0.16 - 2.80 N/A	136 - 1.68 -219% 0.22 - 10.00 N/A
Cd, diss (ug/L)	85 0.12 - 0% 0.02 - 0.50 0.08	136 0.17 - -38% 0.01 - 0.30 0.32
Cr, diss (ug/L)	85 2.7 - 0% 0.5 - 14.0 2.3	136 1.5 - 46% 0.2 - 8.0 1.4
Cu, diss (ug/L)	85 15.1 - 0% 2.9 - 64.0 13.2	136 10.3 - 32% 2.9 - 120.0 10.9
Ni, diss (ug/L)	85 1.9 - 0% 0.4 - 12.0 2.0	136 1.8 - 6% 0.2 - 7.1 1.2
Pb, diss (ug/L)	85 0.43 - 0% 0.07 - 4.80 0.75	136 0.50 - -17% 0.08 - 8.60 0.99

Grouped Long Strips Concentration		
Constituent	**Grouped Control** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Long Strips (>10ft)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
Zn, diss (ug/L)	85 55.9 - 0% 2.8 - 1100.0 134.6	136 14.1 - 75% 3.0 - 73.0 10.5
Total Metals		
As, total (ug/L)	85 1.4 - 0% 0.4 - 6.9 1.0	136 3.3 - -142% 0.7 - 12.0 2.4
Cd, total (ug/L)	85 0.5 - 0% 0.1 - 6.1 0.7	136 0.8 - -60% 0.1 - 52.0 4.5
Cr, total (ug/L)	85 8.7 - 0% 2.4 - 34.0 5.1	136 6.2 - 28% 0.5 - 36.0 6.6
Cu, total (ug/L)	85 50.1 - 0% 9.6 - 160.0 26.3	136 20.0 - 60% 5.6 - 170.0 18.2
Ni, total (ug/L)	85 7.4 - 0% 1.6 - 33.0 4.9	136 6.4 - 12% 0.7 - 35.0 6.0
Pb, total (ug/L)	85 16.4 - 0% 1.9 - 93.0 13.0	136 12.6 - 23% 0.2 - 240.0 31.1
Zn, total (ug/L)	85 245.0 - 0% 23.0 - 5700.0 611.1	136 45.7 - 81% 7.4 - 340.0 48.7

[1]The most appropriate statistic (arithmetic mean, geometric

Grouped Long Strips Concentration		
Constituent	**Grouped Control** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Long Strips (>10ft)** **N** **Arith. Mean** **Geom. Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**

mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

5.5 CONSTITUENT LOADING ASSESSMENT

Data assessments were performed on the constituent loads for 25 out of 29 constituents (excluding temperature, pH, turbidity, and conductivity). Since most stations differ from each other in drainage areas, a standardized method was used to calculate the normalized load for each storm event at each station so that various comparisons can be conducted between stations.

Conventional Constituents

Statistically significant decreases in conventional constituent loads were observed for the following groups: strips, succulents, groundcover, short strip widths, and long strip widths (>10ft). No statistically significant changes in conventional constituent loads were observed for grouped swales. The sample size for grouped swales was significantly smaller than for the other grouped BMPs. Grouped swale analysis sample size ranged from 7 to 8 data points, while the other grouped BMPs' sample size ranged from 29 to 166 data points. It should be noted that the smaller sample size may affect the statistical results causing changes in loading to show no statistically significant difference.

See Table 5-29 below which presents the loading assessments per statistical grouping, with the corresponding grouped control station results located directly below the grouped test results.

Table 5-29: Grouped BMPs – Statistical Analysis of Conventionals Loading

LOADING ASSESSMENT - CONVENTIONAL CONSTITUENTS						
Grouped Strips	**Grouped Swales**	**Grouped Succulents**	**Grouped Groundcover**	**Grouped Low Shrubs**	**Grouped Short Strips**	**Grouped Long Strips (>10ft)**
N	**N**	**N**	**N**	**N**	**N**	**N**
Arithmetic Mean	**Arithmetic Mean**	**Arithmetic Mean**	**Arithmetic Mean**	**Arithmetic Mean**	**Arithmetic Mean**	**Arithmetic Mean**
Geometric Mean	**Geometric Mean**	**Geometric Mean**	**Geometric Mean**	**Geometric Mean**	**Geometric Mean**	**Geometric Mean**
% Δ btwn Means[1]	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**
Range[2]	**Range[2]**	**Range[2]**	**Range[2]**	**Range[2]**	**Range[2]**	**Range[2]**
Std. Dev.	**Std. Dev.**	**Std. Dev.**	**Std. Dev.**	**Std. Dev.**	**Std. Dev.**	**Std. Dev.**
Test - Hardness as CaCO3 (mg/L)						
162	7	48	62	62	34	128
-	-	-	-	1607	855	-
370.18	1166.776	645.484	204.38	-	-	339.34
85%	39%	70%	93%	64%	82%	86%
9.05 - 22005.30	91.160 - 7345.331	27.532 - 6040.636	3.0 - 7345.0	9 - 22005	5.75 - 3330.8	9.05 - 22005.30
N/A	N/A	N/A	N/A	3745	912	N/A
Control - Hardness as CaCO3 (mg/L)						
72	8	56	29	34	41	72
-	-	-	-	4476	4678	-
2416.32	1921.766	2186.375	2838.41	-	-	2416.32
0%	0%	0%	0%	0%	0%	0%
302.53 - 10627.27	472.349 - 12362.203	302.531 - 10627.268	472 - 21392	630 - 10627	629.7 - 21392.3	302.53 - 10627.27
N/A	N/A	N/A	N/A	2603	3768	N/A
Test - TOC (mg/L)						
162	7	48	62	62	34	128
-	496.70	-	-	-	-	-
105.43	-	137.69	67.97	151.56	136.41	98.69
79%	19%	71%	85%	80%	81%	80%
4.31 - 4373.00	39.67 - 2130.15	5.710 - 933.257	6.3 - 2130.1	4.31 - 4372.00	27.2 - 1985.2	4.31 - 4373.00
N/A	729.60	N/A	N/A	N/A	N/A	N/A
Control - TOC (mg/L)						
71	8	55	29	34	41	71
-	615.80	-	-	-	-	-
497.70	-	482.51	446.75	769.70	712.80	497.70
0%	0%	0%	0%	0%	0%	0%
116.69 - 4121.20	85.31 - 3227.91	116.691 - 3534.682	85 - 4121	148.44 - 4121.20	95 - 4121	116.69 - 4121.20
N/A	1059.30	N/A	N/A	N/A	N/A	N/A

LOADING ASSESSMENT - CONVENTIONAL CONSTITUENTS						
Grouped Strips	**Grouped Swales**	**Grouped Succulents**	**Grouped Groundcover**	**Grouped Low Shrubs**	**Grouped Short Strips**	**Grouped Long Strips (>10ft)**
N **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
Test - DOC (mg/L)						
158 - 81.13 78% 2.72 - 3225.39 N/A	7 310.80 - 8.3% 31.23 - 1175.25 389.70	48 - 99.983 71% 4.436 - 553.763 N/A	59 - 50.60 84% 3.8 - 1175.3 N/A	61 313.5 - 58% 2.7 - 3225.4 531.1	33 - 98.84 81% 5.3 - 582.4 N/A	125 - 76.63 79% 2.72 - 3225.39 N/A
Control - DOC (mg/L)						
70 - 361.41 0% 38.79 - 2464.32 N/A	8 338.90 - 0.0% 63.98 - 1442.26 451.40	55 - 350.724 0% 38.791 - 2464.320 N/A	28 - 325.06 0% 64.0 - 1581.2 N/A	33 743.4 - 0% 100.4 - 2464.3 586.4	40 - 523.79 0% 78.2 - 2464.3 N/A	70 - 361.41 0% 38.79 - 2464.32 N/A

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

Sediments

Statistically significant decreases in sediment loads were observed for the following groupings: strips, succulents, groundcovers, low shrubs, short strip widths, and long strip widths (>10ft). No statistically significant decreases in sediment loads were observed for grouped swales. The sample size for grouped swales was significantly smaller than for the other grouped BMPs. Grouped swale analysis sample size ranged from 7 to 8 data points, while the other grouped BMPs' sample size ranged from 29 to 164 data points. It should be noted that the smaller sample size may affect the statistical results causing changes in loading to show no statistically significant difference.

See Table 5-30 below which presents the loading assessments per statistical grouping, with the corresponding grouped control station results located directly below the grouped test results.

Table 5-30: Grouped BMPs – Statistical Analysis of Sediments Loading

LOADING ASSESSMENT - Sediment						
Grouped Strips	**Grouped Swales**	**Grouped Succulents**	**Grouped Groundcover**	**Grouped Low Shrubs**	**Grouped Short Strips**	**Grouped Long Strips (>10ft)**
N	**N**	**N**	**N**	**N**	**N**	**N**
Arithmetic Mean	**Arithmetic Mean**	**Arithmetic Mean**	**Arithmetic Mean**	**Arithmetic Mean**	**Arithmetic Mean**	**Arithmetic Mean**
Geometric Mean	**Geometric Mean**	**Geometric Mean**	**Geometric Mean**	**Geometric Mean**	**Geometric Mean**	**Geometric Mean**
% Δ btwn Means[1]	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**
Range[2]	**Range[2]**	**Range[2]**	**Range[2]**	**Range[2]**	**Range[2]**	**Range[2]**
Std. Dev.	**Std. Dev.**	**Std. Dev.**	**Std. Dev.**	**Std. Dev.**	**Std. Dev.**	**Std. Dev.**
Test - TDS (g/acre)						
164	7	49	62	63	35	130
-	-	2032	-	2228	-	-
506.74	1266.484	-	310.13	-	531.66	486.38
80%	38%	42%	91%	56%	87%	81%
2.29 - 43729.96	178.944 - 8079.864	2.286 - 9060.954	13 - 3918	12 - 43730	13 - 3918	2.29 - 43729.96
N/A	N/A	2072	N/A	6192	N/A	N/A
Control - TDS (g/acre)						
73	8	57	29	34	41	73
-	-	3475	-	5112	-	-
2497.39	2050.830	-	3304.37	-	3983.83	2497.39
0%	0%	0%	0%	0%	0%	0%
23.05 - 13857.88	693.122 - 9615.047	23.047 - 13857.884	570 - 28833	570 - 13858	570 - 28833	23.05 - 13857.88
N/A	N/A	3306	N/A	3457	N/A	N/A
Test - TSS (g/acre)						
166	7	49	63	64	35	132
-	-	-	-	1129	-	-
228.15	407.076	505.73	117.10	-	487.85	182.55
92%	49%	78%	97%	84%	91%	94%
1.44 - 26681.78	16.882 - 2928.828	13.074 - 26681.778	3.0 - 3146.3	1 - 10382	14 - 4580	1.44 - 26681.78
N/A	N/A	N/A	N/A	1745	N/A	N/A
Control - TSS (g/acre)						
73	8	57	29	34	41	73
-	-	-	-	7231	-	-
2966.09	790.764	2337.88	3932.38	-	5442.53	2966.09
0%	0%	0%	0%	0%	0%	0%
26.06 - 19877.33	157.450 - 8928.258	26.060 - 15930.960	157 - 68827	358 - 19877	358 - 68827	26.06 - 19877.33
N/A	N/A	N/A	N/A	5168	N/A	N/A

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

Nutrients

Statistically significant decreases in all nutrient loads were observed for the following groupings: groundcovers and short strip widths.

For grouped strips, statistically significant decreases in nutrient loads were observed for ammonia, nitrite, nitrate, TKN, and total phosphorous. No statistically significant changes in loads were observed for ortho-p.

Grouped swales demonstrated statistically significant decreases in nutrient loads for nitrite. No statistically significant changes in loads were observed for ammonia, nitrate, ortho-p, total phosphorus and TKN. The sample size for grouped swales was significantly smaller than for the other grouped BMPs. Grouped swale analysis sample size ranged from 7 to 9 data points, while the other grouped BMPs' sample size ranged from 24 to 163 data points. It should be noted that the smaller sample size may affect the statistical results causing changes in loading to show no statistically significant difference.

For grouped succulents, statistically significant increases in nutrient loads were observed for ortho-p. Statistically significant decreases in loads were observed for ammonia, nitrite, nitrate, and TKN. No statistically significant changes in loads were observed for total phosphorus.

Grouped low shrubs demonstrated statistically significant decreases in nutrient loads for ammonia, nitrite, ortho-p, total phosphorus, and TKN. No statistically significant changes in loads were observed for nitrate.

For grouped long strips (>10ft), statistically significant decreases were observed in nutrient loads for ammonia, nitrite, nitrate, total phosphorus, and TKN. No statistically significant changes were observed in loads for ortho-p. See Table 5-31 below.

Table 5-31: Grouped BMPs – Statistical Analysis of Nutrients Loading

LOADING ASSESSMENT - Nutrients						
Grouped Strips	**Grouped Swales**	**Grouped Succulents**	**Grouped Groundcover**	**Grouped Low Shrubs**	**Grouped Short Strips**	**Grouped Long Strips (>10ft)**
N	**N**	**N**	**N**	**N**	**N**	**N**
Arithmetic Mean	**Arithmetic Mean**	**Arithmetic Mean**	**Arithmetic Mean**	**Arithmetic Mean**	**Arithmetic Mean**	**Arithmetic Mean**
Geometric Mean	**Geometric Mean**	**Geometric Mean**	**Geometric Mean**	**Geometric Mean**	**Geometric Mean**	**Geometric Mean**
% Δ btwn Means[1]	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**
Range[2]	**Range[2]**	**Range[2]**	**Range[2]**	**Range[2]**	**Range[2]**	**Range[2]**
Std. Dev.	**Std. Dev.**	**Std. Dev.**	**Std. Dev.**	**Std. Dev.**	**Std. Dev.**	**Std. Dev.**
Test - Ammonia NH3-N (g/acre)						
163	7	49	62	62	34	130
3.82	-	4.480	-	-	-	3.16
-	3.854	-	1.55	1.59	3.38	-
87%	71%	83%	94%	95%	90%	89%
0.03 - 32.33	0.444 - 55.090	0.033 - 27.183	0.13 - 55.09	0.03 - 32.33	0.13 - 29.64	0.03 - 32.33
6.10	N/A	7.230	N/A	N/A	N/A	5.68
Control - Ammonia NH3-N (g/acre)						
72	8	56	29	33	40	72
29.70	-	26.880	-	-	-	29.70
-	13.105	-	26.13	32.98	32.95	-
0%	0%	0%	0%	0%	0%	0%
1.47 - 157.96	3.999 - 116.754	1.467 - 157.962	4.0 - 176.7	1.47 - 157.96	1.47 - 176.72	1.47 - 157.96
25.46	N/A	26.020	N/A	N/A	N/A	25.46
Test - Nitrite NO2-N (g/acre)						
161	7	52	55	61	32	130
-	-	-	-	-	0.62	-
0.17	1.000	0.249	0.12	0.19	-	0.13
94%	52%	90%	96%	96%	90%	95%
0.01 - 7.05	0.253 - 3.673	0.009 - 7.047	0.01 - 3.67	0.01 - 4.16	0.00 - 2.78	0.01 - 7.05
N/A	N/A	N/A	N/A	N/A	0.69	N/A
Control - Nitrite NO2-N (g/acre)						
71	9	56	24	32	32	71
-	-	-	-	-	6.19	-
2.82	2.089	2.457	3.48	5.08	-	2.82
0%	0%	0%	0%	0%	0%	0%
0.23 - 15.81	0.533 - 6.868	0.228 - 15.813	0.53 - 10.10	0.89 - 15.81	0.89 - 15.81	0.23 - 15.81
N/A	N/A	N/A	N/A	N/A	3.48	N/A
Test - Nitrate NO3-N (g/acre)						
162	7	52	55	62	32	130
-	14.26	10.770	3.66	31.70	-	-
2.61	-	-	-	-	6.12	2.11
90%	50%	70%	92%	51%	89%	92%
0.04 - 896.11	2.53 - 65.14	0.372 - 68.461	0.05 - 65.13	0.04 - 896.11	0.00 - 79.87	0.04 - 896.11
N/A	22.54	15.430	8.89	121.90	N/A	N/A
Control - Nitrate NO3-N (g/acre)						
72	9	57	24	33	33	72
-	28.51	35.870	46.30	64.60	-	-
26.90	-	-	-	-	53.84	26.90
0%	0%	0%	0%	0%	0%	0%
1.65 - 197.07	3.33 - 142.26	1.645 - 197.070	3.33 - 142.26	16.62 - 197.07	16.62 - 197.07	1.65 - 197.07
N/A	43.66	38.640	37.63	41.20	N/A	N/A

LOADING ASSESSMENT - Nutrients						
Grouped Strips	**Grouped Swales**	**Grouped Succulents**	**Grouped Groundcover**	**Grouped Low Shrubs**	**Grouped Short Strips**	**Grouped Long Strips (>10ft)**
N	**N**	**N**	**N**	**N**	**N**	**N**
Arithmetic Mean	**Arithmetic Mean**	**Arithmetic Mean**	**Arithmetic Mean**	**Arithmetic Mean**	**Arithmetic Mean**	**Arithmetic Mean**
Geometric Mean	**Geometric Mean**	**Geometric Mean**	**Geometric Mean**	**Geometric Mean**	**Geometric Mean**	**Geometric Mean**
% Δ btwn Means[1]	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**
Range[2]	**Range[2]**	**Range[2]**	**Range[2]**	**Range[2]**	**Range[2]**	**Range[2]**
Std. Dev.	**Std. Dev.**	**Std. Dev.**	**Std. Dev.**	**Std. Dev.**	**Std. Dev.**	**Std. Dev.**
Test - Ortho-P, diss (g/acre)						
157	7	47	55	62	33	125
3.977	-	5.210	-	-	2.15	4.428
-	4.764	-	1.74	1.71	-	-
22%	-108%	-52%	68%	68%	74%	13%
0.010 - 28.613	0.304 - 26.413	0.010 - 26.503	0.11 - 26.41	0.12 - 28.61	0.00 - 5.99	0.010 - 28.613
5.197	N/A	6.077	N/A	N/A	1.64	5.685
Control - Ortho-P, diss (g/acre)						
68	9	53	24	33	33	68
5.072	-	3.436	-	-	8.15	5.072
-	2.293	-	5.42	5.33	-	-
0%	0%	0%	0%	0%	0%	0%
0.005 - 22.86	0.380 - 47.883	0.005 - 14.398	0.38 - 47.88	0.04 - 22.29	0.043 - 22.287	0.005 - 22.286
5.354	N/A	3.780	N/A	N/A	5.90	5.354
Test - Total Phosphorus (g/acre)						
163	7	48	62	63	35	129
-	-	8.889	-	6.43	4.40	6.99
3.14	6.184	-	2.75	-	-	-
64%	-42%	15%	82%	72%	86%	52%
0.10 - 44.70	0.355 - 51.417	0.102 - 34.283	0.2 - 51.4	0.15 - 44.70	0.18 - 18.66	0.10 - 44.70
N/A	N/A	9.042	N/A	8.04	3.97	8.43
Control - Total Phosphorus (g/acre)						
73	8	57	29	34	41	73
-	-	10.405	-	23.04	30.86	14.58
8.74	4.345	-	15.63	-	-	-
0%	0%	0%	0%	0%	0%	0%
0.11 - 55.56	0.070 - 123.622	0.114 - 49.827	0.1 - 376.7	0.11 - 55.56	0.11 - 376.69	0.11 - 55.56
N/A	N/A	10.466	N/A	16.60	57.63	14.52
Test - TKN (g/acre)						
164	7	49	62	63	35	130
-	-	-	-	-	-	-
14.28	20.373	17.71	10.53	16.93	18.52	13.07
83%	41%	76%	89%	88%	87%	85%
0.65 - 439.72	3.900 - 67.452	0.821 - 194.926	1.1 - 84.1	0.65 - 439.72	1.13 - 202.62	0.65 - 439.72
N/A	N/A	N/A	N/A	N/A	N/A	N/A
Control - TKN (g/acre)						
73	8	57	29	34	41	73
-	-	-	-	-	-	-
84.44	34.761	74.00	94.44	140.33	138.19	84.44
0%	0%	0%	0%	0%	0%	0%
13.61 - 1039.24	13.063 - 116.754	13.614 - 573.872	13.1 - 1134.7	26.93 - 1039.24	26.9 - 1134.7	13.61 - 1039.24
N/A	N/A	N/A	N/A	N/A	N/A	N/A

[1]The most appropriate statistic (arithmetic mean, geometric mean, or median) was used to calculate the percent difference.
[2]Caltrans practice is to report values between the method detection level and the reporting limit.

Metals

Statistically significant decreases in dissolved and total metal loads were observed for the following groupings: strips, succulents, groundcover, low shrubs, short strip widths and long strip (>10ft) widths. No statistically significant changes in dissolved and total metal loads were observed for grouped swales. The sample size for grouped swales was significantly smaller than for the other grouped BMPs. Grouped swale analysis sample size ranged from 7 to 8 data points, while the other grouped BMPs' sample size ranged from 29 to 166 data points. It should be noted that the smaller sample size may affect the statistical results causing changes in loading to show no statistically significant difference.

See Table 5-32 below which presents the loading assessments per statistical grouping, with the corresponding grouped control station results located directly below the grouped test results.

Table 5-32: Grouped BMPs – Statistical Analysis of Metals Loading

LOADING ASSESSMENT – METALS DISSOLVED						
Grouped Strips	**Grouped Swales**	**Grouped Succulents**	**Grouped Groundcover**	**Grouped Low Shrubs**	**Grouped Short Strips**	**Grouped Long Strips (>10ft)**
N	**N**	**N**	**N**	**N**	**N**	**N**
Arithmetic Mean	**Arithmetic Mean**	**Arithmetic Mean**	**Arithmetic Mean**	**Arithmetic Mean**	**Arithmetic Mean**	**Arithmetic Mean**
Geometric Mean	**Geometric Mean**	**Geometric Mean**	**Geometric Mean**	**Geometric Mean**	**Geometric Mean**	**Geometric Mean**
% Δ btwn Means[1]	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**
Range[2]	**Range[2]**	**Range[2]**	**Range[2]**	**Range[2]**	**Range[2]**	**Range[2]**
Std. Dev.	**Std. Dev.**	**Std. Dev.**	**Std. Dev.**	**Std. Dev.**	**Std. Dev.**	**Std. Dev.**
Test - As, diss (mg/acre)						
166	7	49	63	64	35	132
23.75	-	-	-	26.69	-	25.8
-	36.307	12.718	7.81	-	9.63	-
59%	33%	52%	91%	69%	86%	55%
0.10 - 338.24	1.351 - 293.813	0.408 - 114.276	0.1 - 293.8	0.47 - 338.24	0.18 - 96.38	0.10 - 338.24
36.46	N/A	N/A	N/A	48.56	N/A	39.72
Control - As, diss (mg/acre)						
73	8	57	29	34	41	73
57.43	-	-	-	86.74	-	57.43
-	54.163	26.682	83.68	-	67.11	-
0%	0%	0%	0%	0%	0%	0%
1.30 - 277.78	6.998 - 343.395	1.303 - 197.972	7.0 - 511.6	12.88 - 277.78	12.9 - 511.6	1.30 - 277.78
56.49	N/A	N/A	N/A	59.10	N/A	56.49

LOADING ASSESSMENT – METALS DISSOLVED						
Grouped Strips **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Swales** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Succulents** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Groundcover** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Low Shrubs** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Short Strips** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Long Strips (>10ft)** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
Test - Cd, diss (mg/acre)						
166 - 0.80 89% 0.01 - 84.32 N/A	7 - 3.947 36% 0.169 - 36.727 N/A	49 - 1.305 81% 0.042 - 24.867 N/A	63 - 0.39 95% 0.01 - 36.73 N/A	64 - 1.34 90% 0.02 - 84.32 N/A	35 - 1.42 88% 0.01 - 84.32 N/A	132 - 0.67 91% 0.01 - 36.24 N/A
Control - Cd, diss (mg/acre)						
73 - 7.55 0% 0.16 - 101.02 N/A	8 - 6.178 0% 0.875 - 68.679 N/A	57 - 7.036 0% 0.163 - 101.023 N/A	29 - 7.84 0% 0.87 - 68.68 N/A	34 - 12.83 0% 1.73 - 101.02 N/A	41 - 11.58 0% 1.12 - 101.02 N/A	73 - 7.55 0% 0.16 - 101.02 N/A
Test - Cr, diss (mg/acre)						
166 - 7.09 96% 0.05 - 600.81 N/A	7 - 54.872 51% 2.870 - 624.353 N/A	49 - 23.736 86% 0.654 - 600.812 N/A	63 22.4 - 88% 0.0 - 624.4 86.5	64 45.4 - 82% 0.1 - 229.5 59.1	35 - 11.70 93% 0.1 - 228.0 N/A	132 - 6.00 96% 0.05 - 600.81 N/A
Control- Cr, diss (mg/acre)						
73 - 158.54 0% 2.77 - 1368.36 N/A	8 - 112.730 0% 24.492 - 1373.578 N/A	57 - 169.525 0% 2.769 - 1368.357 N/A	29 185.0 - 0% 13.6 - 1373.6 251	34 245.7 - 0% 24.2 - 697.0 187.3	41 - 157.43 0% 13.6 - 697.0 N/A	73 - 158.54 0% 2.77 - 1368.36 N/A

LOADING ASSESSMENT – METALS DISSOLVED						
Grouped Strips	**Grouped Swales**	**Grouped Succulents**	**Grouped Groundcover**	**Grouped Low Shrubs**	**Grouped Short Strips**	**Grouped Long Strips (>10ft)**
N	**N**	**N**	**N**	**N**	**N**	**N**
Arithmetic Mean	**Arithmetic Mean**	**Arithmetic Mean**	**Arithmetic Mean**	**Arithmetic Mean**	**Arithmetic Mean**	**Arithmetic Mean**
Geometric Mean	**Geometric Mean**	**Geometric Mean**	**Geometric Mean**	**Geometric Mean**	**Geometric Mean**	**Geometric Mean**
% Δ btwn Means[1]	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**	**% Δ btwn Means[1]**
Range[2]	**Range[2]**	**Range[2]**	**Range[2]**	**Range[2]**	**Range[2]**	**Range[2]**
Std. Dev.	**Std. Dev.**	**Std. Dev.**	**Std. Dev.**	**Std. Dev.**	**Std. Dev.**	**Std. Dev.**
Test - Cu, diss (mg/acre)						
166	7	49	63	64	35	132
-	-	-	99	238.0	-	-
58.62	315.450	112.843	-	-	95.68	50.25
93%	39%	87%	89%	85%	91%	94%
1.09 - 1570.41	32.075 - 1615.973	5.603 - 1409.482	2.05 - 1615.97	1.1 - 1570.4	2.3 - 911.9	1.09 - 1570.41
N/A	N/A	N/A	247	299.9	N/A	N/A
Control - Cu, diss (mg/acre)						
73	8	57	29	34	41	73
-	-	-	939	1578.0	-	-
862.64	516.461	880.949	-	-	1065.29	862.64
0%	0%	0%	0%	0%	0%	0%
48.86 - 5399.18	127.961 - 2815.835	48.863 - 5399.176	127.96 - 3898.90	172.6 - 5399.2	173.0 - 5399.0	48.86 - 5399.18
N/A	N/A	N/A	875.8	1298.3	N/A	N/A
Test - Ni, diss (mg/acre)						
166	7	49	63	64	35	132
-	-	-	15.0	51.0	-	-
9.50	44.389	17.099	-	-	13.60	8.41
91%	47%	84%	89%	79%	91%	92%
0.11 - 591.92	4.558 - 220.360	0.871 - 130.880	0.3 - 220.4	0.1 - 591.9	0.28 - 136.78	0.11 - 591.92
N/A	N/A	N/A	32.8	89.8	N/A	N/A
Control - Ni, diss (mg/acre)						
73	8	57	29	34	41	73
-	-	-	132.3	240.6	-	-
101.29	83.680	104.167	-	-	152.17	101.29
0%	0%	0%	0%	0%	0%	0%
5.86 - 1079.84	26.659 - 618.110	5.864 - 1079.835	22.4 - 744.1	22.4 - 1079.8	22.4 - 1079.8	5.86 - 1079.84
N/A	N/A	N/A	161.7	251.6	N/A	N/A

LOADING ASSESSMENT – METALS DISSOLVED						
Grouped Strips **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Swales** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Succulents** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Groundcover** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Low Shrubs** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Short Strips** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Long Strips (>10ft)** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
Test - Pb, diss (mg/acre)						
166 - 1.51 91% 0.02 - 429.87 N/A	7 - 4.609 44% 0.169 - 53.251 N/A	49 - 5.88 68% 0.187 - 429.869 N/A	63 - 0.47 95% 0.02 - 53.25 N/A	64 7.47 - 73% 0.03 - 72.48 12.75	35 - 1.73 87% 0.04 - 18.24 N/A	132 - 1.42 92% 0.02 - 429.87 N/A
Control- Pb, diss (mg/acre)						
73 - 16.86 0% 0.81 - 287.78 N/A	8 - 8.207 0% 0.875 - 54.943 N/A	57 - 18.52 0% 0.814 - 137.705 N/A	29 - 9.77 0% 0.9 - 287.8 N/A	34 27.55 - 0% 1.38 - 287.78 49.41	41 - 13.48 0% 0.89 - 287.78 N/A	73 - 16.86 0% 0.81 - 287.78 N/A
Test - Zn, diss (mg/acre)						
166 - 81.21 96% 0.96 - 3792.14 N/A	7 - 464.054 56% 37.139 - 4039.932 N/A	49 - 134.16 94% 7.004 - 3398.960 N/A	62 192.00 - 86% 2.9 - 3920.9 628.00	64 494 - 95% 1 - 3792 718	35 - 160.61 94% 5.7 - 2006.2 N/A	132 269.00 - 95% 0.96 - 3792.14 589.00
Control- Zn, diss (mg/acre)						
73 - 1919.85 0% 48.86 - 98984.89 N/A	8 - 1059.974 0% 186.610 - 10988.625 N/A	57 - 2356.66 0% 48.863 - 98984.887 N/A	30 1398.00 - 0% 82.9 - 10179.0 1835.00	34 10064 - 0% 83 - 98985 18064	41 - 2913.18 0% 83 - 98985 N/A	73 5449.00 - 0% 48.86 - 98984.89 12994.00

LOADING ASSESSMENT – METALS TOTAL						
Grouped Strips **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Swales** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Succulents** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Groundcover** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Low Shrubs** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Short Strips** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Long Strips (>10ft)** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
Test - As, total (mg/acre)						
166 40.31 - 67% 0.16 - 410.72 55.11	7 - 46.063 37% 1.857 - 367.267 N/A	49 - 24.730 57% 0.784 - 224.689 N/A	63 - 10.74 93% 0.2 - 367.3 N/A	64 47.46 - 75% 0.53 - 410.72 65.40	35 - 17.81 88% 0.23 - 111.03 N/A	132 42.60 - 65% 0.16 - 410.72 59.81
Control - As, total (mg/acre)						
73 120.81 - 0% 1.95 - 681.82 122.41	8 - 73.479 0% 9.622 - 549.431 N/A	57 - 57.226 0% 1.955 - 354.242 N/A	29 - 153.39 0% 9.6 - 1069.6 N/A	34 190.67 - 0% 22.90 - 681.82 139.25	41 - 148.12 0% 22.9 - 1069.6 N/A	73 120.81 - 0% 1.95 - 681.81 122.41
Test - Cd, total (mg/acre)						
166 - 1.49 94% 0.02 - 107.02 N/A	7 - 6.713 45% 0.338 - 73.453 N/A	49 - 2.945 85% 0.087 - 40.615 N/A	63 - 0.62 98% 0.02 - 107.02 N/A	64 11.24 - 86% 0.02 - 84.56 16.36	35 - 2.32 95% 0.04 - 42.16 N/A	132 - 1.29 95% 0.02 - 107.02 N/A
Control - Cd, total (mg/acre)						
73 - 24.31 0% 0.33 - 799.69 N/A	8 - 12.219 0% 2.624 - 68.679 N/A	57 - 19.767 0% 0.326 - 202.046 N/A	29 - 33.65 0% 2.6 - 799.7 N/A	34 79.75 - 0% 8.59 - 799.69 135.83	41 - 45.15 0% 8.6 - 799.7 N/A	73 - 24.31 0% 0.33 - 799.69 N/A

LOADING ASSESSMENT – METALS TOTAL						
Grouped Strips **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Swales** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Succulents** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Groundcover** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Low Shrubs** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Short Strips** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Long Strips (>10ft)** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
Test - Cr, total (mg/acre)						
166 162.7 - 79% 0.2 - 2880.6 383.5	7 - 154.625 39% 6.753 - 1432.340 N/A	49 - 76.554 83% 1.568 - 2880.605 N/A	63 - 12.39 98% 0.2 - 1432.3 N/A	64 137.1 - 87% 0.3 - 732.9 171.8	35 139.8 - 87% 0.33 - 693.92 168.5	132 - 23.06 96% 0.19 - 2880.61 N/A
Control- Cr, total (mg/acre)						
73 793.2 - 0% 5.9 - 3535.3 723.5	8 - 255.188 0% 49.859 - 2747.156 N/A	57 - 438.342 0% 5.864 - 2302.575 N/A	29 - 639.70 0% 50.0 - 5581.0 N/A	34 1030.6 - 0% 83.0 - 3535.3 802.7	41 1102.5 - 0% 83.0 - 5580.6 1041.9	73 - 514.40 0% 5.86 - 3535.34 N/A
Test - Cu, total (mg/acre)						
166 - 116.63 96% 2.95 - 4691.27 N/A	7 - 571.349 51% 50.645 - 3525.759 N/A	49 - 269.078 91% 8.405 - 4691.272 N/A	63 - 54.05 98% 3.0 - 3525.8 N/A	64 550 - 90% 3 - 3331 723	35 - 231.83 94% 4.0 - 3331.0 N/A	132 - 94.73 97% 2.95 - 4691.27 N/A
Control - Cu, total (mg/acre)						
73 - 3146.36 0% 118.90 - 14878.18 N/A	8 - 1164.445 0% 306.573 - 10988.625 N/A	57 - 3077.891 0% 118.899 - 14878.17 N/A	29 - 2465.13 0% 307 - 18602 N/A	34 5670 - 0% 777 - 14878 3997	41 - 4117.49 0% 577 - 18602 N/A	73 - 3146.36 0% 118.90 - 14878.18 N/A

LOADING ASSESSMENT – METALS TOTAL						
Grouped Strips **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Swales** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Succulents** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Groundcover** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Low Shrubs** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Short Strips** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Long Strips (>10ft)** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
Test - Ni, total (mg/acre)						
166 - 31.82 92% 0.37 - 2457.53 N/A	7 - 124.213 37% 7.597 - 771.260 N/A	49 - 74.069 79% 1.568 - 2457.532 N/A	63 - 15.55 97% 0.5 - 771.3 N/A	64 125.5 - 87% 0.4 - 809.4 162.3	35 101.4 - 90% 0.49 - 430.23 105.5	132 - 27.09 94% 0.37 - 2457.53 N/A
Control - Ni, total (mg/acre)						
73 - 423.69 0% 9.12 - 3282.81 N/A	8 - 197.947 0% 51.609 - 1648.294 N/A	57 - 351.426 0% 9.121 - 1842.060 N/A	29 - 562.84 0% 52 - 5116 N/A	34 974.6 - 0% 186.1 - 3282.8 738.9	41 1039.8 - 0% 186.1 - 5115.5 955.2	73 - 423.69 0% 9.12 - 3282.81 N/A
Test - Pb, total (mg/acre)						
166 303.1 - 79% 0.09 - 5968.29 813.1	7 - 87.795 48% 4.558 - 954.893 N/A	49 - 155.40 84% 2.101 - 5968.292 N/A	63 - 4.55 99% 0.1 - 954.9 N/A	64 204.0 - 88% 0.2 - 1290.7 274.7	35 - 41.02 96% 0.2 - 1290.7 N/A	132 - 20.39 98% 0.09 - 5968.29 N/A
Control- Pb, total (mg/acre)						
73 1416.7 - 0% 14.66 - 6730.60 1327.3	8 - 167.503 0% 31.490 - 2609.798 N/A	57 - 1000.24 0% 14.659 - 6730.603 N/A	29 - 447.20 0% 31 - 5581 N/A	34 1653.6 - 0% 157.4 - 6730.6 1589.1	41 - 1008.28 0% 120 - 6731 N/A	73 - 910.51 0% 14.66 - 6730.60 N/A

LOADING ASSESSMENT – METALS TOTAL						
Grouped Strips **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Swales** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Succulents** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Groundcover** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Low Shrubs** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Short Strips** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**	**Grouped Long Strips (>10ft)** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means[1]** **Range[2]** **Std. Dev.**
Test - Zn, total (mg/acre)						
166 - 253.41 98% 6.31 - 16406.23 N/A	7 - 1413.749 59% 87.784 - 10283.464 N/A	49 - 607.89 94% 14.008 - 16406.232 N/A	63 - 95.49 99% 9.4 - 4039.9 N/A	64 1518 - 96% 6 - 10131 2151	35 - 588.75 97% 49 - 10131 N/A	132 - 200.14 98% 6.31 - 16406.23 N/A
Control - Zn, total (mg/acre)						
73 - 11092.23 0% 195.45 - 512921.68 N/A	8 - 3422.067 0% 853.073 - 37086.608 N/A	57 - 10551.25 0% 195.450 - 512921.685 N/A	29 - 6496.38 0% 187 - 69757 N/A	34 40260 - 0% 3452 - 512922 85755	41 - 19574.83 0% 2485 - 512922 N/A	73 - 11092.23 0% 195.45 - 512921.68 N/A

5.6 RUNOFF VOLUME ASSESSMENT

The results presented below for runoff volumes should be considered conservative. Although a portion of the available data was omitted from the statistical analyses presented below (see Section 5.3), comparisons indicate that had all data been included, there would be no substantial change in the results for constituents already showing a statistically significant difference between the EOP and test stations.

Statistically significant reductions in runoff volumes were observed for the following groupings: strips, succulents, groundcover, low shrubs, short strip widths and long strip widths. No statistically significant changes in runoff volumes were observed for grouped swales. The sample size for grouped swales was significantly smaller than for the other grouped BMPs. Grouped swale analysis sample size ranged from 7 to 9 data points, while the other grouped BMPs' sample size ranged from 30 to 169 data points. It should be noted that the smaller sample size may affect the statistical results causing changes in loading to show no statistically significant difference. See Table 5-33 below which presents the loading assessments per statistical grouping, with the corresponding grouped control station results located directly below the grouped test results.

Table 5-33: Runoff Volume Results – Statistical Analysis of Runoff Volumes

RUNOFF VOLUME RESULTS						
Test (Grouped Strips) **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means** **Range[2]** **Std. Dev.**	**Test (Grouped Swales)** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means** **Range[2]** **Std. Dev.**	**Test (Grouped Succulents)** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means** **Range[2]** **Std. Dev.**	**Grouped Groundcover** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means** **Range[2]** **Std. Dev.**	**Test (Grouped Low Shrubs)** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means** **Range[2]** **Std. Dev.**	**Grouped Short Strips** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means** **Range[2]** **Std. Dev.**	**Grouped Long Strips (>10ft)** **N** **Arithmetic Mean** **Geometric Mean** **% Δ btwn Means** **Range[2]** **Std. Dev.**
Test-Volumes						
169 - 6823 90% 54 - 190461 N/A	7 - 39458.31 18% 1688.16 - 367266.57 N/A	52 - 12258.808 81% 466.935 - 190460.55 N/A	63 3425 95% 54 - 367267 N/A	64 31756 - 76% 208 - 138783 38429	35 12283 87% 106 - 138784 N/A	135 - 5682 92% 54 - 190461 N/A
Control-Volumes						
73 - 70545 0% 1629 - 354242 N/A	9 - 47954.12 0% 6331.44 - 686789.04 N/A	57 - 64472.883 0% 1628.753 - 354242.282 N/A	30 71254 0% 6331 - 686789 N/A	34 132972 - 0% 14312 - 354242 87029	41 94089 0% 8015 - 465050 N/A	73 - 70545 0% 1629 - 354242 N/A

5.7 STUDY COMPARISONS

As described in Section 1.2, past studies performed by Caltrans have served as learning experiences which help shape future study questions. The following subsections cover comparisons of the ORVTS Study with other past Caltrans studies (RVTS, Highway Characterization Study and BMP Pilot Study). The results of these comparisons, presented in Tables 5-34 to 5-38 were based on a rudimentary comparison of data obtained from these studies. A thorough statistical comparison would be required to provide more conclusive information.

5.7.1 ORVTS Study vs RVTS Study

Concentration

Monitoring in the RVTS Study was performed during five separate wet seasons between 2001 and 2008. The Sacramento and Yorba Linda ORVTS flow and water quality data were compared to that from the relevant RVTS stations.

The primary differences in the setup between the RVTS and ORVTS locations include:

- Vegetative cover characteristics (vegetation type, height, density, cover and strip width, etc.).
- Soil characteristics due to soil amendments during planting of the new ornamental vegetation.
- Runoff collection structures. Concrete channels were used for RVTS while six-inch PVC pipes were used for ORVTS.

Using the analytical data from both the five-year RVTS Study and data from the 2009-2012 ORVTS Study, the average of the EMCs for strips at each location were calculated for each constituent.

Sacramento I-5:

Table 5-34 presents a comparison of the calculated average EMCs between ORVTS and RVTS data analysis results. For both RVTS and ORVTS, the table presents the average EMC at the EOP, the average EMC for all four strips, a comparison of concentration reduction or increase from EOP data results, relative percent differences and percentage point differences.

Table 5-34: Concentration Reduction Comparison between RVTS and ORVTS at Sacramento Location

Constituent	Sacramento RVTS			Sacramento ORVTS			ORVTS vs RVTS		
	EOP	Four Strips - Effluent		EOP	Four Strips - Effluent		Relative Percent Difference (RPD)		*Percent Difference Between Percent Change
	Average EMC	Average EMC	Percent Change from EOP	Average EMC	Average EMC	Percent Change from EOP	RPD between EOP	RPD between Effluents	
Hardness as $CaCO_3$ (mg/L)	33.58	53.92	-60.60%	40.95	73.15	-78.60%	-20%	-30%	-18%
TDS (mg/L)	56.74	105.5	-85.90%	52.38	115.29	-120.10%	8%	-9%	-34%
TSS (mg/L)	69.38	32.68	52.90%	96.38	58.28	39.50%	-33%	-56%	-13%
TOC (mg/L)	8.27	12.23	-47.80%	8	29.7	-271.30%	3%	-83%	-224%
DOC (mg/L)	7.46	10.95	-46.70%	4.97	18.95	-281.30%	40%	-54%	-235%
Ammonia NH_3-N (mg/L)	0.58	0.62	-6.50%	0.45	0.91	-102.20%	25%	-38%	-96%
Nitrate NO_3-N (mg/L)	0.48	0.4	16.40%	0.43	0.64	-48.80%	11%	-46%	-65%
TKN (mg/L)	1.63	1.5	8.00%	1.95	8.21	-321.00%	-18%	-138%	-329%
Total Phosphorus (mg/L)	0.3	0.33	-9.80%	0.36	1.05	-191.70%	-18%	-104%	-182%
Ortho-P, Diss (mg/L)	0.09	0.25	-188.70%	0.07	0.65	-828.60%	25%	-89%	-640%
As, Diss (ug/L)	1.01	2.67	-165.70%	1.26	3.48	-176.20%	-22%	-26%	-11%
As, Total (ug/L)	1.8	3.21	-78.60%	2.62	4.52	-72.50%	-37%	-34%	6%
Cd, Diss (ug/L)	0.18	0.22	-22.60%	0.1	0.15	-50.00%	57%	38%	-27%
Cd, Total (ug/L)	0.46	0.31	32.70%	0.87	1.01	-16.10%	-62%	-106%	-49%
Cr, Diss (ug/L)	6.78	12.89	-90.00%	1.32	0.7	47.00%	135%	179%	137%
Cr, Total (ug/L)	11.79	19.01	-61.30%	12	4.99	58.40%	-2%	117%	120%
Cu, Diss (ug/L)	6.83	5.72	16.20%	10.53	11.48	-9.00%	-43%	-67%	-25%
Cu, Total (ug/L)	19.44	8.96	53.90%	41.57	18.23	56.20%	-73%	-68%	2%
Ni, Diss (ug/L)	2.16	2.42	-12.20%	1.2	1.62	-35.00%	57%	40%	-23%
Ni, Total (ug/L)	5.75	3.32	42.30%	11.27	5.99	46.90%	-65%	-57%	5%
Pb, Diss (ug/L)	0.98	0.98	0.00%	0.27	0.17	37.00%	114%	141%	37%
Pb, Total (ug/L)	4.82	1.81	62.40%	8.51	1.58	81.40%	-55%	14%	19%
Zn, Diss (ug/L)	17.64	13.3	24.60%	10.47	14.76	-41.00%	51%	-10%	-66%
Zn, Total (ug/L)	88.12	31.05	64.80%	168.93	39.23	76.80%	-63%	-23%	12%

Positive percentage numbers indicate average EMC reductions when compared to the EOP, and negative percentage numbers indicate average EMC increases when compared to the EOP.

* This value is the percentage point difference between the Percent Change from EOP. [Example Formula: (ORVTS Percent Change from EOP) – (RVTS Percent Change from EOP) = Percent Difference Between Percent Change]

As shown in Table 5-34, both ORVTS and RVTS stations located in Sacramento displayed various percent concentration differences between the EOP and the average EMC of the strips. Specific details are summarized below:

- For 8 of the 24 constituents compared, ORVTS control data displayed significantly higher (RPD greater than -25%) initial concentration values than that of the RVTS control data.
- For 15 of the 24 constituents compared, ORVTS test locations performed worse (RPD less than -25%) than that of the RVTS Study test locations in concentration reduction.
- For 12 of the 24 constituents compared, ORVTS percent differences between the percent change from EOP were worse (greater than -25 percentage point difference) than those of the RVTS Study locations.

Table 5-34B presents a further comparison at Sacramento using the calculated average EMCs between ORVTS and RVTS data analysis results for grouped strips approximately 4 to 6 meters in length. For both RVTS and ORVTS, the table presents the average EMC at the EOP, the average EMC for the appropriate strips, a comparison of concentration reduction or increase from EOP data results, relative percent differences and percentage point differences.

Table 5-34B: Concentration Reduction Comparison between Select RVTS and ORVTS Strips (4-6 m) at Sacramento Location

Constituent	Sacramento RVTS			Sacramento ORVTS			RVTS vs ORVTS		
	EOP	Two Strips - Effluent		EOP	Three Strips - Effluent		Relative Percent Difference (RPD)		*Percent Difference Between Percent Change
	Average EMC	Average EMC	Percent Change from EOP	Average EMC	Average EMC	Percent Change from EOP	RPD between EOP	RPD between Effluents	
Hardness as $CaCO_3$ (mg/L)	33.58	46.1	-37.30%	40.95	79.07	-93.10%	-20%	-53%	-56%
TDS (mg/L)	56.74	102.73	-81.00%	52.38	124.26	-137.20%	8%	-19%	-56%
TSS (mg/L)	69.38	35.84	48.30%	96.38	37.44	61.20%	-33%	-4%	13%
TOC (mg/L)	8.27	12.22	-47.80%	8	27.66	-245.80%	3%	-77%	-198%
DOC (mg/L)	7.46	11.28	-51.20%	4.97	20.31	-308.70%	40%	-57%	-258%
Ammonia NH_3-N (mg/L)	0.58	0.59	-2.20%	0.45	0.92	-105.20%	25%	-44%	-103%
Nitrate NO_3-N (mg/L)	0.48	0.44	7.40%	0.43	0.66	-52.70%	11%	-40%	-60%
TKN (mg/L)	1.63	1.62	0.80%	1.95	9.16	-369.60%	-18%	-140%	-370%
Total Phosphorus (mg/L)	0.3	0.4	-34.70%	0.36	1.14	-215.70%	-18%	-96%	-181%
Ortho-P, Diss (mg/L)	0.09	0.3	-233.20%	0.07	0.75	-976.20%	25%	-86%	-743%
As, Diss (ug/L)	1.01	2.77	-174.70%	1.26	3.95	-213.20%	-22%	-35%	-39%
As, Total (ug/L)	1.8	3.42	-89.80%	2.62	4.88	-86.40%	-37%	-35%	3%
Cd, Diss (ug/L)	0.18	0.24	-32.40%	0.1	0.15	-53.30%	57%	46%	-21%
Cd, Total (ug/L)	0.46	0.35	23.90%	0.87	1.24	-42.90%	-62%	-112%	-67%
Cr, Diss (ug/L)	6.78	15.04	-121.80%	1.32	0.72	45.70%	135%	182%	168%
Cr, Total (ug/L)	11.79	21.43	-81.80%	12	4.06	66.10%	-2%	136%	148%
Cu, Diss (ug/L)	6.83	5.7	16.60%	10.53	11.92	-13.20%	-43%	-71%	-30%
Cu, Total (ug/L)	19.44	8.71	55.20%	41.57	17.45	58.00%	-73%	-67%	3%
Ni, Diss (ug/L)	2.16	2.49	-15.30%	1.2	1.65	-37.80%	57%	41%	-23%
Ni, Total (ug/L)	5.75	3.38	41.30%	11.27	5.15	54.30%	-65%	-42%	13%
Pb, Diss (ug/L)	0.98	1	-2.30%	0.27	0.18	33.30%	114%	139%	36%
Pb, Total (ug/L)	4.82	1.79	62.90%	8.51	1.23	85.50%	-55%	37%	23%
Zn, Diss (ug/L)	17.64	12.34	30.10%	10.47	14.62	-39.60%	51%	-17%	-70%
Zn, Total (ug/L)	88.12	30.57	65.30%	168.93	28.96	82.90%	-63%	5%	18%

Positive percentage numbers indicate average EMC reductions when compared to the EOP, and negative percentage numbers indicate average EMC increases when compared to the EOP.

* This value is the percentage point difference between the Percent Change from EOP.

As shown in Table 5-34B, both ORVTS and RVTS 4-6 meter stations located in Sacramento displayed various percent concentration differences between the EOP and the average EMC of the strips. Specific details are summarized below:

- For 8 of the 24 constituents compared, ORVTS control data displayed significantly higher (RPD greater than -25%) initial concentration values than that of the RVTS control data.
- For 14 of the 24 constituents compared, ORVTS test locations performed worse (RPD less than -25%) than that of the RVTS Study test locations in concentration reduction.
- For 13 of the 24 constituents compared, ORVTS percent differences between the percent change from EOP were worse (greater than -25 percentage point difference) than those of the RVTS Study locations.

Yorba Linda SR-91:

Table 5-35 presents a comparison of the calculated average EMCs between ORVTS and RVTS data analysis results. For both RVTS and ORVTS, the table presents the average EMC at the EOP, the average EMC for all four strips, a comparison of concentration reduction or increase from EOP data results, relative percent differences and percentage point differences.

Table 5-35: Concentration Reduction Comparison between RVTS and ORVTS at Yorba Linda Location

Constituent	Yorba Linda RVTS			Yorba Linda ORVTS			RVTS vs ORVTS		
	EOP	Four Strips - Effluent		EOP	Four Strips - Effluent		Relative Percent Difference (RPD)		*Percent Difference Between Percent Change
	Average EMC	Average EMC	Percent Change from EOP	Average EMC	Average EMC	Percent Change from EOP	RPD between EOP	RPD between Effluents	
Hardness as $CaCO_3$ (mg/L)	36.17	39.33	-8.70%	38.6	57.49	-48.90%	-6%	-38%	-40%
TDS (mg/L)	88.36	91.69	-3.80%	48.65	81.15	-66.80%	58%	12%	-63%
TSS (mg/L)	79.96	110.63	-38.40%	43.65	55.78	-27.80%	59%	66%	11%
TOC (mg/L)	18.96	23.22	-22.50%	12.81	14.75	-15.10%	39%	45%	7%
DOC (mg/L)	17.13	20.69	-20.80%	9.19	11.43	-24.40%	60%	58%	-4%
Ammonia NH_3-N (mg/L)	0.76	0.46	39.90%	0.43	0.12	72.10%	55%	117%	32%
Nitrate NO_3-N (mg/L)	1.11	1.46	-32.20%	0.66	0.99	-50.00%	51%	38%	-18%
TKN (mg/L)	2.06	2.05	0.50%	1.77	1.49	15.80%	15%	32%	15%
Total Phosphorus (mg/L)	0.25	0.55	-124.00%	0.14	0.31	-121.40%	56%	56%	3%
Ortho-P, Diss (mg/L)	0.14	0.58	-321.50%	0.04	0.27	-575.00%	111%	73%	-254%
As, Diss (ug/L)	1.24	1.44	-15.80%	0.49	1.22	-149.00%	87%	17%	-133%
As, Total (ug/L)	1.95	2.34	-20.00%	1.08	1.96	-81.50%	57%	18%	-62%
Cd, Diss (ug/L)	0.25	0.19	21.70%	0.19	0.22	-15.80%	27%	-15%	-38%
Cd, Total (ug/L)	0.82	0.59	27.70%	0.45	0.53	-17.80%	58%	11%	-46%
Cr, Diss (ug/L)	2.86	3.1	-8.30%	2.45	1.37	44.10%	15%	77%	52%
Cr, Total (ug/L)	6.08	6.2	-2.00%	6.53	5.13	21.40%	-7%	19%	23%
Cu, Diss (ug/L)	22.02	16.52	25.00%	20.23	8.49	58.00%	8%	64%	33%
Cu, Total (ug/L)	44.92	29.43	34.50%	54.85	17.73	67.70%	-20%	50%	33%
Ni, Diss (ug/L)	5.26	3.54	32.80%	3.51	2.03	42.20%	40%	54%	9%
Ni, Total (ug/L)	7.12	6.18	13.20%	7.21	5.3	26.50%	-1%	15%	13%
Pb, Diss (ug/L)	2.68	2.28	14.90%	0.22	0.33	-50.00%	170%	149%	-65%
Pb, Total (ug/L)	20.78	18.14	12.70%	16.4	7.78	52.60%	24%	80%	40%
Zn, Diss (ug/L)	177.24	34.57	80.50%	174.1	15.62	91.00%	2%	76%	11%
Zn, Total (ug/L)	350.08	120.6	65.60%	551	50.36	90.90%	-45%	82%	25%

Positive percentage numbers indicate average EMC reductions when compared to the EOP, and negative percentage numbers indicate average EMC increases when compared to the EOP.

* This value is the percentage point difference between the Percent Change from EOP.

As shown in Table 5-35 both the ORVTS and RVTS stations located in Yorba Linda displayed various percent concentration differences between the EOP and the average EMC of the strips. Specific details are summarized below:

- For total zinc, ORVTS control data displayed a significantly higher (RPD greater than -25%) initial concentration value than that of RVTS control data.
- For all constituents, with the exception of hardness, ORVTS test locations performed comparable to (RPD within ±25%), or better than (RPD greater than 25%), the RVTS Study test locations in concentration reduction.
- For 8 of the 24 constituents compared, ORVTS percent differences between the percent change from EOP were worse (greater than -25 percentage point difference) than those of the RVTS Study locations.

Table 5-35B presents a further comparison at Yorba Linda using the calculated average EMCs between ORVTS and RVTS data analysis results for grouped strips approximately 4 to 6 meters in length. For both RVTS and ORVTS, the table presents the average EMC at the EOP, and the average EMC for the appropriate strips, a comparison of concentration reduction or increase from EOP data results, relative percent differences and percentage point differences.

Table 5-35B: Concentration Reduction Comparison between Select RVTS and ORVTS Strips (4–6 m) at Yorba Linda Location

Constituent	Yorba Linda RVTS			Yorba Linda ORVTS			RVTS vs ORVTS		
	EOP	Two Strips (4-6 meters) Effluent		EOP	Three Strips (6 meters) Effluent		Relative Percent Difference (RPD)		*Percent Difference Between Percent Change
	Average EMC	Average EMC	Percent Change from EOP	Average EMC	Average EMC	Percent Change from EOP	RPD between EOP	RPD between Effluents	
Hardness as $CaCO_3$ (mg/L)	36.17	38.33	-6.00%	38.6	68.9	-78.50%	-6%	-57%	-73%
TDS (mg/L)	88.36	97.9	-10.80%	48.65	100.59	-106.80%	58%	-3%	-96%
TSS (mg/L)	79.96	113.06	-41.40%	43.65	71.03	-62.70%	59%	46%	-21%
TOC (mg/L)	18.96	26.95	-42.10%	12.81	17	-32.70%	39%	45%	9%
DOC (mg/L)	17.13	24.68	-44.00%	9.19	13.38	-45.60%	60%	59%	-2%
Ammonia NH_3-N (mg/L)	0.76	0.41	46.00%	0.43	0.11	74.40%	55%	115%	28%
Nitrate NO_3-N (mg/L)	1.11	1.38	-24.50%	0.66	1.19	-79.80%	51%	15%	-55%
TKN (mg/L)	2.06	2.22	-7.90%	1.77	1.76	0.80%	15%	23%	9%
Total Phosphorus (mg/L)	0.25	0.62	-146.00%	0.14	0.4	-183.30%	56%	43%	-37%
Ortho-P, Diss (mg/L)	0.14	1	-614.30%	0.04	0.38	-841.70%	111%	90%	-227%
As, Diss (ug/L)	1.24	1.27	-2.30%	0.49	1.59	-225.20%	87%	-22%	-223%
As, Total (ug/L)	1.95	2.26	-15.70%	1.08	2.51	-132.70%	57%	-10%	-117%
Cd, Diss (ug/L)	0.25	0.19	24.60%	0.19	0.25	-33.30%	27%	-27%	-58%
Cd, Total (ug/L)	0.82	0.54	33.90%	0.45	0.68	-51.90%	58%	-23%	-86%
Cr, Diss (ug/L)	2.86	3.31	-15.70%	2.45	1.23	49.80%	15%	92%	66%
Cr, Total (ug/L)	6.08	6.08	0.00%	6.53	5.65	13.50%	-7%	7%	14%
Cu, Diss (ug/L)	22.02	17.62	20.00%	20.23	8.51	58.00%	8%	70%	38%
Cu, Total (ug/L)	44.92	27.64	38.50%	54.85	16.44	70.00%	-20%	51%	32%
Ni, Diss (ug/L)	5.26	3.83	27.10%	3.51	2.39	31.90%	40%	46%	5%
Ni, Total (ug/L)	7.12	6.21	12.70%	7.21	6.42	11.00%	-1%	-3%	-2%
Pb, Diss (ug/L)	2.68	2.56	4.30%	0.22	0.38	-72.70%	170%	148%	-77%
Pb, Total (ug/L)	20.78	20.3	2.30%	16.4	8.58	47.70%	24%	81%	45%
Zn, Diss (ug/L)	177.24	35.71	79.90%	174.1	14.72	91.50%	2%	83%	12%
Zn, Total (ug/L)	350.08	96.23	72.50%	551	48.96	91.10%	-45%	65%	19%

Positive percentage numbers indicate average EMC reductions when compared to the EOP, and negative percentage numbers indicate average EMC increases when compared to the EOP.

* This value is the percentage point difference between the Percent Change from EOP.

As shown in Table 5-35B both the ORVTS and RVTS 4-6 meter stations located in Yorba Linda displayed various percent concentration differences between the EOP and the average EMC of the strips. Specific details are summarized below:

- For total zinc, ORVTS control data displayed a significantly higher (RPD greater than -25%) initial concentration value than that of RVTS control data.
- For all constituents, with the exception of hardness and dissolved cadmium, ORVTS test locations performed comparable to (RPD within ±25%), or better than (RPD greater than 25%), the RVTS Study test locations in concentration reduction.
- For 10 of the 24 constituents compared, ORVTS percent differences between the percent change from EOP were worse (greater than -25 percentage point difference) than those of the RVTS Study locations.

Runoff Volume

Volume reductions for both the ORVTS and RVTS strips were calculated using the following method:

$$\%\ \text{Volume Reduction} = \frac{\dfrac{\text{Seasonal Vol@EOP}}{\text{DA@EOP}} - \dfrac{\text{Volume@(hwy + strip or swale)}}{\text{DA@(hwy + strip or swale)}}}{\dfrac{\text{Seasonal Vol@EOP}}{\text{DA@EOP}}}$$

Where:

Seasonal Vol@ EOP:	Total accepted volume measured at the EOP station during the monitored seasons
DA@ EOP:	Drainage area of EOP station
Seasonal Vol@ [Hwy+Strip or swale]:	Total accepted volume measured at [highway + strip or swale] station during the monitored seasons
DA@ [Hwy+Strip or swale]:	Drainage area of [highway+strip or swale] station

Results are presented in Table 5-36 below. Data used for runoff volume reduction calculations only included those storm events where data was accepted for both the test station and its corresponding control station. No statistical analyses were performed for these comparisons.

Table 5-36: Comparison of Runoff Volume Reductions between RVTS and ORVTS at Two Locations

Location Name	RVTS				ORVTS				RVTS vs ORVTS
	Station ID	Strip Width (ft)	Percent Slope	Percent Volume Reduction	Station ID	Strip Width (ft)	Percent Slope	Percent Volume Reduction	*Percent Difference Between Percent Volume Reductions
Sacramento	3-214	3.6	5	41.70%	3-362	9	10	97.10%	-55%
	3-215	15	33	71.70%	3-363	24.5	33	98.90%	-27%
	3-216	21.7	33	78.70%	3-364	23.5	33	97.10%	-18%
	3-217	27.6	33	77.10%	3-365	24.5	33	99.00%	-22%
Yorba Linda	12-226	5.9	14	36.60%	12-346	10	4	69.50%	-33%
	12-227	16.1	14	20.90%	12-347	21	6	69.40%	-49%
	12-228	24.9	14	21.20%	12-348	21	4	96.00%	-75%
	12-229	42.7	14	62.20%	12-349	21	3	92.30%	-30%

* This value is the percentage point difference between the Percent Change from EOP.

As shown in Table 5-36 both the ORVTS and RVTS locations displayed varying percent volume reductions between the control and test stations, ranging from 20% to 99%. Volume reductions at the ORVTS locations consistently exceeded volume reductions at the RVTS locations by more than 25 percentage points with the exception of Sacramento's stations 3-216 and 3-217, which exceeded the RVTS location by 18 and 22 percentage points respectively.

5.7.2 ORVTS Study vs Highway Characterization Study

Concentration

Per the Caltrans Discharge Characterization Study Report (Caltrans, 2003d), summary statistics were calculated to characterize stormwater runoff quality from a variety of Caltrans facilities. This subsection presents a comparison of highway facilities characterization data to the results of this Study. Table 5-37 presents Study comparison data. Listed are the median constituent concentrations for highway facility runoff monitored per the Caltrans Discharge Characterization Study, and the median constituent concentrations from the ORVTS Study test strips and swales.

Table 5-37: Median Concentration Comparison to Statewide Characterization Studies Data

Constituent	Caltrans 2003 Characterization Study Median (mg/L)	ORTVS Study - Strips		ORTVS Study - Swales		Relative Percent Difference (RPD)	
		Strips Test Median (mg/L)	Percent Change from 2003 Median	Swale Test Median (mg/L)	Percent Change from 2003 Median	RPD Strips and 2003 Median	RPD Swales and 2003 Median
Conventional Constituents							
Hardness	26.90	44.00	-63.6%	44.00	-63.6%	-48.2%	-48.2%
TOC	15.30	14.40	5.9%	6.60	56.9%	6.1%	79.5%
DOC	13.10	11.00	16.0%	5.70	56.5%	17.4%	78.7%
Sediments							
TDS	60.30	66.00	-9.5%	55.00	8.8%	-9.0%	9.2%
TSS	59.10	28.50	51.8%	10.00	83.1%	69.9%	142.1%
Nutrients							
Ammonia (NH_3-N)	0.77	0.22	71.4%	0.03	96.10%	111.1%	185.0%
Nitrate as Nitrogen (NO_3-N)	0.60	0.32	46.7%	0.00	100.00%	60.9%	200.0%
TKN	1.40	1.70	-21.4%	0.64	54.29%	-19.4%	74.5%
Total Phosphorus	0.18	0.42	-133.3%	0.21	-16.67%	-80.0%	-15.4%
Dissolved ortho-P	0.06	0.27	-350.0%	0.00	100.00%	-127.3%	200.0%
Metals (Total and Dissolved)							
Arsenic (As, dissolved)	0.70	1.50	-114.3%	0.60	14.29%	-72.7%	15.4%
Arsenic (As, total)	1.10	2.30	-109.1%	0.80	27.27%	-70.6%	31.6%
Cadmium (Cd, dissolved)	0.13	0.10	23.1%	0.10	23.08%	26.1%	26.1%
Cadmium (Cd, total)	0.44	0.19	56.8%	0.17	61.36%	79.4%	88.5%
Chromium (Cr, dissolved)	2.20	0.90	59.1%	2.70	-22.73%	83.9%	-20.4%
Chromium (Cr, total)	5.80	3.75	35.3%	4.10	29.31%	42.9%	34.3%
Copper (Cu, dissolved)	10.20	8.00	21.6%	7.30	28.43%	24.2%	33.1%
Copper (Cu, total)	21.10	15.00	28.9%	11.00	47.87%	33.8%	62.9%
Lead (Pb, dissolved)	1.20	0.20	83.3%	0.20	83.33%	142.9%	142.9%
Lead (Pb, total)	12.70	3.75	70.5%	2.00	84.25%	108.8%	145.6%
Nickel (Ni, dissolved)	3.40	1.35	60.3%	0.96	71.76%	86.3%	111.9%
Nickel (Ni, total)	7.70	4.20	45.5%	1.80	76.62%	58.8%	124.2%
Zinc (Zn, dissolved)	40.40	12.00	70.3%	11.00	72.77%	108.4%	114.4%
Zinc (Zn, total)	111.20	35.50	68.1%	28.90	74.01%	103.2%	117.5%

Source: *Caltrans Discharge Characterization Study Report; Table 3-2: Median Constituent Concentration from Summary Statistics for Highway Facilities: Statewide Characterization Studies Data Monitoring Years 2000/01-2002/03 (Caltrans 2003).*

As shown in Table 5-37, strips and swales in the ORVTS Study displayed various percent differences in water quality improvement when compared to the Caltrans Characterization Study median concentrations. Specific details are summarized below:

- For 19 of the 24 compared constituents, ORVTS strips showed comparable (RPD greater than ±25%), or better (RPD greater than 25%) water quality when compared to the 2003 Characterization Study.
- For all constituents, with the exception of hardness, ORVTS swales showed comparable (RPD greater than ±25%), or better (RPD greater than 25%) water quality when compared to the 2003 Characterization Study.

5.7.3 ORVTS Study vs BMP Pilot Study

The BMP Retrofit Pilot Program (BMP Program) designed and constructed BMPs, and assessed the constituent removal of the various types of BMPs (i.e., media filters, biofiltration, infiltration devices, extended detention basins, drain inlet inserts, wet basin, oil-water separators, and continuous deflective separation units). The *BMP Retrofit Pilot Program Final Report* (Caltrans 2004) presents the activities, findings, results, and evaluations for that project. The Carlsbad (Palomar) swale was a site studied during the BMP Program. This swale is also one of the GRVTS locations monitored during the ORVTS Study. Results from the ORVTS Study were compared to those from the BMP Program for this location.

The primary difference between setups for the Carlsbad (Palomar) swale location in the BMP Program and the GRVTS location in the ORVTS Study includes:

- Vegetation cover characteristics (vegetation type, height, density, and strip width, etc.). For the BMP Program, the swale was constructed as a vegetated swale with grass and forbs. Over time, however, adjacent ornamental vegetation (*C. edulis*) encroached into the swale area and is now the dominant species, as identified during the ORVTS Study.

Using the analytical data from both the BMP Program and data from the 2009-2012 ORVTS Study, the average EMCs for each station of this location were calculated for each constituent.

Concentration

Carlsbad I-5: A comparison of the calculated average EMCs between the ORVTS Study and the BMP Program is presented in Table 5-38. The table presents for both the BMP Program and the ORVTS Study, the average EMC at the EOP, and the average EMC at the swale effluent. A concentration reduction or increase is identified in comparison to the corresponding EOP data results.

Table 5-38: Concentration Reduction Comparison Between BMP Program and ORVTS Study at Carlsbad (Palomar) Swale

Constituent	BMP Retrofit Pilot Program			ORVTS Study			ORVTS vs BMP Retrofit Pilot Program		
	EOP	Swale		EOP	Swale		Relative Percent Difference (RPD)		Percent Difference Between Percent Change
	Average EMC	Average EMC	Percent Change from EOP	Average EMC	Average EMC	Percent Change from EOP	RPD between EOP	RPD between Effluents	
Hardness as $CaCO_3$ (mg/L)	40.9	33.0	19.3%	37.16	46.00	-23.8%	9.6%	-32.9%	-43.1%
TDS (mg/L)	76.3	96.6	-26.6%	64.68	97.54	-50.8%	16.5%	-1.0%	-24.2%
TSS (mg/L)	86.0	35.6	58.6%	69.47	12.08	82.6%	21.3%	98.7%	24.0%
TOC (mg/L)	14.7	14.8	-0.5%	10.65	11.91	-11.8%	32.0%	21.6%	-11.3%
DOC (mg/L)	12.8	13.0	-1.3%	7.58	8.32	-9.8%	51.2%	43.9%	-8.5%
TKN (mg/L)	2.4	1.9	19.8%	1.82	0.79	56.6%	27.5%	82.5%	36.8%
Total Phosphorus (mg/L)	0.4	0.4	4.5%	0.23	0.28	-21.7%	54.0%	35.3%	-26.2%
As, diss (ug/L)	0.9	0.6	26.1%	0.54	0.47	13.0%	50.0%	24.3%	-13.1%
As, total (ug/L)	2.8	2.2	20.8%	1.34	0.62	53.7%	70.5%	112.1%	32.9%
Cd, diss (ug/L)	0.2	0.2	-7.1%	0.15	0.13	13.3%	28.6%	42.4%	20.4%
Cd, total (ug/L)	0.8	0.5	43.4%	0.52	0.17	67.3%	42.4%	98.5%	23.9%
Cr, diss (ug/L)	4.3	3.8	11.0%	5.95	4.53	23.9%	-32.2%	-17.5%	12.9%
Cr, total (ug/L)	6.4	4.9	22.4%	12.39	5.96	51.9%	-63.8%	-19.5%	29.5%
Cu, diss (ug/L)	16.9	18.8	-11.1%	17.19	6.93	59.7%	-1.7%	92.3%	70.8%
Cu, total (ug/L)	37.4	10.3	72.5%	70.91	11.52	83.8%	-61.9%	-11.2%	11.3%
Pb, diss (ug/L)	3.5	2.6	26.0%	0.44	0.28	36.4%	155.3%	161.1%	10.4%
Pb, total (ug/L)	46.9	24.0	48.8%	37.63	5.12	86.4%	21.9%	129.7%	37.6%
Ni, diss (ug/L)	2.6	2.1	16.5%	2.82	1.00	64.5%	-8.1%	71.0%	48.0%
Ni, total (ug/L)	6.5	3.6	44.0%	8.49	1.62	80.9%	-26.6%	75.9%	36.9%
Zn, diss (ug/L)	61.1	36.4	40.4%	44.89	14.96	66.7%	30.6%	83.5%	26.3%
Zn, total (ug/L)	203.5	82.0	59.7%	255.58	32.38	87.3%	-22.7%	86.8%	27.6%

NA = Not available. The average EMCs at both the EOP and the effluent stations are below the detection limits; therefore, percent average EMC reductions could not be calculated.

Positive percentage numbers indicate average EMC reductions when compared to the EOP, and negative percentage indicate average EMC increases when compared to the EOP.

*This value is the percentage point difference between the Percent Change from EOP.

As shown in Table 5-38, both the BMP Program and the ORVTS Study stations at the Carlsbad (Palomar) swale show various percent concentration differences between the EOP and swale effluent. Specific details are summarized below:

- For 4 of the 21 constituents compared, ORVTS control data displayed a significantly higher (RPD greater than -25%) initial concentration value than that of BMP Retrofit Pilot Study control data.

- For all constituents compared (with the exception of hardness), ORVTS swale locations performed comparable to (RPD within ±25%), or better than (RPD greater than 25%), or better than, the BMP Retrofit Pilot Study in concentration reduction (RPD greater than -25%).
- For almost all of the compared constituents (with the exception of hardness and total phosphorus), ORVTS swale locations displayed comparable or greater percentage point differences (a greater than 25 percentage point difference) than those of the BMP Retrofit Pilot Study.

SECTION 6 CONCLUSIONS

The following subsections present general conclusions based on the tiered analysis structure presented in Section 5, which was performed from data collected during the 2009-2012 monitoring seasons of the ORVTS Study. As detailed in Section 5.3, all data points collected under the entire Study period were not included in the statistical analysis comparisons. Inclusion of these additional data points may affect the statistical results causing some of the reductions and/or increases in concentrations, constituent loading, and runoff volume to be statistically significant where they currently may not be exhibited as such.

Primary analyses included the comparison of the average EMC concentrations, runoff volumes, and constituent loading for grouped strip or swale stations against that of corresponding EOP stations. All sites monitored under this Study contained an adjacent EOP station at each location. Secondary analyses included the comparison of the average EMC concentrations for grouped succulents, groundcover, or low shrubs with that of the grouped EOP stations. Secondary analysis also included the comparison of the average EMC concentrations for grouped short strip widths and long strip widths with that of the grouped EOP stations. Overall observations and conclusions of the Study are summarized below.

For the statistical tables included in this section, the following legend of coloring shall apply:

Standard Table Legend:

Red = Statistically significant increase at a 90-percent confidence level

Green = Statistically significant reduction at a 90-percent confidence level

Gray = Results not statistically significant at a 90-percent confidence level

6.1 STUDY COMPARISONS

As described in Sections 1.2 and 5.7, past studies performed by Caltrans serve as learning experiences which help shape future study questions. Section 5.7 presented past study data in comparisons with previously collected water quality information. The following subsections summarize those results which were based on a rudimentary comparison of data. A thorough statistical comparison would be required to provide more conclusive information.

6.1.1 ORVTS Study vs RVTS Study

Concentration - Sacramento I-5 Sites:

Comparison using data from Sacrament test strips revealed that the RVTS stations planted with grasses and forbs performed comparable to the ORVTS strip stations planted with ornamental vegetation (see Table 5-34 and 5-34B). Comparable performance is noted here by observing that RVTS stations provided concentration reductions for only 4 to 13 percent of additional constituents from that of the ORVTS stations (11 versus 8 constituent concentration reductions for all strips; 10 versus 9 constituent concentration reductions for 4-6 meter strips).

Concentration – Yorba Linda SR-91 Sites:

Comparison using data from Yorba Linda test strips revealed that the RVTS stations planted with grasses and forbs performed comparable to that of the ORVTS stations planted with ornamental vegetation. Comparable performance is noted here by observing that RVTS stations provided concentration reductions for only 4 to 8 percent of additional constituents from that of the ORVTS stations (12 versus 11 constituent concentration reductions for all strips; 12 versus 10 constituent concentration reductions for 4-6 meter strips).

Runoff Volume Reduction

Comparison using data from the RVTS Study revealed that the ORVTS stations provided greater reduction in runoff volumes when compared to the RVTS stations. The improvement in runoff volume reduction is likely due to soil amendments and more bioturbation by the ornamental roots.

6.1.2 ORVTS Study vs Highway Characterization Study

Concentration

When comparing the Characterization Study summary statistics to that of the median concentrations for the ORVTS test sites, confirmed reductions are seen for the majority of constituents with the exception of hardness, TDS, TKN, total phosphorous, dissolved ortho-phosphate, dissolved and total arsenic, and dissolved chromium (See Table 5-37). These observations are in conformance with the overall observations of the Study, which suggest that the vegetation may increase nutrient and arsenic concentrations in runoff discharge. Furthermore, the Caltrans Discharge Characterization Study Report identified that said constituents are low priority for continued monitoring based on their relative low concentrations measured in runoff, their correlations with other parameters, or the lack of an obvious transportation-related source.

6.1.3 ORVTS Study vs BMP Pilot Study

Concentration – Carlsbad I-5 Sites:

Comparison using the data from the BMP Retrofit Pilot Study revealed that the Pilot Study swales planted with grasses and forbs performed comparable to that of the ORVTS swales planted with ornamental vegetation (See Table 5-38). Comparable performance is noted here by observing that ORVTS stations provided concentration reductions for only 5 percent of additional constituents from that of the BMP Retrofit Pilot Study (17 versus 16 constituent concentration reductions).

6.2 FINDINGS

The fundamental conclusion from the ORVTS Study's statistical analyses is that the incorporation of ornamental vegetation into highway drainage design provides effective treatment for constituent reduction by providing benefits via reduction of runoff volume and constituent loading. A qualitative summary of the Study's results are presented in Table 6-1.

Table 6-1: Qualitative Summary of ORVTS Study Data

General Highway Runoff	Swales	Strips			Succulents	Groundcover	Low Shrubs
		In General	Short	Long			
Runoff Constituent Concentration Reduction							
Conventionals							
Sediments							
Nutrients							
Dissolved Metals							
Total Metals							
Runoff Volume Reduction							
Volume							
Runoff Constituent Load Reduction							
Conventionals							
Sediments							
Nutrients							
Dissolved Metals							
Total Metals							

Summary Color Legend					
Mixed Colors	Generally No Statistical Change	Majority Red	Generally a Statistical Increase	Majority Green	Generally a Statistical Decrease

Key findings for the Study's objectives, as summarized in Table 6-1, are described below.

- Effectiveness of strips and swales planted with ornamental vegetation in treating highway runoff in terms of constituent concentration, runoff volume, and constituent load reduction:
    - Strips and swales planted with ornamental vegetation yields statistically mixed results for reduction of constituent concentrations in highway runoff.
    - Strips and swales planted with ornamental vegetation yields statistically mixed results for reduction in the volume of highway runoff.
        - Swales planted with ornamental vegetation did not exhibit a statistically significant change in volume reduction. Smaller sample sizes for the grouped swales may affect statistical results causing changes in volume to show no statistically significant difference.
        - Strips planted with ornamental vegetation exhibit statistically significant reductions in the volume of highway runoff.
    - Strips and swales planted with ornamental vegetation yields statistically significant reductions in constituent loadings in highway runoff.

- Impact of ornamental vegetation types (succulents, groundcover and low shrubs) on the treatment performance of strips planted with ornamental vegetation in terms of constituent concentration, runoff volume, and constituent load reduction:
    - Ornamental vegetation yields statistically mixed results for reduction of constituent concentrations in highway runoff.
    - Ornamental vegetation yields statistically significant reductions in the volume of highway runoff.
    - Ornamental vegetation yields statistically significant reductions in constituent loadings in highway runoff.
- Impact of strip width on the treatment performance of strips planted with ornamental vegetation in terms of constituent concentration, runoff volume, and constituent load reduction:
    - Long and short strip widths planted with ornamental vegetation yields statistically mixed results for reduction of constituent concentrations in highway runoff.
    - Long and short strip widths planted with ornamental vegetation yields statistically significant reductions in the volume of highway runoff
    - Long and short strip widths planted with ornamental vegetation yields statistically significant reductions in constituent loadings in highway runoff.
- Study Comparisons:
    - Ornamental vegetation's performance with respect to constituent reduction is comparable to that of grasses and forbs.
    - Ornamental vegetation's performance with respect to volume reduction is better than that of grasses and forbs.
    - Ornamental vegetation displayed improved water quality with respect to constituent concentration, than that of the 2003 Discharge Characterization Study.

Concentration Reductions

Concentration reductions in the ORVTS Study varied depending on the constituent of interest. The mixed results suggest that use of ornamental vegetation in highway design may actually increase the concentration of some constituents, such as nutrients and arsenic. Potential sources for these increases may be from the plants themselves, soil texture, irrigation water (i.e. hardness), and added soil amendments (i.e. mulch). However, the significant reduction of constituent loads and runoff volumes observed within the Study enhance the benefits of this BMPs treatment effectiveness on reducing concentrations via runoff volume reduction.

Loading Reductions

Loading reductions were observed in the ORVTS Study for all vegetation types, with the exception of swales planted with ornamental vegetation. Runoff volume reduction occurring within the ornamental vegetation, via infiltration or losses, is the primary contributor to the observed reductions.

Runoff Volume Reductions

Runoff volume reductions were observed in the ORVTS Study for all vegetation types, with the exception of swales planted with ornamental vegetation. As discussed in Section 5.5, the sample size for swales was significantly smaller than for the other analyzed BMPs, and may have affected the observed results. The overall significant reduction in runoff volume is key to both constituent concentration and loading reductions. Potential sources for runoff volume reductions may be soil amendments, plant storage systems (i.e. stem, leaf, and root), evapotranspiration, bioturbation and infiltration.

SECTION 7 FUTURE CONSIDERATIONS

Below is a summary of future considerations.

- This ORVTS Study collected data for the 2009-2010, 2010-2011, and the 2011-2012 monitoring seasons, producing a significant amount of data. However, data for the partial 2011-2012 monitoring season were not incorporated into the analysis comparisons that were conducted for this report. Additionally, data regarding events where the EOP registered flow but the test strips or swale stations did not, were included in the statistical comparisons for the EOP data set, but were not included for the corresponding strip or swale data set as zero or undetected flow. Zero or undetected flows were likely due to 100% losses (i.e. losses due to infiltration, interception, surface storage, and evapotranspiration). Consideration should also be given to incorporating these additional data points in the analyses for this Study. Inclusion of these additional data points may affect the statistical results causing some of the reductions in concentrations, volume and runoff to become statistically significant, particularly for swales.
- Future data assessments may include comparing the characteristics of the storms for which flow, rainfall, and water quality data were collected in the ORVTS study to the characteristics of storms that are typical of each study location's general vicinity. Storm characteristics to be compared might include frequency of occurrence, intensity, and duration. This information may help put the findings into context with respect to the representativeness of common or frequent storms that occur throughout the various study locations.
- For future studies, it is critical to establish accurate survey data of tributary drainage areas. As-built data is often outdated and insufficient to accurately measure the drainage area. Therefore, accurate survey data is critical for preventing irregularities in volumetric runoff coefficients (i.e. runoff volume divided by rainfall volume).
- Total nitrogen is calculated as the sum of nitrate, nitrite, and TKN. Nitrate, nitrite, and TKN are among the monitored constituents for this study; however, total nitrogen was not calculated or assessed for this report. Future assessments or reporting may consider assessing total nitrogen data.
- Based on the complications faced in obtaining accurate flow data during the Study, it is recommended for future consideration to develop a program-wide QA/QC process for obtaining and reviewing flow data for accuracy and representativeness.
- Locations where AC dike or curb is removed, and vegetated slopes retrofitted to receive highway runoff sheet flow, should consider typical existing roadway drainage design which tends to concentrate flows at the edge of pavement, preventing flows from being distributed evenly across the BMP. Ideally, roadway drainage should be designed to distribute flows evenly across the BMPs. BMP design should take into account finish grade elevations of the top of mulch to ensure the mulch is lower than the pavement or shoulder edge and, therefore, does not impede flow across the BMP.

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