ORNAMENTAL ROADSIDE VEGETATED TREATMENT SITES (ORVTS) STUDY

Final 2009-2010 SUMMARY REPORT

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EXECUTIVE SUMMARY

Objectives

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

- Evaluate the effectiveness of strips and swales planted with ornamental vegetation in treating highway runoff in terms of pollutant concentration, runoff volume, and pollutant load reduction.
- Determine the impact of strip width and ornamental vegetation type on the treatment performance of strips planted with ornamental vegetation in terms of pollutant concentration, runoff volume, and pollutant load reduction.
- Evaluate the variability of similar and adjacent strips planted with ornamental vegetation at the same locations in terms of pollutant concentration, runoff volume, and pollutant load reduction.
- Assess variability between ornamental vegetation and grasses and forbs in treating highway runoff by comparing the results from the ORVTS Study and previous studies such as the Roadside Vegetated Treatment Sites (RVTS) Study and the BMP Retrofit Pilot 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 pollutant 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 vegetation. The ORVTS Study is comprised of two types of locations: the Groundcover Roadside Vegetated Treatment Sites (GRVTS) at seven locations and the Expanded Roadside Vegetated Treatment Sites (ERVTS) at two locations. The GRVTS locations were selected to assess the treatment performance (in terms of concentration, volume, and load reduction) of roadside slopes having established ornamental vegetation (more than two years since planting). The ERVTS locations were selected to assess the treatment performance of roadsides slopes having newly established ornamental vegetation. All locations are in California. The two ERVTS include vegetated strips located in Sacramento and Yorba Linda. Five of the seven GRVTS include vegetated strips in the following locations: Napa, San Mateo, Camarillo, Westminster, and San Diego. The other two GRVTS include vegetated swales in Newbury Park and Carlsbad (Palomar). The 2009-2010 season was the first monitoring season for this study.

Methodology

At each ERVTS location, there is one Edge-of-Pavement (EOP) station and four strip stations with various strip widths and/or ornamental vegetation types. Flow-weighted composite samples were collected and analyzed for specific constituents determined as the pollutants-of-concern (POCs) for this study. At each GRVTS strip location, there is one EOP station and two strip stations with identical strip widths 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. This study setup assumes that the EOP stations represent highway runoff (i.e., control) and the strip and swale stations represent the ORVTS effluent (i.e., treatment). Various comparisons were performed on selected stations to address the various study objectives.

Monitoring and sampling of storm water at the ORVTS were conducted during the 2009-2010 wet season (October 2009 to April 2010). The collection systems and monitoring equipment were installed and tested at each site before the beginning of the wet season. Regular site maintenance was performed to maintain the proper functionality of equipment and vegetation growth throughout the season. Quarterly vegetation assessments were conducted from July 2009 to August 2010.

Initially, a total of 29 stations from the nine ORVTS locations were configured for monitoring and sampling, targeting a goal of eight to twelve storm events for the monitoring season. At each monitoring location, rain gauges, flow meters, and automated samplers were deployed to record rainfall and flow data and collect flow-weighted composite samples for laboratory analyses. Detailed equipment setups at each location and the sampling protocol are presented in the *Operations, Maintenance, and Monitoring Plan, Ornamental Roadside Vegetated Treatment Sites* (ORVTS) *Study* (ORVTS OM&M Plan) (Caltrans, 2009). During the season, monitoring at all three stations at the San Diego GRVTS was discontinued after the first four storms due to substantial recurring bypass issues (where highway runoff was being inadvertently directed away from the study strips) that were not apparent when the location was selected. One strip station at the San Mateo GRVTS was also discontinued after the first three storms due to similar issues. At the end of the season, a comprehensive data review was performed on all hydrologic (flow and rainfall) and analytical data collected from all monitored sites to identify representative data for data assessments. Based on the data review, 17 strip and swale stations and eight EOP stations at eight ORVTS generated representative data.

Various data analyses were performed on the data qualified from the data review process. Analyses included statistical analyses on concentration and load data on an event-by-event basis. Analyses on runoff volume and load data were performed on both an event-by-event basis and a seasonal basis. Based on the results of these data analyses, various comparisons were performed between the strip/swale stations and the EOP stations, and between the strip/swale stations themselves. These comparisons were used to address the various study questions.

Overall Findings

1) Effectiveness of strips planted with ornamental vegetation in treating highway runoff
Strips planted with ornamental vegetation appear to be effective in reducing concentrations of some constituents (total cadmium, dissolved chromium, dissolved and total copper, dissolved and total zinc, and total lead). However, the strips appear to have caused concentration increases of some constituents (dissolved arsenic, total phosphorus, and dissolved ortho-phosphate). Almost all 15 strips showed substantial load reductions for all constituents except for total phosphorus and dissolved ortho-phosphate. These load reductions are mostly due to all 15 strips having substantial volume reductions (with season-based percent volume reductions ranging from 53.3 to 98.7 percent).

2) Effectiveness of swales planted with ornamental vegetation in treating highway runoff
Swales planted with ornamental vegetation appear to be effective in reducing concentrations of some constituents (ammonia, nitrate, nitrite, TKN, total arsenic, total cadmium, dissolved and total copper, total lead, dissolved nickel, dissolved and total zinc). However, the swales appear to have caused concentration increases of total phosphorus and dissolved ortho-phosphate. Both swales appear to be effective in reducing pollutant load for all constituents except for TSS, total phosphorus, dissolved ortho-phosphate, total cadmium, and dissolved lead. These load reductions are mostly due to substantial volume reductions at both swales (with season-based percent volume reductions of 71.9 and 95.9 percent). It should be noted that only one data point was available for data assessments on load at the Carlsbad (Palomar) swale location; therefore, confidence on load results at this location is low.

3) Impact of strip width on effectiveness of strips planted with ornamental vegetation in treating highway runoff
Overall, whether or not a longer strip provides better concentration reduction appears to be dependent on the constituent of interest, as well as the location. This may be due to location-specific characteristics other than strip width such as average annual daily traffic (AADT), soil composition, etc. A more detailed understanding of this may be gained as more data become available.

Longer strips do not appear to provide exceptionally better volume or load reduction than shorter strips.

4) Impact of ornamental vegetation type on the effectiveness of strips planted with ornamental vegetation in treating highway runoff
Overall, it appears that whether or not a particular ornamental vegetation type provides exceptionally better concentration reduction than any other type depends on the constituent of interest, as well as the location. This may be due to location-specific characteristics other than ornamental vegetation type, such as AADT, soil composition, etc. A more detailed understanding of this may be gained as more data becomes available.

Some ornamental vegetation types appear to provide equivalent or better volume reduction than other types. The observed differences may be due to location-specific characteristics other than ornamental vegetation type, such as soil type or storm characteristics. Overall, good to excellent volume reduction was consistently observed for all ornamental vegetation types.

Whether or not a particular ornamental vegetation type provides exceptionally better load reduction than any other type appears to sometimes depend on the constituent of interest, as well as the location. This may be due to location-specific characteristics other than ornamental vegetation type, such AADT, soil composition, soil type, storm characteristics, etc. A more detailed understanding of this may be gained as more data become available.

5) Assessment of variability between similar and adjacent strips planted with ornamental vegetation in treating highway runoff

Overall, although differences in concentration, volume, and load reductions were observed between duplicate stations, most differences were not found to be statistically significant, or were fairly small. If this trend continues as more data becomes available, it may provide further understanding of the comparisons being conducted for the other ORVTS study questions.

6) Assessment of variability between ornamental vegetation and grasses and forbs in treating highway runoff

Overall, the ORVTS Study's ornamental vegetation appears to have provided equivalent or better concentration reductions (or small concentration increases) than the grasses and forbs assessed in previous studies. The ornamental vegetation provided better volume reductions. Although load reductions were not specifically assessed, it is expected that ornamental vegetation would also provide better load reductions given their performance for concentration and volume reduction.

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SECTION 1 INTRODUCTION

1.1 OBJECTIVES

The Ornamental Roadside Vegetated Treatment Sites (ORVTS) Study was implemented to assess the treatment performance of roadside slopes planted with ornamental vegetation in regards to reductions of runoff volume and pollutant concentration and load. The objectives of this study are to:

- Evaluate the effectiveness of strips and swales planted with ornamental vegetation in treating highway runoff in terms of pollutant concentration, runoff volume, and pollutant load reduction.
- Determine the impact of strip width and ornamental vegetation type on the treatment performance of strips planted with ornamental vegetation in terms of pollutant concentration, runoff volume, and pollutant load reduction.
- Evaluate the variability of similar and adjacent strips planted with ornamental vegetation at the same locations in terms of pollutant concentration, runoff volume, and pollutant load reduction.
- Compare data from the ORVTS Study, during which the study areas were planted with ornamental vegetation, to data from previous studies such as the Roadside Vegetated Treatment Sites (RVTS) Study and the BMP Retrofit Pilot Program (BMP Program) when the study areas were planted with grasses and forbs.

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

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 pollutants. The RVTS Study (Caltrans, 2008b) was a water quality monitoring project conducted by the California Department of Transportation (Caltrans) from 2000 to 2008 designed to evaluate the pollutant 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. This study concluded that roadside slopes planted with standard forbs and grasses result in large reductions in concentration and load for several constituents-of-concern in highway runoff. Based on the findings of the RVTS Study (Caltrans, 2008b) vegetated roadside slopes were suggested as an effective best management practice (BMP) for treating freeway runoff in terms of contaminant concentration and load reduction.

The Roadside Erosion Control and Management 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. This 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. This 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 this study was ornamental vegetative box plots were 100-percent effective treatment on controlling overland flow for all the flows tested in the experiment. This was accomplished through infiltration and vegetative absorption due to root channels and surface organic matter. Differences amongst vegetation types and measured parameters of water quality were not observed; therefore, future studies were recommended. These previous studies served as learning experiences and established future study questions that lead to the development of the ORVTS Study.

The ORVTS Study is comprised of two types of study sites: the Expanded Roadside Vegetated Treatment Sites (ERVTS); and the Groundcover Roadside Vegetated Treatment Sites (GRVTS). The ERVTS locations were selected to assess the treatment performance of roadside slopes with newly established ornamental vegetation planted in summer 2009. The GRVTS locations were selected to assess the treatment performance of roadside slopes with existing ornamental vegetation planted prior to summer 2009. In addition, the ERVTS were also selected to provide a comparison of the treatment potential from ornamental vegetation to the grasses and forbs studied in the original RVTS Study (Caltrans, 2008b), thus providing a side-by-side comparison.

1.3 PROJECT OVERVIEW

The 2009-2010 season was the first monitoring season for this study. Initially, a total of 29 stations from nine project locations (two ERVTS and seven GRVTS) were configured for monitoring and sampling, targeting a goal of 8 to 12 storm events for the monitoring season. The monitoring stations are distributed throughout California in the following counties: Napa, Orange, Sacramento, San Diego, San Mateo, and Ventura. Detailed information on the selected locations is presented 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* (Site Selection Technical Memorandum) (Caltrans, 2007). At each monitoring location, rain gauges, flow meters, and automated samplers were deployed to record rainfall and flow data and to collect flow-weighted composite samples for laboratory analyses. Detailed information on the monitoring procedures and protocols is presented in the *Operations, Maintenance, and Monitoring Plan, Ornamental Roadside Vegetated Treatment Sites (ORVTS) Study* (ORVTS OM&M Plan) (Caltrans, 2009).

Various assessments were performed on the collected information that included rainfall and flow data, analytical data, and results of vegetation surveys. Various comparisons were performed between strip/swale stations and Edge-of-Pavement (EOP) stations, and between the strip/swale stations themselves. These comparisons help to evaluate the performance of the vegetated strips and swales in treating storm water runoff. They also help to evaluate if any characteristics (e.g., strip width, vegetation type) of the vegetated strips and swales impact their performances. This *ORVTS 2009-2010 Summary Report* is the first end-of-season report written for the ORVTS Study. This report documents the monitoring activities, findings, data assessments, and conclusions of the 2009-2010 monitoring and sampling at the ORVTS.

1.4 PROJECT LOCATIONS

After evaluating 50 potential locations for GRVTS, 13 locations were recommended for the 2009-2010 monitoring season. Further information on each recommended location is provided in Appendix B. Prior to the start of the wet season, these locations were inspected for barriers or

current construction activities. Seven locations from the 13 recommended locations were selected for GRVTS application.

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.

Detailed information of these ERVTS and GRVTS is described in the following sub-sections. Table 1-1 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 1-1 shows the location of each selected ORVTS. Table 1-2 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 1-1: ORVTS Vegetation Identification Guide

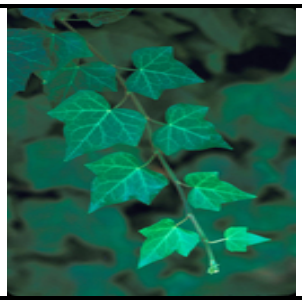
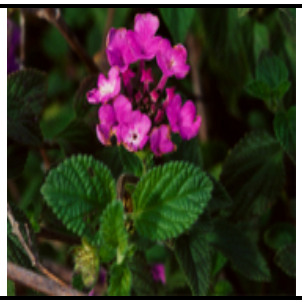
			
Binomial Name: *Baccharis pilularis*	Binomial Name: *Carpobrotus edulis*	Binomial Name: *Hedera helix*	Binomial Name: *Iva hayesiana*
Text Abbreviation: *B. pilularis*	Text Abbreviation: *C. edulis*	Text Abbreviation: *H. helix*	Text Abbreviation: *I. hayesiana*
Common Name: Twin Peaks	Common Name: Ice Plant	Common Name: Common or English Ivy	Common Name: San Diego Marsh Elder
Plant Type: Shrub	Plant Type: Perennial Herb	Plant Type: Vine/Shrub	Plant Type: Perennial Herb
			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	Plant Type: Shrub	Plant Type: Succulent	

Figure 1-1: Statewide ORVTS Locations

Table 1-2: 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	2,200 3,700 3,700	4-307 4-308 4-309	N/A *H. helix* *H. helix*	N/A 35 35	0 15 15	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	9,240 8,800 8,800	4-310 4-311 4-312	N/A *C. edulis* *C. edulis*	N/A 9 12	0 16 16	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 9 9	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)

1.4.1 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 are 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 were monitored for the 2009-2010 season, including the existing EOP station from the RVTS Study.

One station is located at the EOP (Station 3-213) and has 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) are vegetated strips with different characteristics. Station 3-362 has an approximate strip width of 10 feet, a 9-percent slope, a drainage area of approximately 4,500 ft^2, and is planted with *H. helix* (Common or English Ivy). Stations 3-363, 3-364, and 3-365 each have an approximate strip width of 25 feet and a 33-percent slope. Station 3-363 has a drainage area of approximately 5,630 ft^2 and is vegetated with *B. pilularis* (Twin Peaks). Station 3-364 has a drainage are of approximately 5,630 ft^2 and is vegetated with *M. parvifolium* (Creeping Myoporum). Station 3-365 has a drainage area of approximately 5,740 ft^2 and is vegetated with *H. helix*. All four vegetated strip stations have 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 1-2 shows a plan view of the pilot facilities at the Sacramento ERVTS.

1.4.2 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 are 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 were monitored for the 2009-2010 season, including the existing EOP station from the RVTS Study.

One station is located at the EOP (Station 12-225) and has 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) are vegetated strips with different characteristics. Station 12-346 has an approximate strip width of 10 feet, a 4-percent slope, a drainage area of approximately 12,200 ft^2, and is vegetated with *I. hayesiana* (San Diego Marsh Elder). Stations 12-347, 12-348, and 12-349 each have an approximate strip width of 21 feet. Station 12-347 has a 6-percent slope, a drainage area of approximately 13,000 ft^2, and is vegetated with *I. hayesiana*. Station 12-348 has a 4-percent slope, a drainage area of approximately 13,900 ft^2, and is vegetated with *S. mandraliscae* (Blue Finger). Station 12-349 has a 3-percent slope, a drainage area of approximately 13,200 ft^2, and is vegetated with *L.*

montevidensis (Purple Lantana). All four vegetated strip stations have 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 1-3 shows a plan view of the pilot facilities at the Yorba Linda ERVTS.

1.4.3 Napa Hwy 29 GRVTS Strip

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

The Napa GRVTS are 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 the 2009-2010 season.

One station is located at the EOP (Station 4-307) and has a drainage area of approximately 2,200 ft^2. The other two stations (4-308 and 4-309) are both vegetated strips with similar characteristics. Both stations have an approximate strip width of 15 feet, a 15-percent slope, a drainage area of approximately 3,700 ft^2, and are vegetated with *H. helix* (Common or English Ivy). All three stations have 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 1-4 shows a plan view of the pilot facilities at the Napa GRVTS.

1.4.4 San Mateo Hwy 380 GRVTS Strip

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

The San Mateo GRVTS are located along westbound Highway 380 just west of the El Camino Real on-ramp to 380 at PM 5.47 in the City of San Bruno, San Mateo County, California (Caltrans District 4). Three stations were monitored for the 2009-2010 season.

One station is located at the EOP (Station 4-310) and has a drainage area of approximately 9,240 ft^2. The other two stations (4-311 and 4-312) are both vegetated strips with similar characteristics. Both stations have an approximate strip width of 16 feet, a drainage area of approximately 8,800 ft^2, and are vegetated with *C. edulis* (Ice Plant). Station 4-311 has a slope of 9 percent while station 4-312 has a slope of 12 percent. All three stations have 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 1-5 shows a plan view of the pilot facilities at the San Mateo GRVTS.

1.4.5 Camarillo Hwy 101 GRVTS Strip

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

The Camarillo GRVTS are 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 2009-2010 season.

One station is located at the EOP (Station 7-340) and has a drainage area of approximately 9,000 ft^2. The other two stations (7-341 and 7-342) are both vegetated strips with similar characteristics. Both stations have an approximate strip width of nine feet, a 25-percent slope, and are vegetated with *C. edulis* (Ice Plant). Station 7-341 has a drainage area of approximately 10,575 ft^2 and Station 7-342 has a drainage area of approximately 18,990 ft^2. All stations have 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 1-6 shows a plan view of the pilot facilities at the Camarillo GRVTS.

1.4.6 Westminster I-405 GRVTS Strip

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

The biostrips are 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 the 2009-2010 season.

One station is located at the EOP (Station 12-343) and has a drainage area of approximately 4,600 ft^2. The other two stations (12-344 and 12-345) are both vegetated strips with similar characteristics. Both stations have an approximate strip width of 15 feet, a drainage area of approximately 6,000 ft^2, and are vegetated with *C. edulis* (Ice Plant). Station 12-344 has a slope of 18 percent while station 12-345 has a slope of 22 percent. All three stations have 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 1-7 shows a plan view of the pilot facilities at the Westminster GRVTS.

1.4.7 San Diego SR 52 GRVTS Strip

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

The biostrips are 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). Three stations were monitored for the 2009-2010 season.

One station is located at the EOP (Station 11-328) and has a drainage area of approximately 6,200 ft^2. The other two stations (11-329 and 11-330) are both vegetated strips with similar characteristics. Both stations have an approximate strip width of 15 feet, a drainage area of approximately 1,500 ft^2, and are vegetated with *C. edulis* (Ice Plant). Station 11-329 has a slope of 9 percent while station 11-330 has a slope of 7 percent. All three stations have 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 1-8 shows a plan view of the pilot facilities at the San Diego GRVTS.

1.4.8 Newbury Park Hwy 101 GRVTS Swale

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

The bioswale is 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 is between the highway and the off-ramp and can be accessed from the highway shoulder. Two stations were monitored for the 2009-2010 season.

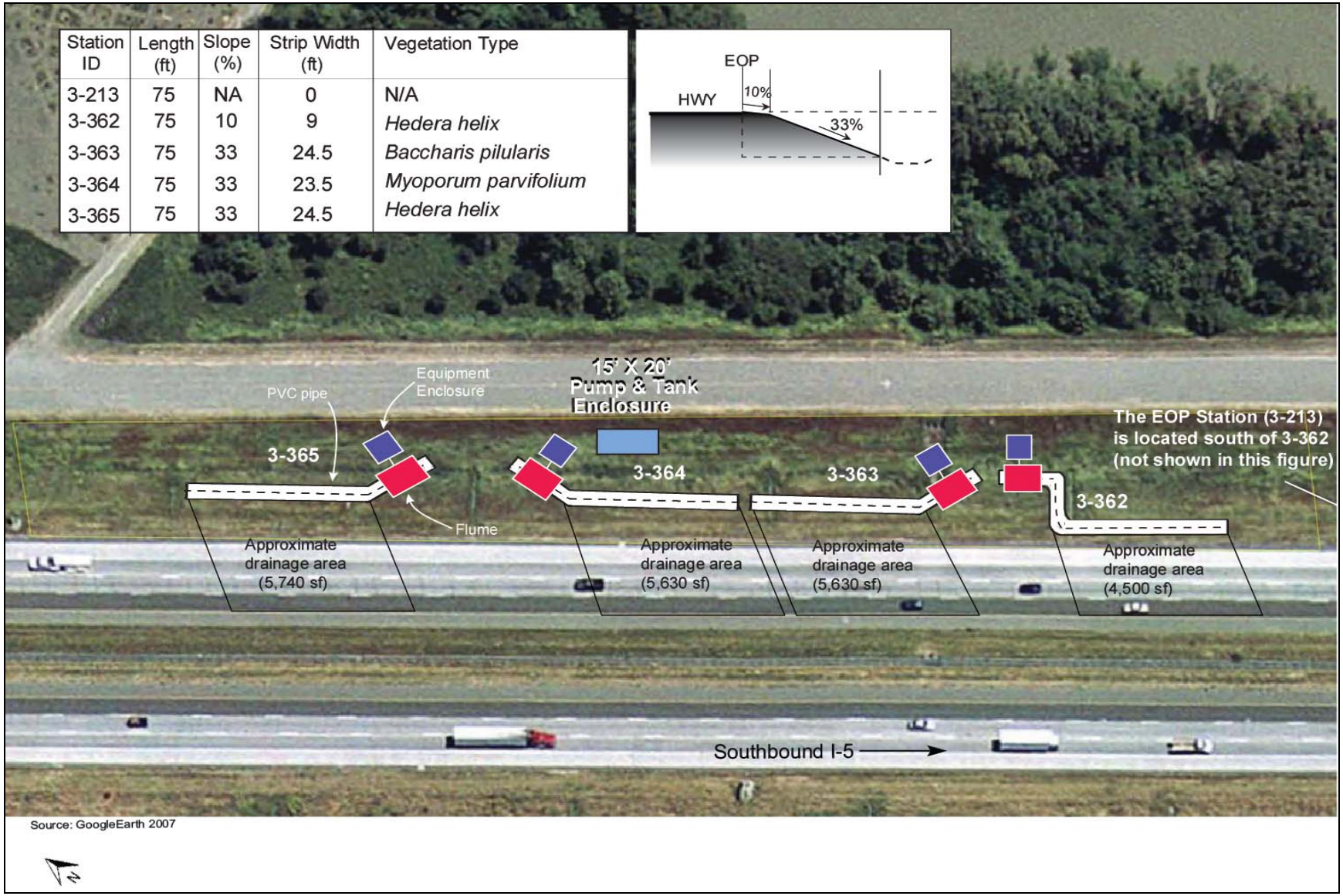
One station is located at the EOP (Station 7-338) and has a drainage area of approximately 44,740 ft^2. The other station (7-339) is a vegetated swale with an approximate swale length of 148 feet, a width varying between two and 26 feet, a 1.4-percent slope, a drainage area of approximately 49,800 ft^2, and is 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 enters 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 is a triangular area that consists of the outside shoulder and gore area. This triangular area is 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.

1.4.9 Carlsbad (Palomar) I-5 GRVTS Swale

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

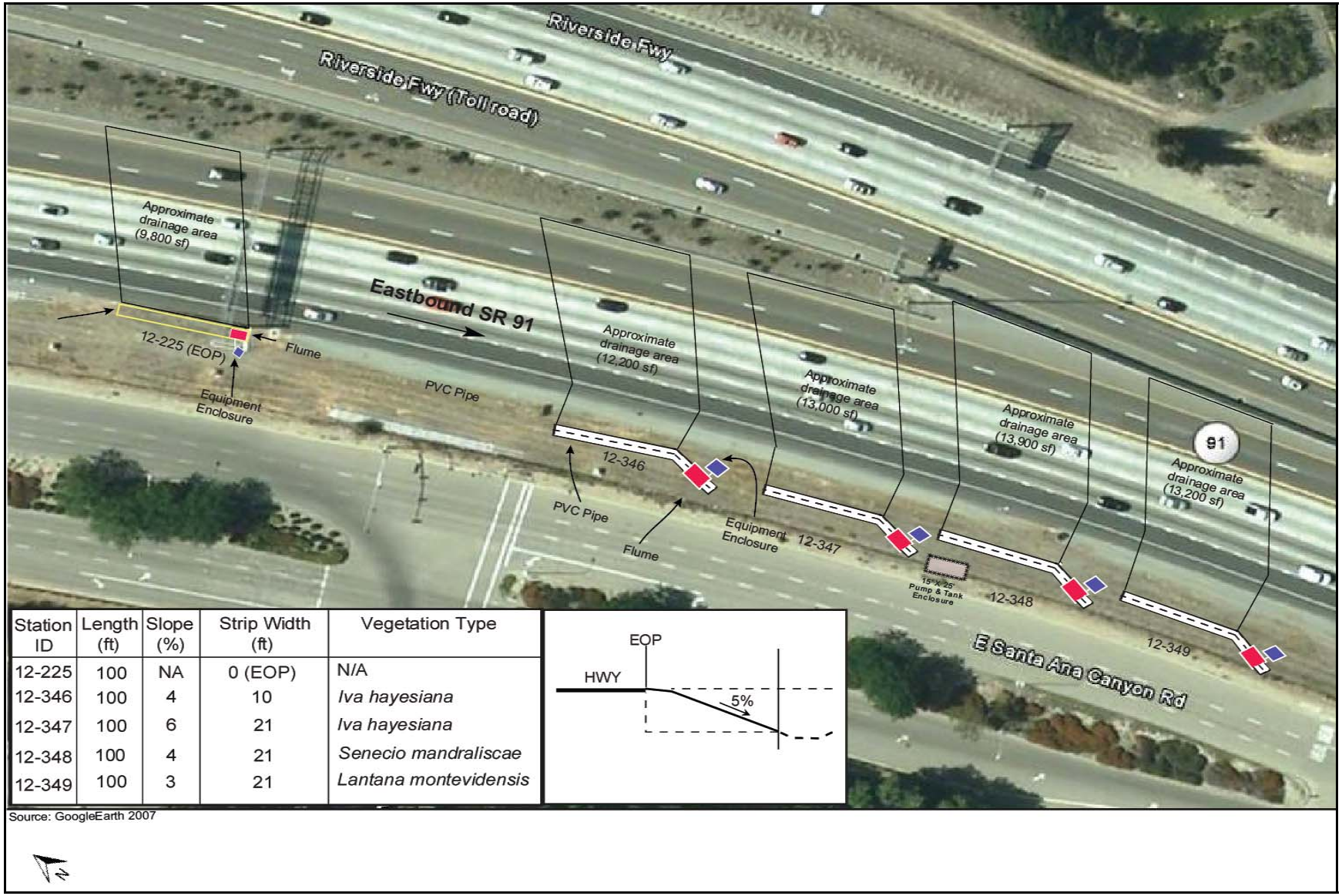
The bioswale is located along southbound I-5 between Cannon Road and Palomar Airport Road at PM 47 in the City of Carlsbad, San Diego County, California (Caltrans District 11). This location was designed as a bioswale for the Caltrans Best Management Practices (BMP) Retrofit Pilot Study (Caltrans 2004).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

One station is located at the EOP (Station 11-326), where sheet flow from the freeway is 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 is approximately 185,300 ft^2. Station 11-327 is composed of three concrete approach channels interspersed by three bioswale segments. Runoff is directed through the first concrete approach channel that is 80 feet long and is followed by a 130-foot long bioswale segment. The flow then drains through the second concrete channel that is 45 feet long and is followed by a 75-foot long bioswale segment. Lastly, the flow is directed through the third concrete channel that is 50 feet long and is followed by a 160-foot long bioswale segment. Runoff is then monitored through a second monitoring flume and discharged into an existing drainage inlet. The existing storm drain discharges into an underground concrete box culvert that crosses I-5. All concrete channels run north to south and have an approximate width of 2.2 feet. The swales also run north to south and each has 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 enters 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 1-10 shows a plan view of the pilot facilities at the Carlsbad (Palomar) GRVTS swale.



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*

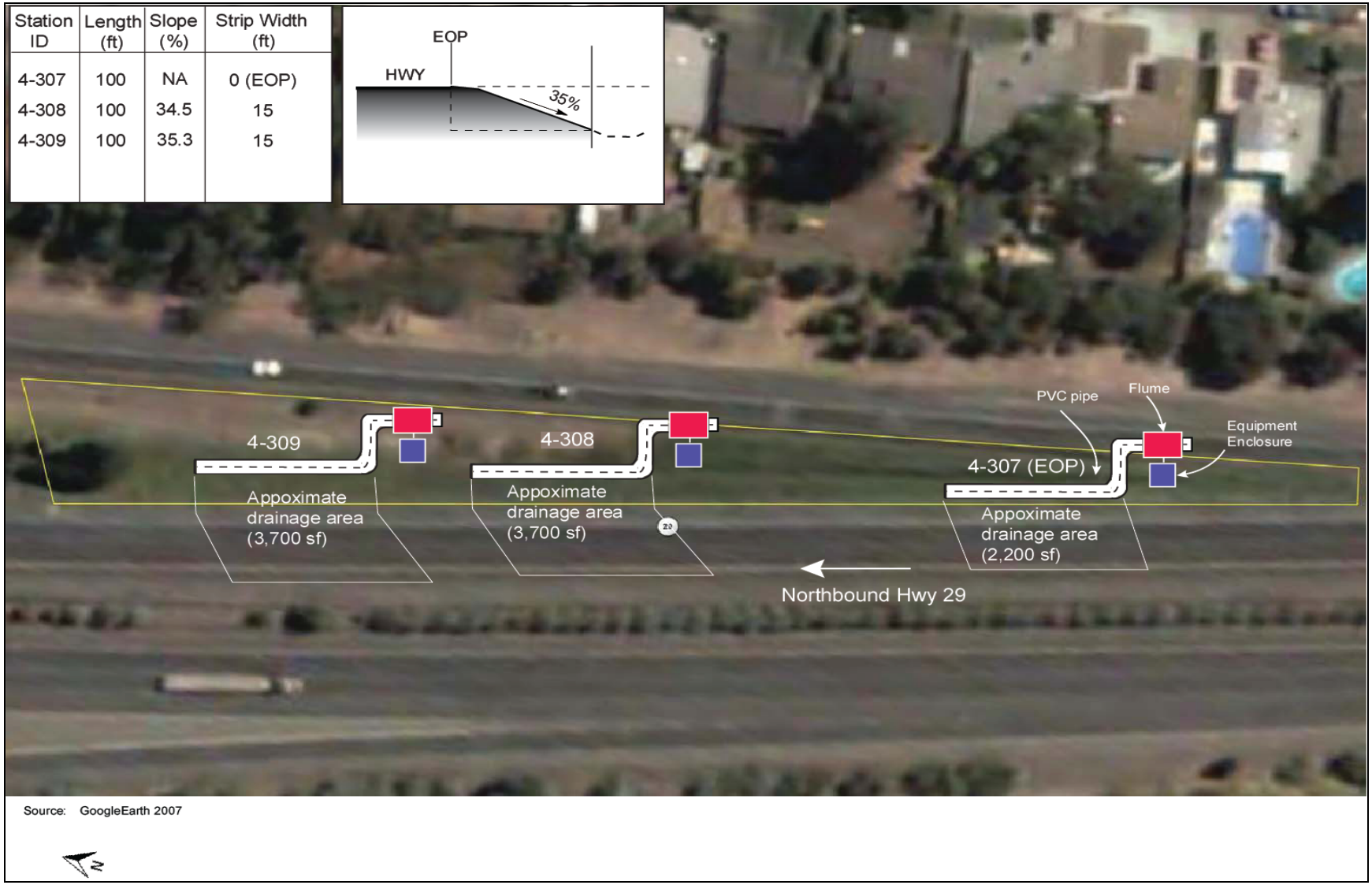
Figure 1-2: Conceptual Plan View of Sacramento I-5 ERVTS Strip
Vegetation: *B. pilularis* (Twin Peaks), *H. helix* (Common or English Ivy), and *M. parvifolium* (Creeping Myoporum)



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*

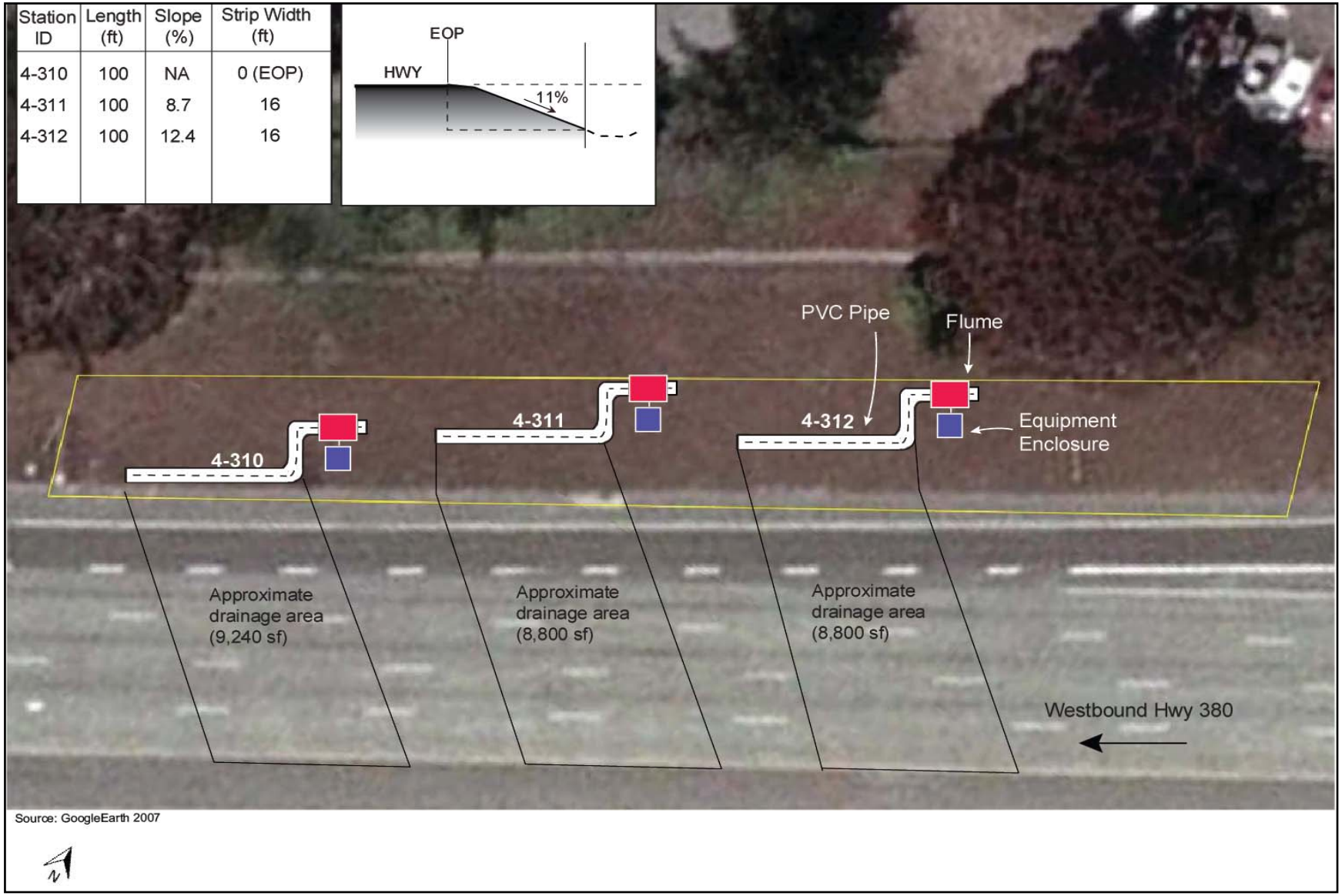
Source: GoogleEarth 2007

Figure 1-3: 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)



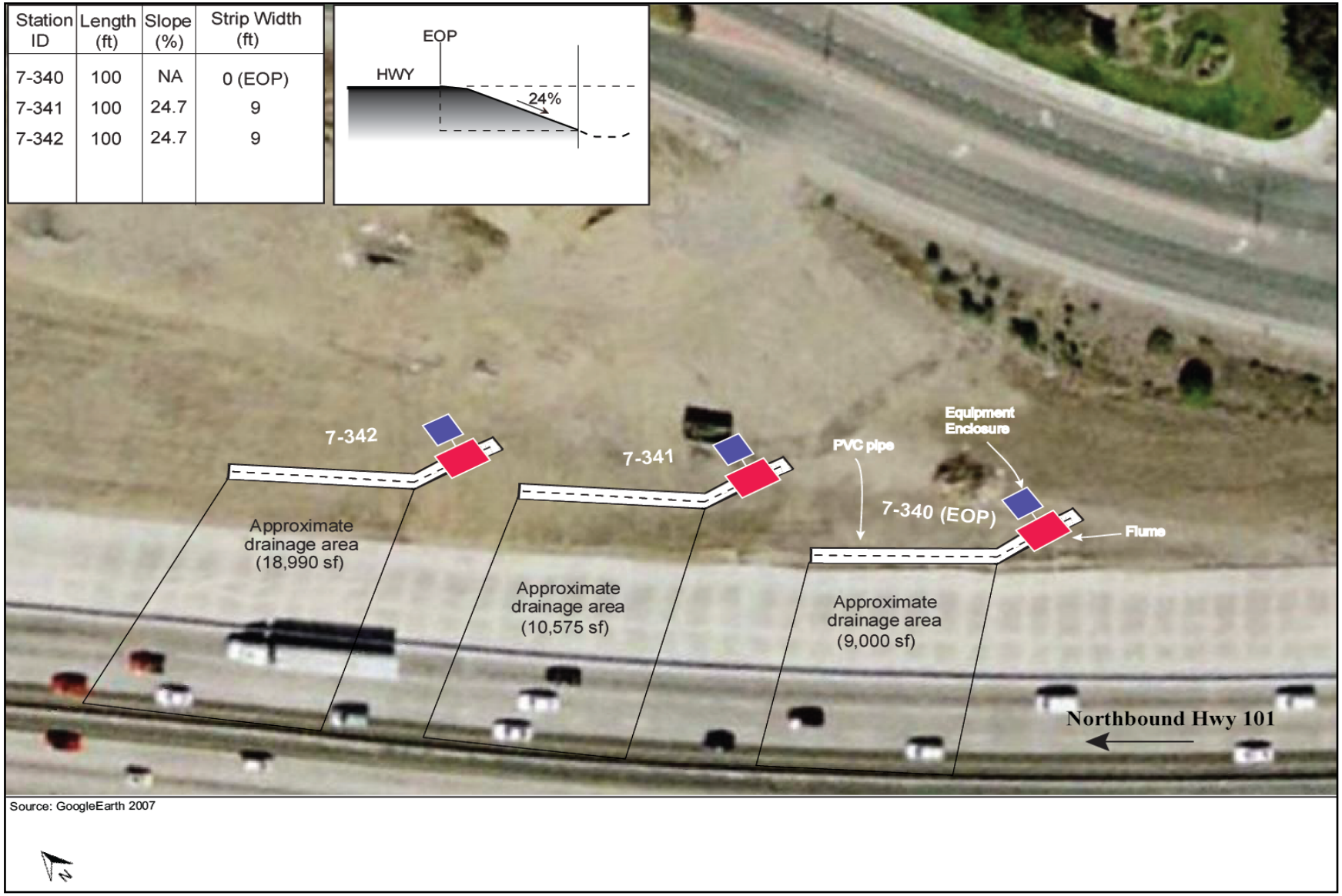
Station ID	Length (ft)	Slope (%)	Strip Width (ft)
4-307	100	NA	0 (EOP)
4-308	100	34.5	15
4-309	100	35.3	15

Figure 1-4: Conceptual Plan View of Napa Hwy 29 GRVTS Strip Vegetation: *C. edulis* (Ice Plant)



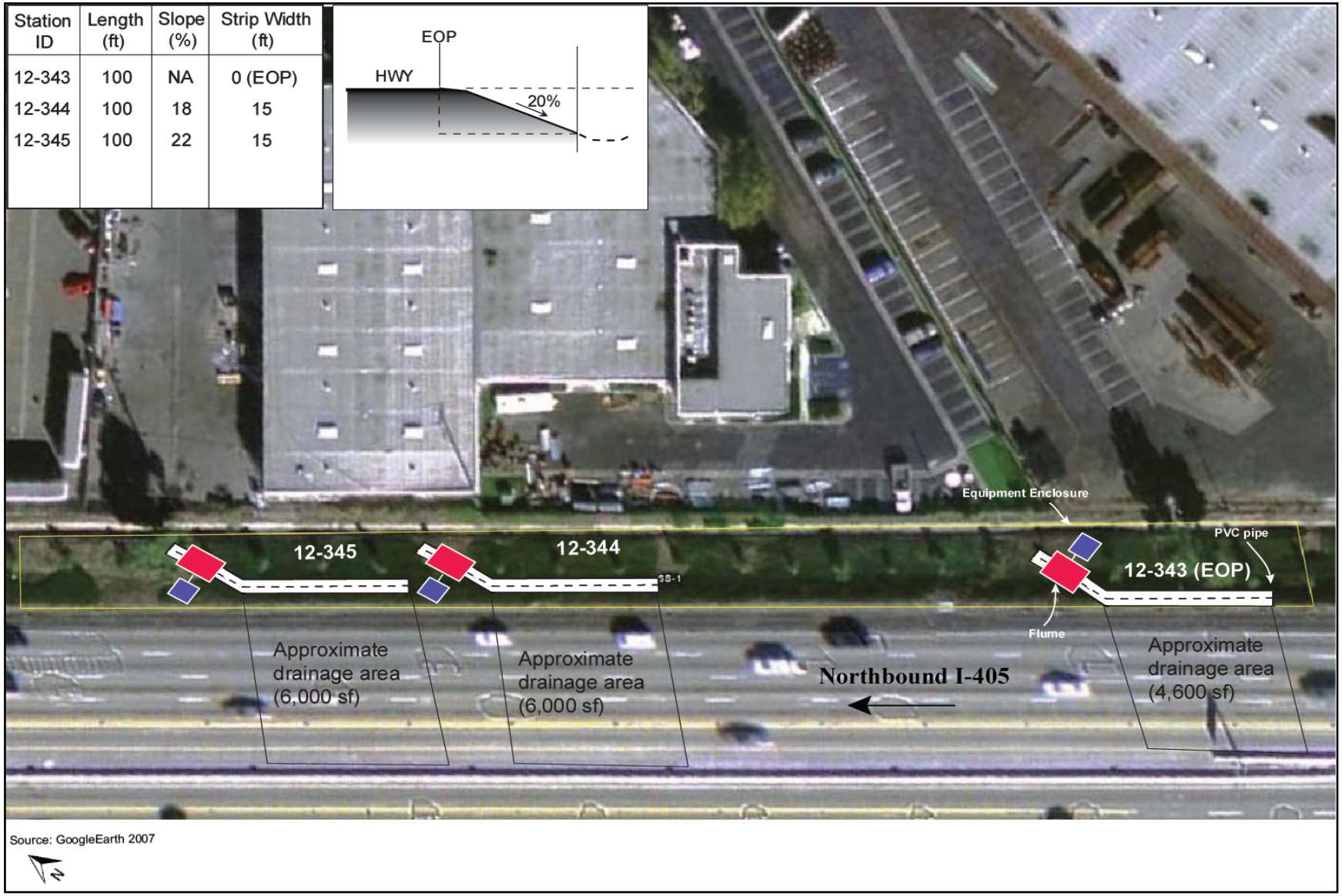
Station ID	Length (ft)	Slope (%)	Strip Width (ft)
4-310	100	NA	0 (EOP)
4-311	100	8.7	16
4-312	100	12.4	16

Figure 1-5: Conceptual Plan View of San Mateo Hwy 380 GRVTS Strip Vegetation: *C. edulis* (Ice Plant)



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 1-6: Conceptual Plan View of Camarillo Hwy 101 GRVTS Strip Vegetation: *C. edulis* (Ice Plant)



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 1-7: Conceptual Plan View of Westminster I-405 GRVTS Strip Vegetation: *C. edulis* (Ice Plant)

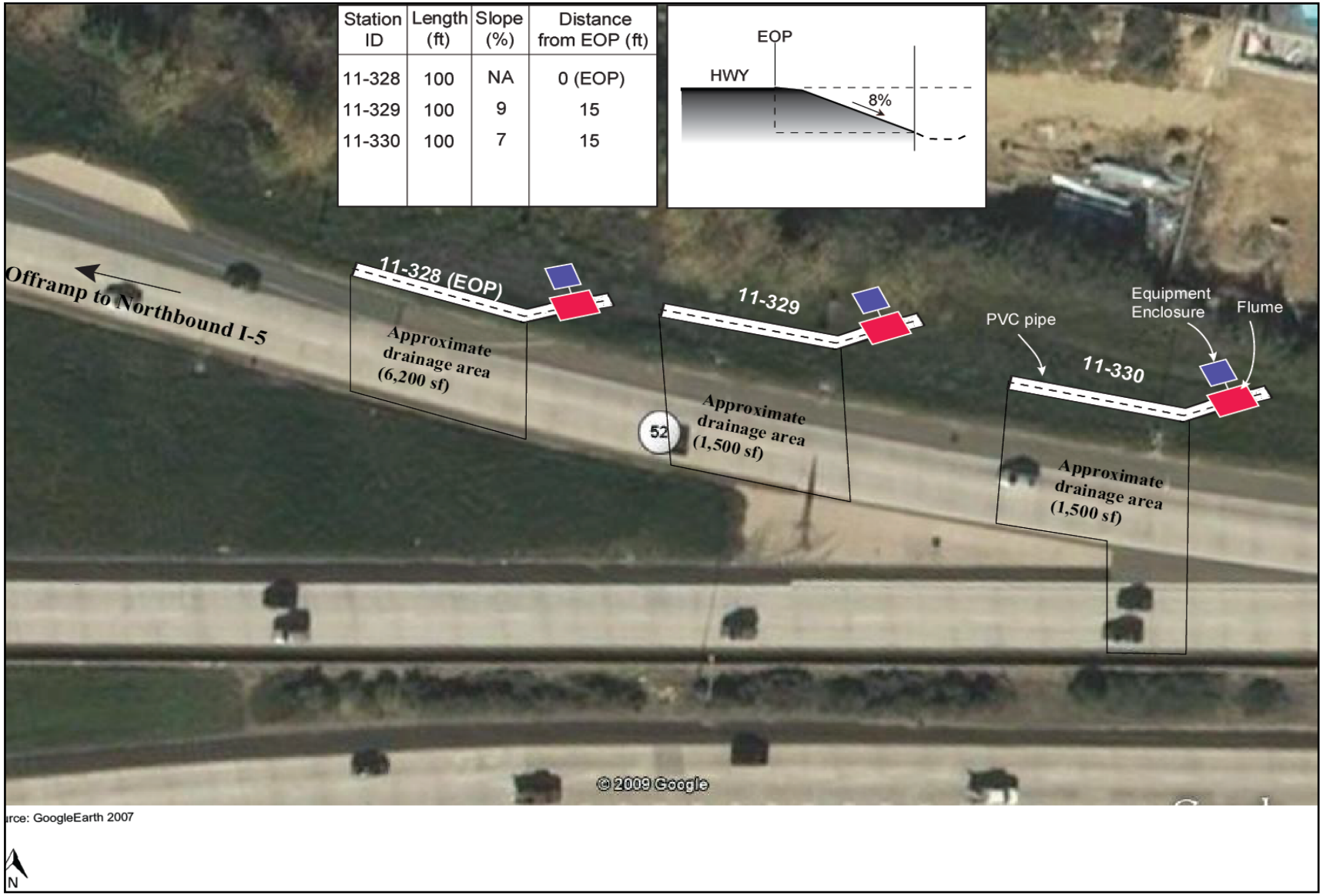
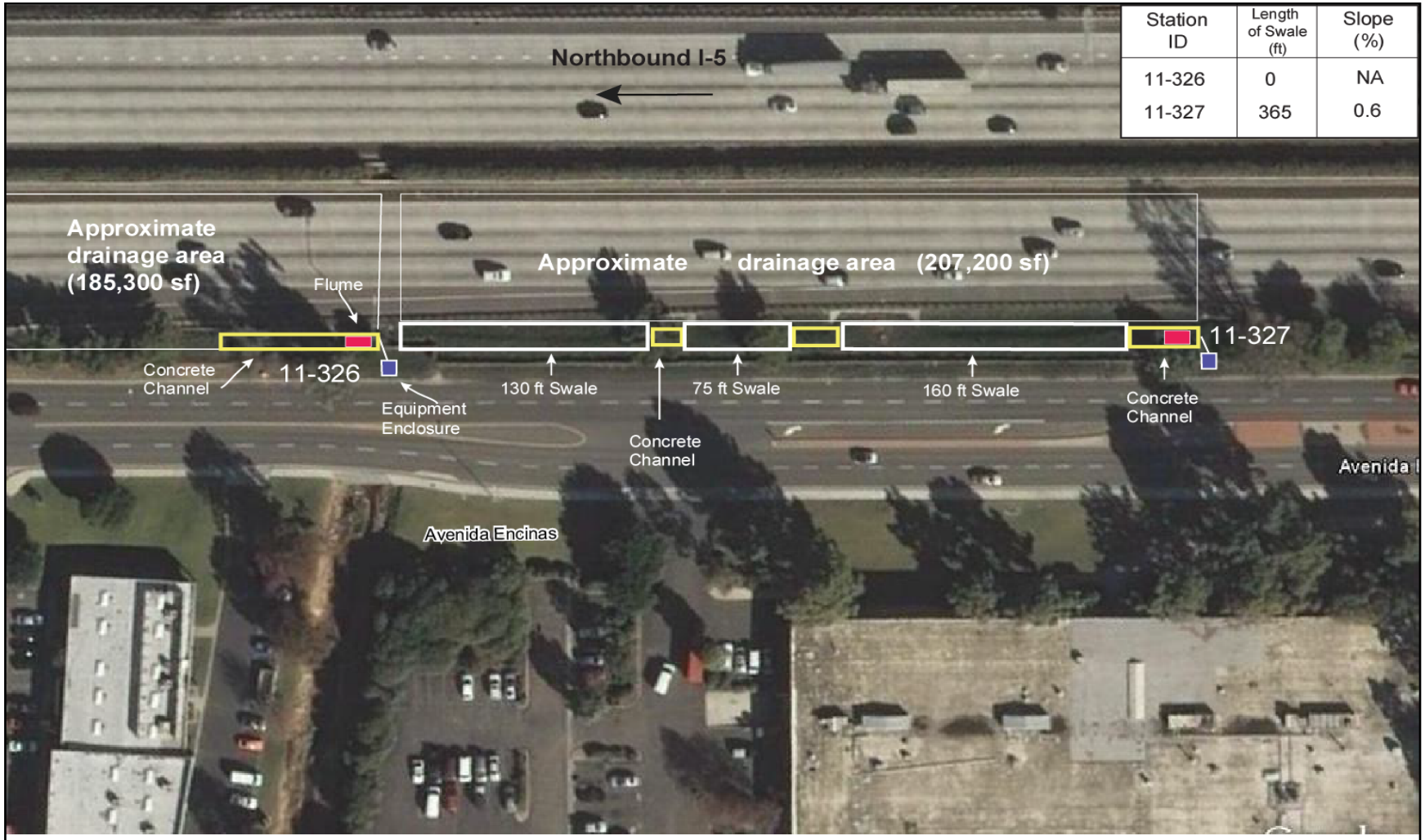


Figure 1-8: Conceptual Plan View of San Diego SR 52 GRVTS Strip Vegetation: *C. edulis* (Ice Plant)

Figure 1-9: Conceptual Plan View of Newbury Park Hwy 101 GRVTS Swale
Vegetation: *M. parvifolium* (Creeping Myoporum)



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

Source: Aerials Express 2006

Figure 1-10: Conceptual Plan View of Carlsbad (Palomar) I-5 GRVTS Swale
Vegetation: *C. edulis* (Ice Plant)

1.5 REPORT ORGANIZATION

The report is organized as follows:

Section 1 – Introduction

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

Section 2 – Study Approach

- This section presents the methodology and approaches of the hydrologic and water quality monitoring for this study. It provides detailed information on the activities conducted for this study including hydrologic and water quality monitoring, vegetation assessments, data management and reporting, and operation and maintenance.

Section 3 – Results

- This section presents findings and results from the monitoring during the 2009-2010 season. 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 4 – Data Assessment and Findings

- This section presents the methodology, results, and discussions of data assessments, including Analysis of Variance (ANOVA) on concentration and load data and various calculations and comparisons, to address the various study objectives.

Section 5 – Conclusions

- This section presents general conclusions drawn from the 2009-2010 ORVTS Study. It addresses the study objectives such as the effectiveness of roadside strips planted with ornamental vegetation in reducing pollutant concentration, runoff volume, and pollutant load.

Section 6 – Future Considerations

- This section presents study and data assessment subjects for future considerations for the ORVTS Study. It discusses experiences learned from the 2009-2010 monitoring season that could be useful to incorporate during future years of this study.

Section 7 – References

- This section consists of a bibliography of reference documentation and past monitoring studies.

SECTION 2 STUDY APPROACH

2.1 STUDY DESIGN

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). Monitoring included hydrologic and water quality monitoring, site inspections and maintenance, and vegetation assessments.

This study setup assumes that the EOP stations represent highway runoff or influent (i.e., control) and the strip and swale stations represent the ORVTS effluent (i.e., treatment) with the aim of comparing the runoff volume and pollutant concentration and load of strip or swale runoff to that of the highway runoff. At each ERVTS location, there is 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 2-1 at the EOP and the strip stations. At each GRVTS strip location, there is 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

Monitoring was performed from October 1, 2009, to April 30, 2010 (2009-2010 monitoring season). During the monitoring season, 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).

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 2-1 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 2-1: Selected Analytical Constituents

Analyte	Analytical Procedure	Reporting Limits and Units
Conventional Constituents		
Hardness as $CaCO_3$ (hardness)	EPA 130.1	2 mg/L
Total Dissolved Solids (TDS)	EPA 160.1 (SM 2540C)	1 mg/L
Total Suspended Solids (TSS)	EPA 160.2 (SM 2540D)	1 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
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).

2.2 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 2.1.

2.2.1 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 all ERVTS and GRVTS strip locations except for the Napa and San Mateo locations, where 60-degree V-type trapezoidal flumes were used. At the Newbury Park GRVTS swale location, a 2-inch, 45-degree trapezoidal flume was used for the EOP station and a 60-degree V-type flume was used for the swale station. At the Carlsbad (Palomar) GRVTS swale location, two 12-inch H flumes were used for both the EOP and swale stations.

2.2.2 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 top of 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.

2.3 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 2-1 following methods prescribed in the Guidance Manual. 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).

2.3.1 Sampling Methods

The storm water sampling equipment described below is designed to collect composite samples of storm water runoff in a flow-weighted manner. Components installed for sampling purposes include 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) are 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.

2.3.2 Constituents and Analytical Methods

As shown in Table 2-1, 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.

2.4 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 storm water monitoring projects. Each activity is discussed below.

2.4.1 Event Data Downloading and Summaries

For each monitoring station, rainfall, flow, and sampling data were downloaded after every storm event. Data was 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).

2.4.2 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 both the Caltrans Laboratory EDD Error Checker and Automated Data Validation Software, as described in Section 3.2.3 and Appendix I.

2.5 VEGETATION ASSESSMENTS

Quarterly vegetation assessments were conducted according to the following schedule: summer (July to August 2009); fall (October to November 2009); winter (January to February 2010); spring (April to May 2010); and summer (July to August 2010). The purpose of the vegetation

assessments was to characterize the vegetation conditions (e.g., density, height, species, etc.), as the conditions are potentially important factors that may impact the performance of the strips and swales in reducing pollutant concentration and/or load.

The surveys 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 2009-2010 vegetation assessments are discussed in Section 3.1.4.

2.6 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. Site-specific maintenance requirements are presented in Appendix E of the ORVTS OM&M Plan (Caltrans, 2009).

SECTION 3 RESULTS

3.1 SUMMARY OF DATA COLLECTION

During the 2009-2010 season, monitoring and sampling activities were conducted at all nine ORVTS locations. Most monitored locations performed as expected and were monitored according to the ORVTS OM&M Plan (Caltrans, 2009). Table 3-1 summarizes the monitoring activities at each location. Sampling at all three stations at the San Diego location was discontinued after the first four monitored storm events due to substantial recurring bypass issues at both strip stations. One strip station (4-311) at the San Mateo location was discontinued after the first three monitored storm events due to substantial recurring bypass issues at this station. Information on these stations is also presented in Table 3-1.

Table 3-1: 2009-2010 ORVTS Monitoring Summary

Station Name	Station ID	Number of Storm Events Monitored	Number of Events with Representative Samples[(d)]	Vegetation Assessment Conducted
Sacramento EOP	3-213	12	11	NA
Sacramento 9-ft Strip	3-362	12	9	8/2009, 11/2009, 2/2010, 5/2010, 8/2010
Sacramento 25-ft Strip	3-363	12	10	8/2009, 11/2009, 2/2010, 5/2010, 8/2010
Sacramento 24-ft Strip	3-364	12	10	8/2009, 11/2009, 2/2010, 5/2010, 8/2010
Sacramento 25-ft Strip	3-365	12	10	8/2009, 11/2009, 2/2010, 5/2010, 8/2010
Yorba Linda EOP	12-225	12	12	NA
Yorba Linda 10-ft Strip	12-346	12	11	8/2009, 11/2009, 3/2010, 5/2010, 8/2010
Yorba Linda 21-ft Strip	12-347	12	10	8/2009, 11/2009, 3/2010, 5/2010, 8/2010
Yorba Linda 21-ft Strip	12-348	12	9	8/2009, 11/2009, 3/2010, 5/2010, 8/2010
Yorba Linda 21-ft Strip	12-349	12	9	8/2009, 11/2009, 3/2010, 5/2010, 8/2010
Napa EOP	4-307	11	9	NA
Napa 15-ft Strip	4-308	11	7	8/2009, 11/2009, 1/2010, 4/2010, 7/2010
Napa 15-ft Strip	4-309	11	9	8/2009, 11/2009, 1/2010, 4/2010, 7/2010
San Mateo EOP	4-310	11	11	NA
San Mateo 16-ft Strip[(a)]	4-311	3	0	8/2009, 11/2009, 1/2010, 4/2010, 7/2010
San Mateo 16-ft Strip	4-312	11	11	8/2009, 11/2009, 1/2010, 4/2010, 7/2010
Camarillo EOP	7-340	5	5	NA
Camarillo 9-ft Strip	7-341	5	4	11/2009, 1/2010, 5/2010, 7/2010
Camarillo 9-ft Strip	7-342	5	5	11/2009, 1/2010, 5/2010, 7/2010

Table 3-1: Monitoring Summary 2009-2010 (continued)

Station Name	Station ID	Number of Storm Events Monitored	Number of Events with Representative Samples[d]	Vegetation Assessment Conducted
Westminster EOP	12-343	12	10	NA
Westminster 15-ft Strip[e]	12-344	12	3	8/2009, 11/2009, 3/2010, 5/2010, 8/2010
Westminster 15-ft Strip[e]	12-345	12	2	8/2009, 11/2009, 3/2010, 5/2010, 8/2010
San Diego EOP[b]	11-328	4	4	NA
San Diego 15-ft Strip[c]	11-329	4	0	8/2009, 11/2009, 3/2010, 5/2010, 8/2010
San Diego 15-ft Strip[c]	11-330	4	0	8/2009, 11/2009, 3/2010, 5/2010, 8/2010
Newbury Park Swale Influent	7-338	5	5	NA
Newbury Park Swale Effluent	7-339	5	4	11/2009, 1/2010, 5/2010, 7/2010
Carlsbad (Palomar) Swale Influent	11-326	12	4	NA
Carlsbad (Palomar) Swale Effluent	11-327	12	7	8/2009, 11/2009, 3/2010, 5/2010, 8/2010

(a) Sampling at this station was discontinued after the first three events due to recurring bypass issues.

(b) Sampling at this station was discontinued after the first four events due to recurring bypass issues at Stations 11-329 and 11-330.

(c) Sampling at these stations was discontinued after the first four events due to recurring bypass issues.

(d) 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 3.2 and 3.3.

(e) During several storm events, insufficient volume was collected at the Westminster strips following high levels of infiltration, resulting in only 2 to 3 samples being collected and analyzed during the 2009-2010 season.

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

3.2 DATA REVIEW

Comprehensive data review was performed on data collected during the 2009-2010 season by each responsible consultant. Data review was performed on a storm-by-storm and station-by-station basis. The hydrologic (flow and rainfall) data, as well as the analytical data, were reviewed. The data was 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 forms included as Appendix F.

3.2.1 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. Some operational issues occurred during the 2009-2010 monitoring season, some of which were recurring. Sampling at the stations with substantial issues was terminated after the first few monitored storms as described in Section 3.1. 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 2009-2010 monitoring season are listed below in Table 3-2 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 Forms) 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 3-2.

Table 3-2: Summary of Observation and Monitoring Issues 2009-2010

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 infiltration, until saturation was reached, but this was considered part of the strip treatment system.	A
The highway asphalt shoulder allowed runoff to infiltrate, but this was considered treatment within the EOP.	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 reach collection system, 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 significant, but other times it was minimal.	A/R
Parked vehicles caused depressions that diverted flow away from the collection stations or allowed infiltration. Sometimes this was significant, but other times it was minimal.	A/R
Flow Measurements	
Elevated vegetation at the entrance of swales caused back water ponding in the flume, but ponding was minimal.	A
Small amounts of debris blocked bubbler, causing elevated flow measurements, but amount of elevated flow appeared minimal.	A[(a)]

A = Accept data

R = Reject data

A/R = Accept or Reject data on a case-by-case basis

(a) = Also a hydrograph issue.

Table 3-2: Summary of Observation and Monitoring Issues 2009-2010 (continued)

Flow Data Issues	**Criteria**
Flow Measurements	
Trash or large amounts of debris caused ponding of water, resulting in a significance degree of elevated flow measurements.	R[(a)]
Noise reflected in flow data. Sometimes the noise was minimal, other times it was significant. Sometimes significant noise could be subtracted to estimate a more accurate flow. Other times the flow could not be corrected.	A/R[(a)]
Flow and rainfall measurements are 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[(a)]
Equipment Malfunction	
Flow meter did not register flow correctly during dry periods and could be corrected on a hydrograph.	A[(a)]
Battery interrupted flow meter operation.	A[(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[(a)]
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[(a)]
Bubbler line clogged or froze.	R[(a)]
Downloaded data corrupted.	R[(a)]
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

A = Accept data

R = Reject data

A/R = Accept or Reject data on a case-by-case basis

(a) = Also a hydrograph issue.

3.2.1.1 Flow Data Issues

Flow data issues commonly occurred during the monitoring season. These issues were associated with diversion of flow, irregularity in flow measurements, and equipment malfunction. These issues are described below.

Diversion of Flow

Certain stations had significant sheet flow diversion from stations, while others had minimal to none. Figures 3-1a through 3-1d show pictures of both minimal and significant bypass. Figure 3-1e 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 infiltration 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 infiltration 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, the data were accepted when the recorded rainfall volume from the strip was similar to the runoff volume, based on the conclusion that some runoff from the EOP entered the strip. Data were rejected, however, when the rainfall volume from the strip was much greater than the recorded flow volume.
- When parked vehicles caused depressions in the ground that diverted flow away from the collection station, data were accepted if the diversion was minimal to none and favored infiltration (when the recorded rainfall volume from the strip was similar to the runoff volume). Data were rejected, however, in all cases when the rainfall volume from the strip was much greater than the recorded flow volume.

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 3-1f 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 a minimal amount of water to pond in a flume, data were accepted in all cases.
- When only small amounts of debris blocked the bubbler line, causing elevated flow measurements, these elevations were considered to be minimal and data were accepted in all cases after corrections were preformed on hydrographs.
- 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 if the noise could be eliminated when recreating a hydrograph. If fluctuations in recorded flow data could not be corrected accurately with confidence, data were rejected.
- 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

Prior to the start of the monitoring season, all monitoring equipment was evaluated to help improve the performance of the equipment throughout the season. 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 and recreation of the hydrograph could not be done accurately based on data from adjacent stations or event or historical data, 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.

3.2.1.2 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 sample analysis of all constituents, but the requisite number of aliquots was collected, data were accepted for all cases.
- 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 was 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 3-1: 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 infiltration. 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.

3.2.2 Hydrograph Reviews

For each monitored storm event at each station, the Caltrans Hydrology Tool 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 1-2 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 3-2. Review of these hydrographs is discussed in Section 3.2. Criteria to accept or reject data for hydrograph issues are described in Section 3.2.1.1 and in Appendix F. Finalized hydrographs are included as part of the PSTMs presented in Appendix E.

3.2.3 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 I. Following the review, data points were assigned data qualifiers, as appropriate:

- U – The analyte was analyzed for, but was not detected above the Method Detection Limit (MDL). Examples include:
  - When applying blank contamination qualification on organics methods, sample results below the reporting limit are raised to the reporting limit and qualified.
  - The method blank result for an inorganic sample is 3.0 μg/L. The sample result for the same analyte is 4.8 μg/L. The reporting limit is 5.0 μg/L. Since the sample is less than five times the method blank, the sample result would be qualified as ‘U’ due to method blank contamination.
  - The method blank result for an inorganic sample is 3.0 μg/L. The sample result for the same analyte is 27 μg/L. The reporting limit is 5.0 μg/L. Since the sample is less than ten times the method blank, the sample result would be qualified as ‘U’, due to blank contamination for common laboratory contaminants.
- J – The result is an estimated quantity. The associated numerical value is the approximate concentration of the analyte in the sample and is not 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:

- When a result is less than the projected reporting limit (RL) but higher than the method detection limit (MDL).
- The Laboratory Control Spikes (LCS) percent recovery is 65 percent for acetone. The acceptance criteria are 70-130 percent. The associated data will be qualified as estimated results due to low bias. For non-detected associated data, see example for 'UJ' qualification.
- The Matrix Spike/Matrix Spike Duplicate (MS/MSD) percent recovery for TKN is 150 percent. The acceptance criteria are 80-120 percent. The associated data will be qualified as estimated results due to high bias.

- R – The result is rejected because it was not detected and has a serious deficiency in meeting QA/QC criteria. Examples of when 'R' data qualifiers are applied include:
  - The LCS percent recovery is eight percent for acetone. This is below the serious deficiency percent recovery for organics of ten percent. All non-detected associated data will be qualified as rejected (R). The serious deficiency percent recovery for inorganics is 50 percent.
  - A sample was preserved and analyzed in 29 days, which exceeded the holding time requirement of 14 days. This exceeds the serious deficiency of two times the required holding time. All non-detected associated data will be qualified as rejected (R).
  - The MS/MSD percent recovery for acetone is zero percent. This meets the serious deficiency percent recovery for organics of zero percent. All non-detected associated data will be qualified as rejected (R). The serious deficiency percent recovery for inorganics is 30 percent.
- UJ – The analyte was analyzed for, but was not detected above the MDL. The associated value is approximate and may be inaccurate or imprecise due to exceedance of laboratory QA/QC acceptance criteria signifying bias within the analytical procedures while the samples were being analyzed. An example of when 'UJ' data qualifiers are applied is presented below.
  - The method blank result for acetone is 1.0 μg/L. The sample result for acetone is 4.0 μg/L. The reporting limit for acetone in water is 5.0 μg/L. Since the samples is less than ten times the blank, the sample result would be qualified as 'U'. In addition, the associated LCS percent recovery is 65 percent for acetone. The acceptance criteria are 70-130 percent. The final qualifier taking both of these QA/QC deficiencies into account would be 'UJ'.

In general, data are qualified with a U, J, R, or UJ 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 I.

For the 2009-2010 monitoring effort at the nine monitored project locations, none of the data was rejected based on QA/QC exceedances. This monitoring season resulted in 8,559 chemical measurements. Of these, 1,245 values (15 percent) required data qualification of U, J, or UJ.

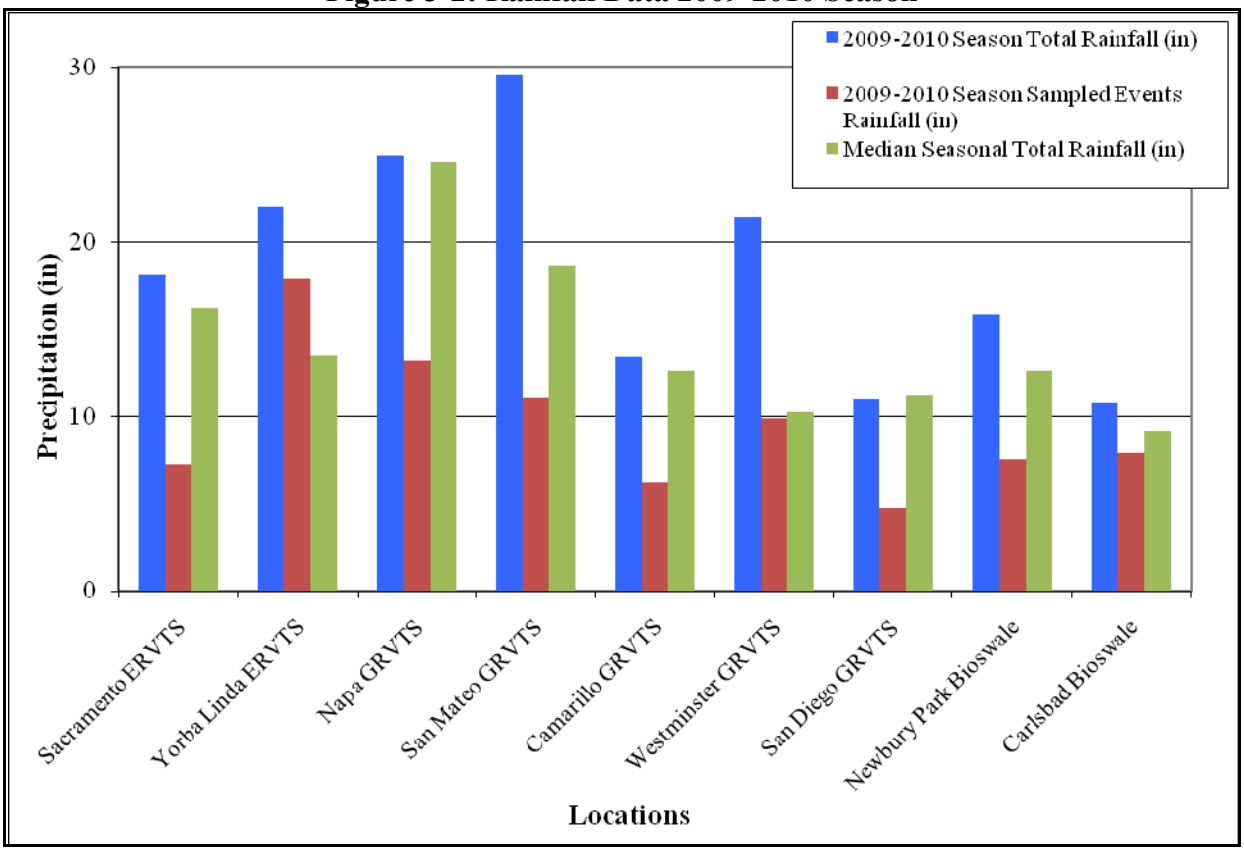
3.3 HYDROLOGY RESULTS

During the 2009-2010 monitoring season, the total number of sampling events ranged from five at Camarillo and Newbury Park to twelve at Yorba Linda. During each monitored storm event, flow and rainfall data were recorded at one-minute intervals as discussed in Section 2.2. Discussions on the hydrology results are presented in the following sub-sections.

3.3.1 Precipitation Results

Generally, most precipitation falls between October 1 and April 30 in both Northern and Southern California. During the 2009-2010 season (October 1, 2009, to April 30, 2010), the seasonal rainfall measured at the ORVTS locations ranged from 10.82 to 22.02 inches for Southern California, and from 18.10 to 29.51 inches for Northern California. Figure 3-2 shows a comparison between the median seasonal rainfall (green-colored bars) and the total rainfall measured by rain gauges at each location for both sampled storm events (red-colored bars) and for the entire 2009-2010 season (blue-colored bars). The median seasonal rainfall data were acquired from the Western Regional Climate Center website (http://www.wrcc.dri.edu/Climsum.html).

Figure 3-2: Rainfall Data 2009-2010 Season



(a) Median seasonal rainfall is from the Western Regional Climate Center website: http://www.wrcc.dri.edu

(b) Monitoring at the San Diego location was terminated after the first four storms events (from December 7, 2009, to January 18, 2010) due to substantial recurring bypass issues.

3.3.2 Flow Data

As described in Section 2.2, flow data were collected at one-minute intervals for each monitored storm and throughout the entire monitoring season 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 and non-sampled events at each station are included in Appendix L.

3.3.3 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 3.2.2, 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 3-3. 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 season as determined by a linear regression of the RO/RF data from all events). Various plots (runoff vs. rainfall and R_V over time) are presented in Appendix C.

Table 3-3: Summary Volumetric Runoff Coefficient 2009-2010 Season

Station Description	Station ID	Ornamental Vegetation Type	Number of Data Points	Range of Volumetric Runoff Coefficient (R_V)	Overall R_V[(e)]	R^2
Sacramento EOP	3-213	-	11	0.561 – 1.599	1.23	0.73
Sacramento 9-ft Strip	3-362	*H. helix*	10	0.016 – 0.129	0.07	0.47
Sacramento 24.5-ft Strip	3-363	*B. pilularis*	11	0.002 – 0.045	0.01	0.09
Sacramento 23.5-ft Strip	3-364	*M. parvifolium*	11	0.015 – 0.066	0.03	0.39
Sacramento 24.5-ft Strip	3-365	*H. helix*	11	0.003 – 0.064	0.03	0.51
Yorba Linda EOP	12-225	-	10	0.89 – 1.19	1.06	0.97
Yorba Linda 10-ft Strip	12-346	*I. hayesiana*	11	0.00 – 0.52	0.41	0.92
Yorba Linda 21-ft Strip	12-347	*I. hayesiana*	9	0.27 – 0.70	0.51	0.88
Yorba Linda 21-ft Strip	12-348	*S. mandraliscae*	1	0.13[(d)]	0.13	NA
Yorba Linda 21-ft Strip	12-349	*L. montevidensis*	6	0.12 – 0.24	0.16	0.71
Napa EOP	4-307	-	10	0.029 – 0.694	0.30	0.37
Napa 15-ft Strip	4-308	*H. helix*	7	0.001 – 0.030	0.005	0.17
Napa 15-ft Strip	4-309	*H. helix*	11	0.004 – 0.031	0.02	0.84
San Mateo EOP	4-310	-	9	0.93 – 2.08	1.45	0.95
San Mateo 16-ft Strip	4-311[(a)]	*C. edulis*	0	NA	NA	NA
San Mateo 16-ft Strip	4-312	*C. edulis*	8	0.03 – 0.86	0.53	0.85
Camarillo EOP	7-340	-	5	0.47 – 1.53	1.23	0.71
Camarillo 9-ft Strip	7-341	*C. edulis*	5	0.04 – 0.20	0.11	0.50
Camarillo 9-ft Strip	7-342	*C. edulis*	5	0.04 – 0.73	0.36	0.42
Westminster EOP	12-343	-	10	0.144 – 0.764	0.47	0.80
Westminster 15-ft Strip	12-344	*C. edulis*	12	0.003 – 0.076	0.05	0.63
Westminster 15-ft Strip	12-345	*C. edulis*	10	0.000 – 0.173	0.04	0.62
San Diego EOP	11-328[(b)]	-	4	0.73 – 1.83	1.44	0.97
San Diego 15-ft Strip	11-329[(c)]	*C. edulis*	0	NA	NA	NA
San Diego 15-ft Strip	11-330[(c)]	*C. edulis*	0	NA	NA	NA
Newbury Park Swale Influent	7-338	-	5	1.66 – 2.22	1.78	0.96
Newbury Park Swale Effluent	7-339	*M. parvifolium*	4	0.44 – 0.57	0.53	0.99
Carlsbad (Palomar) Swale Influent	11-326	-	5	0.272 – 0.534	0.50	0.96
Carlsbad (Palomar) Swale Effluent	11-327	*C. edulis*	2	0.010 – 0.025	0.02	0.87

NA = Not available.

(a) Monitoring at this station was discontinued after the first three storms due to recurring substantial bypass issues.

(b) Monitoring at this station was discontinued after the first four events due to recurring bypass issues at Stations 11-329 and 11-330.

(c) Monitoring at this station was discontinued after the first four events due to recurring bypass issues.

(d) Following the data review process, only one data point was deemed valid.

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

As shown in Table 3-3 and the associated plots in Appendix C, the overall volumetric runoff coefficients (R_V's) range from 0.005 at Napa (15-foot strip) to 1.78 at Newbury Park (EOP). Possible causes of these variations are discussed below in detail.

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 1.23, and the event R_V's range from 0.56 to 1.6 with an R^2 of 0.73. The variation of event R_V's may be caused by flow noise; however, the overall R_V appears to be reasonable given the reasonable R^2 value. 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 0.07, and the event R_V's range from 0.02 to 0.13 with an R^2 of 0.47. The strip Station 3-363 has an overall Rv of 0.01, and the event R_V's range from 0.002 to 0.045 with an R^2 of 0.09. The strip Station 3-364 has an overall R_V of 0.03, and the event R_V's range from 0.015 to 0.066 with an R^2 of 0.39. The strip Station 3-365 has an overall R_V of 0.03, and the event R_V's range from 0.003 to 0.064 with an R^2 of 0.51. The low R^2 of 0.09 at Station 3-363 was possibly caused by two potential outliers (the storm event on December 12, 2009, with a R_V of 0.002, and the storm event on January 25, 2010, with a R_V of 0.045).

Overall, the R_V values are reasonable. Based on field observations, the low R_V values of all four strips are most likely due to runoff infiltration occurring within the vegetated strip areas. Field notes indicate that, at Station 3-362, infiltration also occurred at the construction joint of the Portland cement concrete and asphalt concrete pavement.

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 1.06, and the event R_V's range from 0.89 to 1.19 with an R^2 of 0.97. The overall R_V appears to be reasonable given the high R^2 value. The strip Station 12-346 has an overall R_V of 0.41, and the event R_V's range from 0.00 to 0.52 with an R^2 of 0.92. The strip Station 12-347 has an overall Rv of 0.51, and the event R_V's range from 0.27 to 0.70 with an R^2 of 0.88. The strip Station 12-348 has only one data point (i.e., flow and rainfall data from only one storm event was available based on the data review process as described in Section 3.2), and the R_V is 0.13. The strip Station 12-349 has an overall R_V of 0.16, and the event R_V's range from 0.12 to 0.24 with an R^2 of 0.71.

Overall, the R_V values for Stations 12-225, 12-346, and 12-347 are reasonable. The R_V values for Stations 12-348 and 12-349 are questionable because flow data for only one out of twelve storms were accepted for Station 12-348. Flow data for six out of twelve storms were accepted for Station 12-349. The rejection of flow data at these two stations is due to substantial bypass that occurred during storm events, bypass caused by the gravel shoulder being higher than the pavement. The low average Rv's at these two stations are possibly due to a combination of

factors such as infiltration within vegetated strip areas, minor bypass occurring due to the gravel shoulder being higher than the pavement, and flow noise.

Napa Hwy 29 GRVTS Strip

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

For the Napa location, the overall R_V for the EOP station (4-307) is 0.30, and the event R_V's range from 0.03 to 0.70 with an R^2 of 0.37. The overall R_V appears to be low for an EOP station. Based on information collected during the season, this is mostly due to runoff infiltrating into the asphalt pavement, which appears to be permeable, before it reaches the collection pipe, as indicated in Figure 3-1(d). The strip Station 4-308 has an overall R_V of 0.005, and the event R_V's range from 0.001 to 0.03 with an R^2 of 0.17. The strip Station 4-309 has an overall R_V of 0.02, and the event R_V's range from 0.004 to 0.031 with an R^2 of 0.84. Based on field observations, the low R_V values at both strip stations are mostly due to runoff infiltrating into the asphalt pavement and substantial infiltration occurring within the vegetated strip areas. It should be noted that the low R^2 value of 0.17 for Station 4-308 indicates high variation of the R_V values, which is likely due to flow noise.

San Mateo Hwy 380 GRVTS Strip

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

For the San Mateo location, the overall R_V for the EOP station (4-310) is 1.45, and the event R_V's range from 0.93 to 2.08 with an R^2 of 0.95. No accepted flow data were available for Station 4-311 because monitoring at this station was terminated after the first four events due to recurring bypass issues. The overall R_V appears too reasonable. The strip Station 4-312 has an overall R_V of 0.53, and the event R_V's range from 0.03 to 0.86 with an R^2 of 0.85. The R_V values for both Stations 4-310 and 4-312 appear to be reasonable given the high R^2 values.

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 1.23, and the event R_V's range from 0.47 to 1.53 with an R^2 of 0.71. The strip Station 7-341 has an overall R_V of 0.11, and the event R_V's range from 0.04 to 0.20 with an R^2 of 0.50. The strip Station 7-342 has an overall R_V of 0.36, and the event R_V's range from 0.04 to 0.73 with an R^2 of 0.42. Based on field observations, the overall R_V for the EOP station appears to be reasonable. The low R_V values at both strip stations are mostly due to substantial infiltration occurring within the vegetated strip areas. Another possible contributing factor could be minor bypass flow entering the EOP during some of the storm events.

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 0.47, and the event R_V's range from 0.14 to 0.76 with an R^2 of 0.80. The strip Station 12-344 has an overall R_V of 0.05, and the event R_V's range from 0.003 to 0.076 with an R^2 of 0.63. The strip Station 12-345 has an overall R_V of 0.04, and the event R_V's range from 0.000 to 0.173 with an R^2 of 0.62. 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 infiltration beneath the collection pipe.

San Diego SR 52 GRVTS Strip

Stations: 11-328, 11-329 (*C. edulis*), and 11-330 (*C. edulis*)
Monitoring and sampling at the San Diego location was discontinued after the first four storms due to substantial recurring bypass issues, leading to no representative data being collected. Analysis of flow data from this location was, therefore, not performed.

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 1.78, and the event R_V's range from 1.66 to 2.22 with an R^2 of 0.96. 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 mounded vegetation downstream of the flume. Attempts were made to correct the flow data for ponding; however, the corrected flow data still generated high Rv's. The overall R_V for the swale influent station is 0.53, which appears to be reasonable. The event R_V's range from 0.44 to 0.57, with an R^2 of 0.99. The reduction of runoff at this station is mostly due to infiltration occurring within the swale.

Carlsbad (Palomar) I-5 GRVTS Swale

Stations: 11-326 and 11-327 (*C. edulis*)
For the Carlsbad (Palomar) location, the overall R_V for the swale influent station is 0.50, and the event R_V's range from 0.27 to 0.53 with an R^2 of 0.96. Based on information collected during the season, it was observed that the inlet design of the channel caused minor to substantial flow bypass for various monitored storms. As a result, flow data for only five out of twelve storms for the influent station (11-326), and only two out of twelve storms for the effluent station (11-327), were accepted and used for calculations. Details of the data evaluation are presented in the data review forms included in Appendix F. The overall R_V for the swale effluent station is 0.02, and the event R_V's range from 0.01 to 0.03 with an R^2 of 0.87. Possible causes of the low R_V include substantial infiltration that occurred within the swale, the estimated drainage area of the swale effluent station being higher than the actual drainage area, and bypass that occurred at the influent station.

3.4 WATER QUALITY DATA

As shown in Table 3-1, during the 2009-2010 season a total of three to twelve 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 D.

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.

3.5 VEGETATION ASSESSMENT

Quarterly vegetation assessments were conducted for all strips and swales during the period from July 2009 to August 2010. A standard procedure was used for the 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 3-1 presents the dates of the vegetation assessments. Detailed results are presented in Appendix A.2. The impact on concentration, infiltration, and load due to various ornamental vegetation types is further discussed in Section 4.5.

SECTION 4 DATA ASSESSMENTS AND FINDINGS

As summarized in Section 1, the primary study questions for the ORVTS Study include:

1. For various roadside strips planted with ornamental vegetation, how much treatment of highway runoff is occurring in terms of concentration, volume, and load reduction?
2. For various roadside swales planted with ornamental vegetation, how much treatment of highway runoff is occurring in terms of concentration, volume, and load reduction?
3. What is the difference in treatment between strips having the same type of ornamental vegetation but different strip widths?
4. What is the difference in treatment between strips having approximately the same strip width but different types of ornamental vegetation?
5. What is the difference in treatment between strips having approximately the same strip width and the same ornamental vegetation?
6. How does the treatment of highway runoff measured in this study compare to that measured for the RVTS Study and the BMP Retrofit Pilot Program?

Various data analyses were performed on concentration, runoff volume, and load data. The following subsections present the data assessment methodologies, findings, and discussions.

4.1 METHODOLOGY

This section presents the methodologies of analyses on concentration, runoff volume, and load data. Based on results of these analyses, various comparisons were conducted between strips/swales and their EOP stations and among the strips/swales themselves to address each of the study questions. The following terms are discussed in the following sections:

- The Event Mean Concentration (EMC) of a constituent is the concentration of this constituent from a flow-weighted sample collected during a monitored storm event at a station.
- The average EMC of a constituent is the arithmetic mean of all EMCs of this constituent at a station.
- The normalized runoff depth for a storm event at a monitoring station is calculated as: Normalized runoff depth = Vol/DA
    - Where Vol = recorded volume at this station
    - DA = drainage area of this station
- The volumetric runoff coefficient (R_v) for a storm event at a monitoring station is calculated as: R_v = Vol/DA/RF
    - Where RF = recorded rainfall depth for the storm event at this location
- The normalized load for constituent for a storm event at a monitoring station is calculated as Normalized Load = Vol/DA*EMC

Analysis of Variance (ANOVA) was performed on both concentration and load data for this report.

An ANOVA tests the hypothesis that the means of two or more populations are equal. The null hypothesis states that all population means are equal while the alternative hypothesis states that at least one is different. If the p-value from an ANOVA run is less than the specified alpha (alpha is the probability of making a Type I error, which is the probability of rejecting the null hypothesis when it is correct), then it is concluded that the mean of at least one population is statistically different at the specified confidence level (one minus alpha). To identify which of the population means are different, a multiple comparison method such as Tukey-Kramer's Honestly Significant Difference (HSD) can be used. Assumptions of the ANOVA test include:

- Errors of populations are independent from each other.
- The distribution of errors within each population is normal.
- Population variances are equal.

For this report, the ANOVA compares a strip or swale station to its EOP station and the strip stations to other strip stations. The ANOVA initially assumes that the average EMCs (or the normalized load) from all stations at a project location are the same (i.e., null hypothesis). The alternative hypothesis is that the average EMC (or the normalized load) of at least one station is statistically different at the specified confidence level (one minus alpha). If the p-value resulting from the ANOVA test is less than the specified alpha, then the null hypothesis is rejected and the alternative hypothesis is accepted. To further examine which stations have different average EMCs or normalized loads, the Tukey-Kramer HSD test is performed simultaneously to make multiple comparisons between all stations. For example, at a GRVTS location, there is one EOP station and two strip stations. If the ANOVA test rejects the null hypothesis, the alternative hypothesis is accepted, concluding that the average EMC (or the normalized load) of at least one of the three stations is different from the others. The Tukey-Kramer HSD performs multiple comparisons between these three stations (EOP vs. Strip Station 1, EOP vs. Strip Station 2, and Strip Station 1 vs. Strip Station 2) to determine if statistically significant differences exists between the average EMCs (or the normalized loads) at any two of these three stations at the specified confidence level.

The statistical software Minitab® was used for the ANOVA in this study. For constituents at each of the eight project locations as discussed in Section 1.3, the ANOVA was performed with an alpha of 0.10, or equivalently, the ANOVA runs had a 90-percent confidence level.

The assumptions of the ANOVA were not validated, primarily due to cost-benefit considerations and because the limited data available to date were collected from only one wet season monitored thus far. Future data assessments may consider including validation of the ANOVA assumptions.

4.1.1 Data Assessment on Concentration Data

Twenty six (26) out of the twenty nine (29) constituents listed in Table 2-1 were included in the data analyses on concentration data. Three (3) constituents (temperature, pH, and conductivity) were excluded from the data analyses because they are not relevant water quality indicators for

the purpose of evaluations on concentration reductions for this study. Based on the results of the data review process described in Section 3.2, and using the qualified concentration data, for each of the 26 constituents at each station the average EMC at each station was calculated using the Caltrans DAT as discussed in Section 3.5. The calculated average EMCs were used to calculate percent concentration reductions.

As discussed in Section 4.1, ANOVA was performed on the concentration data to determine if statistically significant differences exist between the average EMCs at different stations. The ANOVAs on concentration analysis results summary for the ORVTS Study are presented in Tables 4-4 through 4-9, 4-16, and 4-17. Detailed output results are presented in Appendix J.1. The ANOVA results were used in various comparisons between the vegetated strips within each location to evaluate their performance in reducing pollutant concentrations. Detailed data assessment discussions are presented in Sections 4.2 to 4.7.

Power Analysis

A power analysis was performed on the analytical results to provide information for determining the locations where monitoring should continue. The power analysis estimates the number of future monitoring years that will be required at each of the eight project locations to provide a dataset that will demonstrate statistical significance at a specified confidence level and power, if it exists, in treatment performance (the observed reductions in concentrations). Detailed methodology and findings of the power analysis are presented in the Power Analysis Technical Memorandum included as Appendix H of this report.

4.1.2 Data Assessment on Runoff Volume Data

Based on the results of the data review process described in Section 3.2, and using the qualified rainfall and flow data from each location, runoff volume and percent volume reduction (percent volume reduction was calculated only for non-EOP stations) were compiled. Data used for the calculations include flow and rainfall from only the sampled events and not the non-sampled events. For each strip station and swale effluent station, percent volume reduction was calculated on both an event basis and a seasonal basis.

Event Basis Volume Reduction Calculations:

Event basis percent volume reduction for a storm event at a station is calculated as:

$$\%\ volume\ reduction = \frac{\left[\frac{Vol@EOP}{DA@EOP} - \frac{Vol@(hwy + strip\ or\ swale)}{DA@(hwy + strip\ or\ swale)}\right]}{\frac{Vol@EOP}{DA@EOP}}$$

Where:
Vol@ EOP = volume measured at EOP station for a storm event
DA@ EOP = drainage area of EOP station
Vol@ [Hwy+Strip or swale] = volume measured at [highway + strip or swale] station for a event
DA@ [Hwy+Strip or swale] = drainage area of [highway+strip or swale] station

A summary of the event basis volume reduction calculations is presented in Table 4-1.

Seasonal Basis Volume Reduction Calculations:

Seasonal basis percent volume reduction at a station is calculated as:

$$\%\ volume\ reduction = \frac{\left[\frac{Seasonal\ Vol@EOP}{DA@EOP} - \frac{Seasonal\ Vol@(hwy + strip\ or\ swale)}{DA@(hwy + strip\ or\ swale)}\right]}{\frac{Seasonal\ Vol@EOP}{DA@EOP}}$$

Where:
Seasonal Vol@ EOP = total volume measured at EOP station during the season
DA@ EOP = drainage area of EOP station
Seasonal Vol@ [Hwy+Strip or swale] = total volume measured at [highway + strip or swale] station during the season
DA@ [Hwy+Strip or swale] = drainage area of [highway+strip or swale] station

Results of the seasonal basis volume reduction calculations are presented in Table 4-1.

Table 4-1: Percent Volume Reduction at Vegetated Strips and Swales

Location	Station ID	Strip Width or Swale Length (ft)	Tributary Area (acre)	Number of Storm Events	Range of Event Rainfall Depth (in)	Total Rain (in)	% Volume Reduction Range (Event Basis)	% Seasonal Volume Reduction
Sacramento	3-362	9	0.103	10	0.14 - 1.22	2.99	91.1% - 97.1%	94.5%
	3-363	24.5	0.129	11	0.14 - 1.22	3.17	94.4% - 99.7%	98.7%
	3-364	23.5	0.129	11	0.14 - 1.22	3.17	90.3% - 98.6%	97.3%
	3-365	24.5	0.132	12	0.14 - 1.22	6.53	95.6% - 99.5%	97.8%
Yorba Linda	12-346	10	0.280	11	0.42 - 3.41	17.89	37.5% - 91.7%	62.1%
	12-347	21	0.298	9	0.42 - 3.41	13.70	28.4% - 99.8%	53.3%
	12-348	21	0.319	1	0.42 - 3.41	1.56	89.4% - 89.4%	89.4%
	12-349	21	0.303	6	0.42 - 3.41	12.79	78.1% - 99.1%	86.8%
Napa	4-308	15	0.085	8	0.20 - 4.30	9.83	83.5% - 99.6%	97.6%
	4-309	15	0.085	11	0.20 - 4.30	12.46	58.4% - 98.5%	95.3%
San Mateo	4-312	16	0.202	8	0.18 - 2.86	7.07	49.4% - 97.0%	63.4%
Camarillo	7-341	9	0.243	5	0.55 - 1.94	6.20	85.7% - 95.9%	91.2%
	7-342	9	0.436	5	0.55 - 1.94	6.20	47.8% - 91.1%	71.2%
Westminster	12-344	15	0.138	12	0.11 - 2.96	10.53	24.1% - 99.6%	95.3%
	12-345	15	0.138	10	0.11 - 2.96	9.63	78.2% - 100.0%	96.0%
Newbury Park	7-339	148	1.143	4	0.46 - 2.35	5.12	58.6% - 100.0%	71.9%
Carlsbad (Palomar)	11-327	365	4.757	2	0.25 - 0.64	0.89	95.4% - 97.6%	95.9%

4.1.3 Data Assessment on Load Data

Data assessments were performed on the pollutant 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 caculate the normalized load for each storm event at each station so that various comparisons can be conducted between stations. Calculations of load data were performed on both event basis and seasonal basis:

Event Basis Load Calculations:

Event basis load a constituent for a storm event at a station is calculated as:

$$normalized\ load = \frac{Vol}{DA} \times EMC$$

Where:
Vol = volume measured at a station for a storm event
DA = drainage area of this station

As discussed in Section 4.1, for each location, an ANOVA was performed on the normalized load data to help determine if statistically significant differences exist between the normalized loads at different stations. Summary results of the ANOVA on normalized load data are presented in Tables 4-10 to 4-15, 4-18, and 4-19. Detailed output results are presented in Appendix J.2. The ANOVA results were used in various comparisons between the vegetated strips within each location to evaluate their performance in reducing pollutant load. Detailed data assessment discussions are presented in Sections 4.2 to 4.7.

Seasonal Basis Load Calculations:

Seasonal basis percent load reduction for a constituent at a station is calculated as:

$$\%\ load\ reduction = \frac{\left\{\sum\left(\frac{Vol@BOP}{DA@BOP} \times EMC@BOP\right) - \sum\left[\frac{Vol@(hwy + strip\ or\ swale)}{DA@(hwy + strip\ or\ swale)} \times EMC@(hwy + strip\ or\ swale)\right]\right\}}{\sum\left(\frac{Vol@BOP}{DA@BOP} \times EMC@BOP\right)}$$

Results of the seasonal load reduction calculations are presented in Tables 4-2 and 4-3.

Table 4-2: Seasonal Percent Load Reductions at ERVTS (Strip vs. EOP)

Constituent	Sacramento				Yorba Linda			
	3-362	**3-363**	**3-364**	**3-365**	**12-346**	**12-347**	**12-348**	**12-349**
	9-ft	**24.5-ft**	**23.5-ft**	**24.5-ft**	**10-ft**	**21-ft**	**21-ft**	**21-ft**
	Hedera helix	***Baccharis pilularis***	***Myoporum parvifolium***	***Hedera helix***	***Iva hayesiana***	***Iva hayesiana***	***Senecio mandraliscae***	***Lantana montevidensis***
Hardness as $CaCO_3$	94.1%	98.2%	96.4%	96.3%	71.6%	-43.3%	47.0%	75.6%
TDS	94.5%	98.3%	94.4%	96.3%	77.7%	-85.9%	49.7%	56.5%
TSS	90.6%	99.4%	99.5%	99.0%	75.4%	80.1%	94.9%	61.5%
TOC	94.5%	97.9%	91.8%	94.6%	68.3%	-8.8%	72.8%	72.4%
DOC	88.5%	95.4%	81.5%	91.3%	76.6%	-4.5%	68.2%	73.2%
Ammonia (NH_3-N)	91.4%	94.8%	95.1%	98.1%	78.2%	79.7%	97.9%	96.3%
Nitrate (NO_3-N)	93.9%	98.7%	99.0%	97.8%	75.0%	-139.2%	94.7%	62.4%
Nitrite (NO_2-N)	96.9%	99.3%	98.8%	99.1%	85.8%	81.5%	98.7%	96.4%
TKN	87.8%	97.5%	89.7%	94.5%	78.1%	7.9%	76.6%	75.1%
Total Phosphorus	88.9%	96.7%	90.5%	93.3%	74.6%	-24.3%	57.6%	6.1%
Ortho-P, diss	85.0%	95.6%	82.3%	87.5%	67.0%	-66.4%	15.2%	-29.6%
As, diss	93.9%	97.1%	93.9%	94.2%	71.9%	-55.2%	49.1%	36.6%
As, total	94.4%	98.2%	96.4%	96.2%	73.5%	6.6%	64.2%	51.1%
Cd, diss	96.3%	98.9%	97.1%	98.6%	63.5%	54.5%	89.4%	79.1%
Cd, total	98.9%	99.9%	99.8%	99.7%	84.1%	58.2%	71.7%	76.3%
Cr, diss	98.0%	99.5%	99.0%	99.5%	73.1%	71.4%	95.5%	91.0%
Cr, total	95.4%	99.6%	99.6%	99.0%	71.6%	75.0%	93.7%	78.0%
Cu, diss	95.7%	98.9%	97.5%	98.3%	82.5%	70.1%	88.3%	88.2%
Cu, total	97.7%	99.7%	99.3%	99.4%	82.2%	85.4%	95.7%	92.8%
Pb, diss	98.0%	99.0%	97.4%	98.2%	79.0%	10.8%	57.6%	-6.2%
Pb, total	97.8%	99.8%	99.8%	99.6%	83.8%	86.8%	94.6%	87.0%
Ni, diss	92.4%	98.7%	97.1%	97.8%	87.0%	52.2%	84.4%	81.3%
Ni, total	94.6%	99.4%	99.4%	98.8%	82.2%	66.9%	88.3%	74.8%
Zn, diss	95.1%	98.4%	96.1%	97.8%	95.7%	90.6%	97.8%	96.1%
Zn, total	98.4%	99.8%	99.6%	99.7%	95.4%	92.4%	97.5%	95.0%

NA = Not available. The concentration(s) at this station and/or its respective EOP station is(are) below the detection limit(s); therefore, percent load reductions could not be calculated.

Seasonal percent reduction calculations were based on all monitored events, but do not include non-monitored event data.

Numbers in the table are the calculated percent cumulative load reduction (positive numbers indicate load reductions, and negative numbers as highlighted in gray indicate load increases as compared to loads at the EOP).

Table 4-3: Seasonal Percent Load Reductions at GRVTS (Strip/Swale vs. EOP)

Constituent	Napa		San Mateo	Camarillo		Westminster		Newbury Park	Carlsbad (Palomar)
	4-308	4-309	4-312	7-341	7-342	12-344	12-345	7-339	11-327
	15-ft		16-ft	9-ft		15-ft		148-ft	365-ft
Hardness as $CaCO_3$	95.9%	98.2%	57.8%	84.2%	69.8%	67.0%	46.4%	79.9%	90.2%
TDS	95.0%	97.7%	32.8%	73.2%	70.0%	-34.2%	-43.0%	75.0%	89.1%
TSS	96.4%	97.7%	7.1%	93.8%	92.0%	11.5%	49.5%	58.8%	99.9%
TOC	95.5%	96.6%	48.2%	87.8%	81.6%	-18.5%	24.4%	69.0%	65.6%
DOC	94.7%	96.4%	48.3%	89.6%	82.8%	-18.8%	30.0%	71.6%	80.0%
Ammonia (NH_3-N)	98.4%	92.8%	84.6%	96.1%	91.4%	83.8%	84.7%	86.4%	99.9%
Nitrate (NO_3-N)	97.3%	95.0%	18.1%	97.7%	90.0%	16.5%	72.8%	83.6%	99.9%
Nitrite (NO_2-N)	98.5%	96.3%	67.3%	98.1%	91.1%	81.7%	64.3%	87.0%	99.7%
TKN	94.1%	94.9%	53.4%	90.8%	78.8%	56.7%	34.7%	78.3%	96.8%
Total Phosphorus	94.0%	86.5%	-10.6%	31.0%	15.0%	38.3%	-48.9%	44.8%	91.5%
Ortho-P, diss	92.9%	73.3%	-84.9%	-37.4%	-89.9%	-31.0%	-666.0%	19.2%	90.2%
As, diss	96.2%	85.5%	61.3%	69.3%	53.0%	56.2%	28.5%	74.1%	96.7%
As, total	94.5%	88.5%	10.7%	74.1%	60.3%	68.4%	65.7%	74.8%	96.9%
Cd, diss	97.0%	95.9%	69.1%	90.7%	71.2%	92.7%	91.1%	71.9%	95.4%
Cd, total	97.0%	95.9%	67.7%	93.5%	91.6%	85.2%	85.1%	69.6%	98.8%
Cr, diss	99.1%	98.2%	72.5%	94.4%	77.6%	86.3%	85.7%	81.0%	96.7%
Cr, total	98.2%	97.4%	42.3%	94.3%	83.2%	83.9%	83.6%	68.7%	97.0%
Cu, diss	98.0%	97.9%	79.9%	91.7%	73.0%	83.2%	68.5%	73.5%	98.7%
Cu, total	98.1%	98.5%	76.5%	95.6%	87.9%	83.3%	81.9%	79.9%	98.9%
Pb, diss	96.9%	94.5%	69.0%	89.8%	39.5%	48.2%	7.1%	36.9%	96.5%
Pb, total	95.7%	94.5%	20.7%	89.7%	82.9%	39.3%	10.6%	72.5%	99.1%
Ni, diss	98.1%	97.2%	70.1%	87.3%	76.6%	86.8%	83.3%	78.6%	98.7%
Ni, total	97.5%	96.7%	1.0%	92.3%	84.0%	81.6%	81.2%	68.0%	98.7%
Zn, diss	96.8%	98.2%	88.3%	92.1%	65.8%	93.8%	91.1%	82.3%	99.0%
Zn, total	97.4%	98.7%	76.6%	96.6%	89.8%	78.4%	75.6%	80.4%	99.2%

NA = Not available. The concentration(s) at this station and/or its respective EOP station is(are) below the detection limit(s); therefore, percent load reductions could not be calculated.

Seasonal percent load reduction calculations were based on all monitored events, but do not include non-monitored event data.

Numbers in the table are the calculated percent cumulative load reduction (positive numbers indicate load reductions, and negative numbers as highlighted in gray indicate load increases as compared to loads at the EOP).

4.2 EFFECTIVENESS OF STRIPS

This section addresses the study question of how much treatment of highway runoff is occurring in terms of concentration, volume, and load reduction for various roadside strips planted with ornamental vegetation. Data analyses results and discussions on concentration, infiltration, and load data for the ERVTS and GRVTS strip locations are presented in the following subsections.

4.2.1 Concentration

At each ERVTS and GRVTS strip location, the average EMCs at each strip station were compared to the average EMCs at the respective EOP station to evaluate the benefits of vegetated strips in treating roadway storm water runoff. Percent mean concentration reductions for each strip station in comparison with its respective EOP station are shown in Appendix A of the *Power Analysis Technical Memorandum* (included as Appendix G of this report). Tables 4-4 to 4-9 summarize the ANOVA on concentration results at each ORVTS strip location.

Sacramento I-5 ERVTS Strip

The results of the ANOVA on concentration data at the Sacramento ERVTS location are presented in Table 4-4. The table presents the number of data points, mean concentration, mean percent difference, the range of EMCs, and the standard deviation per station. Each constituent with a concentration reduction or increase in comparison to the EOP is also identified in Table 4-4.

Table 4-4: Concentration Statistics for Sacramento I-5 ERVTS Strip

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	3-362 N Mean Mean % Δ Range Std. Dev.	3-363 N Mean Mean % Δ Range Std. Dev.	3-364 N Mean Mean % Δ Range Std. Dev.	3-365 N Mean Mean % Δ Range Std. Dev.
Hardness as $CaCO_3$ (mg/L)	11 43.455 0.0% 26-80 18.296	9 48.667 -12.0% 40-60 6.740	9 71.333 -64.2% 22-196 59.887	10 63.000 -45.0% 22-180 57.620	10 71.600 -64.8% 42-170 45.765
TDS (mg/L)	11 64.364 0.0% 36-114 25.859	9 85.000 -32.1% 39-182 52.093	10 107.500 -67.0% 22-252 81.478	10 144.500 -124.5% 60-322 101.840	10 115.100 -78.8% 52-220 54.070
TSS (mg/L)	11 120.273 0.0% 54-238 66.370	9 117.889 2.0% 21-411 138.492	10 42.600 64.6% 12-174 58.494	10 15.400 87.2% 8-24 5.354	10 34.200 71.6% 12-91 25.563
TOC (mg/L)	11 8.800 0.0% 2.8-37.9 12.413	9 57.144 -549.4% 8.2-370 158.360	9 24.067 -173.5% 8.2-42.1 11.223	10 33.680 -282.7% 17.1-80.1 21.218	10 28.280 -221.4% 20.7-45.5 8.617
DOC (mg/L)	10 4.800 0.0% 2.5-10.1 2.691	8 17.875 -272.4% 3-49.7 19.431	8 17.863 -272.1% 6.8-32.2 8.735	9 23.489 -389.4% 9-67.3 20.795	9 17.433 -263.2% 10.8-35.8 8.698
Turbidity (NTU)	10 112.030 0.0% 53.1-290 89.112	8 130.363 -16.4% 24-532 206.721	9 104.089 7.1% 7-641 263.876	9 13.878 87.6% 5.2-29.5 8.918	9 36.311 67.6% 10-127 42.962
Ammonia NH_3-N (mg/L)	11 0.499 0.0% 0.26-1.16 0.317	9 0.727 -45.7% 0.11-2.28 0.751	10 1.431 -186.8% 0.24-8.64 3.324	10 0.736 -47.5% 0.19-1.68 0.532	10 0.588 -17.8% 0.12-1.32 0.377
Nitrate NO_3-N (mg/L)	10 0.776 0.0% 0.22-2 0.645	8 0.645 16.9% ND-1.55 0.549	9 0.502 35.3% 0.12-1.22 0.354	9 0.230 70.4% 0.01-0.54 0.202	9 0.672 13.4% 0.07-1.21 0.415
Nitrite NO_2-N (mg/L)	10 0.091 0.0% 0.04-0.31 0.100	8 0.156 -71.4% 0.01-0.91 0.413	9 0.032 64.8% 0.01-0.1 0.032	9 0.034 62.6% ND-0.09 0.027	9 0.037 59.3% 0.01-0.08 0.025
TKN (mg/L)	11 2.129 0.0% 1.03-6.08 1.768	9 4.813 -126.1% 1.31-10.6 3.357	9 3.526 -65.6% 1.7-6.22 1.748	10 5.596 -162.8% 1.9-8.64 2.028	10 4.519 -112.3% 1.73-8.79 2.242

Table 4-4: Concentration Statistics for Sacramento I-5 ERVTS Strip (continued)

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	3-362 N Mean Mean % Δ Range Std. Dev.	3-363 N Mean Mean % Δ Range Std. Dev.	3-364 N Mean Mean % Δ Range Std. Dev.	3-365 N Mean Mean % Δ Range Std. Dev.
Total Phosphorus (mg/L)	11 0.430 0.0% 0.17-1.22 0.358	9 0.832 -93.5% 0.25-1.73 0.595	10 0.744 -73.0% 0.28-1.81 0.524	10 0.997 -131.9% 0.42-1.69 0.371	10 0.977 -127.2% 0.5-2.08 0.512
Ortho-P, diss (mg/L)	10 0.164 0.0% 0.07-0.61 0.200	8 0.444 -170.7% 0.14-1.23 0.406	9 0.418 -154.9% 0.18-0.82 0.240	9 0.719 -338.4% 0.32-1.29 0.301	9 0.688 -319.5% 0.39-1.43 0.367
As, diss (ug/L)	11 1.436 0.0% 1-2.8 0.676	9 1.656 -15.3% 1.1-2.9 0.595	10 3.400 -136.8% 0.9-8.1 2.489	10 3.040 -111.7% 1.1-10 3.151	10 3.250 -126.3% 1.9-5.7 1.308
As, total (ug/L)	11 3.316 0.0% 1.9-6.9 1.770	9 2.600 21.6% 2-4 0.677	10 4.250 -28.2% 1-9.3 3.077	10 3.730 -12.5% 1.3-12 3.787	10 4.180 -26.1% 2.4-8.4 1.981
Cd, diss (ug/L)	11 <0.1 0.0% ND-0.2 NA	9 <0.1 NA ND-0.1 NA	10 <0.1 NA ND-0.1 NA	10 <0.1 NA ND-0.2 NA	10 <0.1 NA ND-0.1 NA
Cd, total (ug/L)	11 0.722 0.0% ND-1.8 0.473	9 0.178 75.3% ND-0.4 0.125	10 0.065 91.0% ND-0.1 0.024	10 <0.1 NA ND- ND NA	10 <0.1 NA ND-0.2 NA
Cr, diss (ug/L)	11 1.291 0.0% 0.8-1.7 0.297	9 0.700 45.8% 0.4-1 0.242	10 0.610 52.7% 0.2-1.2 0.319	10 0.580 55.1% 0.3-1.2 0.315	10 0.470 63.6% 0.2-0.8 0.205
Cr, total (ug/L)	11 14.182 0.0% 7-34 8.655	9 7.156 49.5% 1.8-20 6.264	10 3.580 74.8% 0.6-17 6.121	10 1.520 89.3% ND-3.5 0.960	10 3.480 75.5% 0.8-13 4.227
Cu, diss (ug/L)	11 10.291 0.0% 5.6-23 5.559	9 12.111 -17.7% 5.4-28 8.777	10 9.020 12.4% 4.3-19 4.817	10 9.520 7.5% 5.2-17 3.763	10 10.290 0.0% 6-26 7.071
Cu, total (ug/L)	11 46.364 0.0% 27-77 16.942	9 22.111 52.3% 11-41 10.215	10 13.100 71.7% 5.6-24 5.789	10 12.800 72.4% 6.9-19 3.754	10 14.470 68.8% 8-31 7.399

Table 4-4: Concentration Statistics for Sacramento I-5 ERVTS Strip (continued)

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	3-362 N Mean Mean % Δ Range Std. Dev.	3-363 N Mean Mean % Δ Range Std. Dev.	3-364 N Mean Mean % Δ Range Std. Dev.	3-365 N Mean Mean % Δ Range Std. Dev.
Pb, diss (ug/L)	11 0.119 0.0% ND-0.5 0.164	9 0.127 -6.7% ND-0.4 0.135	10 0.134 -12.6% 0.08-0.2 0.058	10 0.155 -30.3% ND-0.4 0.112	10 0.137 -15.1% ND-0.2 0.054
Pb, total (ug/L)	11 9.827 0.0% 4.9-17 4.080	9 2.533 74.2% 0.6-5.5 1.647	10 1.100 88.8% 0.3-4.3 1.436	10 0.640 93.5% 0.2-1.5 0.401	10 0.980 90.0% 0.4-3.3 1.039
Ni, diss (ug/L)	11 1.373 0.0% 0.6-3.5 0.906	9 1.889 -37.6% ND-5.5 1.720	10 1.230 10.4% 0.2-2 0.556	10 1.260 8.2% 0.4-1.9 0.483	10 1.270 7.5% 0.8-2 0.378
Ni, total (ug/L)	11 13.482 0.0% 6.3-33 8.676	9 8.067 40.2% 2.8-19 6.330	10 7.510 44.3% 0.7-32.8 11.387	10 2.330 82.7% 1.1-4.1 1.023	10 4.310 68.0% 1.9-14 4.334
Zn, diss (ug/L)	11 9.655 0.0% 4.6-19 4.521	9 21.089 -118.4% 5.5-54 20.152	10 14.690 -52.1% 4.6-31 9.507	10 17.060 -76.7% 6.6-31 8.750	10 15.010 -55.5% 6.9-32 8.712
Zn, total (ug/L)	11 191.636 0.0% 98-380 89.949	9 99.778 47.9% 24-470 186.510	10 29.600 84.6% 12-57 15.291	10 26.600 86.1% 15-40 8.893	10 25.400 86.7% 12-40 10.566

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

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

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

No color = Increase but not statistically significant at a 90-percent confidence level

As shown in Table 4-4, the ANOVA on concentration data at the Sacramento ERVTS demonstrates the following:

- Three or more strip stations show concentration reductions in TSS, turbidity, ammonia, nitrite, total and dissolved chromium, total and dissolved copper, total lead, total and dissolved nickel, and total zinc at each strip station as compared to the EOP.
- Constituents that demonstrate a statistically significant concentration reduction (at a 90-percent confidence level) in all four stations were dissolved and total chromium, total copper, total lead, and total zinc. TSS shows a statistically significant concentration reduction at three stations. Two stations show statistically significant concentration

reductions for turbidity, total cadmium, and total nickel. Ammonia and nitrite show statistically significant concentration reductions at one station.

- Three or more strip stations show concentration increases in hardness, TDS, TOC, DOC, ammonia, TKN, total phosphorus, dissolved ortho-P, dissolved arsenic, dissolved lead, and dissolved zinc at each strip station as compared to the EOP.
- Constituents that demonstrate a statistically significant concentration increase (at a 90-percent confidence level) at two stations were total phosphorus, dissolved ortho-P, and dissolved arsenic. Total dissolved solids and DOC both show a statistically significant concentration increase at one station.
- Overall, each strip at the Sacramento ERVTS reduced TSS, resulting in a reduction of all total metals and dissolved chromium. Reduction of turbidity may also have been a contributing factor in the reduction of heavy metals. All strips show an increase in ammonia, TKN, total phosphorus, and dissolved ortho-P in comparison to the EOP. The increases in nitrogen and phosphorus are believed to originate from the plants themselves, since no additional fertilizers were utilized on the strips. The only constituent that did not yield a result was dissolved cadmium, since it was not detected above the MDL.

Yorba Linda SR 91 ERVTS Strip

The ANOVA on concentration data at the Yorba Linda ERVTS location is presented in Table 4-5. The table presents the number of data points, mean concentration, mean percent difference, the range of EMCs, and the standard deviation per station. Each constituent with a concentration reduction or increase in comparison to the EOP is also identified in Table 4-5.

Table 4-5: Concentration Statistics for Yorba Linda SR-91 ERVTS Strip

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	12-346 N Mean Mean % Δ Range Std. Dev.	12-347 N Mean Mean % Δ Range Std. Dev.	12-348 N Mean Mean % Δ Range Std. Dev.	12-349 N Mean Mean % Δ Range Std. Dev.
Hardness as $CaCO_3$ (mg/L)	12 33.333 0.0% 18-66 14.638	11 26.545 20.4% 12-68 17.412	10 79.000 -137.0% 18-388 137.192	9 112.667 -238.0% 32-274 91.110	9 63.556 -90.7% 22-198 63.546
TDS (mg/L)	12 53.750 0.0% 20-154 45.089	11 38.455 28.5% 12-172 56.313	10 107.900 -100.7% 22-422 158.541	9 166.222 -209.3% 37-500 161.512	9 117.778 -119.1% 26-324 102.257
TSS (mg/L)	12 44.917 0.0% 24-79 18.005	11 36.818 18.0% 17-133 27.874	10 26.400 41.2% 12-46 11.249	9 26.111 41.9% 8-43 11.796	9 155.889 -247.1% 29-367 114.127
TOC (mg/L)	12 11.900 0.0% 3.9-36.7 10.740	11 9.427 20.8% 3.6-30.6 9.097	10 18.130 -52.4% 1.9-47.4 14.617	9 17.333 -45.7% 6.7-35.6 9.882	9 17.567 -47.6% 8.5-28.1 7.013
DOC (mg/L)	12 8.042 0.0% 1.5-21.5 6.812	11 6.045 24.8% 1.9-24.1 7.578	10 13.240 -64.6% 1.6-42.6 13.417	9 13.467 -67.5% 4.8-27.8 7.818	9 12.711 -58.1% 5.3-22.4 6.782
Turbidity (NTU)	12 37.174 0.0% 17.6-75.3 19.611	11 22.841 38.6% 12.6-34.1 7.780	10 26.980 27.4% 14.8-57.9 13.913	9 25.239 32.1% 11.3-35.75 9.045	9 59.000 -58.7% 15-103.3 27.065
Ammonia NH_3-N (mg/L)	11 0.380 0.0% ND-1.02 0.325	10 0.180 52.6% 0.01-0.57 0.175	10 0.153 59.7% ND-0.57 0.190	9 0.106 72.1% ND-0.54 0.220	9 0.107 71.8% ND-0.54 0.215
Nitrate NO_3-N (mg/L)	12 0.714 0.0% 0.26-2.19 0.645	11 0.603 15.5% 0.14-2.9 0.965	10 2.181 -205.5% 0.095-16.8 6.762	9 0.802 -12.3% 0.06-4.33 1.673	9 2.152 -201.4% 0.25-10.3 3.888

Table 4-5: Concentration Statistics for Yorba Linda SR-91 ERVTS Strip (continued)

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	12-346 N Mean Mean % Δ Range Std. Dev.	12-347 N Mean Mean % Δ Range Std. Dev.	12-348 N Mean Mean % Δ Range Std. Dev.	12-349 N Mean Mean % Δ Range Std. Dev.
Nitrite NO_2-N (mg/L)	11 0.058 0.0% 0.02-0.16 0.046	10 0.018 69.0% ND-0.06 0.020	10 0.018 69.0% ND-0.08 0.027	9 0.014 76.1% ND-0.07 0.022	9 0.013 77.0% ND-0.06 0.018
TKN (mg/L)	12 1.594 0.0% 0.42-4.65 1.314	11 0.985 38.2% 0.32-3.5 1.058	10 2.027 -27.2% 0.65-6.22 1.887	9 1.963 -23.1% 0.98-5.14 1.510	9 2.014 -26.3% 1.29-4.18 1.033
Total Phosphorus (mg/L)	12 0.117 0.0% ND-0.49 0.152	11 0.101 13.7% 0.03-0.37 0.114	10 0.219 -87.2% 0.07-0.45 0.120	9 0.403 -244.4% 0.28-0.69 0.147	9 0.554 -373.5% 0.38-0.95 0.197
Ortho-P, diss (mg/L)	12 0.042 0.0 ND-0.16 0.047	11 0.051 -21.4 ND-0.23 0.080	10 0.134 -219.0% 0.06-0.33 0.094	9 0.287 -583.3% 0.2-0.54 0.125	9 0.311 -640.5% 0.2-0.44 0.080
As, diss (ug/L)	12 0.508 0.0% 0.3-1 0.243	11 0.382 24.8% 0.2-1 0.260	10 1.360 -167.7% 0.6-2.8 0.837	9 2.344 -361.4% 1-3.8 0.830	9 1.589 -212.8% 1.1-2.1 0.362
As, total (ug/L)	12 1.092 0.0% 0.7-1.9 0.370	11 0.818 25.1% 0.4-1.8 0.414	10 1.860 -70.3% 1-3.4 0.919	9 3.000 -174.7% 1.4-4.6 0.924	9 2.967 -171.7% 2-4 0.617
Cd, diss (ug/L)	12 0.229 0.0% ND-0.5 0.183	11 0.127 44.4% ND-0.8 0.224	10 0.180 21.4% ND-0.6 0.195	9 0.537 -134.5% ND-3 1.264	9 0.181 21.0% ND-0.3 0.104
Cd, total (ug/L)	12 0.492 0.0% 0.2-1 0.254	11 0.191 61.2% 0.1-0.4 0.099	10 0.400 18.7% 0.2-0.8 0.217	9 0.967 -96.5% 0.3-4.9 2.021	9 0.711 -44.5% 0.4-1.2 0.247
Cr, diss (ug/L)	12 2.033 0.0% 1.1-2.9 0.540	11 1.336 34.3% 0.8-2.5 0.529	10 1.220 40.0% 0.8-2.1 0.471	9 1.089 46.4% 0.8-2 0.432	9 1.200 41.0% 0.8-2 0.476
Cr, total (ug/L)	12 5.825 0.0% 3-8.8 1.658	11 4.427 24.0% 2.1-9.1 2.138	10 3.100 46.8% 2-4.2 0.780	9 3.244 44.3% 2.3-4.4 0.832	9 8.078 -38.7% 3.8-16 4.163

Table 4-5: Concentration Statistics for Yorba Linda SR-91 ERVTS Strip (continued)

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	12-346 N Mean Mean % Δ Range Std. Dev.	12-347 N Mean Mean % Δ Range Std. Dev.	12-348 N Mean Mean % Δ Range Std. Dev.	12-349 N Mean Mean % Δ Range Std. Dev.
Cu, diss (ug/L)	12 19.950 0.0% 7-60 18.187	11 8.318 58.3% 3.9-21 5.588	10 8.480 57.5% 5.8-15 3.292	9 9.756 51.1% 6.4-15 2.755	9 7.978 60.0% 5.9-14 2.853
Cu, total (ug/L)	12 50.750 0.0% 29-90 20.885	11 23.727 53.2% 13-42 9.097	10 13.820 72.8% 9.2-22 4.054	9 14.788 70.9% 12-24 4.385	9 19.667 61.2% 14-31 6.218
Pb, diss (ug/L)	12 0.261 0.0% ND-1 0.300	11 0.162 37.9% ND-0.8 0.270	10 0.320 -22.6% 0.1-0.8 0.228	9 0.300 -14.9% 0.2-0.6 0.150	9 0.533 -104.2% 0.2-2.8 1.138
Pb, total (ug/L)	12 15.950 0.0% 7.9-31 6.703	11 7.564 52.6% 3.8-15 3.657	10 5.090 68.1% 3.8-7.9 1.395	9 4.678 70.7% 3.2-6.4 1.237	9 12.078 24.3% 5.3-22 5.710
Ni, diss (ug/L)	12 3.683 0.0% 1.3-12 3.716	11 1.273 65.4% 0.5-4.1 1.205	10 2.320 37.0% 1.1-6.6 2.031	9 2.867 22.2% 1.1-4.7 1.194	9 2.489 32.4% 1.4-4.5 1.001
Ni, total (ug/L)	12 7.142 0.0% 3.7-17 4.332	11 3.391 52.5% 1.7-7.6 1.801	10 4.120 42.3% 2.4-8.2 2.030	9 5.089 28.7% 2.7-8.6 1.824	9 8.522 -19.3% 4.8-15 3.465
Zn, diss (ug/L)	12 190.583 0.0% 50-1100 369.033	11 17.818 90.7% 9-39 9.957	10 17.140 91.0% 8.2-37 11.167	9 14.367 92.5% 9.5-27 6.001	9 16.056 91.6% 6.4-46 14.209
Zn, total (ug/L)	12 699.167 0.0% 130-5700 2205.617	11 65.000 90.7% 39-110 23.991	10 34.900 95.0% 21-68 16.158	9 34.111 95.1% 24-48 8.213	9 59.333 91.5% 26-98 24.586

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

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

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

No color = Increase but not statistically significant at a 90-percent confidence level

As shown in Table 4-5, the ANOVA on concentration data at the Yorba Linda ERVTS demonstrates the following:

- Three or more strip stations show concentration reductions in TSS, turbidity, ammonia, nitrite, dissolved cadmium, total and dissolved chromium, total and dissolved copper, total lead, total and dissolved nickel, and total and dissolved zinc at each strip station as compared to the EOP.
- Constituents that demonstrate a statistically significant concentration reduction (at a 90-percent confidence level) at all four stations are nitrite, dissolved chromium, total and dissolved copper, and dissolved zinc. Total lead shows a statistically significant concentration reduction at three stations. Two stations show statistically significant concentration reductions in total chromium. Total nickel shows a statistically significant concentration reduction at one station.
- Three or more strip stations show concentration increases in hardness, TDS, TOC, DOC, ammonia, TKN, total phosphorus, dissolved ortho-P, total and dissolved arsenic, and dissolved lead at each strip station as compared to the EOP.
- Constituents that demonstrate a statistically significant concentration increase (at a 90-percent confidence level) at all three stations are dissolved ortho-P, dissolved arsenic, and total arsenic. Total phosphorus shows a statistically significant concentration increase at two stations, while hardness has a statistically significant concentration increase at one station.
- Overall, three out of four strips at the Yorba Linda ERVTS reduced TSS, therefore resulting in a reduction of all total metals and dissolved chromium. Reduction of turbidity at three out of four strips may also have been a contributing factor in assisting the reduction of heavy metals. One strip has a significant increase in TSS and turbidity, which may be due to additional internal strip erosion. Three out of four strips show increases in TKN and total phosphorus, while dissolved ortho-P increased for all strips. The increases in nitrogen and phosphorus are believed to originate from the plants themselves, since no additional fertilizers were utilized on the strips.

Napa Hwy 29 GRVTS Strip

The ANOVA on concentration data at the Napa GRVTS location is presented in Table 4-6. The table presents the number of data points, mean concentration, mean percent difference, the range of EMCs, and the standard deviation per station. Each constituent with a concentration reduction or increase in comparison to the EOP is also identified in Table 4-6.

Table 4-6: Concentration Statistics for Napa Hwy 29 GRVTS Strip

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	4-308 N Mean Mean % Δ Range Std. Dev.	4-309 N Mean Mean % Δ Range Std. Dev.
Hardness as $CaCO_3$ (mg/L)	9 17.560 0.0% 2-32 9.150	8 14.113 -19.6% 2-32 12.059	9 9.211 47.5% 2-26 8.311
TDS (mg/L)	9 23.890 0.0% 8-46 14.430	8 18.302 23.4% 0.1-50 18.342	10 16.350 31.6% 0.1-64 21.580
TSS (mg/L)	9 13.110 0.0% 4-36 11.430	8 17.375 -32.5% 2-53 18.486	10 13.386 -2.1% 0.5-35 11.694
TOC (mg/L)	9 4.200 0.0% 2.1-7.8 1.802	8 4.388 -4.5% 1.2-11.4 4.189	9 2.344 44.2% 1.3-4.2 1.293
DOC (mg/L)	9 3.011 0.0% 1.7-5.9 1.423	8 3.063 -1.7% 1.2-8.3 3.177	9 1.822 39.5% 0.9-3.4 1.123
Turbidity (NTU)	9 8.389 0.0% 5-14 3.620	8 5.314 36.7% 3.4-8.3 2.869	10 6.421 23.5% 3-12.3 3.841
Ammonia NH_3-N (mg/L)	9 0.337 0.0% 0.02-0.9 0.302	8 0.159 52.7% 0.05-0.47 0.167	9 0.257 23.6% 0.06-0.7 0.221
Nitrate NO_3-N (mg/L)	9 0.187 0.0% 0.04-0.4 0.125	8 0.179 3.9% 0.05-0.62 0.224	10 0.161 14.0% 0.1-0.28 0.083

Table 4-6: Concentration Statistics for Napa Hwy 29 GRVTS Strip (continued)

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	4-308 N Mean Mean % Δ Range Std. Dev.	4-309 N Mean Mean % Δ Range Std. Dev.
Nitrite NO_2-N (mg/L)	9 0.012 0.0% 0.005-0.02 0.007	8 0.008 33.3% 0.005-0.02 0.006	10 0.011 8.3% 0.005-0.02 0.007
TKN (mg/L)	9 0.853 0.0% 0.22-1.89 0.585	8 0.870 -2.0% 0.59-1.59 0.474	9 0.694 18.6% 0.28-1.6 0.506
Total Phosphorus (mg/L)	9 0.067 0.0% 0.004-0.18 0.055	8 0.110 -64.7% 0.004-0.29 0.103	9 0.149 -121.5% 0.004-0.35 0.121
Ortho-P, diss (mg/L)	9 0.040 0.0% 0.0015-0.11 0.039	8 0.080 -102.4% 0.03-0.16 0.055	10 0.113 -185.4% 0.03-0.26 0.080
As, diss (ug/L)	9 0.172 0.0% 0.05-0.3 0.100	8 0.441 -156.6% 0.05-2.6 1.195	10 0.300 -74.4% 0.2-0.5 0.136
As, total (ug/L)	9 0.244 0.0% 0.1-0.5 0.138	8 0.613 -150.6% 0.2-3.2 1.442	10 0.500 -104.5% 0.3-0.9 0.254
Cd, diss (ug/L)	9 <0.1 0.0% 0.05-0.05 NA	8 <0.1 NA 0.05-0.05 NA	10 <0.1 NA 0.05-0.05 NA
Cd, total (ug/L)	9 <0.1 0.0% 0.05-0.05 NA	8 <0.1 NA 0.05-0.05 NA	10 <0.1 NA 0.05-0.05 NA
Cr, diss (ug/L)	9 0.856 0.0% 0.3-2 0.655	8 0.191 77.7% 0.0045-0.4 0.202	10 0.221 74.2% 0.1-0.8 0.257
Cr, total (ug/L)	9 1.767 0.0% 0.4-5.4 1.745	8 1.114 37.0% 0.4-3.5 1.219	10 1.011 42.8% 0.4-2.1 0.692

Table 4-6: Concentration Statistics for Napa Hwy 29 GRVTS Strip (continued)

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	4-308 N Mean Mean % Δ Range Std. Dev.	4-309 N Mean Mean % Δ Range Std. Dev.
Cu, diss (ug/L)	9 3.922 0.0% 2.4-7 1.611	8 2.013 48.7% 0.7-4.8 1.709	10 1.640 58.2% 1-3.1 0.929
Cu, total (ug/L)	9 6.956 0.0% 3.8-13 3.244	8 3.850 44.6% 1.8-8 2.541	10 3.210 53.8% 1.7-7.7 2.245
Pb, diss (ug/L)	9 0.060 0.0% 0.04-0.2 0.080	8 0.112 -87.1% 0.04-0.5 0.220	10 0.109 -81.7% 0.04-0.2 0.053
Pb, total (ug/L)	9 0.989 0.0% 0.1-2 0.717	8 1.773 -79.2% 1-4.4 1.463	10 2.948 -198.1% 0.9-9.5 3.291
Ni, diss (ug/L)	9 0.811 0.0% 0.3-2.1 0.618	8 0.407 49.8% 0.1-1.3 0.458	10 0.370 54.4% 0.2-0.8 0.214
Ni, total (ug/L)	9 1.433 0.0% 0.7-2.7 0.748	8 1.213 15.4% 0.7-2.8 0.853	10 1.290 10.0% 0.8-2.8 0.802
Zn, diss (ug/L)	9 14.400 0.0% 9.7-24 5.518	8 9.375 34.9% 6.4-17 5.083	10 4.430 69.2% 3.1-6.5 1.644
Zn, total (ug/L)	9 27.667 0.0% 11-53 14.085	8 18.863 31.8% 11-29 9.931	10 10.720 61.3% 6.3-28 8.049

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

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

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

No color = Increase but not statistically significant at a 90-percent confidence level

As shown in Table 4-6, the ANOVA on concentration data at the Napa GRVTS demonstrates the following:

- Both strip stations show concentration reductions in hardness, TDS, turbidity, ammonia, nitrate, nitrite, total and dissolved chromium, total and dissolved copper, total and dissolved nickel, and total and dissolved zinc as compared to the EOP.
- Constituents that demonstrate a statistically significant concentration reduction (at a 90-percent confidence level) at both stations are dissolved chromium and dissolved copper. Total copper, dissolved nickel, dissolved zinc, and total zinc show statistically significant concentration reductions at one station.
- Both strip stations show concentration increases in TSS, total phosphorus, dissolved ortho-P, total and dissolved arsenic, and total and dissolved lead as compared to the EOP.
- No constituents exhibit a statistically significant concentration increase at both stations. Dissolved ortho-P shows a statistically significant concentration increase at one station.
- One strip station shows a concentration reduction, while the other station shows a concentration increase in both hardness and TKN in comparison to the EOP. Neither the reduction nor the increase of these constituents is statistically significant.
- Overall, both strips at the Napa GRVTS reduce TDS and turbidity, therefore resulting in a reduction of all heavy metals, excluding total and dissolved arsenic and total and dissolved lead. Both strips show an increase in TSS, which may be due to internal strip erosion. Both strips reduce ammonia, nitrate, and nitrite, while total phosphorus and dissolved ortho-P show increases. Overall, the plant demand for nitrogen was higher than for phosphorus at this site. The only constituent that did not yield a result was dissolved cadmium, since it was not detected above the minimal detection limit. Overall, the results for TOC, DOC, and TKN are inconclusive, with each station performing in a fashion opposite the other.

San Mateo Hwy 380 GRVTS Strip

The ANOVA on concentration data at the San Mateo GRVTS location is presented in Table 4-7. The table presents the number of data points, mean concentration, mean percent difference, the range of EMCs, and the standard deviation per station. Each constituent with a concentration reduction or increase in comparison to the EOP is also identified in the Table 4-7.

Table 4-7: Concentration Statistics for San Mateo Hwy 380 GRVTS Strip

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	4-312 N Mean Mean % Δ Range Std. Dev.
Hardness as $CaCO_3$ (mg/L)	11 34.909 0.0% 22-46 6.742	11 41.636 -19.3% 20-60 13.488
TDS (mg/L)	11 43.426 0.0% ND-76 21.292	11 64.909 -49.5% 42-92 18.261
TSS (mg/L)	11 37.091 0.0% 9-78 22.530	11 61.909 -66.9% 15-218 66.194
TOC (mg/L)	11 7.145 0.0% 1.6-14.6 4.457	11 8.609 -20.5% 3.9-14.8 3.463
DOC (mg/L)	11 4.618 0.0% 1.2-9.7 3.012	11 5.691 -23.2% 2.5-11.5 2.889
Turbidity (NTU)	11 32.500 0.0% 12.4-80.3 22.355	11 41.336 -27.2% 21.7-88.6 21.648
Ammonia NH_3-N (mg/L)	11 0.356 0.0% 0.1-0.69 0.210	11 0.194 45.5% ND-0.44 0.145
Nitrate NO_3-N (mg/L)	11 0.329 0.0% 0.1-0.6 0.176	11 0.821 -149.4% 0.39-1.74 0.453

Table 4-7: Concentration Statistics for San Mateo Hwy 380 GRVTS Strip (continued)

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	4-312 N Mean Mean % Δ Range Std. Dev.
Nitrite NO_2-N (mg/L)	11 0.044 0.0% ND-0.08 0.025	11 0.038 13.8% ND-0.07 0.017
TKN (mg/L)	11 1.123 0.0% 0.33-2.29 0.590	11 1.309 -16.6% 0.25-2.48 0.598
Total Phosphorus (mg/L)	11 0.097 0.0% 0.04-0.22 0.065	11 0.193 -98.1% 0.07-0.33 0.085
Ortho-P, diss (mg/L)	11 0.028 0.0% ND-0.06 0.017	11 0.091 -229.9% 0.04-0.19 0.048
As, diss (ug/L)	11 0.373 0.0% 0.2-0.6 0.114	11 0.664 -78.0% 0.3-2.6 0.840
As, total (ug/L)	11 0.700 0.0% 0.4-1.2 0.256	11 1.518 -116.9% 0.7-3.3 0.852
Cd, diss (ug/L)	11 <0.1 0.0% ND-0.1 NA	11 <0.1 NA ND- ND NA
Cd, total (ug/L)	11 0.224 0.0% ND-0.4 0.117	11 0.134 40.1% ND-0.4 0.118
Cr, diss (ug/L)	11 6.955 0.0% 2.6-14 3.300	11 4.818 30.7% 0.6-8 2.027
Cr, total (ug/L)	11 12.618 0.0% 6.3-26 6.158	11 14.364 -13.8% 3.2-35 9.230

Table 4-7: Concentration Statistics for San Mateo Hwy 380 GRVTS Strip (continued)

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	4-312 N Mean Mean % Δ Range Std. Dev.
Cu, diss (ug/L)	11 23.818 0.0% 8-63 17.147	11 12.309 48.3% 6.8-27 6.356
Cu, total (ug/L)	11 67.727 0.0% 31-160 40.565	11 33.000 51.3% 13-57 14.447
Pb, diss (ug/L)	11 0.891 0.0% 0.1-4.8 1.651	11 1.491 -67.3% 0.1-8.6 2.986
Pb, total (ug/L)	11 17.409 0.0% 3.9-32 9.874	11 23.145 -33.0% 6-67 18.953
Ni, diss (ug/L)	11 1.600 0.0% 0.6-3.3 0.923	11 1.382 13.6% 0.8-2.9 0.700
Ni, total (ug/L)	11 6.309 0.0% 2.4-13 3.351	11 10.518 -66.7% 4.2-29 8.152
Zn, diss (ug/L)	11 28.091 0.0% 15-49 12.271	11 16.991 39.5% 5.5-68 21.503
Zn, total (ug/L)	11 124.64 0.0% 47-230 56.102	11 62.64 49.7% 25-120 28.193

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

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

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

No color = Increase but not statistically significant at a 90-percent confidence level

As shown in Table 4-7, the San Mateo GRVTS demonstrates the following:

- One strip station exhibits concentration reductions in ammonia, nitrite, total cadmium, dissolved chromium, total and dissolved copper, dissolved nickel, and total and dissolved zinc as compared to the EOP. Constituents that demonstrate a statistically significant concentration reduction (at a 90-percent confidence level) at this station are ammonia, total cadmium, dissolved chromium, total and dissolved copper, and dissolved zinc.
- One strip station exhibits concentration increases in hardness, TDS, TSS, TOC, DOC, turbidity, ammonia, TKN, total phosphorus, dissolved ortho-P, total and dissolved arsenic, total chromium, and total and dissolved lead as compared to the EOP. Constituents that demonstrate a statistically significant concentration increase (at a 90-percent confidence level) at this station are TDS, ammonia, total phosphorus, dissolved ortho-P, and total arsenic.
- Overall, the strip at the San Mateo GRVTS shows increases in TDS, TSS, and turbidity, but this did not impact the reduction of key heavy metals mentioned above. The strips reduce ammonia and nitrite, but show increases in total phosphorus and dissolved ortho-P. In general, the plant demand for nitrogen was higher than for phosphorus at this site. The only constituent that did not yield a result was dissolved cadmium, since it was not detected above the MDL.

Camarillo Hwy 101 GRVTS Strip

The ANOVA on concentration data at the Camarillo GRVTS location is presented in Table 4-8. The table presents the number of data points, mean concentration, mean percent difference, the range of EMCs, and the standard deviation per station. Each constituent with a concentration reduction or increase in comparison to the EOP is also identified in the Table 4-8.

Table 4-8: Concentration Statistics for Camarillo Hwy 101 GRVTS Strip

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	7-341 N Mean Mean % Δ Range Std. Dev.	7-342 N Mean Mean % Δ Range Std. Dev.
Hardness as $CaCO_3$ (mg/L)	5 37.800 0.0% 34-44 4.419	4 56.500 -49.5% 40-78 17.833	5 40.400 -6.9% 38-46 3.908
TDS (mg/L)	5 40.000 0.0% 32-53 9.081	4 101.750 -154.4% 54-174 59.281	5 52.200 -30.5% 36-82 20.635
TSS (mg/L)	5 39.600 0.0% 8-54 21.845	4 29.000 26.8% 10-62 27.505	5 15.000 62.1% 8-38 17.587
TOC (mg/L)	5 6.460 0.0% 2.9-9.3 2.699	4 7.825 -21.1% 5.4-11.3 2.855	5 5.220 19.2% 3-9.7 3.105
DOC (mg/L)	5 4.780 0.0% 2.2-7.5 2.172	4 5.600 -17.2% 4.1-9.1 3.021	5 3.840 19.7% 1.8-7.8 2.742
Turbidity (NTU)	5 46.140 0.0% 19.4-82.6 25.719	4 35.350 23.4% 20.1-58 18.573	5 25.920 43.8% 17.1-40.8 10.328
Ammonia NH_3-N (mg/L)	5 0.158 0.0% 0.07-0.35 0.134	4 0.120 24.1% ND-0.34 0.200	5 0.079 50.0% ND-0.27 0.137
Nitrate NO_3-N (mg/L)	5 0.418 0.0% 0.21-0.72 0.218	4 0.158 62.2% 0.03-0.43 0.229	5 0.190 54.5% 0.07-0.32 0.118

Table 4-8: Concentration Statistics for Camarillo Hwy 101 GRVTS Strip (continued)

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	7-341 N Mean Mean % Δ Range Std. Dev.	7-342 N Mean Mean % Δ Range Std. Dev.
Nitrite NO_2-N (mg/L)	5 0.052 0.0% 0.03-0.09 0.028	4 0.016 68.7% ND-0.05 0.023	5 0.026 50.0% ND-0.05 0.023
TKN (mg/L)	5 0.822 0.0% 0.41-1.5 0.474	4 0.958 -16.5% 0.67-1.21 0.251	5 0.680 17.3% 0.37-1.05 0.308
Total Phosphorus (mg/L)	5 0.100 0.0% 0.05-0.16 0.050	4 0.723 -623.0% 0.51-0.96 0.207	5 0.374 -274.0% 0.22-0.7 0.226
Ortho-P, diss (mg/L)	5 0.033 0.0% ND-0.05 0.019	4 0.568 -1621.2% 0.42-0.78 0.174	5 0.312 -845.5% 0.17-0.59 0.192
As, diss (ug/L)	5 0.680 0.0% 0.5-0.8 0.136	4 2.050 -201.5% 1.4-2.7 0.599	5 1.160 -70.6% 0.9-1.4 0.213
As, total (ug/L)	5 1.100 0.0% 0.8-1.4 0.304	4 2.675 -143.2% 2.1-3.4 0.621	5 1.520 -38.2% 1.2-2 0.358
Cd, diss (ug/L)	5 <0.1 0.0% ND- ND NA	4 <0.1 NA ND- ND NA	5 <0.1 NA ND- ND NA
Cd, total (ug/L)	5 0.180 0.0% ND-0.3 0.126	4 0.175 2.8% 0.1-0.3 0.103	5 0.060 66.7% ND -0.1 0.022
Cr, diss (ug/L)	5 1.940 0.0% 1.4-2.7 0.662	4 1.350 30.4% 0.7-2.2 0.705	5 1.420 26.8% 0.6-2.6 0.829
Cr, total (ug/L)	5 5.120 0.0% 2.6-7.5 2.188	4 3.625 29.2% 2.2-6.3 2.242	5 2.780 45.7% 1.7-4.1 1.083

Table 4-8: Concentration Statistics for Camarillo Hwy 101 GRVTS Strip (continued)

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	7-341 N Mean Mean % Δ Range Std. Dev.	7-342 N Mean Mean % Δ Range Std. Dev.
Cu, diss (ug/L)	5 6.380 0.0% 3.9-9.6 2.502	4 5.425 15.0% 3.8-8.6 2.596	5 5.020 21.3% 3.4-6 1.133
Cu, total (ug/L)	5 23.720 0.0% 9.6-37 10.953	4 13.600 42.7% 7.3-30 14.630	5 9.080 61.7% 7-12 2.306
Pb, diss (ug/L)	5 0.188 0.0% ND -0.3 0.093	4 0.175 6.9% 0.1-0.2 0.050	5 0.260 -38.3% 0.1-3.3 0.397
Pb, total (ug/L)	5 5.400 0.0% 2-8.3 2.488	4 5.725 -6.0% 4.2-9.4 3.172	5 2.920 45.9% 0.1-4.7 1.269
Ni, diss (ug/L)	5 0.940 0.0% 0.6-1.5 0.390	4 1.100 -17.0% 0.8-1.5 0.336	5 0.780 17.0% 0.5-1.2 0.299
Ni, total (ug/L)	5 3.740 0.0% 1.6-5.5 1.603	4 3.075 17.8% 2.3-4.6 1.254	5 1.960 47.6% 1.3-2.9 0.669
Zn, diss (ug/L)	5 5.40 0.0% 2.8-7.4 1.854	4 4.800 11.1% 3.1-7.3 2.058	5 6.820 -26.3% 3.4-9.1 2.480
Zn, total (ug/L)	5 65.200 0.0% 23-87 29.288	4 29.500 54.8% 16-64 31.056	5 21.800 66.6% 14-33 7.953

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

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

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

No color = Increase but not statistically significant at a 90-percent confidence level

As shown in Table 4-8, the Camarillo GRVTS demonstrates the following:

- Both strip stations show concentration reductions in TSS, turbidity, ammonia, nitrate, total cadmium, total and dissolved chromium, total and dissolved copper, total nickel, and total zinc as compared to the EOP.
- One constituent, total zinc, shows a statistically significant concentration reduction (at a 90-percent confidence level) at both stations. Nitrate, total copper, and total nickel show statistically significant concentration reductions at one station.
- Both strip stations show concentration increases in hardness, TDS, total phosphorus, dissolved ortho-P, and total and dissolved arsenic as compared to the EOP.
- Constituents that demonstrate a statistically significant concentration reduction (at a 90-percent confidence level) in both stations were total phosphorus and dissolved ortho-P. Hardness, TDS, and total and dissolved arsenic each show a statistically significant concentration increase at one station.
- One strip station shows a concentration reduction, while the other station shows a concentration increase in TOC, DOC, nitrite, TKN, dissolved and total lead, and dissolved nickel. Only one constituent, dissolved lead, shows a statistically significant reduction, while no statistically significant increases were identified.
- Overall, both strips at the Camarillo GRVTS reduced TSS and turbidity, therefore resulting in a reduction of the key heavy metals mentioned above. Both strips show an increase in TDS, which may be due to an increase in internal strip erosion. Both strips show reductions in ammonia and nitrate, while showing increases in total phosphorus and dissolved ortho-P. In general, the plant demand for nitrogen was higher than for phosphorus at this site. Overall, the results for TOC, DOC, nitrite, TKN, total and dissolved lead, and dissolved zinc are inconclusive since each station behaved in an opposite direct of the other. The only constituent that did not yield a result was dissolved cadmium, since it was not detected above the MDL.

Westminster I-405 GRVTS Strip

The ANOVA on concentration data at the Westminster GRVTS location is presented in Table 4-9. The table presents the number of data points, mean concentration, mean percent difference, the range of EMCs, and the standard deviation per station. Each constituent with a concentration reduction or increase in comparison to the EOP is also identified in the Table 4-9.

Table 4-9: Concentration Statistics for Westminster I-405 GRVTS Strip

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	12-344 N Mean Mean % Δ Range Std. Dev.	12-345 N Mean Mean % Δ Range Std. Dev.
Hardness as $CaCO_3$ (mg/L)	9 25.333 0.0% 14-38 8.339	2 55.000 -117.1% 50-60 7.071	2 38.000 -50.0% 34-42 5.657
TDS (mg/L)	10 41.400 0.0% 21-100 30.942	3 201.000 -385.5% 87-276 122.872	2 129.000 -211.6% 82-176 66.47
TSS (mg/L)	10 54.600 0.0% 6-148 48.639	3 102.000 -86.8% 20-264 190.854	2 86.000 -57.5% 28-144 82.02
TOC (mg/L)	8 6.838 0.0% 1.8-16.4 4.898	2 34.750 -408.2% 32.1-37.4 3.748	2 23.500 -243.7% 22-25.1 2.192
DOC (mg/L)	8 4.500 0.0% 1.1-10.6 3.269	2 23.500 -422.2% 22.9-24.1 0.849	2 15.700 -248.9% 14.5-16.9 1.697
Turbidity (NTU)	10 24.545 0.0% 7.6-73.4 21.718	3 21.367 12.9% 9.1-41.4 22.031	2 17.300 29.5% 10.3-24.3 9.900
Ammonia NH_3-N (mg/L)	10 0.339 0.0% ND -0.96 0.342	3 0.220 35.1% 0.2-0.24 0.022	2 0.115 66.1% 0.06-0.17 0.078
Nitrate NO_3-N (mg/L)	10 0.400 0.0% 0.18-1.01 0.311	3 1.113 -178.3% 0.44-1.65 0.709	2 0.210 47.5% 0.1-0.32 0.156

Table 4-9: Concentration Statistics for Westminster I-405 GRVTS Strip (continued)

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	12-344 N Mean Mean % Δ Range Std. Dev.	12-345 N Mean Mean % Δ Range Std. Dev.
Nitrite NO_2-N (mg/L)	10 0.038 0.0% ND-0.14 0.047	3 0.015 60.5% ND-0.03 0.013	2 0.013 67.1% ND-0.02 0.011
TKN (mg/L)	10 2.219 0.0% 0.23-10.2 3.573	3 4.250 -91.5% 2.13-7.04 2.939	2 2.795 -26.0% 2.34-3.25 0.643
Total Phosphorus (mg/L)	10 0.144 0.0% 0.04-0.29 0.090	2 0.655 -354.9% 0.54-0.77 0.163	2 0.740 -413.9% 0.48-1 0.368
Ortho-P, diss (mg/L)	10 0.035 0.0% ND-0.07 0.025	3 0.280 -700.0% 0.14-0.36 0.158	2 0.305 -771.4% 0.3-0.31 0.007
As, diss (ug/L)	10 0.440 0.0% 0.2-0.8 0.189	3 1.200 -172.7% 0.7-1.6 0.526	2 1.150 -161.4% 1.1-1.2 0.071
As, total (ug/L)	10 1.070 0.0% 0.5-1.9 0.409	3 1.967 -83.8% 0.9-3 1.171	2 2.000 -86.9% 1.7-2.3 0.424
Cd, diss (ug/L)	10 <0.1 0.0% ND-0.2 NA	3 0.067 NA ND-0.1 0.029	2 0.075 NA ND-0.1 0.035
Cd, total (ug/L)	10 0.550 0.0% 0.1-1.2 0.356	3 0.500 9.1% 0.1-1.2 0.788	2 0.600 -9.1% 0.2-1 0.566
Cr, diss (ug/L)	10 1.800 0.0% 1-3.1 0.743	3 1.300 27.8% 0.8-2.3 0.866	2 1.300 27.8% 0.6-2 0.990
Cr, total (ug/L)	10 6.180 0.0% 2.4-11 3.016	3 5.200 15.9% 1.8-12 5.889	2 5.800 6.1% 2.4-9.2 4.808

Table 4-9: Concentration Statistics for Westminster I-405 GRVTS Strip (continued)

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	12-344 N Mean Mean % Δ Range Std. Dev.	12-345 N Mean Mean % Δ Range Std. Dev.
Cu, diss (ug/L)	10 12.770 0.0% 3.5-30 9.249	3 12.833 -0.5% 8.5-17 4.743	2 11.500 9.9% 11-12 0.707
Cu, total (ug/L)	10 55.000 0.0% 13-120 32.788	3 39.667 27.9% 13-82 46.162	2 47.500 13.6% 28-67 27.580
Pb, diss (ug/L)	10 0.420 0.0% 0.2-0.8 0.200	3 2.600 -519.0% 1.6-4.2 1.749	2 2.700 -542.9% 2.6-2.8 0.141
Pb, total (ug/L)	10 32.130 0.0% 7.3-93 27.812	3 94.667 -194.6% 20-230 154.423	2 156.500 -387.1% 73-240 118.090
Ni, diss (ug/L)	10 1.990 0.0% 0.9-4.5 1.260	3 1.600 19.6% 1-2.2 0.669	2 1.350 32.2% 1.3-1.4 0.071
Ni, total (ug/L)	10 6.290 0.0% 2-14 3.573	3 5.300 15.7% 1.8-11 6.263	2 5.700 9.4% 3.2-8.2 3.536
Zn, diss (ug/L)	10 31.000 0.0% 19-46 7.662	3 17.333 44.1% 14-19 2.887	2 17.000 45.2% 16-18 1.414
Zn, total (ug/L)	10 208.500 0.0% 51-520 153.007	3 148.333 28.9% 31-370 256.625	2 185.000 11.3% 70-300 162.600

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

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

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

No color = Increase but not statistically significant at a 90-percent confidence level

As shown in Table 4-9, the Westminster GRVTS demonstrates the following:

- Both strip stations show concentration reductions in turbidity, ammonia, nitrite, total and dissolved chromium, total copper, total and dissolved nickel, and total and dissolved zinc (whether statistically significant or not at a 90-percent confidence level) as compared to the EOP.
- One constituent, dissolved zinc, shows a statistically significant concentration reduction at both stations. One constituent, total copper, shows a statistically significant concentration reduction at one station.
- Both strip stations show concentration increases in hardness, TDS, TSS, TOC, DOC, TKN, total phosphorus, dissolved ortho-P, total and dissolved arsenic, and total and dissolved lead at each strip station as compared to the EOP.
- Constituents that show a statistically significant concentration reduction (at a 90-percent confidence level) at both stations were TOC, DOC, total phosphorus, dissolved ortho-P, total arsenic, and dissolved lead. Hardness, TDS, and total lead show a statistically significant concentration increase at one station.
- One strip station shows a concentration reduction, while the other station shows a concentration increase in nitrate, total cadmium, and total lead. Only one constituent, nitrate, shows a statistically significant increase, while no statistically significant reductions were identified.
- Overall, both strips at the Westminster GRVTS show increases in TDS and TSS and a reduction in turbidity. The increases in TDS and TSS do not impact the reduction of the key heavy metals mentioned above. Both strips show reductions in ammonia and nitrite, and show increases in TKN, total phosphorus, and dissolved ortho-P. In general, the plant demand for nitrogen was slightly higher than for phosphorus at this site. Overall, the results for nitrate, total cadmium, and dissolved copper are inconclusive since each station performed in a fashion opposite the other. The only constituent that did not yield a result was dissolved cadmium, since it was not detected above the MDL.

San Diego SR 52 GRVTS Strip

Monitoring at the San Diego location was terminated after the first four storms due to substantial recurring bypass issues at both strip stations. Therefore, no data from this location are available for discussion.

4.2.2 Volume Reduction

Volume reduction on an event and seasonal basis for each strip station was calculated using the method described in Section 4.1. Results are presented in Table 4-1.

As shown in Table 4-1, substantial volume reduction occurred for runoff at all 15 vegetated strip stations throughout the 2009-2010 monitoring season. Seasonal volume reduction of the ERVTS strips ranges from 53.3 to 98.7 percent. Seasonal volume reduction of the GRVTS strips ranges from 63.4 to 97.6 percent. Overall, the strips performed very well in reducing runoff volume. The volume reductions on an event and seasonal basis for each ERVTS and GRVTS location are described below.

The Sacramento ERVTS seasonal reduction ranges from 94.5 to 98.7 percent. Station 3-362 shows a seasonal volume reduction of 94.5 percent for ten monitored storms, with an event volume reduction ranging from 91.1 to 97.1 percent. Station 3-363 shows a seasonal volume reduction of 98.7 percent for 11 monitored storms, with an event volume reduction ranging from 94.4 to 99.7 percent. Station 3-364 shows a seasonal volume reduction of 97.3 percent for 11 monitored storms, with an event volume reduction ranging from 90.3 to 98.6 percent. Station 3-365 shows a seasonal volume reduction of 97.8 percent for 12 monitored storms, with an event volume reduction ranging from 95.6 to 99.5 percent.

The Yorba Linda ERVTS seasonal reduction ranges from 53.3 to 89.4 percent. Station 12-346 shows a seasonal volume reduction of 62.1 percent for 11 monitored storms, with an event volume reduction ranging from 37.5 to 91.7 percent. Station 12-347 shows a seasonal volume reduction of 53.3 percent for nine monitored storms, with an event volume reduction ranging from 28.4 to 99.8 percent. Station 12-348 shows a seasonal and event volume reduction of 89.4 percent for one monitored storm. Station 12-349 shows a seasonal volume reduction of 86.8 percent for six monitored storms, with an event volume reduction ranging from 78.1 to 99.1 percent.

The Napa GRVTS at Station 4-308 shows a seasonal volume reduction of 97.6 percent for eight monitored storms, with an event volume reduction ranging from 83.5 to 99.6 percent. Station 4-309 shows a seasonal volume reduction of 95.3 percent for 11 monitored storms, with an event volume reduction ranging from 58.4 to 98.5 percent.

The San Mateo GRVTS at Station 4-312 shows a seasonal volume reduction of 63.4 percent for eight monitored storms, with an event volume reduction ranging from 49.4 to 97.0 percent.

The Camarillo GRVTS at Station 7-341 shows a seasonal volume reduction of 91.2 percent for five monitored storms, with an event volume reduction ranging from 85.7 to 95.9 percent. Station 7-342 shows a seasonal volume reduction of 71.2 percent for five monitored storms, with an event volume reduction ranging from 47.8 to 91.1 percent.

The Westminster GRVTS at Station 12-344 shows a seasonal volume reduction of 95.3 percent for 12 monitored storms, with an event volume reduction ranging from 24.1 to 99.6 percent.

Station 12-345 shows a seasonal volume reduction of 96.0 percent for ten monitored storms, with an event volume reduction ranging from 78.2 to 100.0 percent.

4.2.3 Load

At each ERVTS and GRVTS strip location, the pollutant loads at each strip station were compared to those at the EOP to evaluate the benefits of the vegetated strips in reducing pollutant loads from roadway storm water runoff. For each location, an ANOVA on storm event-based load data was performed and seasonal loads were calculated as described in Section 4.1. Tables 4-2 and 4-3 summarize the percent seasonal load reductions for each ERVTS and GRVTS strip station. Tables 4-10 to 4-15 summarize the treatment performance of each ERVTS and GRVTS strip station in comparison with its respective EOP station, based on results of the ANOVA on load data. Detailed output results of the ANOVA on load data are presented in Appendix J.2.

Sacramento I-5 ERVTS Strip

The ANOVA on load data at the Sacramento ERVTS location is presented in Table 4-10. This table presents the number of data points, mean load, mean percent difference, the range of load data, and the standard deviation per station. Each constituent with a load reduction or increase in comparison to the EOP is also identified in Table 4-10.

Table 4-10: Load Statistics for Sacramento I-5 ERVTS Strip

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	3-362 N Mean Mean % Δ Range Std. Dev.	3-363 N Mean Mean % Δ Range Std. Dev.	3-364 N Mean Mean % Δ Range Std. Dev.	3-365 N Mean Mean % Δ Range Std. Dev.
Hardness as $CaCO_3$ (g/acre)	11 3,986 0.0% 645-18,554 5,150	8 258 93.5% 45-777 239	10 89 97.8% 0.0-448 140	10 168 95.8% 21-780 235	10 202 94.9% 9.88-1,098 334
TDS (g/acre)	11 5,551 0.0% 854-25,007 6,867	8 305 94.5% 125-803 220	10 118 97.9% 12-576 169	10 370 93.3% 61-1,721 501	10 272 95.1% 15-1,421 422
TSS (g/acre)	11 10,923 0.0% 1,633-59,694 16,618	8 700 93.6% 18-2,570 862	10 40 99.6% 5.45-178 52	10 34 99.7% 6.97-69 22	10 75 99.3% 3.01-289 89
TOC (g/acre)	11 763 0.0% 95-4,148 1,220	8 57 92.6% 27-113 28	10 20 97.3% 0.0-63 19	10 81 89.4% 17-281 88	10 49 93.6% 6.26-136 46
DOC (g/acre)	11 313 0.0% 0.0-1,371 379	8 31 90.2% 0.0-54 19	10 13 95.8% 0.0-40 12	10 46 85.3% 0.0-166 49	10 24 92.2% 0.0-70 22
Ammonia NH_3-N (g/acre)	11 39 0.0% 6.24-153 42	8 2.44 93.7% 0.409-7.99 2.45	10 1.41 96.4% 0.061-9.03 2.72	10 1.46 96.2% 0.353-3.79 1.11	10 0.70 98.2% 0.162-1.87 0.52
Nitrate NO_3-N (g/acre)	11 37 0.0% 0.0-133 36	8 2.01 94.5% 0.0-3.36 1.10	10 0.36 99.0% 0.0-0.88 0.30	10 0.27 99.3% 0.0-0.59 0.18	10 0.69 98.1% 0.0-1.75 0.60
Nitrite NO_2-N (g/acre)	11 4.51 0.0% 0-16 4.56	8 0.146 96.8% 0.0-0.39 0.122	10 0.023 99.5% 0.0-0.06 0.023	10 0.054 98.8% 0.019-0.16 0.053	10 0.035 99.2% 0.0-0.07 0.024

Table 4-10: Load Statistics for Sacramento I-5 ERVTS Strip (continued)

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	3-362 N Mean Mean % Δ Range Std. Dev.	3-363 N Mean Mean % Δ Range Std. Dev.	3-364 N Mean Mean % Δ Range Std. Dev.	3-365 N Mean Mean % Δ Range Std. Dev.
TKN (g/acre)	11 176 0.0% 27-984 274	8 13.8 92.1% 6.8-22 6.1	10 2.6 98.5% 0.0-5.38 1.9	10 11.3 93.6% 3.53-20 6.7	10 6.0 96.6% 1.43-16 4.6
Total Phosphorus (g/acre)	11 46 0.0% 6.08-327 94	8 2.41 94.8% 1.14-5.00 1.23	10 0.64 98.6% 0.147-1.89 0.54	10 2.13 95.4% 0.634-5.18 1.51	10 1.46 96.8% 0.173-3.59 1.18
Ortho-P, diss (g/acre)	11 9.27 0.0% 0.0-40 11.6	8 1.12 87.9% 0.0-1.81 0.603	10 0.299 96.8% 0.0-0.76 0.238	10 1.39 85.0% 0.0-3.85 1.225	10 0.959 89.7% 0.0-2.52 0.932
As, diss (mg/acre)	11 115 0.0% 23-444 122	8 7.17 93.8% 1.77-16 4.58	10 4.19 96.4% 0.474-19 5.63	10 7.85 93.2% 0.750-30 9.56	10 7.58 93.4% 0.476-29 9.35
As, total (mg/acre)	11 240 0.0% 48-928 254	8 13.1 94.5% 2.42-28 9.7	10 5.1 97.9% 0.527-21 6.5	10 9.7 96.0% 0.886-37 11.9	10 9.7 96.0% 0.565-34 11.6
Cd, diss (mg/acre)	11 5.87 0.0% 0.562-20 5.73	8 0.339 NA 0.044-1.29 0.405	10 0.060 NA 0.017-0.16 0.044	10 0.150 NA 0.034-0.49 0.145	10 0.126 NA 0.012-0.65 0.189
Cd, total (mg/acre)	11 54 0.0% 9.68-202 56	8 0.72 98.7% 0.088-2.59 0.85	10 0.06 99.9% 0.017-0.16 0.04	10 0.11 99.8% 0.034-0.27 0.08	10 0.18 99.7% 0.012-0.65 0.22
Cr, diss (mg/acre)	11 112 0.0% 14-323 97	8 3.45 96.9% 0.650-12 3.53	10 0.69 99.4% 0.105-2.74 0.81	10 1.34 98.8% 0.273-4.27 1.26	10 1.01 99.1% 0.075-5.17 1.51
Cr, total (mg/acre)	11 1119 0.0% 1329	8 46 95.9% 1.59-125 47	10 3.3 99.7% 0.316-13 4.0	10 3.7 99.7% 0.341-11 3.3	10 8.8 99.2% 0.188-41 12.8
Cu, diss (mg/acre)	11 747 0.0% 174-2,380 666	8 36 95.2% 18-73 17	10 8.1 98.9% 1.09-17 5.0	10 18 97.6% 5.76-37 9.0	10 14 98.2% 2.23-39 10.4

Table 4-10: Load Statistics for Sacramento I-5 ERVTS Strip (continued)

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	3-362 N Mean Mean % Δ Range Std. Dev.	3-363 N Mean Mean % Δ Range Std. Dev.	3-364 N Mean Mean % Δ Range Std. Dev.	3-365 N Mean Mean % Δ Range Std. Dev.
Cu, total (mg/acre)	11 3992 0.0% 581-16,134 4491	8 85 97.9% 26-194 58	10 11 99.7% 2.95-24 7	10 25 99.4% 9.51-53 13	10 22 99.4% 3.006-54 18
Pb, diss (mg/acre)	11 10 0.0% 0.450-55 15	8 0.550 94.6% 0.093-2.59 0.855	10 0.139 98.6% 0.030-0.46 0.135	10 0.458 95.5% 0.027-2.14 0.643	10 0.205 98.0% 0.021-0.47 0.147
Pb, total (mg/acre)	11 919 0.0% 121-4,840 1,349	8 16 98.3% 0.528-38 15	10 0.9 99.9% 0.158-3.13 0.9	10 1.5 99.8% 0.204-3.74 1.3	10 2.2 99.8% 0.094-11 3.1
Ni, diss (mg/acre)	11 120 0.0% 23-645 179	8 7.09 94.1% 1.86-21 6.72	10 1.30 98.9% 0.105-4.57 1.31	10 2.93 97.6% 0.384-10.15 2.78	10 2.43 98.0% 0.276-10 3.02
Ni, total (mg/acre)	11 1030 0.0% 194-4,437 1215	8 47 95.4% 2.82-119 44	10 4.9 99.5% 0.369-14 4.5	10 5.6 99.5% 1.09-17 4.9	10 10.2 99.0% 0.476-45 13.9
Zn, diss (mg/acre)	11 756 0.0% 83-1,855 605	8 48 93.7% 25-98 22	10 12 98.4% 0.962-21 6.8	10 31 95.9% 12-64 16	10 19 97.5% 5.76-53 14
Zn, total (mg/acre)	11 15,314 0.0% 2,501-60,501 16,812	8 238 98.4% 49-531 169	10 25 99.8% 6.32-59 16	10 51 99.7% 22-91 25	10 37 99.8% 9.41-105 33

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

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

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

No color = Increase but not statistically significant at a 90-percent confidence level

As shown in Table 4-10, all four vegetated strip stations at the Sacramento ERVTS show statistically significant reductions in loads at a 90-percent confidence level for all constituents except for total phosphorus when compared to the loads at the EOP. Loads of total phosphorus at all four strip stations indicate substantial reductions (over 90 percent reductions), however, these reductions are not statistically significant at a 90-percent confidence level mostly due to the fact that event-based load for total phosphorus at the EOP station had a high standard deviation and that more data points may e needed to demonstrate statistical significance.

The seasonal load reduction results as presented in Table 4-2 show:

- At Station 3-362, the seasonal load reduction of the constituents ranges from 87.8 percent for TKN to 98.9 percent for total cadmium, with reductions of most constituents above 90 percent.
- At Station 3-363, the seasonal load reduction of the constituents ranges from 94.8 percent for ammonia to 99.9 percent for total cadmium, with reductions of almost all constituents above 98 percent.
- At Station 3-364, the seasonal load reduction of the constituents ranges from 81.5 percent for DOC to 99.8 percent for both total lead and total cadmium, with reductions of the majority of the constituents above 95 percent.
- At Station 3-365, the seasonal load reduction of the constituents ranges from 87.5 percent for dissolved ortho-P to 99.7 percent for total cadmium, with reductions of the majority of the constituents above 95 percent.

Overall, the vegetated strips at this location appear to perform very well in reducing pollutant loads of roadway storm water runoff, mostly due to volume reduction.

Yorba Linda SR 91 ERVTS Strip

The ANOVA on load data at the Yorba Linda ERVTS location is presented in Table 4-11. The table presents the number of data points, mean load, mean percent difference, the range of load data, and the standard deviation per station. Each constituent with a load reduction or increase in comparison to the EOP is also identified in Table 4-11.

Table 4-11: Load Statistics for Yorba Linda SR-91 ERVTS Strip

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	12-346 N Mean Mean % Δ Range Std. Dev.	12-347 N Mean Mean % Δ Range Std. Dev.	12-348 N Mean Mean % Δ Range Std. Dev.	12-349 N Mean Mean % Δ Range Std. Dev.
Hardness as $CaCO_3$ (g/acre)	12 5,037 0.0% 630-10,627 3,362	11 1,560 69.0% 350-3,331 1,062	9 6,277 -24.6% 586-22,006 8,568	1 1,816 63.9% NA NA	6 1,612 68.0% 952-2,892 764
TDS (g/acre)	12 6,761 0.0% 1,339-13,858 4,560	11 1,561 76.9% 530-3,465 964	9 9,544 -41.2% 586-43,730 14,713	1 3,067 54.6% NA NA	6 3,501 48.2% 1,178-6,789 2,124
TSS (g/acre)	12 7,059 0.0% 358-15,931 4,692	11 2,112 70.1% 250-4,580 1,391	9 1,956 72.3% 270-3,964 1,200	1 626 91.1% NA NA	6 4,495 36.3% 911-10,382 3,227
TOC (g/acre)	12 1,540 0.0% 261-3,535 1,238	11 516 66.5% 88-1,985 529	9 1,648 -7.0% 169-4,373 1,431	1 274 82.2% NA NA	6 464 69.9% 360-544 75
DOC (g/acre)	12 1,036 0.0% 100-2,464 819	11 270 73.9% 59-582 165	9 1,127 -8.7% 134-3,225 1,040	1 236 77.2% NA NA	6 328 68.3% 252-437 60
Ammonia NH_3-N (g/acre)	12 44 0.0% 0.0-158 46	11 9.87 77.4% 0.0-30 9.10	9 9.62 78.0% 0.13-32 10.08	1 1.21 97.2% NA NA	6 1.58 96.4% 0.04-4.28 1.59
Nitrate NO_3-N (g/acre)	12 87 0.0% 22-197 62	11 23 73.9% 6.38-70 20	9 163 -88.0% 3.75-953 326	1 3.6 95.8% NA NA	6 33 62.2% 7.49-96 32
Nitrite NO_2-N (g/acre)	12 7.11 0.0% 0.0-16 5.76	11 1.012 85.8% 0.23-2.78 1.017	9 1.28 82.0% 0.15-4.54 1.63	1 0.101 98.6% NA NA	6 0.323 95.5% 0.08-0.61 0.190

Table 4-11: Load Statistics for Yorba Linda SR-91 ERVTS Strip (continued)

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	12-346 N Mean Mean % Δ Range Std. Dev.	12-347 N Mean Mean % Δ Range Std. Dev.	12-348 N Mean Mean % Δ Range Std. Dev.	12-349 N Mean Mean % Δ Range Std. Dev.
TKN (g/acre)	12 215 0.0% 38-574 188	11 52 76.0% 12-203 54	9 158 26.7% 24-440 150	1 28 87.0% NA NA	6 61 71.5% 42-103 24
Total Phosphorus (g/acre)	12 17 0.0% 0.06-44 13	11 5.07 70.0% 0.94-12 3.33	9 17 -0.8% 3.05-45 13	1 7.26 57.0% NA NA	6 17 -1.8% 11-29 6.18
Ortho-P, diss (g/acre)	12 6.77 0.0% 0.02-14 5.36	11 2.45 63.9% 0.07-5.55 1.71	9 10.46 -54.5% 2.11-28 8.67	1 4.84 28.5% NA NA	6 10.27 -51.6% 4.76-16 3.58
As, diss (mg/acre)	12 69 0.0% 13-125 38	11 21 70.2% 6.26-42 12	9 105 -52.5% 25-338 96	1 48 29.9% NA NA	6 54 22.3% 21-79 19
As, total (mg/acre)	12 164 0.0% 23-354 100	11 48 70.5% 10-111 30	9 144 11.7% 32-411 114	1 55 66.7% NA NA	6 108 33.9% 66-208 51
Cd, diss (mg/acre)	12 27 0.0% 4.29-101 26	11 11 60.8% 0.74-84 25	9 15 46.6% 1.17-36 13	1 4.04 85.1% NA NA	6 7.10 73.9% 1.50-18 6.38
Cd, total (mg/acre)	12 77 0.0% 8.59-202 57	11 13 83.4% 2.23-42 12	9 33 57.8% 4.69-85 25	1 16 79.1% NA NA	6 26 65.8% 16-49 12
Cr, diss (mg/acre)	12 340 0.0% 33-697 234	11 97 71.6% 10-228 73	9 102 70.1% 9.38-230 69	1 18 94.6% NA NA	6 43 87.3% 15-61 19
Cr, total (mg/acre)	12 967 0.0% 83-2,303 670	11 301 68.9% 26-694 212	9 245 74.7% 29-471 142	1 57 94.2% NA NA	6 319 67.0% 119-733 212
Cu, diss (mg/acre)	12 2,339 0.0% 563-5,399 1,599	11 443 81.1% 110-912 259	9 665 71.6% 117-1,570 432	1 222 90.5% NA NA	6 261 88.8% 100-403 107

Table 4-11: Load Statistics for Yorba Linda SR-91 ERVTS Strip (continued)

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	12-346 N Mean Mean % Δ Range Std. Dev.	12-347 N Mean Mean % Δ Range Std. Dev.	12-348 N Mean Mean % Δ Range Std. Dev.	12-349 N Mean Mean % Δ Range Std. Dev.
Cu, total (mg/acre)	12 7,587 0.0% 1,159-14,878 4,750	11 1,492 80.3% 225-3,331 949	9 1,085 85.7% 176-2,174 629	1 262 96.5% NA NA	6 715 90.6% 410-1,405 381
Pb, diss (mg/acre)	12 29 0.0% 5.73-90 24	11 6.78 76.6% 1.25-18 5.42	9 25 13.2% 3.52-72 22	1 8.07 72.2% NA NA	6 24 17.2% 3.28-108 42
Pb, total (mg/acre)	12 2,713 0.0% 157-6,731 2,042	11 489 82.0% 48-1,291 351	9 387 85.7% 59-681 219	1 97 96.4% NA NA	6 484 82.2% 167-1,160 345
Ni, diss (mg/acre)	12 435 0.0% 107-1,080 339	11 61 86.0% 16-137 39	9 183 57.9% 32-592 183	1 50 88.4% NA NA	6 77 82.3% 43-104 22
Ni, total (mg/acre)	12 999 0.0% 186-1,842 618	11 202 79.8% 30-430 123	9 318 68.2% 54-809 226	1 85 91.5% NA NA	6 319 68.1% 151-672 181
Zn, diss (mg/acre)	12 21,508 0.0% 3,683-98,986 26,616	11 1,034 95.2% 213-2,006 644	9 1,429 93.4% 141-3,781 1,165	1 242 98.9% NA NA	6 579 97.3% 130-1,781 602
Zn, total (mg/acre)	12 76,472 0.0% 7,586-512,928 139,484	11 4,233 94.5% 550-10,131 2,967	9 2,814 96.3% 328-7,143 2,036	1 666 99.1% NA NA	6 2,276 97.0% 817-5,069 1,466

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

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

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

No color = Increase but not statistically significant at a 90-percent confidence level

As shown in Table 4-11, at the Yorba Linda ERVTS, for both strip Stations 12-346 and 12-348 the loads of all constituents show a reduction as compared to the EOP, whether statistically significant or not at a 90-percent confidence level. The loads of a few constituents at strip Stations 12-347 and 12-349 show increases as compared to the EOP, none of which are statistically significant at a 90-percent confidence level. Note that only one storm event produced representative rainfall and flow data at Station 12-348. Limited data points throughout the season may have contributed to non-significant findings, specifically for total phosphorus.

The calculated seasonal load reduction results as presented in Table 4-2 show:

- At Station 12-346, the seasonal loads of all constituents show a decrease when compared to loads at the EOP, with reductions ranging from 67.0 percent for dissolved ortho-P to 95.7 percent for dissolved zinc, and with reductions for most constituents above 70 percent.
- At Station 12-347, the seasonal loads of all constituents except for hardness, TDS, TOC, DOC, nitrate, total phosphorus, dissolved ortho-P, and dissolved arsenic show a decrease when compared to loads at the EOP. The seasonal loads of the rest of the constituents show reductions ranging from 6.6 percent for total arsenic to 92.4 percent for total zinc.
- At Station 12-348 (only one storm event produced representative rainfall and flow data at this station), the calculated loads of all constituents show a decrease when compared to loads at the EOP, with reduction ranging from 15.2 percent for dissolved ortho-P to 98.7 percent for nitrite, and with reductions for most constituents above 85 percent.
- At Station 12-349, the seasonal load of dissolved ortho-P and dissolved lead both show increases when compared to the loads at the EOP. The seasonal loads of all other constituents show reductions ranging from 6.1 percent for total phosphorus to 96.4 percent for nitrite.

Overall, the vegetated strips at this location appear to perform well in reducing pollutant loads of roadway storm water runoff, mostly due to volume reduction.

Napa Hwy 29 GRVTS Strip

The ANOVA on load data at the Napa GRVTS location is presented in Table 4-12. The table presents the number of data points, mean load, mean percent difference, the range of load data, and the standard deviation per station. Each constituent with a load reduction or increase in comparison to the EOP is also identified in Table 4-12.

Table 4-12: Load Statistics for Napa Hwy 29 GRVTS Strip

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	4-308 N Mean Mean % Δ Range Std. Dev.	4-309 N Mean Mean % Δ Range Std. Dev.
Hardness as $CaCO_3$ (g/acre)	8 522 0.0% 26-1,928 601	5 30 94.2% 1.06-94 39	9 13 97.5% 0.0-48 17
TDS (g/acre)	8 377 0.0% 46-701 200	5 483 -28.0% 0.01-2,362 1,051	9 13 96.5% 0.19-45 14
TSS (g/acre)	8 449 0.0% 47-2,278 753	5 508 -13.0% 1.91-2,504 1,116	9 12 97.3% 1.25-24 8.7
TOC (g/acre)	8 86 0.0% 9.04-184 54	5 111 -28.0% 0.54-539 239	9 2.7 96.9% 0.0-6.59 2.2
DOC (g/acre)	8 64 0.0% 6.57-149 43	5 81 -27.1% 0.21-392 174	9 2.05 96.8% 0.0-6.06 1.8
Ammonia NH_3-N (g/acre)	8 4.85 0.0% 0.90-9.64 3.36	5 0.52 89.4% 0.03-2.36 1.03	9 0.26 94.6% 0.0-0.57 0.21
Nitrate NO_3-N (g/acre)	8 3.96 0.0% 0.54-7.89 2.68	5 5.91 -49.4% 0.01-29 13	9 0.20 94.9% 0.02-0.55 0.17
Nitrite NO_2-N (g/acre)	8 0.357 0.0% 0.03-0.90 0.385	5 0.052 85.4% 0.0-0.24 0.103	9 0.012 96.6% 0.0-0.04 0.012

Table 4-12: Load Statistics for Napa Hwy 29 GRVTS Strip (continued)

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	4-308 N Mean Mean % Δ Range Std. Dev.	4-309 N Mean Mean % Δ Range Std. Dev.
TKN (g/acre)	8 18 0.0% 3.11-63.08 19	5 9.54 45.8% 0.10-45 20	9 0.75 95.7% 0.0-1.85 0.66
Total Phosphorus (g/acre)	8 1.46 0.0% 0.18-5.26 1.77	5 2.79 -91.6% 0.01-14 6.10	9 0.16 89.3% 0.0-0.40 0.15
Ortho-P, diss (g/acre)	8 0.651 0.0% 0.07-1.96 0.636	5 1.55 -138.1% 0.01-7.56 3.36	9 0.121 81.4% 0.03-0.32 0.100
As, diss (mg/acre)	8 3.07 0.0% 0.49-6.55 2.23	5 25 -703.3% 0.02-123 55	9 0.37 87.9% 0.05-1.25 0.36
As, total (mg/acre)	8 5.35 0.0% 0.82-18 5.30	5 30 -468.4% 0.02-151 68	9 0.58 89.2% 0.09-1.75 0.49
Cd, diss (mg/acre)	8 1.41 0.0% 0.08-4.38 1.40	5 0.500 NA 0.01-2.36 1.04	9 0.060 NA 0.01-0.12 0.044
Cd, total (mg/acre)	8 1.41 0.0% 0.08-4.38 1.40	5 0.500 NA 0.01-2.36 1.04	9 0.060 NA 0.01-0.12 0.044
Cr, diss (mg/acre)	8 17 0.0% 2.14-44 13	5 2.93 82.7% 0.0-14 6.29	9 0.245 98.6% 0.02-0.75 0.229
Cr, total (mg/acre)	8 41 0.0% 3.45-158 50	5 16 62.2% 0.37-76 34	9 1.00 97.6% 0.34-2.50 0.70
Cu, diss (mg/acre)	8 90 0.0% 9.70-237 73	5 47 48.0% 0.17-227 101	9 1.85 97.9% 0.26-3.99 1.22

Table 4-12: Load Statistics for Napa Hwy 29 GRVTS Strip (continued)

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	4-308 N Mean Mean % Δ Range Std. Dev.	4-309 N Mean Mean % Δ Range Std. Dev.
Cu, total (mg/acre)	8 207 0.0% 15-876 281	5 78 62.5% 0.35-378 168	9 3.4 98.4% 0.53-7.99 2.3
Pb, diss (mg/acre)	8 1.98 0.0% 0.15-8.76 2.81	5 4.76 -140.2% 0.01-24 10.5	9 0.098 95.1% 0.02-0.19 0.062
Pb, total (mg/acre)	8 36 0.0% 1.18-175 59	5 42 -18.4% 0.17-208 93	9 2.44 93.2% 0.39-5.02 1.45
Ni, diss (mg/acre)	8 15 0.0% 1.31-26 7.85	5 12 15.7% 0.03-61 27	9 0.34 97.7% 0.10-0.58 0.18
Ni, total (mg/acre)	8 39 0.0% 2.30-158 50	5 27 30.7% 0.19-132 59	9 1.30 96.7% 0.25-2.50 0.74
Zn, diss (mg/acre)	8 314 0.0% 31-876 262	5 139 55.7% 0.89-661 292	9 5.4 98.3% 0.94-11 3.6
Zn, total (mg/acre)	8 818 0.0% 56-3,592 1,156	5 285 65.1% 2.01-1,370 607	9 11 98.7% 2.12-19 6.2

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

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

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

No color = Increase but not statistically significant at a 90-percent confidence level

As shown in Table 4-12, the ANOVA on loads at the Napa location shows that the loads of 12 out of 24 constituents at Station 4-308 are lower than those at the EOP. Four out of the 12 constituent reductions are statistically significant. At Station 4-309, all 24 constituents show load reductions when compared to those at the EOP, and 11 out of the 24 constituent reductions are statistically significant.

The calculated seasonal load reduction results as presented in Table 4-3 show:

- At Station 4-308, the seasonal loads of all constituents show a decrease when compared to loads at the EOP, with reduction ranging from 92.9 percent for dissolved ortho-P to 99.1 percent for dissolved chromium, and with reductions for most constituents above 95 percent.
- At Station 4-309, the seasonal loads of all constituents show a decrease when compared to loads at the EOP, with reduction ranging from 73.3 percent for dissolved ortho-P to 98.7 percent for total zinc, and with reductions for most constituents above 95 percent.

The high seasonal load reductions are mostly due to substantial volume reduction occurring at both strips, as shown in Table 4-1. Overall, results show that the vegetated strips at this location perform very well in reducing pollutant load.

San Mateo Hwy 380 GRVTS Strip

The ANOVA on load data at the San Mateo GRVTS location is presented in Table 4-13. The table presents the number of data points, mean load, mean percent difference, the range of load data, and the standard deviation per station. Each constituent with a load reduction or increase in comparison to the EOP is also identified in Table 4-13.

Table 4-13: Load Statistics for San Mateo Hwy 380 GRVTS Strip

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	4-312 N Mean Mean % Δ Range Std. Dev.
Hardness as $CaCO_3$ (g/acre)	11 11,272 0.0% 780-83,032 23,945	11 4,700 58.3% 28-31,551 9,080
TDS (g/acre)	11 17,590 0.0% 16-152,955 44,994	11 10,343 41.2% 36-82,821 24,174
TSS (g/acre)	11 17,189 0.0% 752-144,214 42,375	11 6,592 61.6% 44-36,481 11,188
TOC (g/acre)	11 1,976 0.0% 209-14,640 4,238	11 1,135 42.6% 5.71-8,677 2,515
DOC (g/acre)	11 1,339 0.0% 127-10,270 2,985	11 715 46.6% 4.44-5,521 1,603
Ammonia NH_3-N (g/acre)	11 53 0.0% 6.44-219 58	11 16 69.2% 0.06-108 32
Nitrate NO_3-N (g/acre)	11 73 0.0% 7.80-481 136	11 111 -52.0% 0.44-917 268
Nitrite NO_2-N (g/acre)	11 5.40 0.0% 1.02-11 3.77	11 2.18 59.7% 0.03-7.05 2.23

Table 4-13: Load Statistics for San Mateo Hwy 380 GRVTS Strip (continued)

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	4-312 N Mean Mean % Δ Range Std. Dev.
TKN (g/acre)	11 359 0.0% 27-2,884 840	11 154 57.0% 0.82-1,144 331
Total Phosphorus (g/acre)	11 52 0.0% 1.90-481 142	11 31 39.5% 0.10-256 75
Ortho-P, diss (g/acre)	11 12 0.0% 0.34-109 32	11 17 -41.2% 0.04-148 44
As, diss (mg/acre)	11 98 0.0% 8.48-656 187	11 64 34.7% 0.41-493 143
As, total (mg/acre)	11 227 0.0% 15-1,748 506	11 151 33.3% 0.87-986 284
Cd, diss (mg/acre)	11 16 0.0% 0.85-109 31	11 6.74 NA 0.03-49 14
Cd, total (mg/acre)	11 81 0.0% 4.18-656 191	11 16 80.8% 0.10-99 29
Cr, diss (mg/acre)	11 1,896 0.0% 99-12,455 3,549	11 667 64.8% 1.36-4,831 1,395
Cr, total (mg/acre)	11 4,300 0.0% 237-32,776 9,497	11 1,715 60.1% 7.25-10,846 3,137
Cu, diss (mg/acre)	11 5,064 0.0% 712-32,776 9,266	11 1,563 69.1% 8.67-11,832 3,429

Table 4-13: Load Statistics for San Mateo Hwy 380 GRVTS Strip (continued)

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	4-312 N Mean Mean % Δ Range Std. Dev.
Cu, total (mg/acre)	11 18,840 0.0% 1,696-135,474 38,943	11 4,314 77.1% 14-30,565 8,814
Pb, diss (mg/acre)	11 386 0.0% 7.59-3,715 1,105	11 135 65.0% 0.23-887 279
Pb, total (mg/acre)	11 8,070 0.0% 326-69,922 20,575	11 2,742 66.0% 12-16,761 4,908
Ni, diss (mg/acre)	11 396 0.0% 54-2,841 814	11 156 60.6% 1.48-1,183 343
Ni, total (mg/acre)	11 2,543 0.0% 139-21,414 6,275	11 1,115 56.2% 6.63-6,409 1,884
Zn, diss (mg/acre)	11 6,261 0.0% 831-39,331 11,090	11 1,480 76.4% 11.73-9,268 2,748
Zn, total (mg/acre)	11 40,100 0.0% 2,883-305,909 88,628	11 7,508 81.3% 25-51,270 14,783

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

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

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

No color = Increase but not statistically significant at a 90-percent confidence level

As shown in Table 4-13, the ANOVA on loads at the San Mateo location shows that the loads of 22 out of 24 constituents at Station 4-312 are lower than those at the EOP. Two out of the 22 constituent reductions are statistically significant. As shown in Table 4-3, the calculated seasonal loads for 22 out of 24 constituents show reductions when compared to the loads at the respective EOP, with reductions ranging from 1.0 to 88.3 percent. The seasonal load reductions are mostly due to volume reductions that occurred within the strip, as shown in Table 4-1. Overall, results show that the vegetated strip at this site performs reasonably well in reducing pollutant load.

Camarillo Hwy 101 GRVTS Strip

The ANOVA on load data at the Camarillo GRVTS location is presented in Table 4-14. The table presents the number of data points, mean load, mean percent difference, the range of load data, and the standard deviation per station. Each constituent with a load reduction or increase in comparison to the EOP is also identified in Table 4-14.

Table 4-14: Load Statistics for Camarillo Hwy 101 GRVTS Strip

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	7-341 N Mean Mean % Δ Range Std. Dev.	7-342 N Mean Mean % Δ Range Std. Dev.
Hardness as $CaCO_3$ (g/acre)	5 5,681 0.0% 2,290-9,874 3,406	4 1,016 82.1% 166-2,030 799	5 1,714 69.8% 215-3,005 1,392
TDS (g/acre)	5 6,207 0.0% 2,238-12,817 4,349	4 1,904 69.3% 225-4,528 1,840	5 1,863 70.0% 365-3,474 1,427
TSS (g/acre)	5 5,340 0.0% 1,975-13,059 4,506	4 358 93.3% 126-573 203	5 430 91.9% 65-791 309
TOC (g/acre)	5 851 0.0% 446-1,306 427	4 116 86.3% 47-203 72	5 157 81.6% 40-237 104
DOC (g/acre)	5 652 0.0% 292-1,136 382	4 78 88.1% 38-128 41	5 112 82.8% 27-206 78
Ammonia NH_3-N (g/acre)	5 21 0.0% 5.84-36 14	4 0.978 95.4% 0.05-1.56 0.682	5 1.812 91.4% 0.02-3.93 1.453
Nitrate NO_3-N (g/acre)	5 53 0.0% 32-97 27	4 1.31 97.5% 0.65-1.79 0.49	5 5.31 90.0% 1.50-9.61 3.98
Nitrite NO_2-N (g/acre)	5 6.28 0.0% 4.54-9.67 2.22	4 0.127 98.0% 0.06-0.21 0.061	5 0.558 91.1% 0.23-1.58 0.574

Table 4-14: Load Statistics for Camarillo Hwy 101 GRVTS Strip (continued)

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	7-341 N Mean Mean % Δ Range Std. Dev.	7-342 N Mean Mean % Δ Range Std. Dev.
TKN (g/acre)	5 135 0.0% 37-370 136	4 15 89.2% 5.03-28 9.78	5 29 78.8% 2.87-74 29
Total Phosphorus (g/acre)	5 16 0.0% 2.60-39 14	4 12 24.0% 3.25-25 9.65	5 14 15.0% 1.56-24 10.44
Ortho-P, diss (g/acre)	5 5.91 0.0% 0.08-12 5.19	4 9.65 -63.2% 2.41-20 7.87	5 11.23 -89.9% 1.24-20 8.80
As, diss (mg/acre)	5 105 0.0% 42-193 73	4 37 64.8% 5.82-70 29	5 50 53.0% 6.52-96 41
As, total (mg/acre)	5 162 0.0% 73-339 110	4 47 70.9% 8.74-88 35	5 64 60.3% 7.82-126 53
Cd, diss (mg/acre)	5 7.65 0.0% 2.60-12 4.56	4 0.81 NA 0.21-1.30 0.49	5 2.20 NA 0.23-3.95 1.81
Cd, total (mg/acre)	5 27 0.0% 3.65-73 27	4 2.13 92.1% 1.25-2.60 0.62	5 2.25 91.6% 0.33-3.95 1.75
Cr, diss (mg/acre)	5 300 0.0% 102-653 228	4 20 93.5% 8.84-36 13	5 67 77.6% 7.17-192 79
Cr, total (mg/acre)	5 756 0.0% 285-1,814 614	4 49 93.5% 26-83 28	5 127 83.2% 11-303 123
Cu, diss (mg/acre)	5 852 0.0% 500-1,620 466	4 77 91.0% 36-141 47	5 230 73.0% 24-459 213

Table 4-14: Load Statistics for Camarillo Hwy 101 GRVTS Strip (continued)

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	7-341 N Mean Mean % Δ Range Std. Dev.	7-342 N Mean Mean % Δ Range Std. Dev.
Cu, total (mg/acre)	5 3,188 0.0% 1,753-7,013 2,182	4 157 95.1% 92-242 65	5 384 88.0% 50-813 337
Pb, diss (mg/acre)	5 26 0.0% 9.87-48 19	4 2.91 88.7% 0.83-5.20 2.18	5 16 39.5% 0.65-63 27
Pb, total (mg/acre)	5 702 0.0% 432-1,403 412	4 79 88.8% 39-130 41	5 120 82.9% 10.43-192 95
Ni, diss (mg/acre)	5 128 0.0% 66-242 71	4 18 85.8% 4.99-39 15	5 30 76.6% 4.56-67 26
Ni, total (mg/acre)	5 516 0.0% 270-1,161 369	4 45 91.4% 19-78 26	5 83 84.0% 8.47-163 69
Zn, diss (mg/acre)	5 789 0.0% 265-1,451 493	4 70 91.2% 30-135 46	5 270 65.8% 36-628 256
Zn, total (mg/acre)	5 9,114 0.0% 4,424-21,039 6,940	4 343 96.2% 202-494 133	5 927 89.8% 91-1,774 799

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

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

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

No color = Increase but not statistically significant at a 90-percent confidence level

As shown in Table 4-14, the ANOVA on loads at the Camarillo location shows that the loads of 23 out of 24 constituents at both strips are lower than the loads at the EOP. At Station 7-341, 17 out of 23 constituent reductions are statistically significant, while 18 out of 23 constituent reductions are statistically significant at Station 7-342. Limited data points throughout the season may have contributed to non-significant findings, specifically for total phosphorus.

The calculated seasonal load reduction results as presented in Table 4-3 show:

- At Station 7-341, the seasonal loads of all constituents except for one (dissolved ortho-P) show a decrease when compared to loads at the EOP, with reduction ranging from 31.0 percent for total phosphorus to 98.1 percent for nitrite, and with reductions for most constituents above 85 percent.
- At Station 7-342, the seasonal loads of all constituents except for one show a decrease when compared to loads at the EOP, with reduction ranging from 15.0 percent for total phosphorus to 92 percent for TSS, and with reductions for most constituents above 75 percent.

The seasonal load reductions are mostly due to volume reduction that occurred within the strip, as shown in Table 4-3. Overall, results show that the vegetated strips at this location perform well in reducing pollutant load.

Westminster I-405 GRVTS Strip

The ANOVA on load data at the Westminster GRVTS location is presented in Table 4-15. The table presents the number of data points, mean load, mean percent difference, the range of load data, and the standard deviation per station. Each constituent with a load reduction or increase in comparison to the EOP is also identified in Table 4-15.

Table 4-15: Load Statistics for Westminster I-405 GRVTS Strip

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	12-344 N Mean Mean % Δ Range Std. Dev.	12-345 N Mean Mean % Δ Range Std. Dev.
Hardness as $CaCO_3$ (g/acre)	9 864 0.0% 0.0-1,340 422	3 565 34.6% 0.0-1,149 575	2 480 44.4% 356-604 175
TDS (g/acre)	9 1,324 0.0% 150-3,526 1,019	3 2,701 -104.0% 76-5,515 2,724	2 1,474 -11.3% 1,456-1,492 26
TSS (g/acre)	9 2,806 0.0% 26-9,823 3,255	3 961 65.8% 19-2,403 1,269	2 859 69.4% 497-1,221 512
TOC (g/acre)	9 230 0.0% 0.0-445 162	3 384 -67.0% 0.0-859 437	2 316 -37.5% 187-446 183
DOC (g/acre)	9 158 0.0% 0.0-365 136	3 254 -61.3% 0.0-554 280	2 212 -34.3% 123-300 125
Ammonia NH_3-N (g/acre)	9 9.33 0.0% 1,56-21 5.67	3 2.36 74.7% 0.21-5.06 2.47	2 1.76 81.1% 0.51-3.02 1.78
Nitrate NO_3-N (g/acre)	9 12 0.0% 1.65-20 5.82	3 15 -27.2% 0.38-29 14	2 2.25 80.6% 1.78-2.71 0.663
Nitrite NO_2-N (g/acre)	9 0.935 0.0% 0.23-2.08 0.582	3 0.132 85.9% 0.01-0.27 0.133	2 0.129 86.2% 0.09-0.17 0.057

Table 4-15: Load Statistics for Westminster I-405 GRVTS Strip (continued)

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	12-344 N Mean Mean % Δ Range Std. Dev.	12-345 N Mean Mean % Δ Range Std. Dev.
TKN (g/acre)	9 54 0.0% 17-133 41	3 49 9.0% 1.86-82 42	2 35 36.4% 28-42 9.9
Total Phosphorus (g/acre)	9 5.65 0.0% 0.42-19 5.54	3 6.47 -14.5% 0.0-12 6.22	2 8.50 -50.4% 8.48-8.52 0.031
Ortho-P, diss (g/acre)	9 1.51 0.0% 0.0-4.65 1.47	3 3.83 -154.1% 0.12-8.27 4.12	2 4.02 -167.0% 2.54-5.50 2.09
As, diss (mg/acre)	9 15 0.0% 1.30-21 5.69	3 16 -11.2% 0.61-37 19	2 15 -0.7% 10.18-20 6.62
As, total (mg/acre)	9 41 0.0% 1.95-86 23	3 25 39.2% 0.78-46 23	2 25 38.8% 20-30 7.56
Cd, diss (mg/acre)	9 4.03 0.0% 0.16-9.49 3.14	3 0.701 NA 0.04-1.15 0.582	2 0.868 NA 0.85-0.89 0.028
Cd, total (mg/acre)	9 24 0.0% 0.33-57 18	3 5.20 78.3% 0.09-11 5.44	2 6.02 74.9% 3.55-8.48 3.48
Cr, diss (mg/acre)	9 72 0.0% 2.77-170 51	3 13 81.5% 0.70-21 11	2 14 80.9% 10.65-17 4.46
Cr, total (mg/acre)	9 259 0.0% 5.86-604 179	3 51 80.4% 1.57-109 54	2 60 76.7% 43-78 25
Cu, diss (mg/acre)	9 402 0.0% 49-796 219	3 172 57.2% 7.41-391 197	2 149 63.0% 102-195 66

Table 4-15: Load Statistics for Westminster I-405 GRVTS Strip (continued)

Constituent	EOP N Mean Mean % Δ Range Std. Dev.	12-344 N Mean Mean % Δ Range Std. Dev.	12-345 N Mean Mean % Δ Range Std. Dev.
Cu, total (mg/acre)	9 2,102 0.0% 119-5,376 1,523	3 436 79.3% 11-747 381	2 533 74.6% 497-568 50
Pb, diss (mg/acre)	9 15 0.0% 0.81-27 8.17	3 39 -154.8% 1.39-97 51	2 36 -136.2% 22-50 20
Pb, total (mg/acre)	9 1,327 0.0% 15-2,920 939	3 964 27.3% 17-2,094 1,050	2 1,666 -25.5% 1,296-2,035 522
Ni, diss (mg/acre)	9 64 0.0% 5.86-104 31	3 22 65.9% 0.87-51 26	2 17 72.9% 12-23 7.93
Ni, total (mg/acre)	9 246 0.0% 9.12-544 153	3 58 76.6% 1.57-100 51	2 63 74.3% 57-70 9.0
Zn, diss (mg/acre)	9 1,193 0.0% 49-2,124 604	3 207 82.6% 12-437 214	2 218 81.7% 153-284 93
Zn, total (mg/acre)	9 8,653 0.0% 195-24,558 7,074	3 1,469 83.0% 27-3,368 1,717	2 1,893 78.1% 1,243-2,544 920

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

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

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

No color = Increase but not statistically significant at a 90-percent confidence level

As shown in Table 4-15, the ANOVA on loads at the Westminster location shows that the loads of 16 out of 24 constituents at both strips are lower than those at the EOP. At both stations, two out of 16 constituent reductions are statistically significant. Limited data points throughout the season may have contributed to non-significant findings, specifically for total phosphorus.

The calculated seasonal load reduction results as presented in Table 4-3 show:

- At Station 12-344, the seasonal loads of all constituents except for TDS, TOC, DOC, and dissolved ortho-P show a decrease when compared to loads at the EOP, with reductions ranging from 11.5 percent for TSS to 93.8 percent for dissolved zinc, and with reductions for most constituents above 70 percent.
- At Station 12-345, the seasonal loads of all constituents except for TSS, total phosphorus, and dissolved ortho-P show a decrease when compared to loads at the EOP, with reductions ranging from 7.1 percent for total lead to 91.1 percent for both dissolved cadmium and dissolved zinc, and with reductions for most constituents above 70 percent.

The high seasonal load reductions are mostly due to substantial volume reduction that occurred at both strips, as shown in Table 4-3. Overall, results show that the vegetated strips at this location perform very well in reducing pollutant load.

San Diego SR 52 GRVTS Strip

Monitoring at the San Diego location was terminated after the first four storms due to substantial recurring bypass issues at the two strip stations. No representative data are available from the strip stations at this location and, therefore, evaluations were not performed.

4.3 EFFECTIVENESS OF SWALES

This section addresses the study question of how much treatment of highway runoff is occurring in terms of concentration, volume, and load reduction for various roadside swales planted with ornamental vegetation.

As described in Section 1.3, each of the two GRVTS swale locations (Carlsbad (Palomar) and Newbury Park) includes one influent station and one effluent station. Data analyses results and discussions on concentration, volume reduction, and load data for these two swales are presented in the following subsections.

4.3.1 Concentration

At each swale location, the average EMCs from the effluent station were compared to the average EMCs from the influent station to evaluate treatment performance of the vegetated swales in reducing pollutant concentrations. The treatment performance of each GRVTS swale in comparison with its respective EOP station, based on results of the ANOVA on concentration data, is summarized in Table 4-2. Discussions on these results are presented in the following two sub-sections.

Newbury Park Hwy 101 GRVTS Swale

The ANOVA on mean concentration data at the Newbury Park GRVTS location is presented in Table 4-16. The table presents the number of data points, mean concentration, mean percent difference, the range of EMCs, and the standard deviation per station. Each constituent with a concentration reduction or increase in comparison to the EOP is also identified in Table 4-16.

Table 4-16: Concentration Statistics for Newbury Park Hwy 101 GRVTS Swale

Constituent	Swale Influent N Mean Mean % Δ Range Std. Dev.	7-339 N Mean Mean % Δ Range Std. Dev.
Hardness as $CaCO_3$ (mg/L)	5 33.400 0.0% 22-50 12.050	5 25.600 23.4% 20-34 6.945
TDS (mg/L)	5 33.200 0.0% 22-52 14.260	5 27.400 17.5% 18-42 10.193
TSS (mg/L)	5 16.200 0.0% 8-27 8.480	5 17.800 -9.9% 4-33 12.519
TOC (mg/L)	5 4.000 0.0% 3-6.4 1.658	5 4.600 -15.0% 3-6.2 1.414
DOC (mg/L)	5 2.980 0.0% 2.1-4.8 1.258	5 3.180 -6.7% 2-4.6 1.136
Turbidity (NTU)	5 19.920 0.0% 11.1-26.4 6.230	5 20.440 -2.6% 8.8-29.5 9.379
Ammonia NH_3-N (mg/L)	5 0.188 0.0% 0.07-0.3 0.094	5 0.095 49.5% 0.0025-0.11 0.025
Nitrate NO_3-N (mg/L)	5 0.210 0.0% 0.1-0.36 0.111	5 0.136 35.2% 0.04-0.23 0.084

Table 4-16: Concentration Statistics Newbury Park Hwy 101 GRVTS Swale (continued)

Constituent	Swale Influent N Mean Mean % Δ Range Std. Dev.	7-339 N Mean Mean % Δ Range Std. Dev.
Nitrite NO_2-N (mg/L)	5 0.032 0.0% 0.02-0.04 0.011	5 0.022 31.3% 0.005-0.04 0.014
TKN (mg/L)	5 0.632 0.0% 0.17-0.99 0.367	5 0.442 30.1% 0.21-0.76 0.241
Total Phosphorus (mg/L)	5 0.086 0.0% 0.05-0.14 0.040	5 0.168 -95.3% 0.1-0.25 0.074
Ortho-P, diss (mg/L)	5 0.040 0.0% 0.02-0.05 0.015	5 0.126 -215.0% 0.07-0.17 0.042
As, diss (ug/L)	5 1.060 0.0% 0.8-1.4 0.247	5 1.000 5.7% 0.7-1.3 0.253
As, total (ug/L)	5 1.400 0.0% 1-1.9 0.378	5 1.300 7.1% 0.8-1.9 0.470
Cd, diss (ug/L)	5 <0.1 0.0% 0.05-0.05 NA	5 <0.1 NA 0.05-0.05 NA
Cd, total (ug/L)	5 0.140 0.0% 0.05-0.2 0.082	5 0.134 4.3% 0.05-0.3 0.133
Cr, diss (ug/L)	5 1.960 0.0% 1.3-2.9 0.660	5 1.480 24.5% 0.8-1.6 0.549
Cr, total (ug/L)	5 4.780 0.0% 2.6-6.7 1.749	5 4.960 -3.8% 2-8.2 2.596

Table 4-16: Concentration Statistics Newbury Park Hwy 101 GRVTS Swale (continued)

Constituent	Swale Influent N Mean Mean % Δ Range Std. Dev.	7-339 N Mean Mean % Δ Range Std. Dev.
Cu, diss (ug/L)	5 7.700 0.0% 5.1-9.6 2.281	5 6.960 9.6% 2.6-9.9 3.056
Cu, total (ug/L)	5 18.000 0.0% 11-24 5.645	5 12.960 28.0% 6.8-21 5.719
Pb, diss (ug/L)	5 0.116 0.0% 0.04-0.2 0.081	5 0.172 -48.3% 0.04-0.6 0.309
Pb, total (ug/L)	5 2.800 0.0% 1.6-3.7 1.030	5 2.520 10.0% 0.8-4.4 1.531
Ni, diss (ug/L)	5 1.260 0.0% 0.8-2 0.550	5 0.930 26.2% 0.5-1.4 0.354
Ni, total (ug/L)	5 3.360 0.0% 1.9-5.2 1.444	5 3.400 -1.2% 1.4-6.6 2.255
Zn, diss (ug/L)	5 13.400 0.0% 12-15 1.371	5 9.080 32.2% 4.9-11 2.899
Zn, total (ug/L)	5 53.300 0.0% 34-68.5 15.943	5 35.600 33.2% 17-65 20.701

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

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

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

No color = Increase but not statistically significant at a 90-percent confidence level

As shown in Table 4-16, the average EMCs of most (15 out of 25) constituents in the effluent at the Newbury Park location are lower than the average EMCs of the influent. Of these constituents, ammonia, total cadmium, and dissolved zinc show a significant concentration reduction at a 90-percent confidence level. For metals specifically, only total chromium, dissolved lead, and total nickel (three out of the 14 total and dissolved metals) show

concentration increases in the swale effluent as compared to the influent. Dissolved ortho-P is the only constituent that shows a significant increase in the swale effluent as compared to the influent. Limited data points throughout the season may have contributed to non-significant findings, specifically for total phosphorus. Overall, results show that the swale provides treatment in reducing the pollutant concentration for most constituents, and that the swale is particularly effective in reducing concentrations of metals.

Carlsbad (Palomar) I-5 GRVTS Swale

The ANOVA on mean concentration data at the Carlsbad (Palomar) GRVTS location is presented in Table 4-17. The table presents the number of data points, mean concentration, mean percent difference, the range of EMCs, and the standard deviation per station. Each constituent with a concentration reduction or increase in comparison to the EOP, whether statistically significant or not, is also identified in Table 4-17.

Table 4-17: Concentration Statistics for Carlsbad (Palomar) I-5 GRVTS Swale

Constituent	Swale Influent N Mean Mean % Δ Range Std. Dev.	11-327 N Mean Mean % Δ Range Std. Dev.
Hardness as $CaCO_3$ (mg/L)	4 41.0 0.0%. 30-58 14.0	7 54.3 -32.4% 32-94 22.4
TDS (mg/L)	4 93.8 0.0%. 43-164 58.1	7 139 -48.4% 68-300 89.2
TSS (mg/L)	4 29.0 0.0%. 18-48 15.8	7 16.8 42.2% 0.5-39 13.1
TOC (mg/L)	4 15.8 0.0%. 7-26.9 9.35	7 16.9 -7.1% 3.9-52.3 19.6
DOC (mg/L)	4 11.1 0.0%. 5.4-19.5 6.89	7 10.7 3.9% 2.3-23.5 7.85
Turbidity (NTU)	4 41.0 0.0%. 35.1-47 5.39	7 20.9 48.9% 8.2-34.2 9.15
Ammonia NH_3-N (mg/L)	4 0.64 0.0%. 0.4-1.17 0.46	7 0.04 93.7% 0.005-0.13 0.05

Table 4-17: Concentration Statistics for Carlsbad (Palomar) I-5 GRVTS Swale (continued)

Constituent	Swale Influent N Mean Mean % Δ Range Std. Dev.	11-327 N Mean Mean % Δ Range Std. Dev.
Nitrate NO_3-N (mg/L)	4 1.12 0.0%. 0.49-1.83 0.61	7 0.24 78.1% 0.02-0.55 0.21
Nitrite NO_2-N (mg/L)	4 0.12 0.0%. 0.04-0.24 0.10	7 0.01 90.5% ND-0.03 0.01
TKN (mg/L)	4 2.12 0.0%. 0.66-7.55 1.17	7 1.03 51.5% 0.57-1.8 0.44
Total Phosphorus (mg/L)	4 0.11 0.0%. 0.05-0.14 0.05	7 0.40 -269.4% 0.18-0.93 0.29
Ortho-P, diss (mg/L)	4 0.06 0.0%. 0.03-0.08 0.03	7 0.29 -399.4% 0.14-0.71 0.23
As, diss (ug/L)	4 0.68 0.0%. 0.6-0.8 0.10	7 0.56 17.5% 0.4-0.9 0.19
As, total (ug/L)	4 1.10 0.0%. 0.9-1.5 0.33	7 0.76 31.2% 0.6-1.1 0.19
Cd, diss (ug/L)	4 <0.1 0.0%. 0.05-0.6 NA	7 <0.1 NA 0.05-0.25 NA
Cd, total (ug/L)	4 0.48 0.0%. 0.2-0.9 0.35	7 0.19 60.0% 0.05-0.4 0.12
Cr, diss (ug/L)	4 3.98 0.0%. 2.2-7 2.47	7 5.81 -46.3% 3.1-8.5 2.07

Table 4-17: Concentration Statistics for Carlsbad (Palomar) I-5 GRVTS Swale (continued)

Constituent	Swale Influent N Mean Mean % Δ Range Std. Dev.	11-327 N Mean Mean % Δ Range Std. Dev.
Cr, total (ug/L)	4 7.40 0.0%. 5.2-12 3.96	7 7.59 -2.5% 4-10 2.23
Cu, diss (ug/L)	4 27.5 0.0%. 16-44 13.6	7 8.27 69.9% 5.6-11 1.96
Cu, total (ug/L)	4 52.5 0.0% 41-77 20.4	7 15.0 71.4% 10-25 5.67
Pb, diss (ug/L)	4 0.43 0.0% 0.1-1.1 0.10	7 0.31 26.1% 0.2-0.5 0.12
Pb, total (ug/L)	4 14.6 0.0% 8.5-180 5.04	7 7.56 48.3% 1.7-25 9.76
Ni, diss (ug/L)	4 4.35 0.0% 2.4-7.1 2.26	7 1.14 73.7% 0.7-1.6 0.34
Ni, total (ug/L)	4 7.03 0.0% 5.5-11 3.59	7 2.01 71.3% 1.3-3.2 0.68
Zn, diss (ug/L)	4 63.5 0.0% 38-99 29.2	7 18.7 70.5% 11-34 8.48
Zn, total (ug/L)	4 145 0.0% 110-210 53.7	7 46.4 68.0% 19-98 28.7

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

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

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

No color = Increase but not statistically significant at a 90-percent confidence level

As shown in Table 4-17, at the Carlsbad (Palomar) location, the average EMCs of the majority of the constituents (20 out of 26) in the effluent are lower than the average EMCs in the influent. Of these constituents, all heavy metals (excluding dissolved and total chromium), nitrogens, TSS, and turbidity show concentration reductions in the swale effluent as compared to the influent. Total phosphorus and dissolved ortho-P are the only constituents with a significant increase at a 90-percent confidence level in the swale effluent as compared to the influent. Limited data points throughout the season may have contributed to these findings. Overall, similar to the observations from the Newbury Park swale location, results show that the Carlsbad (Palomar) swale provides treatment for most constituents in reducing pollutant concentrations, and that the swale is particularly effective in reducing concentrations of metals.

4.3.2 Volume reduction

As shown in Table 4-1, substantial volume reduction occurred at both swale stations throughout the 2009-2010 monitoring season. The Newbury Park GRVTS swale at Station 7-339 shows a seasonal volume reduction of 71.9 percent for four monitored storms ranging, with an event volume reduction ranging from 58.6 to 100.0 percent. The Carlsbad (Palomar) GRVTS swale at Station 11-327 shows a seasonal volume reduction of 95.9 percent for two monitored storms, with an event volume reduction ranging from 95.4 to 97.6 percent.

4.3.3 Load

As described in Section 1.3. Each of the two GRVTS swale locations (Newbury Park and Carlsbad (Palomar)) includes one influent station and one effluent station. At each location, the pollutant loads at the effluent station were compared to those at the influent station to evaluate the treatment performance of the vegetated swales in reducing pollutant loads. The percent seasonal load reductions for each swale are summarized in Table 4-3. The treatment performance of each swale in comparison with its respective EOP station, based on results of the ANOVA on load data, is summarized in Tables 4-18 and 4-19. Discussions on these results are presented in the following two sub-sections. Detailed output results of the ANOVA on load data are presented in Appendix J.2.

Newbury Park Hwy 101 GRVTS Swale

The ANOVA on load data at the Newbury Park GRVTS location is presented in Table 4-18. The table presents the number of data points, mean load, mean percent difference, the range of load data, and the standard deviation per station. Each constituent with a load reduction or increase in comparison to the EOP is also identified in Table 4-18.

Table 4-18: Load Statistics for Newbury Park Hwy 101 GRVTS Swale

Constituent	Swale Influent N Mean Mean % Δ Range Std. Dev.	7-339 N Mean Mean % Δ Range Std. Dev.
Hardness as $CaCO_3$ (g/acre)	5 8,772 0.0% 4,178-13,942 4,258	4 1,507 82.8% 755-2,515 870
TDS (g/acre)	5 8,829 0.0% 4,368-18,589 5,749	4 1,599 81.9% 831-2,308 795
TSS (g/acre)	5 4,772 0.0% 1,519-11,407 4,133	4 1,282 73.1% 151-2,929 1,209
TOC (g/acre)	5 982 0.0% 86-246 305	4 276 71.9% 147-377 110
DOC (g/acre)	5 725 0.0% 452-950 203	4 194 73.2% 109-266 77
Ammonia NH_3-N (g/acre)	5 50 0.0% 21-106 35	4 4.86 90.2% 0.22-14 6.10
Nitrate NO_3-N (g/acre)	5 59 0.0% 5.46-31 53	4 5.89 90.0% 4.50-8.68 1.90
Nitrite NO_2-N (g/acre)	5 8.45 0.0% 3.77-17 5.00	4 0.823 90.3% 0.44-1.51 0.471

Table 4-18: Load Statistics for Newbury Park Hwy 101 GRVTS Swale (continued)

Constituent	Swale Influent N Mean Mean % Δ Range Std. Dev.	7-339 N Mean Mean % Δ Range Std. Dev.
TKN (g/acre)	5 159 0.0% 24-152 110	4 29 81.5% 9.44-67 26
Total Phosphorus (g/acre)	5 27 0.0% 5.65-59 21	4 11 61.2% 3.56-22 8.84
Ortho-P, diss (g/acre)	5 13 0.0% 2.82-21 8.72	4 8.41 33.0% 2.64-15 6.35
As, diss (mg/acre)	5 284 0.0% 132-465 134	4 62 78.2% 30-98 36
As, total (mg/acre)	5 375 179-634 187	4 78 79.1% 34-133 47
Cd, diss (mg/acre)	5 14 0.0% 4.71-21 6.93	4 3.45 NA 1.19-6.29 2.35
Cd, total (mg/acre)	5 39 0.0% 9.50-85 32	4 8.26 78.6% 1.89-18 6.73
Cr, diss (mg/acre)	5 592 0.0% 179-1,225 429	4 83 86.1% 31-142 49
Cr, total (mg/acre)	5 1,369 0.0% 494-2,831 950	4 315 77.0% 76-586 226
Cu, diss (mg/acre)	5 2,060 0.0% 904-3,887 1121	4 425 79.4% 173-879 311

Table 4-18: Load Statistics for Newbury Park Hwy 101 GRVTS Swale (continued)

Constituent	Swale Influent N Mean Mean % Δ Range Std. Dev.	7-339 N Mean Mean % Δ Range Std. Dev.
Cu, total (mg/acre)	5 4,933 0.0% 2,165-10,139 3,142	4 730 85.2% 415-1,154 341
Pb, diss (mg/acre)	5 37 0.0% 3.77-85 34	4 16 57.4% 0.95-53 25
Pb, total (mg/acre)	5 770 0.0% 304-1,394 472	4 169 78.0% 30-328 130
Ni, diss (mg/acre)	5 327 0.0% 188-676 201	4 51 84.3% 33-71 19
Ni, total (mg/acre)	5 889 0.0% 399-1,774 553	4 214 76.0% 53-382 141
Zn, diss (mg/acre)	5 3,695 0.0% 1,318-5,915 1,761	4 557 84.9% 220-976 323
Zn, total (mg/acre)	5 14,869 0.0% 6,025-28,940 9,316	4 2,223 85.0% 642-3,816 1,409

Red = Statistically significant increase at a 90-percent confidence level
Green = Statistically significant reduction at a 90-percent confidence level
Gray = Reduction but not statistically significant at a 90-percent confidence level
No color = Increase but not statistically significant at a 90-percent confidence level

As shown in Table 4-18, the ANOVA on loads at the Newbury Park location shows that all 24 constituents at the swale station demonstrate load reductions when compared to loads from the EOP, with 20 constituents exhibiting statistically significant load reductions at a 90-percent confidence level. As shown in Table 4-3, the calculated seasonal loads for all constituents show reductions when compared to loads from the respective EOP, with reductions ranging from 19.2 percent for dissolved ortho-P to 87.0 percent for nitrite. Limited data points throughout the season may have contributed to non-significant findings, specifically for total phosphorus and dissolved ortho-P. The seasonal load reductions are mostly due to moderate volume reduction

that occurred within the swale, as shown in Table 4-1. Overall, results show that the vegetated swale at this location performs reasonably well in reducing pollutant load.

Carlsbad (Palomar) I-5 GRVTS Swale

The ANOVA on load data at the Carlsbad (Palomar) GRVTS location is presented in Table 4-19. The table presents the number of data points, mean load, mean percent difference, the range of load data, and the standard deviation per station. Each constituent with a load reduction or increase in comparison to the EOP is also identified in Table 4-19.

Table 4-19: Load Statistics for Carlsbad (Palomar) I-5 GRVTS Swale

Constituent	Swale Influent N Mean Mean % Δ Range Std. Dev.	11-327 N Mean Mean % Δ Range Std. Dev.
Hardness as $CaCO_3$ (g/acre)	4 478 0.0% 210-1,125 435	1 110 77.0% NA NA
TDS (g/acre)	4 978 0.0% 479-2,251 854	1 246 74.9% NA NA
TSS (g/acre)	4 348 0.0% 109-633 276	1 0.8 99.8% NA NA
TOC (g/acre)	4 143 0.0% 86-246 71	1 85 40.6% NA NA
DOC (g/acre)	4 103 0.0% 58-190 59	1 38 63.1% NA NA
Ammonia NH_3-N (g/acre)	4 6.62 0.0% 2.48-14 5.10	1 0.008 99.9% NA NA
Nitrate NO_3-N (g/acre)	4 13 0.0% 5.46-31 13	1 0.03 99.8% NA NA
Nitrite NO_2-N (g/acre)	4 1.21 0.0% 0.45-2.81 1.10	1 NA 99.7% NA NA

Table 4-19: Load Statistics for Carlsbad (Palomar) I-5 GRVTS Swale (continued)

Constituent	Swale Influent N Mean Mean % Δ Range Std. Dev.	11-327 N Mean Mean % Δ Range Std. Dev.
TKN (g/acre)	4 26 0.0% 8.40-65 26	1 2.07 91.9% NA NA
Total Phosphorus (g/acre)	4 1.73 0.0% 0.21-4.92 2.16	1 0.42 75.7% NA NA
Ortho-P, diss (g/acre)	4 0.942 0.0% 0.13-2.81 1.256	1 0.275 70.8% NA NA
As, diss (mg/acre)	4 9.38 0.0% 2.86-25 10.30	1 0.81 91.4% NA NA
As, total (mg/acre)	4 14 0.0% 4.29-32 12	1 0.97 92.9% NA NA
Cd, diss (mg/acre)	4 1.61 0.0% 0.56-2.86 0.971	1 0.081 95.0% NA NA
Cd, total (mg/acre)	4 4.54 0.0% 1.26-7.03 2.46	1 0.081 98.2% NA NA
Cr, diss (mg/acre)	4 62 0.0% 9.21-151 67	1 5.02 92.0% NA NA
Cr, total (mg/acre)	4 100 0.0% 25-215 92	1 6.47 93.5% NA NA
Cu, diss (mg/acre)	4 356 0.0% 110-950 398	1 13 96.5% NA NA

Table 4-19: Load Statistics for Carlsbad (Palomar) I-5 GRVTS Swale (continued)

Constituent	Swale Influent N Mean Mean % Δ Range Std. Dev.	11-327 N Mean Mean % Δ Range Std. Dev.
Cu, total (mg/acre)	4 638 0.0% 196-1,477 579	1 16 97.5% NA NA
Pb, diss (mg/acre)	4 5.47 0.0% 2.09-14 5.76	1 0.485 91.1% NA NA
Pb, total (mg/acre)	4 159 0.0% 67-299 109	1 2.8 98.2% NA NA
Ni, diss (mg/acre)	4 55 0.0% 18-148 62	1 1.94 96.5% NA NA
Ni, total (mg/acre)	4 85 0.0% 28-204 81	1 2.59 96.9% NA NA
Zn, diss (mg/acre)	4 820 0.0% 262-2,181 910	1 23 97.2% NA NA
Zn, total (mg/acre)	4 1,720 0.0% 573-3,869 1,491	1 31 98.2% NA NA

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

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

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

No color = Increase but not statistically significant at a 90-percent confidence level

As shown in Table 4-19, the ANOVA on loads at the Carlsbad (Palomar) location shows that all 25 constituents at the swale station demonstrate load reductions when compared to loads from the EOP. However, it should be noted that none of the observed reductions is statistically significant at a 90-percent confidence level, and only one data point is available at the swale station (11-327). Limited data points throughout the season may have contributed to non-significant findings, specifically for total phosphorus. As shown in Table 4-3, the calculated seasonal loads for all 25 constituents show constituent reductions when compared to loads from the respective EOP, with reductions ranging from 65.6 percent for TOC to 99.9 percent for ammonia. The seasonal load reductions are mostly due to high volume reduction that occurred within the swale, as shown in Table 4-1. Overall, results show that the vegetated swale at this location performs very well in reducing pollutant load.

4.4 IMPACT OF STRIP WIDTH ON EFFECTIVENESS OF STRIPS

This section addresses the study question of what the difference is in treatment between strips having the same type of ornamental vegetation but different strip widths. Two types of data analyses were performed to address this study question:

- Comparisons between strips (with the same ornamental vegetation but different strip widths) at each ERVTS location in terms of pollutant concentrations, runoff volume, and pollutant load reductions.
- Comparisons between strips (with the same ornamental vegetation but different strip widths) at different locations but within the same general geographical region (i.e. two Northern ORVTS strip locations were compared to each other and similarly, two Southern ORVTS strip locations were compared) in terms of pollutant concentrations, runoff volume, and pollutant load reductions.

Detailed discussions are presented in the following subsections.

4.4.1 Comparisons within Each ERVTS Location

As discussed in Section 1.4, at the Sacramento ERVTS, the strip Station 3-362 has the same ornamental vegetation type (*H. helix*) as Station 3-365, but has a shorter width (9 feet) than Station 3-365 (25 feet). Similarly, at the Yorba Linda ERVTS, strip Station 12-346 has the same ornamental vegetation type (*I. hayesiana*) as Station 12-347, but has a shorter width (10 feet) than Station 12-347 (21 feet). Data analyses results and discussions on concentration, runoff volume, and load data for these stations are presented in the following subsections.

4.4.1.1 Concentration

The Tukey-Kramer Honestly Significant Difference (HSD) tests were performed on the EMCs at Stations 3-362 and 3-365 to examine the effect of strip width on the pollutant concentrations at the strips with the *H. helix* vegetation at the Sacramento location. Similar tests were performed on the EMCs at Stations 12-346 and 12-347 (both with the *I. hayesiana* vegetation). A summary of the Tukey-Kramer HSD test results at these two locations is presented in Table 4-20.

Table 4-20: Tukey-Kramer HSD Test Results Summary for Concentration and Load Comparisons between Strips with Same Ornamental Vegetation but Different Widths

Concentration			Load		
Constituent	**Sacramento[(a)]**	**Yorba Linda[(b)]**	**Constituent**	**Sacramento[(a)]**	**Yorba Linda[(b)]**
	3–362 (9-ft) vs. 3–365 (25-ft)	**12–346 (10-ft) vs. 12–347 (21-ft)**		**3–362 (9-ft) vs. 3–365 (25-ft)**	**12–346 (10-ft) vs. 12–347 (21-ft)**
Hardness as $CaCO_3$ (mg/L)	+	+	Hardness as $CaCO_3$ (g/acre)	–	+
TDS (mg/L)	+	+	TDS (g/acre)	–	+
TSS (mg/L)	–	–	TSS (g/acre)	–	–
TOC (mg/L)	–	+	TOC (g/acre)	–	+
DOC (mg/L)	–	+	DOC (g/acre)	–	+
Turbidity (NTU)	–	+	Tubidity	NA	NA
Ammonia NH_3–N (mg/L)	–	–	Ammonia NH_3–N (g/acre)	–	–
Nitrate NO_3–N (mg/L)	+	+	Nitrate NO_3–N (g/acre)	–	+
Nitrite NO_2–N (mg/L)	–	–	Nitrite NO_2–N (g/acre)	–	+
TKN (mg/L)	–	+	TKN (g/acre)	–	+
Total Phosphorus (mg/L)	+	+	Total Phosphorus (g/acre)	–	+
Ortho–P, diss (mg/L)	+	+	Orth–P, diss (g/acre)	–	+
As, diss (ug/L)	+	+	As, diss (mg/acre)	+	+
As, total (ug/L)	+	+	As, total (mg/acre)	–	+
Cd, diss (ug/L)	–	+	Cd, diss (mg/acre)	–	+
Cd, total (ug/L)	–	+	Cd, total (mg/acre)	–	+
Cr, diss (ug/L)	–	–	Cr, diss (mg/acre)	–	+
Cr, total (ug/L)	–	–	Cr, total (mg/acre)	–	–
Cu, diss (ug/L)	–	+	Cu, diss (mg/acre)	–	+
Cu, total (ug/L)	–	–	Cu, total (mg/acre)	–	–
Pb, diss (ug/L)	+	+	Pb, diss (mg/acre)	–	+
Pb, total (ug/L)	–	–	Pb, total (mg/acre)	–	–
Ni, diss (ug/L)	–	+	Ni, diss (mg/acre)	–	+
Ni, total (ug/L)	–	+	Ni, total (mg/acre)	–	+
Zn, diss (ug/L)	–	–	Zn, diss (mg/acre)	–	+
Zn, total (ug/L)	–	–	Zn, total (mg/acre)	–	–

Red indicates the average EMC or load at the second station is statistically higher than the average EMC at the first station at a 90-percent confidence level.

Green indicates the average EMC or load at the second station is statistically lower than the average EMC at the first station at a 90-percent confidence level.

(+) Indicates the average EMC or load at the second station is higher than the average EMC at the first station; however, the difference is not statistically significant at a 90-percent confidence level.

(–) Indicates the average EMC or load at the second station is lower than the average EMC at the first station; however, the difference is not statistically significant at a 90-percent confidence level.

(a) *H. helix* vegetation. (b) *I. hayesiana* vegetation.

Sacramento I-5 ERVTS Strip

As shown in Table 4-20, EMC comparisons between Stations (both with the *H. helix* vegetation) 3-362 (9-foot strip) and 3-365 (25-foot strip) indicate:

- For TSS, the average EMC is statistically significantly higher at Station 3-362 than at Station 3-365 at a 90-percent confidence level.
- For 17 constituents (TOC, DOC, turbidity, ammonia, nitrite, TKN, total and dissolved cadmium, total and dissolved chromium, total and dissolved copper, total lead, total and dissolved nickel, and total and dissolved zinc), the average EMCs are higher at Station 3-362 than at Station 3-365, but there was not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.
- For eight constituents (hardness, TDS, nitrate, total phosphorus, dissolved ortho-P, total and dissolved arsenic, and dissolved lead), the average EMCs are lower at Station 3-362 than at Station 3-365, but there was not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.

Overall, at the Sacramento location, the longer strip performed better than the shorter strip for many constituents, but it also performed worse for some other constituents. Whether or not a longer strip provides better concentration reduction appears to be dependent on the constituent of interest.

Yorba Linda SR 91 ERVTS Strip

As shown in Table 4-20, EMCs comparisons between stations (both with *I. hayesiana* vegetation) 12-346 (10-foot strip) and 12-347 (21-foot strip) indicates:

- For two constituents (total and dissolved arsenic), the average EMCs are statistically significantly lower at Station 12-346 than at Station 12-347 at a 90-percent confidence level.
- For nine constituents (TSS, ammonia, nitrite, total and dissolved chromium, total copper, total lead, and total and dissolved zinc), the average EMCs are higher at Station 12-346 than at Station 12-347, but there was not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.
- For 15 constituents (hardness, TDS, TOC, DOC, turbidity, nitrate, TKN, total phosphorus, dissolved ortho-P, total and dissolved cadmium, dissolved copper, dissolved lead, and total and dissolved nickel), the average EMCs are lower at Station 12-346 than at Station 12-347, but there was not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.

Overall, at the Yorba Linda location, the longer strip performed better than the shorter strip for some constituents, but it performed worse for many other constituents. Whether or not a longer strip provides better concentration reduction appears to be dependent on the constituent of interest.

4.4.1.2 Volume Reduction

At each ERVTS location, both event-based and season-based volume reduction data were used to perform comparisons between the two strip stations with the same ornamental vegetation types but different strip widths to see if strip width affected the performance of the strips in runoff volume reduction. A summary of both event-based and season-based volume reductions is presented in Table 4-1.

Sacramento I-5 ERVTS Strip

As shown in Table 4-1, at the Sacramento location, although the station (3-362) with the 9-foot strip width has a broader range of event-based volume reductions (91.1 to 97.1 percent) than the station (3-365) with the 25-foot strip width (95.6 to 99.5 percent), the differences between the two strip stations (both with *H. helix* vegetation) are fairly small and may not be statistically significant. Future assessments may include statistical comparisons (such as ANOVA tests). The station (3-362) with the 9-foot strip width has a slightly lower seasonal volume reduction of 94.5 percent than the station (3-365) with the 25-foot strip width (97.8 percent).

Overall, both stations achieved excellent volume reductions (greater than 90 percent) for both event-based and season-based volume reductions. A longer strip width does not appear to provide exceptionally better volume reduction than a shorter strip.

Yorba Linda SR 91 ERVTS Strip

As shown in Table 4-1, at the Yorba Linda location, although the station (12-347) with the 21-foot strip width has a broader range of event-based volume reduction (28.4 to 99.8 percent) than the station (12-346) with the 10-foot strip width (37.5 to 91.7 percent), the differences between the two strip stations (both with *H. helix* vegetation) are fairly small and may not be statistically significant. The station (12-346) with the 10-foot strip has a slightly higher seasonal volume reduction of 62.1 percent than the station (12-347) with the 21-foot strip width (53.3 percent).

Overall, both stations achieved good volume reductions. A longer strip width does not appear to provide exceptionally better volume reduction than a shorter strip.

4.4.1.3 Load

At the Sacramento location, the Tukey-Kramer HSD tests were performed on normalized load data (as described in Section 4.1) at Stations 3-362 and 3-365 (both with *H. helix* vegetation but with different strip widths) to see if strip width affected the performance of the strips in reducing pollutant load. Similar tests were performed on the normalized load data at Stations 12-346 and 12-347 (both with *I. hayesiana* vegetation but with different strip widths) at the Yorba Linda location. A summary of these Tukey-Kramer HSD results is presented in Table 4-20. Season-based load reductions for stations at the Sacramento and Yorba Linda locations are presented in Table 4-2.

Sacramento I-5 ERVTS Strip

As shown in Table 4-20, event-based load comparisons between Stations 3-362 (9-foot strip width) and 3-365 (25-foot strip width) indicate:

- No differences in any of the constituents between the two stations are statistically significant at a 90-percent confidence level.
- For 24 constituents (hardness, TSS, TDS, TOC, DOC, ammonia, nitrate, nitrite, TKN, total phosphorus, dissolved ortho-P, total arsenic, total and dissolved cadmium, total and dissolved chromium, total and dissolved copper, total and dissolved lead, total and dissolved nickel, and total and dissolved zinc), the loads are higher at Station 3-362 than at Station 3-365, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.
- For dissolved arsenic, the load is lower at Station 3-362 than at Station 3-365, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.

As shown in Table 4-2, season-based load reductions at Station 3-362 range from 87.8 percent for TKN to 98.9 percent for total cadmium. Season-based load reductions at Station 3-365 range from 87.5 percent for dissolved ortho-P to 99.7 percent for both total cadmium and total zinc.

Overall, although the longer strip provided equivalent or better load reductions than the shorter strip for most constituents, excellent load reductions were observed for both strips. It appears that a longer strip does not provide exceptionally better load reduction than a shorter strip.

Yorba Linda SR 91 ERVTS Strip

As shown in Table 4-20, event-based load comparisons between Stations 12-346 (10-foot strip width) and Station 12-347 (21-foot strip width) indicate:

- For five constituents (DOC, total phosphorus, dissolved ortho-P, total and dissolved arsenic), the event-based loads are statistically significantly lower at Station 12-346 than at Station 12-347 at a 90-percent confidence level.
- For six constituents (TSS, ammonia, total chromium, total copper, total lead, and total zinc), the loads are higher at Station 12-346 than at Station 12-347, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.
- For 14 constituents (hardness, TDS, TOC, nitrate, nitrite, TKN, total and dissolved cadmium, dissolved chromium, dissolved copper, dissolved lead, total and dissolved nickel, and dissolved zinc), the loads are lower at Station 12-346 than at Station 12-347, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.

As shown in Table 4-2, season-based load reductions at the station (12-346) with the 10-foot strip range from 63.5 percent for dissolved cadmium to 95.7 percent for dissolved zinc. Season-based load reductions at the station (12-347) with the 21-foot strip range from -139.2 percent (a 139.2-percent increase) for nitrate to 92.4 percent for dissolved zinc.

Overall, while the longer strip performed better than the shorter strip for a few constituents, it performed worse for most other constituents. It appears that a longer strip does not provide exceptionally better load reduction than a shorter strip.

4.4.2 Comparisons between Strips with the Same Ornamental Vegetation Type but Different Widths at Different Locations

As discussed in Section 1.4, Both Sacramento and Napa ORVTS are located in Northern California. Sacramento Station 3-362 has the *H. helix* vegetation and a 9-foot width. Napa Stations 4-308 and 4-309 also have the *H. helix* vegetation but a 15-foot width. Comparisons were performed between Station 3-362 and Stations 4-308/4-309 to see if the 9-foot strip Station 3-362 performed differently than the 15-foot strip Stations 4-308/4-309 in reducing pollutant concentration, runoff volume, and pollutant load.

Both Camarillo and Westminster ORVTS are located in Southern California. Camarillo Stations 7-341 and 7-342 have the same ornamental vegetation (C. *edulis*) and the same width (9-foot). Westminster Stations 12-344 and 12-345 have the same ornamental vegetation (*C. edulis*) and the same width (15-foot). Comparisons were performed between Stations 7-341/7-342 and Stations 12-344/12-345 to see if the 9-foot strip Stations 7-341/7-342 performed differently than the 15-foot strip Stations 12-344/12-345 in reducing pollutant concentration, runoff volume, and pollutant load.

However, it should be noted that there are still many variables (e.g., differences in site characteristics such as soil properties, storm patterns, even in geographically close locations, and other factors) between these compared stations in addition to the difference of strip width.

4.4.2.1 Concentration

Northern California Comparison between Stations 4-308/4-309 and Station 3-362

Average EMCs and average EMC percent reductions from the EOP sites at the Napa 15-foot stations (4-308 and 4-309) and the Sacramento 9-foot station (3-362) are presented in Table 4-21.

Table 4-21: Northern California Concentration Comparison between 15-foot stations (4-308/4-309) and 9-foot station (3-362)

Constituent	Sacramento		Napa		
	3-213 (EOP) Average EMC	3-362[(a)] Average EMC Percent Reduction from EOP	4-307 (EOP) Average EMC	4-308[(b)] Average EMC Percent Reduction from EOP	4-309[(b)] Average EMC Percent Reduction from EOP
Hardness as $CaCO_3$ (mg/L)	43.455	48.667 -12.0%	17.560	14.113 -19.6%	9.211 47.5%
TDS (mg/L)	64.364	85.000 -32.1%	23.890	18.302 23.4%	16.350 31.6%
TSS (mg/L)	120.273	117.889 2.0%	13.110	17.375 -32.5%	13.386 -2.1%
TOC (mg/L)	8.800	57.144 -549.4%	4.200	4.388 -4.5%	2.344 44.2%
DOC (mg/L)	4.800	17.875 -272.4%	3.011	3.063 -1.7%	1.822 39.5%
Turbidity (NTU)	112.030	130.363 -16.4%	8.389	5.314 36.7%	6.421 23.5%
Ammonia NH_3-N (mg/L)	0.499	0.727 -45.7%	0.337	0.159 52.7%	0.257 23.6%
Nitrate NO_3-N (mg/L)	0.776	0.645 16.9%	0.187	0.179 3.9%	0.161 14.0%
Nitrite NO_2-N (mg/L)	0.091	0.156 -71.4%	0.012	0.008 33.3%	0.011 8.3%
TKN (mg/L)	2.129	4.813 -126.1%	0.853	0.870 -2.0%	0.694 18.6%
Total Phosphorus (mg/L)	0.430	0.832 -93.5%	0.067	0.110 -64.7%	0.149 -121.5%
Ortho-P, diss (mg/L)	0.164	0.444 -170.7%	0.040	0.080 -102.4%	0.113 -185.4%
As, diss (ug/L)	1.436	1.656 -15.3%	0.172	0.441 -156.6%	0.300 -74.4%
As, total (ug/L)	3.316	2.600 21.6%	0.244	0.613 -150.6%	0.500 -104.5%
Cd, diss (ug/L)	<0.1	<0.1 NA	<0.1	<0.1 NA	<0.1 NA
Cd, total (ug/L)	0.722	0.178 75.3%	<0.1	<0.1 NA	<0.1 NA
Cr, diss (ug/L)	1.291	0.700 45.8%	0.856	0.191 77.7%	0.221 74.2%
Cr, total (ug/L)	14.182	7.156 49.5%	1.767	1.114 37.0%	1.011 42.8%
Cu, diss (ug/L)	10.291	12.111 -17.7%	3.922	2.013 48.7%	1.640 58.2%
Cu, total (ug/L)	46.364	22.111 52.3%	6.956	3.850 44.6%	3.210 53.8%
Pb, diss (ug/L)	0.119	0.127 -6.7%	0.060	0.112 -87.1%	0.109 -81.7%
Pb, total (ug/L)	9.827	2.533 74.2%	0.989	1.773 -79.2%	2.948 -198.1%
Ni, diss (ug/L)	1.373	1.889 -37.6%	0.811	0.407 49.8%	0.370 54.4%
Ni, total (ug/L)	13.482	8.067 40.2%	1.433	1.213 15.4%	1.290 10.0%
Zn, diss (ug/L)	9.655	21.089 -118.4%	14.400	9.375 34.9%	4.430 69.2%
Zn, total (ug/L)	191.636	99.778 47.9%	27.667	18.863 31.8%	10.720 61.3%

(a) Strip is 9-feet wide and is planted with *H. helix.*

(b) Strip is 15-feet wide and is planted with *H. helix.*

As shown in Table 4-21, comparisons between average EMC percent reductions from the associated EOP station at Stations 4-308/4-309 (15-foot strips with *H. helix*) versus those at Station 3-362 (9-foot strip with *H. helix*) indicate:

- For 10 constituents (TSS, nitrate, total phosphorus, dissolved ortho-P, dissolved cadmium, total and dissolved chromium, total copper, total nickel, and total zinc), the 15-foot Napa strips appear to have comparable EMC percent reductions to the 9-foot Sacramento strip.
- For 10 constituents (TDS, TOC, DOC, turbidity, ammonia, nitrite, TKN, dissolved copper, dissolved nickel, and dissolved zinc), the 15-foot Napa strips appear to have higher EMC percent reductions or lower EMC percent increases than the 9-foot Sacramento strip.
- For four constituents (total and dissolved arsenic and total and dissolved lead), the 15-foot Napa strips appear to have either an EMC percent increase compared to an EMC percent reduction at the 9-foot Sacramento strip, or higher EMC percent increases than the 9-foot Sacramento strip.
- For one constituent (hardness), one of the 15-foot Napa strips (4-308) appears to have a comparable EMC percent increase to the 9-foot Sacramento strip, while the other 15-foot Napa strip (4-309) has a moderate EMC percent reduction.

Overall, the shorter strip performed equivalent to or better than the longer strips for many constituents, but performed worse for many other constituents. Whether or not a longer strip provides better concentration reduction appears to be dependent on the constituent of interest.

Southern California Comparison between Stations 7-341/7-342 and Stations 12-344/12-345

Average EMCs and average EMC percent reductions from the EOP sites at the Camarillo 9-foot stations (7-341 and 7-342) and the Westminster 15-foot stations (12-344 and 12-345) are presented in Table 4-22.

Table 4-22: Southern California Concentration Comparison between 9-foot stations (7-341/7-342) and 15-foot stations (12-344 and 12-345)

Constituent	Camarillo			Westminster		
	7-340 (EOP) Average EMC	7-341 [(a)] Average EMC Percent Reduction from EOP	7-342[(a)] Average EMC Percent Reduction from EOP	12-343 (EOP) Average EMC	12-344[(b)] Average EMC Percent Reduction from EOP	12-345[(b)] Average EMC Percent Reduction from EOP
Hardness as $CaCO_3$ (mg/L)	37.800	56.500 -49.5%	40.400 -6.9%	25.333	55.000 -117.1%	38.000 -50.0%
TDS (mg/L)	40.000	101.750 -154.4%	52.200 -30.5%	41.400	201.000 -385.5%	129.000 -211.6%
TSS (mg/L)	39.600	29.000 26.8%	15.000 62.1%	54.600	102.000 -86.8%	86.000 -57.5%
TOC (mg/L)	6.460	7.825 -21.1%	5.220 19.2%	6.838	34.750 -408.2%	23.500 -243.7%
DOC (mg/L)	4.780	5.600 -17.2%	3.840 19.7%	4.500	23.500 -422.2%	15.700 -248.9%
Turbidity (NTU)	46.140	35.350 23.4%	25.920 43.8%	24.545	21.367 12.9%	17.300 29.5%
Ammonia NH_3-N (mg/L)	0.158	0.120 24.1%	0.079 50.0%	0.339	0.220 35.1%	0.115 66.1%
Nitrate NO_3-N (mg/L)	0.418	0.158 62.2%	0.190 54.5%	0.400	1.113 -178.3%	0.210 47.5%
Nitrite NO_2-N (mg/L)	0.052	0.016 68.7%	0.026 50.0%	0.038	0.015 60.5%	0.013 67.1%
TKN (mg/L)	0.822	0.958 -16.5%	0.680 17.3%	2.219	4.250 -91.5%	2.795 -26.0%
Total Phosphorus (mg/L)	0.100	0.723 -623.0%	0.374 -274.0%	0.144	0.655 -354.9%	0.740 -413.9%
Ortho-P, diss (mg/L)	0.033	0.568 -1621.2%	0.312 -845.5%	0.035	0.280 -700.0%	0.305 -771.4%
As, diss (ug/L)	0.680	2.050 -201.5%	1.160 -70.6%	0.440	1.200 -172.7%	1.150 -161.4%
As, total (ug/L)	1.100	2.675 -143.2%	1.520 -38.2%	1.070	1.967 -83.8%	2.000 -86.9%
Cd, diss (ug/L)	<0.1	<0.1 NA	<0.1 NA	<0.1	0.067 NA	0.075 NA
Cd, total (ug/L)	0.180	0.175 2.8%	0.060 66.7%	0.550	0.500 9.1%	0.500 9.1%
Cr, diss (ug/L)	1.940	1.350 30.4%	1.420 26.8%	1.800	1.300 27.8%	1.300 27.8%
Cr, total (ug/L)	5.120	3.625 29.2%	2.780 45.7%	6.180	5.200 15.9%	5.800 6.1%
Cu, diss (ug/L)	6.380	5.425 15.0%	5.020 21.3%	12.770	12.833 -0.5%	11.500 9.9%
Cu, total (ug/L)	23.720	13.600 42.7%	9.080 61.7%	55.000	39.667 27.9%	47.500 13.6%
Pb, diss (ug/L)	0.188	0.175 6.9%	0.260 -38.3%	0.420	2.600 -519.0%	2.700 -542.9%
Pb, total (ug/L)	5.400	5.725 -6.0%	2.920 45.9%	32.130	94.667 -194.6%	156.500 -387.1%
Ni, diss (ug/L)	0.940	1.100 -17.0%	0.780 17.0%	1.990	1.600 19.6%	1.350 32.2%
Ni, total (ug/L)	3.740	3.075 17.8%	1.960 47.6%	6.290	5.300 15.7%	5.700 9.4%
Zn, diss (ug/L)	5.40	4.800 11.1%	6.820 -26.3%	31.000	17.333 44.1%	17.000 45.2%
Zn, total (ug/L)	65.200	29.500 54.8%	21.800 66.6%	208.500	148.333 28.9%	185.000 11.3%

(a) Strip is 9-feet wide and is planted with *C. edulis.*

(b) Strip is 15-feet wide and is planted with *C. edulis.*

As shown in Table 4-22, comparisons between average EMC percent reductions from the associated EOP station at Stations 7-341 and 7-342 (9-foot strips with *C. edulis*) versus those at Stations 12-344 and 12-345 (15-foot strips with *C. edulis*) indicate:

- For 14 constituents (turbidity, ammonia, nitrite, total phosphorus, dissolved ortho-P, total and dissolved arsenic, dissolved cadmium, total and dissolved chromium, total and dissolved copper, and total and dissolved nickel), the 9-foot Camarillo strips appear to have comparable EMC percent reductions to the 15-foot Westminster strips.
- For nine constituents (hardness, TDS, TSS, TOC, DOC, TKN, total and dissolved lead and total zinc), the 9-foot Camarillo strips appear to have higher EMC percent reductions or lower EMC percent increases than the 15-foot Westminster strips.
- For one constituent (dissolved zinc), the 9-foot Camarillo strips appear to have a lower EMC percent reduction or an EMC percent increase when compared to the 15-foot Westminster strips.
- For two constituents (nitrate and total cadmium), there appears to be an anomaly between the two 15-foot Westminster strips for nitrate and between the two 9-foot Camarillo strips for total cadmium, leading to an inconclusive comparison for those two constituents.

Overall, the shorter strip performed equivalent to or better than the longer strip for most constituents. A longer strip does not appear to provide exceptionally better concentration reductions than a shorter strip.

4.4.2.2 Volume Reduction

Northern California Comparison between Stations 4-308/4-309 and Station 4-362

As shown in Table 4-1, the 15-foot Napa strips (4-308 and 4-309) appear to have comparable event-based volume reductions (although the ranges were broader) and a comparable season-based percent volume reduction when compared to the 9-foot Sacramento strip (3-362).

Overall, it appears that longer strips do not provide exceptionally better volume reductions compared to shorter strips.

Southern California Comparison between Stations 7-341/7-342 and Stations 12-344/12-345

As shown in Table 4-1, the 9-foot Camarillo strips (7-341 and 7-342) appear to have comparable event-based volume reduction ranges and comparable season-based percent volume reductions when compared to the 15-foot Westminster strips (12-344/12-345).

Overall, it appears that longer strips do not provide exceptionally better volume reductions compared to shorter strips.

4.4.2.3 Load

Northern California Comparison between Stations 4-308/4-309 and Station 3-362

Season-based load reductions at the Napa 15-foot stations (4-308 and 4-309) were compared to those at the Sacramento 9-foot station (3-362) and are presented in Table 4-23.

Table 4-23: Northern California Load Comparison between 15-foot stations (4-308/4-309) and 9-foot station (3-362)

Constituent	Sacramento 3-362[a] Seasonal Percent Load Reduction	Napa 4-308[b] Seasonal Percent Load Reduction	Napa 4-309[b] Seasonal Percent Load Reduction
Hardness as $CaCO_3$ (g/acre)	94.1%	95.9%	98.2%
TDS (g/acre)	94.5%	95.0%	97.7%
TSS (g/acre)	90.6%	96.4%	97.7%
TOC (g/acre)	94.5%	95.5%	96.6%
DOC (g/acre)	88.5%	94.7%	96.4%
Ammonia NH_3-N (g/acre)	91.4%	98.4%	92.8%
Nitrate NO_3-N (g/acre)	93.9%	97.3%	95.0%
Nitrite NO_2-N (g/acre)	96.9%	98.5%	96.3%
TKN (g/acre)	87.8%	94.1%	94.9%
Total Phosphorus (g/acre)	88.9%	94.0%	86.5%
Ortho-P, diss (g/acre)	85.0%	92.9%	73.3%
As, diss (mg/acre)	93.9%	96.2%	85.5%
As, total (mg/acre)	94.4%	94.5%	88.5%
Cd, diss (mg/acre)	96.3%	97.0%	95.9%
Cd, total (mg/acre)	98.9%	97.0%	95.9%
Cr, diss (mg/acre)	98.0%	99.1%	98.2%
Cr, total (mg/acre)	95.4%	98.2%	97.4%
Cu, diss (mg/acre)	95.7%	98.0%	97.9%
Cu, total (mg/acre)	97.7%	98.1%	98.5%
Pb, diss (mg/acre)	98.0%	96.9%	94.5%
Pb, total (mg/acre)	97.8%	95.7%	94.5%
Ni, diss (mg/acre)	92.4%	98.1%	97.2%
Ni, total (mg/acre)	94.6%	97.5%	96.7%
Zn, diss (mg/acre)	95.1%	96.8%	98.2%
Zn, total (mg/acre)	98.4%	97.4%	98.7%

(a) Strip is 9-feet wide and is planted with *H. helix.*

(b) Strip is 15-feet wide and is planted with *H. helix.*

As shown in Table 4-23, comparisons between seasonal load reductions at Stations 4-308 and 4-309 (15-foot strips with *H. helix*) and Station 3-362 (9-foot strip with *H. helix*) indicate that overall, it appears for strips with the *H. helix* vegetation in Northern California, the 9-foot strips have a comparable performance to 15-foot strips in terms of reducing pollutant load. All strips in the comparison appear to have substantial seasonal load reductions. Overall, these results indicate that a longer strip does not provide exceptionally better load reduction.

Southern California Comparison between Stations 7-341/7-342 and Stations 12-344/12-345

Seasonal load reductions at the Camarillo 9-foot stations (7-341 and 7-342) were compared to those at the Westminster 15-foot stations (12-344 and 12-345) and are presented in Table 4-24.

Table 4-24: Southern California Load Comparisons between 9-foot stations (7-341/7-342) and 15-foot stations (12-344/12-345)

Constituent	Camarillo 7-341[(a)] Seasonal Percent Load Reduction	Camarillo 7-342[(a)] Seasonal Percent Load Reduction	Westminster 12-344[(b)] Seasonal Percent Load Reduction	Westminster 12-345[(b)] Seasonal Percent Load Reduction
Hardness as $CaCO_3$ (g/acre)	84.2%	69.8%	67.0%	46.4%
TDS (g/acre)	73.2%	70.0%	-34.2%	-43.0%
TSS (g/acre)	93.8%	92.0%	11.5%	49.5%
TOC (g/acre)	87.8%	81.6%	-18.5%	24.4%
DOC (g/acre)	89.6%	82.8%	-18.8%	30.0%
Ammonia NH_3-N (g/acre)	96.1%	91.4%	83.8%	84.7%
Nitrate NO_3-N (g/acre)	97.7%	90.0%	16.5%	72.8%
Nitrite NO_2-N (g/acre)	98.1%	91.1%	81.7%	64.3%
TKN (g/acre)	90.8%	78.8%	56.7%	34.7%
Total Phosphorus (g/acre)	31.0%	15.0%	38.3%	-48.9%
Ortho-P, diss (g/acre)	-37.4%	-89.9%	-31.0%	-666.0%
As, diss (mg/acre)	69.3%	53.0%	56.2%	28.5%
As, total (mg/acre)	74.1%	60.3%	68.4%	65.7%
Cd, diss (mg/acre)	90.7%	71.2%	92.7%	91.1%
Cd, total (mg/acre)	93.5%	91.6%	85.2%	85.1%
Cr, diss (mg/acre)	94.4%	77.6%	86.3%	85.7%
Cr, total (mg/acre)	94.3%	83.2%	83.9%	83.6%
Cu, diss (mg/acre)	91.7%	73.0%	83.2%	68.5%
Cu, total (mg/acre)	95.6%	87.9%	83.3%	81.9%
Pb, diss (mg/acre)	89.8%	39.5%	48.2%	7.1%
Pb, total (mg/acre)	89.7%	82.9%	39.3%	10.6%
Ni, diss (mg/acre)	87.3%	76.6%	86.8%	83.3%
Ni, total (mg/acre)	92.3%	84.0%	81.6%	81.2%
Zn, diss (mg/acre)	92.1%	65.8%	93.8%	91.1%
Zn, total (mg/acre)	96.6%	89.8%	78.4%	75.6%

(a) Strip is 9-feet wide and is planted with *C. edulis.*

(b) Strip is 15-feet wide and is planted with *C. edulis*.

As shown in Table 4-24, comparisons between seasonal load reductions at Stations 7-341 and 7-342 (9-foot strips with *C. edulis*) and Stations 12-344 and 12-345 (15-foot strip with *C. edulis*) indicate:

- For 13 constituents (ammonia, nitrite, total arsenic, total and dissolved cadmium, total and dissolved chromium, total and dissolved copper, total and dissolved nickel, and total and dissolved zinc), the 9-foot Camarillo strips appear to have comparable seasonal load percent reductions to the 15-foot Westminster strips.
- For seven constituents (TDS, TSS, TOC, DOC, TKN, dissolved ortho-P, and total lead), the 9-foot Camarillo strips appear to have higher seasonal load percent reductions than the 15-foot Westminster strips.
- For five constituents (hardness, nitrate, total phosphorus, dissolved arsenic and dissolved lead), there appears to be an anomaly between two strips at the same location for one or both of the locations leading to an inconclusive comparison for those five constituents.

Overall, the shorter strips performed equivalent to or better than the longer strips for most constituents, indicating that a longer strip does not provide exceptionally better load reduction.

4.5 IMPACT OF ORNAMENTAL VEGETATION TYPE ON EFFECTIVENESS OF STRIPS

This section addresses the study question of what is the difference in treatment between strips having approximately the same strip width but different types of ornamental vegetation. Two types of data analyses were performed to address this study question:

- Comparisons between strips (with similar strip widths but different ornamental vegetations) at each ERVTS location in terms of pollutant concentrations, runoff volume, and pollutant load reductions.
- Comparisons between strips (with similar strip widths but different ornamental vegetations) at different locations but within the same general geographical region (i.e. two Northern ORVTS strip locations were compared to each other and similarly, two Southern ORVTS strip locations were compared) in terms of pollutant concentrations, runoff volume, and pollutant load reductions.

Detailed discussions are presented in the following subsections.

4.5.1 Comparisons within Each ERVTS Location

As discussed in Section 1.4, the Sacramento ERVTS location has three stations with different ornamental vegetation types but similar strip width (Station 3-363 has *B. pilularis* vegetation, Station 3-364 has *M. parvifolium* vegetation, and Station 3-365 has *H. helix* vegetation). The Yorba Linda ERVTS location also has three stations with different ornamental vegetation types but the same strip width (Station 12-347 has *I. hayesiana* vegetation, Station 12-348 has *S. mandraliscae* vegetation, and Station 12-349 has *L. montevidensis* vegetation). Data analyses results and discussions on concentration, runoff volume, and load data for these stations are presented in the following subsections.

4.5.1.1 Concentration

At each location, the Tukey-Kramer HSD tests were performed on the EMCs at the three strip stations with similar widths but with different ornamental vegetation types to see if the various types of ornamental vegetation affected the performance of the strips in reducing pollutant concentrations. A summary of the Tukey-Kramer HSD results is presented in Table 4-25.

Table 4-25: Tukey-Kramer HSD Test Results Summary for Concentration Comparisons between Strips with Same Width but Different Ornamental Vegetation

Constituent	Sacramento[a]			Yorba Linda[b]		
	3–363 vs. 3–364	3–363 vs. 3–365	3–364 vs. 3–365	12–347 vs. 12–348	12–347 vs. 12–349	12–348 vs. 12–349
Hardness as $CaCO_3$ (mg/L)	–	+	+	+	–	–
TDS (mg/L)	+	+	–	+	+	–
TSS (mg/L)	–	–	+	–	+	+
TOC (mg/L)	+	+	–	–	–	+
DOC (mg/L)	+	–	–	+	–	–
Turbidity (NTU)	–	–	+	–	+	+
Ammonia NH_3–N (mg/L)	–	–	–	–	–	+
Nitrate NO_3–N (mg/L)	–	+	+	–	–	+
Nitrite NO_2–N (mg/L)	–	+	+	–	–	–
TKN (mg/L)	+	+	–	–	–	+
Total Phosphorus (mg/L)	+	+	–	+	+	+
Ortho–P, diss (mg/L)	+	+	–	+	+	+
As, diss (ug/L)	–	–	+	+	–	–
As, total (ug/L)	–	–	+	+	+	–
Cd, diss (ug/L)	–	–	–	+	–	–
Cd, total (ug/L)	–	+	+	+	+	–
Cr, diss (ug/L)	–	–	–	–	–	+
Cr, total (ug/L)	–	–	+	+	+	+
Cu, diss (ug/L)	+	+	+	+	–	–
Cu, total (ug/L)	–	+	+	+	+	+
Pb, diss (ug/L)	+	–	–	–	+	+
Pb, total (ug/L)	–	–	+	–	+	+
Ni, diss (ug/L)	+	+	+	+	+	–
Ni, total (ug/L)	–	–	+	–	+	+
Zn, diss (ug/L)	+	+	–	–	–	+
Zn, total (ug/L)	–	–	–	–	+	+

Red indicates the average EMC at the second station is statistically higher than the average EMC at the first station at a 90-percent confidence level.

Green indicates the average EMC at the second station is statistically lower than the average EMC at the first station at a 90-percent confidence level.

(+) Indicates the average EMC at the second station is higher than the average EMC at the first station; however, the difference is not statistically significant at a 90-percent confidence level.

(–) Indicates the average EMC at the second station is lower than the average EMC at the first station; however, the difference is not statistically significant at a 90-percent confidence level.

(a) Station 3-363 has *B. pilularis* vegetation, Station 3-364 has *M. parvifolium* vegetation, and Station 3-365 has *H. helix* vegetation.

(b) Station 12-347 has *I. hayesiana* vegetation, Station 12-348 has *S. mandraliscae* vegetation, and Station 12-349 has *L. montevidensis* vegetation.

Sacramento I-5 ERVTS Strip

As shown in Table 4-25, comparisons of average EMCs among Stations 3-363 (*B. pilularis*), 3-364 (*M. parvifolium*), and 3-365 (*H. helix*) indicate that, at a 90-percent confidence level, no average EMC for any constituent at any one station is statistically significantly different when compared with the average EMC for that constituent at any other station. Specific comparisons between stations are summarized below:

- Comparisons between Stations 3-363 (*B. pilularis*) and 3-364 (*M. parvifolium*) indicate:
  - For 16 constituents (hardness, TSS, turbidity, ammonia, nitrate, nitrite, total and dissolved arsenic, total and dissolved cadmium, total and dissolved chromium, total copper, total lead, total nickel, and total zinc), the average EMCs are higher at Station 3-363 than at Station 3-364, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.
  - For ten constituents (TDS, TOC, DOC, TKN, total phosphorus, dissolved ortho-P, dissolved copper, dissolved lead, dissolved nickel, and dissolved zinc), the average EMCs are lower at Station 3-363 than at Station 3-364, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.

- Comparisons between Stations 3-363 (*B. pilularis*) and 3-365 (*H. helix*) indicate:
  - For 13 constituents (TSS, DOC, turbidity, ammonia, total and dissolved arsenic, dissolved cadmium, total and dissolved chromium, total and dissolved lead, total nickel, and total zinc), the average EMCs are higher at Station 3-363 than at Station 3-365, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.
  - For 13 constituents (hardness, TDS, TOC, nitrate, nitrite, TKN, total phosphorus, dissolved ortho-P, total cadmium, total and dissolved copper, dissolved nickel, and dissolved zinc), the average EMCs are lower at Station 3-363 than at Station 3-365, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.

- Comparisons between Stations 3-364 (*M. parvifolium*) and 3-365 (*H. helix*) indicate:
  - For 12 constituents (TDS, TOC, DOC, ammonia, TKN, total phosphorus, dissolved ortho-P, dissolved cadmium, dissolved chromium, dissolved lead, and total and dissolved zinc.), the average EMCs are higher at Station 3-364 than at Station 3-365, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.
  - For 14 constituents (hardness, TSS, turbidity, nitrate, nitrite, total and dissolved arsenic, total cadmium, total chromium, total and dissolved copper, total lead, and total and dissolved nickel), the average EMCs are lower at Station 3-364 than at Station 3-365, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.

Overall, each ornamental vegetation type performed the best for some constituents and the worst for other constituents. No particular ornamental vegetation type stood out as the best performer in terms of concentration reduction. It appears that whether or not a particular ornamental vegetation type provides better concentration reduction than any other type depends on the constituent of interest.

Yorba Linda SR 91 ERVTS Strip

Results of comparisons between the average EMCs among Stations 12-347 (*I. hayesiana*), 12-348 (*S. mandraliscae*), and 12-349 (*L. montevidensis*) are shown in Table 4-25 and are summarized below:

- Comparisons between Stations 12-347 (*I. hayesiana*) and 12-348 (*S. mandraliscae*) indicate:
  - For four constituents (total phosphorus, dissolved ortho-P, and total and dissolved cadmium), the average EMCs are statistically significantly lower at Station 12-347 than at Station 12-348 at a 90-percent confidence level.
  - For 13 constituents (TSS, TOC, turbidity, ammonia, nitrate, nitrite, TKN, dissolved chromium, total and dissolved lead, total nickel, and total and dissolved zinc), the average EMCs are higher at Station 12-347 than at Station 12-348, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.
  - For nine constituents (hardness, TDS, DOC, total and dissolved cadmium, total chromium, total and dissolved copper, and dissolved lead), the average EMCs are lower at Station 12-347 than at Station 12-348, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.

- Comparisons between Stations 12-347 (*I. hayesiana*) and 12-349 (*L. montevidensis*) indicate:
  - For eight constituents (TSS, turbidity, total phosphorus, dissolved ortho-P, total arsenic, total chromium, total lead, and total nickel), the average EMC are statistically significantly lower at Station 12-347 than at Station 12-349 at a 90-percent confidence level.
  - For 12 constituents (hardness, TOC, DOC, ammonia, nitrate, nitrite, TKN, dissolved arsenic, dissolved cadmium, dissolved chromium, dissolved copper, and dissolved zinc), the average EMCs are higher at Station 12-347 than at Station 12-349, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.
  - For six constituents (TDS, total cadmium, total copper, dissolved lead, dissolved nickel, and total zinc), the average EMCs are lower at Station 12-347 than at Station 12-349, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.

- Comparisons between Stations 12-348 (*S. mandraliscae*) and 12-349 (*L. montevidensis*) indicate:
  - For five constituents (TSS, turbidity, total chromium, total lead, and total nickel), the average EMCs are statistically significantly lower at Station 12-348 than at Station 12-349 at a 90-percent confidence level.
  - For dissolved arsenic, the average EMC is statistically significantly higher at Station 12-348 than at Station 12-349 at a 90-percent confidence level.
  - For nine constituents (hardness, TDS, DOC, nitrite, total arsenic, total and dissolved cadmium, dissolved copper, and dissolved nickel), the average EMCs are higher at Station 12-348 than at Station 12-349, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.
  - For 11 constituents (TOC, ammonia, nitrate, TKN, total phosphorus, dissolved ortho-P, dissolved chromium, total copper, dissolved lead, and total and dissolved zinc), the average EMCs are lower at Station 12-348 than at Station 12-349, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.

Overall, each ornamental vegetation type performed the best for some constituents and the worst for other constituents. No particular ornamental vegetation type stood out as the best performer in terms of concentration reduction. It appears that whether or not a particular ornamental vegetation type provides better concentration reduction than any other type depends on the constituent of interest.

4.5.1.2 Volume Reduction

At each ERVTS location, both event-based and season-based volume reduction data were used to perform multiple comparisons among the strip stations with similar strip widths but with different ornamental vegetation types to see if the various types of ornamental vegetation affected the performance of the strips in runoff volume reduction. A summary of both event-based and season-based volume reductions is presented in Table 4-1.

Sacramento I-5 ERVTS Strip

As shown in Table 4-1, Station 3-363 (*B. pilularis*) has an event-based volume reduction range of 94.4 to 99.7 percent and a seasonal volume reduction of 98.7 percent. Station 3-364 (*M. parvifolium*) has an event-based volume reduction range of 90.3 to 98.6 percent and a seasonal volume reduction of 97.3 percent. Station 3-365 (*H. helix*) has an event-based volume reduction range of 95.6 to 99.5 percent and a seasonal volume reduction of 97.8 percent.

Overall, excellent volume reduction was observed for each ornamental vegetation type. It therefore appears that none of these ornamental vegetation types provided exceptionally better volume reduction than any other type.

Yorba Linda SR 91 ERVTS Strip

As shown in Table 4-1, Station 12-347 (*I. hayesiana*) has an event-based volume reduction range of 28.4 to 99.8 percent and a seasonal volume reduction of 53.3 percent. Both the event-based and season-based volume reduction at Station 12-348 (*S. mandraliscae*) is 89.4 percent, because only one storm event at this station produced representative rainfall and flow data. Station 12-

349 (*L. montevidensis*) has an event-based volume reduction range of 78.1 to 99.1 percent and a seasonal volume reduction of 86.8 percent. It should be noted that only one data point is available for assessments on runoff volume data for Station 12-348, and that confidence in data assessments on runoff volume data for this station is low.

Overall, the strip planted with *I. hayesiana* (12-347) performed the worst among the three stations, with a broader range of event-based volume reduction and the lowest seasonal volume reduction. It appears that *S. mandraliscae* and *L. montevidensis* may provide better volume reduction than *I. hayesiana*, although moderate to excellent volume reduction was observed for all ornamental vegetation types.

4.5.1.3 Load

For both the Sacramento location and the Yorba Linda location, the Tukey-Kramer HSD tests were performed on event-based load data at the three strip stations with similar strip widths but with different ornamental vegetation types to see if the various types of ornamental vegetation affected the performance of the strips in reducing pollutant load. A summary of the Tukey-Kramer HSD results is presented in Table 4-26. Season-based load reductions for stations at the Sacramento and Yorba Linda locations are presented in Table 4-2.

Table 4-26: Tukey-Kramer HSD Test Results for Event-Based Load Comparisons between Strips with Same Width but Different Ornamental Vegetation

Constituent	Sacramento[(a)]			Yorba Linda[(b)]		
	3–363 vs. 3–364	3–363 vs. 3–365	3–364 vs. 3–365	12–347 vs. 12–348	12–347 vs. 12–349	12–348 vs. 12–349
Hardness as $CaCO_3$ (mg/L)	+	+	+	–	–	–
TDS (mg/L)	+	+	–	–	–	+
TSS (mg/L)	–	+	+	–	+	+
TOC (mg/L)	+	+	–	–	–	+
DOC (mg/L)	+	+	–	–	–	+
Ammonia NH_3–N (mg/L)	+	–	–	–	–	+
Nitrate NO_3–N (mg/L)	–	–	+	–	–	+
Nitrite NO_2–N (mg/L)	+	+	–	–	–	+
TKN (mg/L)	+	+	–	–	–	+
Total Phosphorus (mg/L)	+	+	–	–	+	+
Ortho–P, diss (mg/L)	+	+	–	–	–	+
As, diss (ug/L)	+	+	–	–	–	+
As, total (ug/L)	+	+	–	–	–	+
Cd, diss (ug/L)	+	+	–	–	–	+
Cd, total (ug/L)	+	+	+	–	–	+
Cr, diss (ug/L)	+	+	–	–	–	+
Cr, total (ug/L)	+	+	+	–	+	+
Cu, diss (ug/L)	+	+	–	–	–	+
Cu, total (ug/L)	+	+	–	–	–	+
Pb, diss (ug/L)	+	+	–	–	–	+
Pb, total (ug/L)	+	+	+	–	+	+
Ni, diss (ug/L)	+	+	–	–	–	+
Ni, total (ug/L)	+	+	+	–	–	+
Zn, diss (ug/L)	+	+	–	–	–	+
Zn, total (ug/L)	+	+	–	–	–	+

(+) Indicates the event-based load at the second station is higher than the event-based load at the first station; however, the difference is not statistically significant at a 90-percent confidence level.

(–) Indicates the event-based load at the second station is lower than the event-based load at the first station; however, the difference is not statistically significant at a 90-percent confidence level.

(a) Station 3-363 has *B. pilularis* vegetation, Station 3-364 has *M. parvifolium* vegetation, and Station 3-365 has *H. helix* vegetation.

(b) Station 12-347 has *I. hayesiana* vegetation, Station 12-348 has *S. mandraliscae* vegetation, and Station 12-349 has *L. montevidensis* vegetation.

Sacramento I-5 ERVTS Strip

As shown in Table 4-26, event-based load comparisons made among Stations 3-363 (*B. pilularis*), 3-364 (*M. parvifolium*), and 3-365 (*H. helix*) indicate that, at a 90-percent confidence level, no load for any constituent at any one station is statistically significantly different from the load of that same constituent at any other station. Specific comparisons among the stations are summarized below:

- Comparisons between Stations 3-363 (*B. pilularis*) and 3-364 (*M. parvifolium*) indicate:
  - For two constituents (TSS and nitrate), the loads are higher at Station 3-363 than at Station 3-364, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.
  - For 23 constituents (hardness, TDS, TOC, DOC, ammonia, nitrite, TKN, total phosphorus, dissolved ortho-P, total and dissolved arsenic, total and dissolved cadmium, total and dissolved chromium, total and dissolved copper, total and dissolved lead, total and dissolved nickel, and total and dissolved zinc), the loads are lower at Station 3-363 than at Station 3-364, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.

- Comparisons between Stations 3-363 (*B. pilularis*) and 3-365 (*H. helix*) indicate:
  - For two constituents (ammonia and nitrate), the loads are higher at Station 3-363 than at Station 3-365, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.
  - For 23 constituents (hardness, TSS, TDS, TOC, DOC, nitrite, TKN, total phosphorus, dissolved ortho-P, total and dissolved arsenic, total and dissolved cadmium, total and dissolved chromium, total and dissolved copper, total and dissolved lead, total and dissolved nickel, and total and dissolved zinc), the loads are lower at Station 3-363 than at Station 3-365, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.

- Comparisons between Stations 3-364 (*M. parvifolium*) and 3-365 (*H. helix*) indicate:
  - For 17 constituents (TDS, TOC, DOC, ammonia, nitrite, TKN, total phosphorus, dissolved ortho-P, dissolved arsenic, dissolved cadmium, dissolved chromium, total and dissolved copper, dissolved lead, dissolved nickel, and total and dissolved zinc), the loads are higher at Station 3-364 than at Station 3-365, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.
  - For seven constituents (hardness, TSS, nitrate, total cadmium, total chromium, total lead, and total nickel), the loads are lower at Station 3-364 than at Station 3-365, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.
  - For total arsenic, the loads are equal at Stations 3-364 and 3-365.

As shown in Table 4-2, season-based load reductions at Station 3-363 range from 94.8 percent for ammonia to 99.9 percent for total cadmium. Season-based load reductions at Station 3-364 range from 81.5 percent for DOC to 99.8 percent for both total cadmium and total lead. Season-based load reductions at Station 3-365 range from 87.5 percent for dissolved ortho-P to 99.7 percent for both total cadmium and total zinc.

Overall, the strip planted with *B. pilularis* (3-363) performed the best among the three stations with loads for 23 out of 25 constituents being lower than loads for those same constituents at both the *M. parvifolium* strip (3-364) and the *H. helix* strip (3-365). However, excellent load reductions were observed for all three ornamental vegetation types. It does not appear that any particular ornamental vegetation type provides exceptionally better load reduction than any other type.

Yorba Linda SR 91 ERVTS Strip

As shown in Table 4-26, event-based load comparisons among Stations 12-347 (*I. hayesiana*), 12-348 (*S. mandraliscae*), and 12-349 (*L. montevidensis*) indicate that, at a 90-percent confidence level, no load for any constituent at any one station is statistically significantly different from the load of that same constituent at any other station. It should be noted that only one data point is available for assessments on load data for Station 12-348, and that confidence in data assessments on load data for this station is low. Specific comparisons among the stations are summarized below:

- Comparisons between Stations 12-347 (*I. hayesiana*) and 12-348 (*S. mandraliscae*) indicate:
  - For all 25 constituents listed in Table 4-22, the loads are higher at Station 12-347 than at Station 12-348, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.

- Comparisons between Stations 12-347 (*I. hayesiana*) and 12-349 (*L. montevidensis*) indicate:
  - For 21 constituents (hardness, TDS, TOC, DOC, ammonia, nitrate, nitrite, TKN, dissolved ortho-P, total and dissolved arsenic, total and dissolved cadmium, dissolved chromium, total and dissolved copper, dissolved lead, total and dissolved nickel, and total and dissolved zinc), the loads are higher at Station 12-347 than at Station 12-349, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.
  - For four constituents (TSS, total phosphorus, total chromium, and total lead), the loads are lower at Station 12-347 than at Station 12-349, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.

- Comparisons between Stations 12-348 (*S. mandraliscae*) and 12-349 (*L. montevidensis*) indicate:
  - For hardness, the load is higher at Station 12-348 than at Station 12-349, but there is not enough evidence to conclude that the difference is statistically significant at a 90-percent confidence level.
  - For 24 constituents (all constituents listed in Table 4-1 except for hardness), the loads are lower at Station 12-348 than at Station 12-349, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.

As shown in Table 4-2, season-based load reductions at Station 12-347 range from -139.2 percent (a 139.2-percent increase) for nitrate to 92.4 percent for dissolved zinc. Season-based load reductions at Station 12-348 range from 15.2 percent for dissolved ortho-P to 98.7 percent for nitrite. Season-based load reductions at Station 12-349 range from -29.6 percent (a 29.6-percent increase) for dissolved ortho-P to 96.4 percent for nitrite.

Overall, the strip planted with *S. mandraliscae* (12-348) performed the best among the three stations, with loads for almost all constituents being lower than loads for those same constituents at both the *I. hayesiana* strip (12-347) and the *L. montevidensis* strip (12-349). However, good to excellent load reductions were observed at the *I. hayesiana* and *L. montevidensis* strips for some constituents. It appears that whether or not a particular ornamental vegetation type provides exceptionally better treatment than any other types depends on the constituent of interest.

4.5.2 Comparisons between Strips with Similar Widths but Different Ornamental Vegetation Type at Different Locations

As discussed in Section 1.4, both Napa and San Mateo ORVTS are located in Northern California. Napa stations 4-308 and 4-309 have the same ornamental vegetation (*H. helix*) and the same width (15 ft). The San Mateo station 4-312 has the *C. edulis* vegetation and a 16-foot width. Comparisons were performed between stations 4-308/4-309 and 4-312 to see if Stations 4-308/4-309 planted with *H. helix* performed differently than station 4-312 planted with *C. edulis* in reducing pollutant concentration, runoff volume, and pollutant load.

Both Camarillo and Yorba Linda ORVTS are located in Southern California. Camarillo stations 7-341 and 7-342 have the same ornamental vegetation (*C. edulis*) and the same width (9-ft). The Yorba Linda station 12-346 has the *I. hayesiana* vegetation and a 10-foot width. Comparisons were performed between stations 7-341/7-342 and 12-346 to see if Stations 7-341/7-342 planted with *C. edulis* performed differently than station 12-346 planted with *I. hayesiana* in reducing pollutant concentration, runoff volume, and pollutant load.

However, it should be noted that there are still many variables (e.g. differences in site characteristics such as soil properties, storm patterns, even in geographically close locations, and other factors) between these compared stations in addition to the difference of ornamental vegetation types. For example, Stations 4-308 and 4-309 have more permeable soils than Station 4-312. Therefore, ornamental vegetation type may not be the only cause of the observed performance differences based on these comparisons. Detailed discussions are presented in the following subsections.

4.5.2.1 Concentration

Northern California Comparison between Stations 4-308/4-309 and Station 4-312

Average EMCs and average EMC percent reductions from the EOP sites at the Napa *H. helix* strips (4-308 and 4-309) and the San Mateo *C. edulis* strip are presented in Table 4-27.

Table 4-27: Northern California Concentration Comparison between *H. helix* stations (4-308/4-309) and *C. edulis* station (4-312)

Constituent	San Mateo		Napa		
	4-310 (EOP) Average EMC	4-312[(a)] Average EMC Percent Reduction from EOP	4-307 (EOP) Average EMC	4-308[(b)] Average EMC Percent Reduction from EOP	4-309[(b)] Average EMC Percent Reduction from EOP
Hardness as $CaCO_3$ (mg/L)	34.909	41.636 -19.3%	17.560	14.113 -19.6%	9.211 47.5%
TDS (mg/L)	43.426	64.909 -49.5%	23.890	18.302 23.4%	16.350 31.6%
TSS (mg/L)	37.091	61.909 -66.9%	13.110	17.375 -32.5%	13.386 -2.1%
TOC (mg/L)	7.145	8.609 -20.5%	4.200	4.388 -4.5%	2.344 44.2%
DOC (mg/L)	4.618	5.691 -23.2%	3.011	3.063 -1.7%	1.822 39.5%
Turbidity (NTU)	32.500	41.336 -27.2%	8.389	5.314 36.7%	6.421 23.5%
Ammonia NH_3-N (mg/L)	0.356	0.194 45.5%	0.337	0.159 52.7%	0.257 23.6%
Nitrate NO_3-N (mg/L)	0.329	0.821 -149.4%	0.187	0.179 3.9%	0.161 14.0%
Nitrite NO_2-N (mg/L)	0.044	0.038 13.8%	0.012	0.008 33.3%	0.011 8.3%
TKN (mg/L)	1.123	1.309 -16.6%	0.853	0.870 -2.0%	0.694 18.6%
Total Phosphorus (mg/L)	0.097	0.193 -98.1%	0.067	0.110 -64.7%	0.149 -121.5%
Ortho-P, diss (mg/L)	0.028	0.091 -229.9%	0.040	0.080 -102.4%	0.113 -185.4%
As, diss (ug/L)	0.373	0.664 -78.0%	0.172	0.441 -156.6%	0.300 -74.4%
As, total (ug/L)	0.700	1.518 -116.9%	0.244	0.613 -150.6%	0.500 -104.5%
Cd, diss (ug/L)	<0.1	<0.1 NA	<0.1	<0.1 NA	<0.1 NA
Cd, total (ug/L)	0.224	0.134 40.1%	<0.1	<0.1 NA	<0.1 NA
Cr, diss (ug/L)	6.955	4.818 30.7%	0.856	0.191 77.7%	0.221 74.2%
Cr, total (ug/L)	12.618	14.364 -13.8%	1.767	1.114 37.0%	1.011 42.8%
Cu, diss (ug/L)	23.818	12.309 48.3%	3.922	2.013 48.7%	1.640 58.2%
Cu, total (ug/L)	67.727	33.000 51.3%	6.956	3.850 44.6%	3.210 53.8%
Ni, diss (ug/L)	1.600	1.382 13.6%	0.811	0.407 49.8%	0.370 54.4%
Ni, total (ug/L)	6.309	10.518 -66.7%	1.433	1.213 15.4%	1.290 10.0%
Pb, diss (ug/L)	0.891	1.491 -67.3%	0.060	0.112 -87.1%	0.109 -81.7%
Pb, total (ug/L)	17.409	23.145 -33.0%	0.989	1.773 -79.2%	2.948 -198.1%
Zn, diss (ug/L)	28.091	16.991 39.5%	14.400	9.375 34.9%	4.430 69.2%
Zn, total (ug/L)	124.64	62.64 49.7%	27.667	18.863 31.8%	10.720 61.3%

(a) Strip is 16-feet wide and is planted with *C. edulis.*

(b) Strip is 15-feet wide and is planted with *H. helix.*

As shown in Table 4-27, comparisons between average EMC percent reductions from the associated EOP station at Stations 4-308/4-309 (15-foot strips with *H. helix*) versus those at Station 4-312 (16-foot strip with *C. edulis*) indicate:

- For 14 constituents (TSS, ammonia, nitrite, total phosphorus, dissolved ortho-P, total and dissolved arsenic, total and dissolved cadmium, total and dissolved copper, dissolved lead, and total and dissolved zinc), the *H. helix* Napa strips appear to have comparable EMC percent reductions to the *C. edulis* San Mateo strip.
- For nine constituents (TDS, TOC, DOC, turbidity, nitrate, dissolved and total chromium, and total and dissolved nickel), the *H. helix* Napa strips appear to have higher EMC percent reductions or lower EMC percent increases than the *C. edulis* San Mateo strip.
- For one constituent (total lead), the *H. helix* Napa strips appear to have higher EMC percent increases than the *C. edulis* San Mateo strip.
- For two constituents (hardness and TKN), one of the *H. helix* Napa strips (4-308) appears to have comparable EMC percent increases to the *C. edulis* San Mateo strip, while the other *H. helix* Napa strip (4-309) has low to moderate EMC percent reductions.

Overall, the Napa *H. helix* strips (4-308 and 4-309) provided comparable concentration reductions for many constituents compared to the San Mateo *C. edulis* strip (4-312), better concentration reduction for many other constituents, and worse concentration reduction for one constituent. It appears that whether a particular ornamental vegetation type provides exceptionally better concentration reduction than another type depends on the constituent of interest.

Southern California Comparison between Stations 7-341/7-342 and Station 12-346

Average EMCs and average EMC percent reductions from the EOP sites at the Camarillo *C. edulis* stations (7-341 and 7-342) and the Yorba Linda *I. hayesiana* station (12-346) are presented in Table 4-28.

Table 4-28: Southern California Concentration Comparison between *C. edulis* stations (7-341/7-342) and *I. hayesiana* station (12-346)

Constituent	Camarillo			Yorba Linda	
	7-340 (EOP) Average EMC	7-341[(a)] Average EMC Percent Reduction from EOP	7-342[(a)] Average EMC Percent Reduction from EOP	12-225 (EOP) Average EMC	12-346[(b)] Average EMC Percent Reduction from EOP
Hardness as $CaCO_3$ (mg/L)	37.800	56.500 -49.5%	40.400 -6.9%	33.333	26.545 20.4%
TDS (mg/L)	40.000	101.750 -154.4%	52.200 -30.5%	53.750	38.455 28.5%
TSS (mg/L)	39.600	29.000 26.8%	15.000 62.1%	44.917	36.818 18.0%
TOC (mg/L)	6.460	7.825 -21.1%	5.220 19.2%	11.900	9.427 20.8%
DOC (mg/L)	4.780	5.600 -17.2%	3.840 19.7%	8.042	6.045 24.8%
Turbidity (NTU)	46.140	35.350 23.4%	25.920 43.8%	37.174	22.841 38.6%
Ammonia NH_3-N (mg/L)	0.158	0.120 24.1%	0.079 50.0%	0.380	0.180 52.6%
Nitrate NO_3-N (mg/L)	0.418	0.158 62.2%	0.190 54.5%	0.714	0.603 15.5%
Nitrite NO_2-N (mg/L)	0.052	0.016 68.7%	0.026 50.0%	0.058	0.018 69.0%
TKN (mg/L)	0.822	0.958 -16.5%	0.680 17.3%	1.594	0.985 38.2%
Total Phosphorus (mg/L)	0.100	0.723 -623.0%	0.374 -274.0%	0.117	0.101 13.7%
Ortho-P, diss (mg/L)	0.033	0.568 -1621.2%	0.312 -845.5%	0.042	0.051 -21.4%
As, diss (ug/L)	0.680	2.050 -201.5%	1.160 -70.6%	0.508	0.382 24.8%
As, total (ug/L)	1.100	2.675 -143.2%	1.520 -38.2%	1.092	0.818 25.1%
Cd, diss (ug/L)	<0.1	<0.1 NA	<0.1 NA	0.229	0.127 44.4%
Cd, total (ug/L)	0.180	0.175 2.8%	0.060 66.7%	0.492	0.191 61.2%
Cr, diss (ug/L)	1.940	1.350 30.4%	1.420 26.8%	2.033	1.336 34.3%
Cr, total (ug/L)	5.120	3.625 29.2%	2.780 45.7%	5.825	4.427 24.0%
Cu, diss (ug/L)	6.380	5.425 15.0%	5.020 21.3%	19.950	8.318 58.3%
Cu, total (ug/L)	23.720	13.600 42.7%	9.080 61.7%	50.750	23.727 53.2%
Ni, diss (ug/L)	0.940	1.100 -17.0%	0.780 17.0%	0.261	0.162 37.9%
Ni, total (ug/L)	3.740	3.075 17.8%	1.960 47.6%	15.950	7.564 52.6%
Pb, diss (ug/L)	0.188	0.175 6.9%	0.260 -38.3%	3.683	1.273 65.4%
Pb, total (ug/L)	5.400	5.725 -6.0%	2.920 45.9%	7.142	3.391 52.5%
Zn, diss (ug/L)	5.40	4.800 11.1%	6.820 -26.3%	190.583	17.818 90.7%
Zn, total (ug/L)	65.200	29.500 54.8%	21.800 66.6%	699.167	65.000 90.7%

(a) Strip is 9-feet wide and is planted with *C. edulis.*

(b) Strip is 10-feet wide and is planted with *I. hayesiana.*

As shown in Table 4-28, comparisons between average EMC percent reductions from the associated EOP station at Stations 7-341/7-342 (9-foot strips with *C. edulis*) versus those at Station 12-346 (10-foot strip with *I. hayesiana*) indicate:

- For 15 constituents (TSS, TOC, DOC, turbidity, ammonia, nitrite, TKN, total and dissolved cadmium, total and dissolved chromium, total copper, total and dissolved nickel, and total lead), the *C. edulis* Camarillo strips appear to have comparable EMC percent reductions to the *I. hayesiana* Yorba Linda strip.
- For 10 constituents (hardness, TDS, total phosphorus, dissolved ortho-P, total and dissolved arsenic, dissolved copper, dissolved lead, and total and dissolved zinc), the *I. hayesiana* Yorba Linda strip appears to have higher EMC percent reductions or lower EMC percent increases than the *C. edulis* Camarillo strips.
- For nitrate, the *I. hayesiana* Yorba Linda strip appears to have a lower EMC percent reduction than the *C. edulis* Camarillo strips.

Overall, the Camarillo *C. edulis* strips (7-341 and 7-342) provided comparable concentration reductions for many constituents compared to the Yorba Linda *I. hayesiana* strip (12-346), better concentration reduction for many other constituents, and worse concentration reduction for one constituent. It appears that whether a particular ornamental vegetation type provides exceptionally better concentration reduction than another type depends on the constituent of interest.

4.5.2.2 Volume Reduction

Northern California Comparison between Stations 4-308/4-309 and Station 4-312

As shown in Table 4-1, the *H. helix* Napa strips (4-308 and 4-309) appear to have narrower event-based volume reduction ranges (83.5 percent to 99.6 percent, and 58.4 percent to 98.5 percent) and higher season-based percent volume reductions (97.6 percent and 95.3 percent) than the *C. edulis* San Mateo strip (4-312) (49.4 percent to 97.0 percent for event-based, 63.4 percent for season-based). It appears that *H. helix* may provide better volume reduction than *C. edulis*, though both ornamental vegetation types provide consistently good to excellent treatment.

Southern California Comparison between Stations 7-341/7-342 and Station 12-346

As shown in Table 4-1, the *C. edulis* Camarillo strips (7-341 and 7-342) appear to have narrower event-based volume reduction ranges (85.7 percent to 95.9 percent, and 47.8 percent to 91.1 percent) and slightly higher season-based percent volume reductions (91.2 percent and 71.2 percent) than the *I. hayesiana* Yorba Linda strip (12-346) (37.5 percent to 91.7 percent for event-based, 62.1 percent for season-based). It appears that *C. edulis* may provide better volume reduction than *I. hayesiana*, though both ornamental vegetation types provide consistently good to excellent treatment.

4.5.2.3 Load

Northern California Comparison between Stations 4-308/4-309 and Station 4-312

Seasonal load reductions at the Napa 15-foot stations (4-308 and 4-309) were compared to those at the San Mateo 16-foot station (4-312), and are presented in Table 4-29.

Table 4-29: Northern California Load Comparison between the *H. helix* stations (4-308/4-309) and the *C. edulis* station (4-312)

Constituent	San Mateo 4-312[(a)]	Napa 4-308[(b)]	Napa 4-309[(b)]
	Seasonal Percent Load Reduction	Seasonal Percent Load Reduction	Seasonal Percent Load Reduction
Hardness as $CaCO_3$ (g/acre)	57.8%	95.9%	98.2%
TDS (g/acre)	32.8%	95.0%	97.7%
TSS (g/acre)	7.1%	96.4%	97.7%
TOC (g/acre)	48.2%	95.5%	96.6%
DOC (g/acre)	48.3%	94.7%	96.4%
Ammonia NH_3-N (g/acre)	84.6%	98.4%	92.8%
Nitrate NO_3-N (g/acre)	18.1%	97.3%	95.0%
Nitrite NO_2-N (g/acre)	67.3%	98.5%	96.3%
TKN (g/acre)	53.4%	94.1%	94.9%
Total Phosphorus (g/acre)	-10.6%	94.0%	86.5%
Ortho-P, diss (g/acre)	-84.9%	92.9%	73.3%
As, diss (mg/acre)	61.3%	96.2%	85.5%
As, total (mg/acre)	10.7%	94.5%	88.5%
Cd, diss (mg/acre)	69.1%	97.0%	95.9%
Cd, total (mg/acre)	67.7%	97.0%	95.9%
Cr, diss (mg/acre)	72.5%	99.1%	98.2%
Cr, total (mg/acre)	42.3%	98.2%	97.4%
Cu, diss (mg/acre)	79.9%	98.0%	97.9%
Cu, total (mg/acre)	76.5%	98.1%	98.5%
Pb, diss (mg/acre)	69.0%	96.9%	94.5%
Pb, total (mg/acre)	20.7%	95.7%	94.5%
Ni, diss (mg/acre)	70.1%	98.1%	97.2%
Ni, total (mg/acre)	1.0%	97.5%	96.7%
Zn, diss (mg/acre)	88.3%	96.8%	98.2%
Zn, total (mg/acre)	76.6%	97.4%	98.7%

(a) Strip is 16-feet wide and is planted with *C. edulis.*

(b) Strip is 15-feet wide and is planted with *H. helix.*

As shown in Table 4-29, comparisons between seasonal load reductions at Stations 4-308 and 4-309 (15-foot strips with *H. helix*) and Station 4-312 (16-foot strip with *C. edulis*) indicate:

- For 12 constituents (ammonia, nitrite, dissolved arsenic, total and dissolved cadmium, dissolved chromium, total and dissolved copper, dissolved nickel, dissolved lead, and total and dissolved zinc), Stations 4-308/4-309 appear to have comparable percent seasonal load reductions as Station 4-312.
- For 13 constituents (hardness, TDS, TSS, TOC, DOC, nitrate, TKN, total phosphorus, dissolved ortho-P, total arsenic, total chromium, total nickel, and total lead), Stations 4-308/4-309 appear to have higher percent seasonal load reductions than Station 4-312.

It should be noted that the Napa *H. helix* strips had much less pollutant load than the San Mateo *C. edulis* strips for all storm events, likely due to the fact that each Napa station has a much smaller drainage area and more permeable soils than the San Mateo station.

Overall, for many constituents, the Napa *H. helix* strips provided comparable load reductions compared to the San Mateo *C. edulis* strip, and provided better load reductions for many other constituents. It appears that whether or not a particular ornamental vegetation type provides exceptionally better treatment than any other type depends on the constituent of interest.

Southern California Comparisons between Stations 7-341/7-342 and Station 12-346

Seasonal load reductions at the Camarillo *C. edulis* stations (7-341 and 7-342) were compared to those at the Yorba Linda *I. hayesiana* Station (12-346), and are presented in Table 4-30.

Table 4-30: Southern California Load Comparison between the *C. edulis* Stations (7-341/7-342) and the *I. hayesiana* Station (12-346)

Constituent	Camarillo 7-341[(a)]	Camarillo 7-342[(a)]	Yorba Linda 12-346[(b)]
	Seasonal Percent Load Reduction	Seasonal Percent Load Reduction	Seasonal Percent Load Reduction
Hardness as $CaCO_3$ (g/acre)	84.2%	69.8%	71.6%
TDS (g/acre)	73.2%	70.0%	77.7%
TSS (g/acre)	93.8%	92.0%	75.4%
TOC (g/acre)	87.8%	81.6%	68.3%
DOC (g/acre)	89.6%	82.8%	76.6%
Ammonia NH_3-N (g/acre)	96.1%	91.4%	78.2%
Nitrate NO_3-N (g/acre)	97.7%	90.0%	75.0%
Nitrite NO_2-N (g/acre)	98.1%	91.1%	85.8%
TKN (g/acre)	90.8%	78.8%	78.1%
Total Phosphorus (g/acre)	31.0%	15.0%	74.6%
Ortho-P, diss (g/acre)	-37.4%	-89.9%	67.0%
As, diss (mg/acre)	69.3%	53.0%	71.9%
As, total (mg/acre)	74.1%	60.3%	73.5%
Cd, diss (mg/acre)	90.7%	71.2%	63.5%
Cd, total (mg/acre)	93.5%	91.6%	84.1%
Cr, diss (mg/acre)	94.4%	77.6%	73.1%
Cr, total (mg/acre)	94.3%	83.2%	71.6%
Cu, diss (mg/acre)	91.7%	73.0%	82.5%
Cu, total (mg/acre)	95.6%	87.9%	82.2%
Pb, diss (mg/acre)	89.8%	39.5%	79.0%
Pb, total (mg/acre)	89.7%	82.9%	83.8%
Ni, diss (mg/acre)	87.3%	76.6%	87.0%
Ni, total (mg/acre)	92.3%	84.0%	82.2%
Zn, diss (mg/acre)	92.1%	65.8%	95.7%
Zn, total (mg/acre)	96.6%	89.8%	95.4%

(a) Strip is 9-feet wide and is planted with *C. edulis.*

(b) Strip is 10-feet wide and is planted with *I. hayesiana.*

As shown in Table 4-30, comparisons between seasonal load reductions at Stations 7-341 and 7-342 (9-foot strips with *C. edulis*) and Station 12-346 (10-foot strip with *I. hayesiana*) indicate:

- For all constituents except for total phosphorus and dissolved ortho-P, the Camarillo *C. edulis* stations appear to have comparable percent seasonal load reductions as the Yorba Linda *I. hayesiana* station.
- For two constituents (total phosphorus and dissolved ortho-P), the Yorba Linda *I. hayesiana* station appears to have higher percent seasonal load reductions than the Camarillo *C. edulis* stations.

Overall, for most constituents, the Yorba Linda *I. hayesiana* strip provided comparable load reductions to the Camarillo *C. edulis* strips. It appears that neither ornamental vegetation type provides exceptionally better treatment than the other type.

4.6 ASSESSMENT OF VARIABILITY BETWEEN SIMILAR AND ADJACENT STRIPS

This section addresses the study question of what the difference is in treatment between strips having both the same approximate strip width and the same ornamental vegetation.

As discussed in Section 1.4, at each GRVTS biostrip location, there is one EOP station and two vegetated strip stations with the same vegetation and similar strip widths to serve as a replicate. Comparisons were performed on concentrations, volume reduction, and load data between the two strip stations to see if local variability exists between the two strips, and to explore the possible causes of the local variability if observed. Discussions on the comparisons are presented in the following sub-sections.

4.6.1 Concentration

At each location, the Tukey-Kramer HSD tests were performed on the EMCs of the two replicate strip stations to see if there are differences between the EMCs at the two stations. A summary of the Tukey-Kramer HSD test results is presented in Table 4-31.

Table 4-31: Tukey-Kramer HSD Test Results Summary for Concentration and Load Comparisons between Replicate Strips

Concentration				Load			
Constituent	Napa[a]	Camarillo[b]	Westminster[c]	Constituent	Napa[a]	Camarillo[b]	Westminster[c]
	4–308 vs. 4-309	7–341 vs. 7–342	12–344 vs. 12–345		4–308 vs. 4–309	7–341 vs. 7–342	12–344 vs. 12–345
Hardness as $CaCO_3$ (mg/L)	–	–	–	Hardness as $CaCO_3$ (g/acre)	–	+	–
TDS (mg/L)	–	–	–	TDS (g/acre)	–	–	–
TSS (mg/L)	–	–	–	TSS (g/acre)	–	+	–
TOC (mg/L)	–	–	–	TOC (g/acre)	–	+	–
DOC (mg/L)	–	–	–	DOC (g/acre)	–	+	–
Turbidity (NTU)	+	–	–	Turbidity	NA	NA	NA
Ammonia NH_3–N (mg/L)	+	–	–	Ammonia NH_3–N (g/acre)	–	+	–
Nitrate NO_3–N (mg/L)	–	+	–	Nitrate NO_3–N (g/acre)	–	+	–
Nitrite NO_2–N (mg/L)	+	+	–	Nitrite NO_2–N (g/acre)	–	+	–
TKN (mg/L)	–	–	–	TKN (g/acre)	–	+	–
Total Phosphorus (mg/L)	+	–	+	Total Phosphorus (g/acre)	–	+	+
Ortho–P, diss (mg/L)	+	–	+	Ortho–P, diss (g/acre)	–	+	+
As, diss (ug/L)	–	–	–	As, diss (mg/acre)	–	+	–
As, total (ug/L)	–	–	+	As, total (mg/acre)	–	+	+
Cd, diss (ug/L)	NA	NA	+	Cd, diss (mg/acre)	–	+	+
Cd, total (ug/L)	NA	–	+	Cd, total (mg/acre)	–	+	+
Cr, diss (ug/L)	–	+	–	Cr, diss (mg/acre)	–	+	+
Cr, total (ug/L)	–	–	+	Cr, total (mg/acre)	–	+	+
Cu, diss (ug/L)	–	–	–	Cu, diss (mg/acre)	–	+	–
Cu, total (ug/L)	–	–	+	Cu, total (mg/acre)	–	+	+
Pb, diss (ug/L)	–	+	+	Pb, diss (mg/acre)	–	+	–
Pb, total (ug/L)	+	–	+	Pb, total (mg/acre)	–	+	+
Ni, diss (ug/L)	–	–	–	Ni, diss (mg/acre)	–	+	–
Ni, total (ug/L)	+	–	+	Ni, total (mg/acre)	–	+	+
Zn, diss (ug/L)	–	+	–	Zn, diss (mg/acre)	–	+	+
Zn, total (ug/L)	–	–	+	Zn, total (mg/acre)	–	+	+

Green indicates the average EMC or load at the second station is statistically lower than that at the first station at a 90-percent confidence level.

(+) Indicates the average EMC or load at the second station is higher than that at the first station; however, the difference is not statistically significant at a 90-percent confidence level.

(–) Indicates the average EMC or load at the second station is lower than that at the first station; however, the difference is not statistically significant at a 90-percent confidence level.

(a) Napa Stations 4-308 and 4-309 both have *H. helix* vegetation and 15-foot strip widths.

(b) Camarillo Stations 7-341 and 7-342 both have *C. edulis* vegetation and 9-foot strip widths.

(c) Westminster Stations 12-344 and 12-345 both have *C. edulis* vegetation and 15-foot strip widths.

Napa Hwy 29 GRVTS Strip

As shown in Table 4-31, EMC comparisons between the two replicate stations (4-308 and 4-309) indicate:

- For dissolved zinc, the average EMC is statistically significantly higher at Station 4-308 than at Station 4-309 at a 90-percent confidence level.
- For 17 constituents (hardness, TDS, TSS, EC, TOC, DOC, nitrate, TKN, total and dissolved arsenic, total and dissolved chromium, total and dissolved copper, dissolved lead, dissolved nickel, and total zinc), the average EMCs are higher at Station 4-308 than at Station 4-309, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.
- For seven constituents (turbidity, ammonia, nitrite, total phosphorus, dissolved ortho-P, total lead, and total nickel), the average EMCs are lower at Station 4-308 than at Station 4-309, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.

Camarillo Hwy 101 GRVTS Strip

As shown in Table 4-31, EMCs comparisons between the two replicate stations (7-341 and 7-342) indicate:

- For six constituents (hardness, total phosphorus, dissolved ortho-P, dissolved arsenic, total aresnic, and total lead), the average EMCs are statistically significantly higher at Station 7-341 than at Station 7-342 at a 90-percent confidence level.
- For 14 constituents (TDS, TSS, EC, TOC, DOC, turbidity, ammonia, TKN, total cadmium, total chromium, total and dissolved copper, total and dissolved nickel, and total zinc), the average EMCs are higher at Station 7-341 than at Station 7-342, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.
- For five constituents (nitrate, nitrite, dissolved chromium, dissolved lead, and dissolved zinc), the average EMCs are lower at Station 7-341 than at Station 7-342, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.

Westminster I-405 GRVTS Strip

As shown in Table 4-31, EMCs comparisons between the two replicate stations (12-344 and 12-345) indicate:

- For three constituents (TOC, DOC, and nitrate), the average EMCs are statistically significantly higher at Station 12-344 than at Station 12-345 at a 90-percent confidence level.
- For 11 constituents (hardness, TDS, TSS, turbidity, ammonia, nitrite, TKN, dissolved arsenic, dissolved copper, dissolved nickel, and dissolved zinc), the average EMCs are

higher at Station 12-344 than at Station 12-345, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.

- For 11 constituents (total phosphorus, dissolved ortho-P, total arsenic, total and dissolved cadmium, total chromium, total copper, total and dissolved lead, total nickel, and total zinc), the average EMCs are lower at Station 12-344 than at Station 12-345, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.
- For dissolved chromium, the average EMC at Station 12-344 is equal to the average EMC at Station 12-345.

As shown in Table 4-31, overall it appears that at all three locations, differences exist in EMCs between the two replicate stations for almost all constituents. However, the differences of only a handful of constituents are statistically significant at a 90-percent confidence level, which is possibly due to the fact that either there is not enough data to demonstrate statistical significance (e.g., Station 12-344 has three data points and Station 12-345 has two data points), or that little variability exists.

4.6.2 Volume Reduction

At each location, both event-based and season-based volume reduction data were used to perform comparisons between the two replicate strip stations to see if any differences exist between the two stations in volume reduction. A summary of both event-based and season-based volume reductions is presented in Table 4-1.

Napa Hwy 29 GRVTS Strip

As shown in Table 4-1, Station 4-309 has a broader range of event-based volume reductions (58.4 to 98.5 percent) than Station 4-308 (83.5 to 99.6 percent). Station 4-309 has a slightly lower seasonal volume reduction of 95.3 percent than Station 4-308 (97.6 percent). Overall, it appears Station 4-308 performed slightly better than Station 4-309 in volume reduction; however, the differences are fairly small and may not be statistically significant.

Camarillo Hwy 101 GRVTS Strip

As shown in Table 4-1, Station 7-342 has a broader range of event-based volume reductions (47.8 to 91.1 percent) than Station 7-341 (85.7 to 95.9 percent). Station 7-341 has a much higher seasonal volume reduction of 91.2 percent than Station 7-342 (71.2 percent). Overall, it appears Station 7-341 performed better than Station 7-342 in volume reduction; however, the differences may not be statistically significant.

Westminster Hwy I-405 GRVTS Strip

As shown in Table 4-1, Station 12-344 has a broader range of event-based volume reductions (24.1 to 99.6 percent) than Station 12-345 (78.2 to 100 percent). Station 12-344 has a similar seasonal volume reduction of 95.3 percent as Station 12-345 (96.0 percent). Overall, it appears Station 12-345 performed slightly better than Station 12-344 in volume reduction; however, the differences are fairly small and may not be statistically significant.

Overall, the differences in percent volume reduction between the two replicate strips at the Napa and Westminster locations are fairly small. Larger differences exist in volume reduction between

the two replicate strips at the Camarillo location. However, these differences may not be statistically significant.

4.6.3 Load

At each location, the Tukey-Kramer HSD tests were performed on event-based normalized load data (as described in Section 4.1) at the two replicate strip stations to see if any differences exist between loads at the two stations. A summary of the Tukey-Kramer HSD test results is presented in Table 4-31. Season-based load reduction results for each station are presented in Table 4-3.

Napa Hwy 29 GRVTS Strip

As shown in Table 4-31, event-based load comparisons between the two stations (4-308 and 4-309) indicate:

- For all constituents, at a 90-percent confidence level, the load at one station is not statistically significantly different than the load of that same constituent at the other station.
- For all 25 constituents listed in Table 4-23, the loads are higher at Station 4-308 than at Station 4-309, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.

As shown in Table 4-3, season-based load reductions at Station 4-308 range from 92.9 percent for dissolved ortho-P to 99.1 percent for dissolved chromium. Season-based load reductions at Station 4-309 range from 73.3 percent for dissolved ortho-P to 98.7 percent for total zinc.

It appears Station 4-309 performed better than Station 4-308 for event-based load reductions. Differences between these two stations in season-based load reductions are fairly small.

Overall, although differences in load reductions were observed, none were found to be statistically significant. It may be that the differences are not statistically significant at the 90-percent confidence level, or there may not be enough data to demonstrate statistical significance.

Camarillo Hwy 101 GRVTS Strip

As shown in Table 4-31, event-based load comparisons between the two stations (7-341 and 7-342) indicate:

- For all constituents, at a 90-percent confidence level, the load at one station is not statistically significantly different than the load of that same constituent at the other station.
- For TDS, the load is higher at Station 7-341 than at Station 7-342, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.
- For all constituents except for TDS, the loads are lower at Station 7-341 than at Station 7-342, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.

As shown in Table 4-3, season-based load reductions at Station 7-341 range from -37.4 percent (a 37.4-percent increase) for dissolved ortho-P to 98.1 percent for TKN. Season-based load reductions at Station 7-342 range from -89.9 percent (an 89.9-percent increase) for dissolved ortho-P, to 91.6 percent for total cadmium.

It appears Station 7-341 performed better than Station 7-342 for event-based load reductions. Differences between these two stations in season-based load reductions are fairly small. Overall, although differences in load reductions were observed, none were found to be statistically significant. It may be that the differences are not statistically significant at the 90-percent confidence level, or there may not be enough data to demonstrate statistical significance.

Westminster I-405 GRVTS Strip

As shown in Table 4-31, event-based load comparisons between the two replicate stations (12-344 and 12-345) indicate:

- For all constituents, at a 90-percent confidence level, the load at one station is not statistically significantly different than the load of that same constituent at the other station.
- For 13 constituents (hardness, TSS, TDS, TOC, DOC, ammonia, nitrate, nitrite, TKN, dissolved arsenic, dissolved copper, dissolved lead, and dissolved nickel), the loads are higher at Station 12-344 than at Station 12-345, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.
- For 12 constituents (total phosphorus, dissolved ortho-P, total arsenic, total and dissolved cadmium, total and dissolved chromium, total copper, total lead, total nickel, and total and dissolved zinc), the loads are lower at Station 12-344 than at Station 12-345, but there is not enough evidence to conclude that the differences are statistically significant at a 90-percent confidence level.

As shown in Table 4-3, season-based load reductions at Station 12-344 range from -34.2 percent (a 34.2-percent increase) for TDS to 93.8 percent for dissolved zinc. Season-based load reductions at Station 12-345 range from -666 percent (a 666-percent increase) for dissolved ortho-P to 91.1 percent for both dissolved cadmium and dissolved zinc.

It appears that any differences between these two stations in both event-based and season-based load reductions are fairly small, and none were found to be statistically significant. It may be that the differences are not statistically significant at the 90-percent confidence level, or there may not be enough data to demonstrate statistical significance.

4.7 VARIABILITY BETWEEN ORNAMENTAL VEGETATION AND GRASSES AND FORBS IN TREATING HIGHWAY RUNOFF

This section addresses the study question of how the treatment of highway runoff by strips/swales planted with ornamental vegetation compare to that by strips/swales planted with grasses and forbs. The performance of ornamental vegetation was compared to that of grasses and forbs by comparing the results from the ORVTS Study to those from two previous studies (the RVTS Study and the BMP Retrofit Pilot Program). The following sub-sections present comparisons between the ERVTS and RVTS results and between the ORVTS Study and the BMP Retrofit Pilot Program results.

4.7.1 Comparison between ERVTS and RVTS Results

As described in Section 1.2, the RVTS Study was a five-year water quality monitoring project undertaken to evaluate the pollutant removal efficiency of existing vegetated side slopes adjacent to freeways. Monitoring in the RVTS Study was performed during five wet seasons between 2001 and 2008. The Sacramento and Yorba Linda ERVTS of the ORVTS Study are located adjacent to the two previous RVTS. At each of the two locations, flow and analytical data from the ERVTS and the RVTS were assessed to compare the treatment potential from ornamental vegetation (newly planted at the ERVTS locations) to the grasses and forbs (studied at the RVTS locations).

The primary differences in the setups at these two locations between RVTS and ERVTS include:

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

4.7.1.1 Concentration

Using the analytical data from both the five-year RVTS Study and the 2009-2010 ORVTS Study, the average of the EMCs for all four strips at each location was calculated for each constituent.

Sacramento I-5

A comparison of the calculated average EMCs between the ERVTS and the RVTS is presented in Table 4-32. The table presents for both RVTS and ERVTS the average EMC at the EOP, and the average EMC for all four strips. Each constituent with a concentration reduction or increase in comparison to the EOP is identified.

Table 4-32: Concentration Reduction Comparison between RVTS and ERVTS at Sacramento Location

Constituent	Sacramento RVTS			Sacramento ERVTS		
	EOP	Four Strips		EOP	Four Strips	
	Average EMC	Average EMC	Percent Change from EOP	Average EMC	Average EMC	Percent Change from EOP
Hardness as $CaCO_3$ (mg/L)	33.58	53.92	-60.6%	43.46	63.65	-46.5%
TDS (mg/L)	56.74	105.50	-85.9%	64.36	113.03	-75.6%
TSS (mg/L)	69.38	32.68	52.9%	120.27	52.52	56.3%
TOC (mg/L)	8.27	12.23	-47.8%	8.80	35.79	-306.7%
DOC (mg/L)	7.46	10.95	-46.7%	4.80	19.17	-299.3%
Ammonia NH_3-N (mg/L)	0.58	0.62	-6.5%	0.50	0.87	-74.4%
Nitrate NO_3-N (mg/L)	0.48	0.40	16.4%	0.78	0.51	34.0%
TKN (mg/L)	1.63	1.50	8.0%	2.13	4.61	-116.7%
Total Phosphorus (mg/L)	0.30	0.33	-9.8%	0.43	0.89	-106.4%
Ortho-P, Diss (mg/L)	0.09	0.25	-188.7%	0.16	0.57	-245.9%
As, Diss (ug/L)	1.01	2.67	-165.7%	1.44	2.84	-97.5%
As, Total (ug/L)	1.80	3.21	-78.6%	3.32	3.69	-11.3%
Cd, Diss (ug/L)	0.18	0.22	-22.6%	<0.1	<0.1	NA
Cd, Total (ug/L)	0.46	0.31	32.7%	0.72	0.12	83.2%
Cr, Diss (ug/L)	6.78	12.89	-90.0%	1.29	0.59	54.3%
Cr, Total (ug/L)	11.79	19.01	-61.3%	14.18	3.93	72.3%
Cu, Diss (ug/L)	6.83	5.72	16.2%	10.29	10.24	0.5%
Cu, Total (ug/L)	19.44	8.96	53.9%	46.36	15.62	66.3%
Ni, Diss (ug/L)	2.16	2.42	-12.2%	1.37	1.41	-2.9%
Ni, Total (ug/L)	5.75	3.32	42.3%	13.48	5.55	58.8%
Pb, Diss (ug/L)	0.98	0.98	0.0%	0.12	0.14	-16.2%
Pb, Total (ug/L)	4.82	1.81	62.4%	9.83	1.31	86.6%
Zn, Diss (ug/L)	17.64	13.30	24.6%	9.66	16.96	-75.7%
Zn, Total (ug/L)	88.12	31.05	64.8%	191.64	45.34	76.3%

NA = Not available. The average EMCs at both the EOP and the strip 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 numbers as highlighted in gray indicate average EMC increases when compared to the EOP.

As shown in Table 4-32 both the ERVTS and RVTS stations at Sacramento show various percent concentration differences between the EOP and the average EMC of the strips. Specific details are summarized below:

- 13 constituents (hardness, TDS, TSS, nitrate, dissolved ortho-P, dissolved arsenic, dissolved and total copper, dissolved and total nickel, dissolved and total lead, and total zinc) demonstrate comparable percent concentration differences for both the RVTS and ERVTS studies.
- For four other constituents (total arsenic, total cadmium, dissolved chromium, and total chromium) the ERVTS performed better than the RVTS.

- For six constituents (TOC, DOC, ammonia, TKN, total phosphorus, and dissolved zinc) the ERVTS performed worse than the RVTS.

Overall at the Sacramento location, the ERVTS stations planted with ornamental vegetation and the RVTS stations with grasses and forbs performed similarly in reducing pollutant concentrations.

Yorba Linda SR-91

A comparison of the calculated average EMCs between the ERVTS and the RVTS is presented in Table 4-33. The table presents for both RVTS and ERVTS the average EMC at the EOP, and the average EMC for all four strips. Each constituent with a concentration reduction or increase in comparison to the EOP is identified.

Table 4-33: Concentration Reduction Comparison between RVTS and ERVTS at Yorba Linda Location

Constituent	Yorba Linda RVTS			Yorba Linda ERVTS		
	EOP	Four Strips		EOP	Four Strips	
	Average EMC	Average EMC	Percent Reduction from EOP	Average EMC	Average EMC	Percent Reduction from EOP
Hardness as $CaCO_3$ (mg/L)	36.17	39.33	-8.7%	33.33	70.44	-111.3%
TDS (mg/L)	88.36	91.69	-3.8%	53.75	107.59	-100.2%
TSS (mg/L)	79.96	110.63	-38.4%	44.92	61.30	-36.5%
TOC (mg/L)	18.96	23.22	-22.5%	11.90	15.61	-31.2%
DOC (mg/L)	17.13	20.69	-20.8%	8.04	11.37	-41.3%
Ammonia NH_3-N (mg/L)	0.76	0.46	39.9%	0.38	0.14	64.1%
Nitrate (mg/L)	1.11	1.46	-32.2%	0.71	1.43	-100.9%
TKN (mg/L)	2.06	2.05	0.5%	1.59	1.75	-9.6%
Total Phosphorus (mg/L)	0.25	0.55	-124.0%	0.12	0.32	-172.9%
Ortho-P, Diss (mg/L)	0.14	0.58	-321.5%	0.04	0.20	-366.1%
As, Diss (ug/L)	1.24	1.44	-15.8%	0.51	1.42	-179.3%
As, Total (ug/L)	1.95	2.34	-20.0%	1.09	2.16	-97.9%
Cd, Diss (ug/L)	0.25	0.19	21.7%	0.23	0.26	-11.9%
Cd, Total (ug/L)	0.82	0.59	27.7%	0.49	0.57	-15.3%
Cr, Diss (ug/L)	2.86	3.10	-8.3%	2.03	1.21	40.4%
Cr, Total (ug/L)	6.08	6.20	-2.0%	5.83	4.71	19.1%
Cu, Diss (ug/L)	22.02	16.52	25.0%	19.95	8.63	56.7%
Cu, Total (ug/L)	44.92	29.43	34.5%	50.75	18.00	64.5%
Ni, Diss (ug/L)	5.26	3.54	32.8%	3.68	2.24	39.3%
Ni, Total (ug/L)	7.12	6.18	13.2%	7.14	5.28	26.1%
Pb, Diss (ug/L)	2.68	2.28	14.9%	0.26	0.33	-26.0%
Pb, Total (ug/L)	20.78	18.14	12.7%	15.95	7.35	53.9%
Zn, Diss (ug/L)	177.24	34.57	80.5%	190.58	16.35	91.4%
Zn, Total (ug/L)	350.08	120.60	65.6%	699.17	48.34	93.1%

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

As shown in Table 4-33 both the ERVTS and RVTS stations at Yorba Linda location show various percent concentration differences between the EOP and the average EMC of the strips. Specific details are summarized below:

- 13 constituents (TSS, TOC, DOC, ammonia, total phosphorus, dissolved ortho-P, dissolved and total copper, dissolved and total nickel, total lead, and dissolved and total zinc), the percent concentration differences are comparable for both the RVTS and ERVTS studies.
- For two other constituents (dissolved and total chromium) the ERVTS performed better than the RVTS.
- For nine constituents (hardness, TDS, nitrate, TKN, dissolved and total arsenic, dissolved and total cadmium, and dissolved lead) the ERVTS performed worse than the RVTS.

Overall at the Yorba Linda location, the RVTS stations planted with grasses and forbs performed slightly better in reducing pollutant concentrations than the ERVTS stations planted with ornamental vegetation.

4.7.1.2 Volume Reduction

Volume reductions on a seasonal basis for both the ERVTS and RVTS strips were calculated using the method described in Section 4.1. Results are presented in Table 4-34. No statistical analyses were performed for these comparisons.

Table 4-34: Comparison of Runoff Volume Reductions between RVTS and ERVTS at Two Locations

Location Name	RVTS			ERVTS		
	Station ID	Strip Width (ft)	Percent Volume Reduction	Station ID	Strip Width (ft)	Percent Volume Reduction
Sacramento	3-214	3.6	41.7%	3-362	9	85.0%
	3-215	15	71.7%	3-363	24.5	96.6%
	3-216	21.7	78.7%	3-364	23.5	93.0%
	3-217	27.6	77.1%	3-365	24.5	95.4%
Yorba Linda	12-226	5.9	36.6%	12-346	10	59.4%
	12-227	16.1	20.9%	12-347	21	49.5%
	12-228	24.9	21.2%	12-348	21	87.4%
	12-229	42.7	62.2%	12-349	21	83.5%

At Sacramento, all RVTS stations have a lower season-based volume reduction (41.7 to 78.7 percent) compared to the ERVTS stations (85 to 96.6 percent). The range of seasonal volume reductions at Sacramento ERVTS was narrower than the range at the Sacramento RVTS.

At Yorba Linda, again all RVTS stations exhibited lower season-based volume reductions (20.9 to 62.2 percent) compared to the ERVTS stations (49.5 to 87.4 percent).

Overall, the ERVTS stations appear to perform much better than the RVTS stations. The improvement in volume reduction could be due to a combination of possible factors such as increased station width, different vegetation at the locations, and/or differences in characteristics of the storms monitored between the two studies.

4.7.2 Comparison between ORVTS and BMP Retrofit Pilot Program Results at Carlsbad (Palomar)

The BMP Retrofit Pilot Program (BMP Program) designed and constructed BMPs, and assessed the pollutant 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 locations studied during the ORVTS Study. Results from the ORVTS Study were compared to those from the BMP Program at this location.

The primary difference between the setups at the Carlsbad (Palomar) swale for the BMP Program and ERVTS Study include:

- Vegetation characteristics (vegetation type, height, density, and strip width, etc.). The swale was vegetated with grass and forbs for the BMP Program. At this location, over time, adjacent ornamental vegetation (*C. edulis*) encroached in the swale area and is now the dominant species, as identified during the ORVTS Study.

4.7.2.1 Concentration

Using the analytical data from both the BMP Program and the 2009-2010 ORVTS Study, the average EMC at each station at this location was calculated for each constituent.

Carlsbad I-5

A comparison of the calculated average EMCs between the ORVTS Study and the BMP Program is presented in Table 4-35. 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. Each constituent with a concentration reduction or increase in comparison to the EOP is identified.

Table 4-35: Concentration Reduction Comparison between BMP Program and ORVTS Study at Carlsbad (Palomar) Swale

Constituent	BMP Retrofit Pilot Program			ORVTS Study		
	EOP	Swale		EOP	Swale	
	Average EMC	Average EMC	Percent Reduction from EOP	Average EMC	Average EMC	Percent Reduction from EOP
Hardness as $CaCO_3$ (mg/L)	40.9	33.0	19.3%	41.0	54.3	-32.4%
TDS (mg/L)	76.3	96.6	-26.6%	93.8	139	-48.4%
TSS (mg/L)	86.0	35.6	58.6%	29.0	16.8	42.2%
TOC (mg/L)	14.7	14.8	-0.5%	15.8	16.9	-7.1%
DOC (mg/L)	12.8	13.0	-1.3%	11.1	10.7	3.9%
Nitrate NO_3-N (mg/L)	1.0	0.9	16.9%	1.12	0.24	78.1%
TKN (mg/L)	2.4	1.9	19.8%	2.12	1.03	51.5%
Total Phosphorus (mg/L)	0.4	0.4	4.5%	0.11	0.40	-269.4%
Ortho-P, diss (mg/L)	0.1	0.2	-79.1%	0.06	0.29	-399.4%
As, diss (ug/L)	0.9	0.6	26.1%	0.68	0.56	17.5%
As, total (ug/L)	2.8	2.2	20.8%	1.10	0.76	31.2%
Cd, diss (ug/L)	0.2	0.2	-7.1%	<0.1	<0.1	NA
Cd, total (ug/L)	0.8	0.5	43.4%	0.48	0.19	60.0%
Cr, diss (ug/L)	4.3	3.8	11.0%	3.98	5.81	-46.3%
Cr, total (ug/L)	6.4	4.9	22.4%	7.40	7.59	-2.5%
Cu, diss (ug/L)	16.9	18.8	-11.1%	27.5	8.27	69.9%
Cu, total (ug/L)	37.4	10.3	72.5%	52.5	15.0	71.4%
Pb, diss (ug/L)	3.5	2.6	26.0%	0.43	0.31	26.1%
Pb, total (ug/L)	46.9	24.0	48.8%	14.6	7.56	48.3%
Ni, diss (ug/L)	2.6	2.1	16.5%	4.35	1.14	73.7%
Ni, total (ug/L)	6.5	3.6	44.0%	7.03	2.01	71.3%
Zn, diss (ug/L)	61.1	36.4	40.4%	63.5	18.7	70.5%
Zn, total (ug/L)	203.5	82.0	59.7%	145	46.4	68.0%

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 numbers as highlighted in gray indicate average EMC increases when compared to the EOP.

As shown in Table 4-35, 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:

- 13 constituents (TDS, TSS, TOC, TKN, dissolved and total arsenic, total cadmium, total copper, dissolved and total lead, total nickel, and dissolved and total zinc) demonstrate comparable percent concentration differences are comparable for both the ORVTS Study and the BMP Program.
- For four constituents (DOC, nitrate, dissolved copper, and dissolved nickel) the ORVTS Study performed better than the BMP Program.
- For five other constituents (hardness, total phosphorus, dissolved ortho-P, dissolved chromium, and total chromium) the ORVTS Study performed worse than the BMP Program.

Overall the Carlsbad (Palomar) swale appears to have performed comparably during both the BMP Program and the ORVTS Study in reducing concentrations of most constituents, although concentration reduction of some heavy metals and nitrogen (TKN and nitrate) were greater during the ORVTS Study.

4.7.2.2 Volume Reduction

Volume reduction on an event and seasonal basis for both the ORVTS Study and the BMP Program was calculated using the method described in Section 4.1. Results are presented in Table 4-36. No statistical analyses were performed for these comparisons.

Table 4-36: Comparison of Runoff Volume Reductions between ORVTS Study and BMP Program at Carlsbad (Palomar)

Location Name	ORVTS Study			BMP Program		
	Number of Data Points	Range of Event Volume Reduction	Seasonal Volume Reduction	Number of Data Points	Range of Event Volume Reduction	Seasonal Volume Reduction
Carlsbad (Palomar)	2	95.4 to 97.6 %	96 %	8	17.5 to 66.7 %	27 %

The Carlsbad (Palomar) swale during the BMP Program had a broader range of event-based volume reductions (17.5 to 66.7 percent) in comparison to the ORVTS Study (95.4 to 97.6 percent). The range of event based volume reductions at Carlsbad during the ORVTS Study was narrower then the range during the BMP Program. On a seasonal basis, Carlsbad (Palomar) during the BMP Program had a lower season-based volume reduction (27 percent) compared to the ORVTS Study (95.9 percent). Future assessments may include a statistical comparison (such as an ANOVA).

Overall, Carlsbad (Palomar) during the ORVTS Study demonstrated more favorable event-based as well as seasonal volume reductions in comparison to the BMP Program. The improvement in volume reduction could be due to a combination of possible factors such as different vegetation at the site and/or differences in characteristics of the storms monitored between the two studies.

SECTION 5 CONCLUSIONS

This section presents general conclusions based on the analyses performed on data collected during the 2009-2010 monitoring season of the ORVTS Study. The general conclusions are discussed in the following subsections to address the primary study objectives as described in Sections 1.1 and 4.

5.1 EFFECTIVENESS OF STRIPS PLANTED WITH ORNAMENTAL VEGETATION IN TREATING HIGHWAY RUNOFF

As discussed in Section 4.2, the effectiveness of strips planted with ornamental vegetation was assessed in terms of runoff volume and pollutant concentration and load reductions.

Concentration

Overall, the strips planted with ornamental vegetation appear to be effective in reducing concentrations of some constituents (total cadmium, dissolved chromium, dissolved and total copper, total lead, and dissolved and total zinc) with most of the strips showing statistically significant concentration reductions at a 90-percent confidence level. However, the strips appear to have caused concentration increases of some constituents (dissolved arsenic, total phosphorus, and dissolved ortho-P) with most of the strips showing statistically significant concentration increases at a 90-percent confidence level. Results indicate the strips may have reduced concentrations of some other constituents (TSS, turbidity, ammonia, nitrate, nitrite, total cadmium, total chromium, and dissolved and total nickel); however, these reductions at most strips were not statistically significant at a 90-percent confidence level. This is possibly due to there not being enough data to demonstrate a statistical difference for these constituents, as only limited data points (two to ten depending on location) were available for data assessments.

Volume Reduction

As discussed in Section 4.2.2, substantial reductions occurred of event-based runoff volume at all 15 vegetated strip stations throughout the 2009-2010 monitoring season. Seasonal volume reduction of the ERVTS strips ranges from 53.3 to 98.7 percent. Seasonal volume reduction of the GRVTS strips ranges from 63.4 to 97.6 percent. Overall, the strips performed very well in reducing runoff volume, indicating that strips planted with ornamental vegetation are effective in reducing runoff volume, most likely due to substantial infiltration occurring within the strips.

Load

Event-based pollutant load results indicate that most strips show statistically significant load reductions for all constituents at a 90-percent confidence level except for TKN, total phosphorus, and dissolved ortho-P. Most strips show load reductions for TKN, but the reductions were not found to be statistically significant, possibly due to limited data points. As shown in Tables 4-2 and 4-3, season-based load results indicate that almost all 15 strips had substantial load reductions for all constituents, with a few exceptions (dissolved ortho-P shows an increase at seven stations; total phosphorus and TDS show increases at three stations; TOC and DOC show increases at two stations; and hardness, nitrate, and dissolved arsenic show increases at one station). Overall, strips planted with ornamental vegetation appear to be effective in the reduction of pollutant loads for all constituents as listed in Table 4-2, except for total phosphorus and dissolved ortho-P.

Total phosphorus is a target design constituent (TDC) according to the Caltrans *Project Planning and Design Guidance* (PPDG) (Caltrans 2010). Results of this study indicate that the strips with ornamental vegetation may have contributed to the concentration increases of total phosphorus and may be a concern in watersheds sensitive to phosphorus loading. Vegetation and soil are suspected to be the sources of phosphorus increases.

5.2 EFFECTIVENESS OF SWALES PLANTED WITH ORNAMENTAL VEGETATION IN TREATING HIGHWAY RUNOFF

As discussed in Section 4.3, the effectiveness of the two swales planted with ornamental vegetation was assessed in terms of runoff volume and pollutant concentration and load reductions.

Concentration

Overall, swales planted with ornamental vegetation appear to be effective in reducing concentrations of certain constituents (ammonia, nitrate, nitrite, TKN, total arsenic, total cadmium, dissolved and total copper, total lead, dissolved nickel, and dissolved and total zinc), as at least one swale shows a statistically significant concentration reduction at a 90-percent confidence level for these constituents. However, the swales appear to have caused concentration increases of both total phosphorus and dissolved ortho-P, with one swale showing a statistically significant concentration increase at a 90-percent confidence level for both total phosphorus and dissolved ortho-P. Possible causes for these concentration increases could be due to contributions from the vegetation and soil within the swales.

Volume Reduction

As discussed in Section 4.3.2, the Newbury Park swale showed a seasonal volume reduction of 71.9 percent for four monitored storms, with event-based volume reductions ranging from 58.6 to 100.0 percent. The Carlsbad (Palomar) swale showed a seasonal volume reduction of 95.9 percent for two monitored storms, with event-based volume reductions ranging from 95.4 to 97.6 percent. It appears that substantial volume reduction occurred at both swales throughout the 2009-2010 monitoring season, indicating that swales planted with ornamental vegetation are effective in reducing runoff volume, most likely due to substantial infiltration occurring within the swales.

Load

Event-based load results indicate that the Newbury Park swale shows a statistically significant load reduction at a 90-percent confidence level for all constituents except for TSS, total phosphorus, dissolved ortho-P, total cadmium, and dissolved lead, all of which show reductions that are not statistically significant. The Carlsbad (Palomar) swale shows reductions for all constituents, but none of the reductions was found to be statistically significant at a 90-percent confidence level. It should be noted that only one data point is available for event-based load data assessments at the Carlsbad (Palomar) location, and there may be not enough data to demonstrate statistical significance. As shown in Table 4-3, seasonal load results indicate that both swales show substantial load reductions for almost all constituents. Both swales appear to be effective in reducing pollutant loads for all constituents except for TSS, total phosphorus, dissolved ortho-P, total cadmium, and dissolved lead.

5.3 IMPACT OF STRIP WIDTH ON TREATMENT OF STRIPS PLANTED WITH ORNAMENTAL VEGETATION IN TREATING HIGHWAY RUNOFF

As discussed in Section 4.4, two types of data analyses were performed to examine the impact of strip width on the treatment effectiveness of strips planted with ornamental vegetation in terms of pollutant concentration, runoff volume, and pollutant load reductions.

Overall, whether or not a longer strip provides better concentration reduction appears to be dependent on the constituent of interest, as well as the location. This may be due to location-specific characteristics other than strip width such as average annual daily traffic (AADT), soil composition, etc. A more detailed understanding of this may be gained as more data become available.

Longer strips do not appear to provide exceptionally better volume or load reduction than shorter strips.

Specific details regarding each comparison are provided below.

5.3.1 Comparisons within Each ERVTS Location

Concentration

At the Sacramento location, the 25-foot *H. helix* strip performed better than the 9-foot *H. helix* strip for many constituents, but it also performed worse for some other constituents. At the Yorba Linda location, the 21-foot *I. hayesiana* strip performed better than the 10-foot *I. hayesiana* strip for some constituents, but it performed worse for many other constituents. Overall, whether or not a longer strip provides better concentration reduction appears to be dependent on the constituent of interest, as well as location-specific characteristics such as vegetation type, soil characteristics, AADT, etc.

Volume Reduction

At both the Sacramento and Yorba Linda locations, both event-based and season-based volume data indicate that differences in volume reduction between the two strips with different widths are fairly small, indicating that longer strip width may not provide exceptionally improved treatment through volume reduction.

Load

At the Sacramento location, although the 25-foot *H. helix* strip provided equivalent or better load reductions than the 9-foot *H. helix* strip for most constituents, excellent load reductions were observed for both. At the Yorba Linda location, while the 21-foot *I. hayesiana* strip performed better than the 10-foot *I. hayesiana* strip for a few constituents, it performed worse for most other constituents. It appears that a longer strip does not provide exceptionally better load reduction than a shorter strip.

5.3.2 Comparisons between Strips at Different Locations

Concentration

The 9-foot *H. helix* strip at Sacramento performed equivalent to or better than the 15-foot *H. helix* strips at Napa for many constituents, but performed worse for many other constituents. The 9-foot *C. edulis* strips at Camarillo performed equivalent to or better than the 15-foot *C. edulis* strips at Westminster for most constituents. Whether or not a longer strip provides better concentration reduction appears to be dependent on the constituent of interest, as well as location-specific characteristics such as vegetation type, soil characteristics, AADT, etc.

Volume Reduction

The 15-foot *H. helix* strips located in Napa appear to have comparable event-based volume reductions (although the ranges were broader) and a comparable season-based percent volume reduction when compared to the 9-foot *H. helix* strip located in Sacramento. The 9-foot *C. edulis* strips located in Camarillo appear to have comparable event-based volume reduction ranges and comparable season-based percent volume reductions when compared to the 15-foot *C. edulis* strips located in Westminster. Overall, it appears that longer strips do not provide exceptionally better volume reductions compared to shorter strips.

Load

The 15-foot *H. helix* strips located in Napa have a comparable load reductions to the 9-foot *H. helix* strip located in Sacramento. The 9-foot *C. edulis* strips located in Camarillo appear to have load reductions that are comparable to the 15-foot *C. edulis* strips located in Westminster. Overall, these results indicate that a longer strip does not provide exceptionally better load reduction.

5.4 IMPACT OF ORNAMENTAL VEGETATION TYPE ON EFFECTIVENESS OF STRIPS IN TREATING HIGHWAY RUNOFF

As discussed in Section 4.5, two types of data analyses were performed to examine the impact of ornamental vegetation type on the treatment effectiveness of strips planted with ornamental vegetation in terms of pollutant concentration, runoff volume, and pollutant load reductions.

Overall, it appears that whether a particular ornamental vegetation type provides exceptionally better concentration reduction than any other type depends on the constituent of interest, as well as the location. This may be due to location-specific characteristics other than ornamental vegetation type, such as AADT, soil composition, etc. A more detailed understanding of this may be gained as more data becomes available.

Some ornamental vegetation types appear to provide equivalent or better volume reduction than other types. The observed differences may be due to location-specific characteristics other than ornamental vegetation type, such as soil type or storm characteristics. Overall, good to excellent volume reduction was consistently observed for all ornamental vegetation types.

Whether or not a particular ornamental vegetation type provides exceptionally better load reduction than any other type appears to sometimes depend on the constituent of interest, as well as the location. This may be due to location-specific characteristics other than ornamental

vegetation type, such AADT, soil composition, soil type, storm characteristics, etc. A more detailed understanding of this may be gained as more data become available.

Specific details regarding each comparison are provided below.

5.4.1 Comparisons within Each ERVTS Location

As discussed in Section 4.5.1, comparisons were performed between strips within each ERVTS location to examine the impact of ornamental vegetation type on the treatment effectiveness of strip planted with ornamental vegetation in terms of runoff volume and pollutant concentration and load reductions. It should be noted that only one data point is available for assessments on runoff volume and load for Station 12-348 at the Yorba Linda location, and that confidence in data assessments on runoff volume and load data for this station is low.

Concentration

Each ornamental vegetation type (*B. pilularis, M. pavifolium, and H. helix* at Sacramento and *I. hayesiana, Senecio mandraliscae,* and *Lantana montevidensis* at Yorba Linda) performed the best for some constituents and the worst for other constituents. No particular ornamental vegetation type stood out as the best performer in terms of concentration reduction. It appears that whether or not a particular ornamental vegetation type provides better concentration reduction than any other type depends on the constituent of interest, as well as location-specific characteristics such as strip width, soil characteristics, AADT, etc.

Volume Reduction

At the Sacramento location, event-based and season-based volume data indicate that only minor differences were observed between the three strips in reducing runoff volume, indicating that ornamental vegetation type has little impact on volume reduction. At the Yorba Linda location, event-based and season-based volume data indicate that Stations 12-348 (*S. mandraliscae*) and 12-349 (*L. montevidensis*) both performed similarly, and both occasionally performed better than Station 12-347 (*I. hayesiana*) in reducing runoff volume. It should be noted that only one data point is available for assessments at Station 12-348. Overall, there does not appear to be a standard trend to indicate whether or not volume reductions differ between strips planted with different types of ornamental vegetation.

Load

At Sacramento the *B. pilularis* strip performed the best among the three ornamental vegetation types, with loads for 23 out of 25 constituents being lower than loads for those same constituents at both the *M. parvifolium* strip and the *H. helix*. However, excellent load reductions were observed for all three ornamental vegetation types. At Yorba Linda, the strip planted with *S. mandraliscae* performed the best among the three ornamental vegetation types, with loads for almost all constituents being lower than loads for those same constituents at both the *I. hayesiana* strip and the *L. montevidensis* strip. However, good to excellent load reductions was observed at the *I. hayesiana* and *L. montevidensis* strips for some constituents.

It appears that whether or not a particular ornamental vegetation type provides exceptionally better treatment than any other types depends on the constituent of interest, as well as location-

specific characteristics such as strip width, soil type, soil composition, AADT, storm characteristics, etc.

5.4.2 Comparisons between Strips at Different Locations

Concentration

The Napa *H. helix* strips provided comparable concentration reductions for many constituents compared to the San Mateo *C. edulis* strip, better concentration reduction for many other constituents, and worse concentration reduction for one constituent. The Camarillo *C. edulis* strips provided comparable concentration reductions for many constituents compared to the Yorba Linda *I. hayesiana* strip, better concentration reduction for many other constituents, and worse concentration reduction for one constituent.

It appears that whether a particular ornamental vegetation type provides exceptionally better concentration reduction than another type depends on the constituent of interest, as well as location-specific characteristics such as strip width, soil characteristics, AADT, etc.

Volume Reduction

The Napa *H. helix* strips provided better volume reduction than the San Mateo *C. edulis* strip. The Camarillo *C. edulis* strips provided better volume reduction than the Yorba Linda *I. hayesiana* strip. However, good to excellent volume reduction was provided by all ornamental vegetation types.

Load

The Napa *H. helix* strips provided comparable load reductions compared to the San Mateo *C. edulis* strip for many constituents, and provided better load reductions for many other constituents. For most constituents, the Yorba Linda *I. hayesiana* strip provided comparable load reductions to the Camarillo *C. edulis* strips.

It appears that whether or not a particular ornamental vegetation type provides exceptionally better treatment than any other types depends on the constituent of interest, as well as location-specific characteristics such as strip width, soil type, soil composition, AADT, storm characteristics, etc.

5.5 ASSESSMENT OF VARIBILITY BETWEEN SIMILAR AND ADJACENT STRIPS IN TREATING HIGHWAY RUNOFF

As discussed in Section 4.6, an evaluation of variability between similar and adjacent strips was performed on strips with the same ornamental vegetation type and similar strip width at each of the three locations (Napa, Camarillo, and Westminster).

Overall, although differences in concentration, volume, and load reductions were observed between duplicate stations, most differences were not found to be statistically significant, or were fairly small. If this trend continues as more data becomes available, it may provide further understanding of the comparisons being conducted for other ORVTS study questions.

Concentration

Observable differences exist between the average EMCs of the two replicate strips at all three locations. However, only a handful of constituents demonstrate a statistically significant difference at a 90-percent confidence level. It may be that there are not enough data to demonstrate statistical significance. As more data becomes available, it may be appropriate to merge data from duplicate stations to better represent the variability of data from each location for future assessments.

Volume Reduction

The differences in percent volume reduction between the two replicate strips at the Napa and Westminster locations are fairly small. However, at the Camarillo location, Station 7-342 has a broader range of event-based volume reductions (47.8 to 91.1 percent) than Station 7-341 (85.7 to 95.9 percent). Station 7-341 has a much higher seasonal volume reduction of 91.2 percent than Station 7-342 (71.2 percent). These results indicate that variability exists in volume reduction between the two replicate strips at the Camarillo location. Whether or not these differences are statistically different was not assessed. Overall, good volume reductions were observed for all locations.

Load

Event-based load data indicate that large differences were observed between the two replicate strips for most constituents at all three locations. However, these differences were not statistically significant at a 90-percent confidence level.

5.6 ASSESSMENT OF VARIABILITY BETWEEN ORNAMENTAL VEGETATION AND GRASSES AND FORBS IN TREATING HIGHWAY RUNOFF

As discussed in Section 4.7, the performance of ornamental vegetation in treating highway runoff was compared to the treatment performance of grasses and forbs by comparing results from the ORVTS Study to those from two previous studies (the RVTS Study and the BMP Program). When comparing the ORVTS Study results to results from the RVTS Study locations, Sacramento and Yorba Linda were the focus. In the comparison of the ORVTS Study to the BMP Program only Carlsbad (Palomar) was evaluated.

Overall, the ORVTS Study's ornamental vegetation appears to have provided equivalent or better concentration reductions (or small concentration increases) than the grasses and forbs assessed in previous studies. The ornamental vegetation provided better volume reductions. Although load reductions were not specifically assessed, it is expected that ornamental vegetation would also provide better load reductions given their performance for concentration and volume reduction.

5.6.1 Comparison between Results from ERVTS Study and RVTS Study

The Sacramento and Yorba Linda ERVTS are located adjacent to the two previous RVTS and were assessed in terms of pollutant concentration and runoff volume. Load comparisons were not performed, but may be considered for future assessments.

Concentration

At the Sacramento location, the ERVTS strip stations planted with ornamental vegetation had comparable performances in reductions or increases of EMCs for most metals to the RVTS strip

stations planted with grasses and forbs. The ERVTS strip stations performed better than the RVTS stations in reductions of EMCs for most conventional constituents. However, the RVTS strip stations performed better than the ERVTS strip stations in reductions of EMCs for most nutrients.

At Yorba Linda, the ERVTS strip stations planted with ornamental vegetation had comparable performances in reductions or increases of EMCs for most metals to the RVTS strip stations planted with grasses and forbs. The ERVTS stations performed better in reductions of EMCs for most conventional constituents and nutrients.

Volume Reduction

At both the Sacramento and Yorba Linda locations, the ERVTS strip stations planted with ornamental vegetation performed better in seasonal volume reduction than the RVTS strip stations planted with grasses and forbs. Possible causes include differences of vegetation type, and soil characteristics.

Load

At both the Sacramento and Yorba Linda locations, load analysis was not performed and has been established as a future consideration in Section 6.

5.6.2 Comparison between Results from ORVTS Study and BMP Retrofit Pilot Program

As discussed in Section 4.7.2, the Carlsbad (Palomar) swale (originally saltgrass, but overtaken by *C. edulis* during the ORVTS Study) was compared to the same location used during the BMP Program.

Concentration

During the ORVTS Study, the Carlsbad (Palomar) swale had a comparable performance to the BMP Program in reductions or increases of EMCs for most metals and conventional constituents. The swale had larger reductions or smaller increases of EMCs for most nutrients during the ORVTS Study than during the BMP Program.

Volume Reduction

The Carlsbad (Palomar) swale appears to have performed much better in both event-based and seasonal-based volume reductions during the ORVTS Study compared to the BMP Program.

Load

At Carlsbad (Palomar) for both studies mentioned above, load analysis was not performed and has been established as a future consideration in Section 6.

SECTION 6 FUTURE CONSIDERATIONS

This report presents monitoring activities, findings, data assessments, and conclusions from the first year of monitoring (2009-2010) for the ORVTS Study. The following items may be considered for future analysis.

- As discussed in Section 4.1, the assumptions of the ANOVA were not validated, primarily due to cost-benefit considerations and because the limited data available to date were collected from only one wet season monitored thus far. Future data assessments may consider including validation of the ANOVA assumptions.
- The ANOVA tests were performed on both event-based concentration and load data, but were not performed on event-based runoff volume data. Future data assessments may consider performing such tests.
- This report includes a general comparison of performance and trends between different locations as well as comparison between locations within the same geographic area of California. Future data assessments may consider more thorough statistical comparison on concentration, volume reduction and load between locations to better identify trends. These analyses may help better determine whether it is reasonable to assume that the results obtained from the study locations can apply to other locations.
- During the 2009-2010 season, all storms that occurred throughout the season were monitored for flow and rainfall data; however, water quality samples were collected for only a select number of storms. Future assessments may include calculating cumulative volumes and load reductions using all flow and rain data from all storms for all seasons (regardless of whether water quality samples were collected or not).
- 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 event-based findings into context with respect to the representativeness of common or frequent storms that occur throughout the various study locations.
- Soil characteristics are important factors that affect the infiltration process within vegetated strips and swales. Future assessments may consider conducting tests and research to characterize soil at the vegetated strips and swales and evaluate their impact on the infiltration process.
- Further data assessments may be performed to investigate the impact of erosion within the strips/swales on water quality discharges. This investigation could lead to improvements in slope design.
- 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 studies or reporting may consider assessing total nitrogen data.

- As discussed in Section 4.7, comparisons between data from the ORVTS Study and previous studies (the RVTS Study and the BMP Program) were performed. However, more detailed and more comprehensive comparisons between the ORVTS Study and previous studies may be considered for future data assessments and reporting. Comparisons may include characteristics of storms that were monitored during the different studies/projects, along with water quality, runoff volume, volumetric runoff coefficients, and loads at the EOP and various strips/swales from the different studies/projects.
- Comparisons conducted in this study indicate than there may be substantial variability between the performance of similar and adjacent strips. Future assessments may include merging datasets for similar and adjacent strips to better capture the variations of strip performance when comparing performances between study locations.

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