Caltrans

Final Report

Roadside Vegetated Treatment Sites (RVTS) Study

CTSW-RT-03- 028

CALTRANS DIVISION OF ENVIRONMENTAL ANALYSIS

NOVEMBER 2003

Executive Summary

The Roadside Vegetated Treatment Sites (RVTS) Study was a 2-year water quality-monitoring project undertaken to evaluate the removal of storm water contaminants by existing vegetated slopes adjacent to freeways. The monitoring period encompassed two wet seasons, generally from October to April 2001-2002 and 2002-2003. The RVTS test sites are located in Sacramento, Redding, Cottonwood, San Rafael, Yorba Linda, Irvine, San Onofre, and Moreno Valley.

The primary objective of this study was to determine if standard roadway design requirements result in buffer strips with treatment equivalent to those specifically engineered for water quality performance. An additional objective was the generation of design criteria for use on new highways or when major reconstruction occurs. Variables such as length, slope, vegetation density, and hydraulic loading were evaluated by studying the runoff through existing vegetated slopes at four locations in northern California and four locations in southern California. At each location, concrete channels approximately 30 m long, were constructed to capture highway runoff after it passed through existing buffer strips of varying widths. The quantity and quality of the runoff discharged from the buffer strip was compared to that observed at the edge of pavement. The performance of each of the vegetated shoulders was evaluated in terms of the changes in concentration for constituents commonly found in highway runoff and the load reduction caused by infiltration of storm water into these areas.

Vegetation may play an important role in the concentration reduction in buffer strips by slowing the velocity of runoff, stabilizing the slope, and stabilizing accumulated sediment in the root zone of the plants. Consequently, a vegetation assessment was conducted at all the RVTS sites on a quarterly basis to characterize the vegetation condition of the test sites. The vegetation was characterized by percent vegetation cover/density, height, plant species composition, and observation on maintenance. Vegetation assessment was conducted at all sites during each season over the duration of the study. The data indicate that vegetation species and height was similar at most sites and no effect on performance was observed.

Each width of the buffer strip was evaluated for the amount of infiltration that occurred based on all events during the study period. The amount of infiltration increased with distance from the edge of pavement. Infiltration rate measurements were performed at three locations (near the edge-of-pavement, at the strip's centroid, and near the concrete collection channel) within each of the 23 biofiltration strips using a Turf-Tec Infiltrometer. Moreno Valley RVTS had the lowest infiltration rates due to the area being situated on cut soils that consistently had very high dry densities and high percentages of relative compaction.

The test sites at three of the four southern California RVTS sites had substantial gopher activity, which likely affected the stormwater sampling results. Sites with gopher activities include: Irvine, Yorba Linda, and San Onofre. The fourth site, Moreno Valley, is likely too dry to support

gophers. Gopher activities created exposed dirt mounds within the test strips and along the edges of the collection ditches resulted in increased suspended sediment concentrations. On the other hand, observations have shown that gopher activities within the test strips enhanced infiltration of runoff, thus enhancing pollutant removal. Study sites with sufficient vegetation and not overrun by gophers produced an effluent quality that was equal to or better than that observed from vegetated buffer strips engineered and operated specifically for water quality improvement.
The results of this study were compared to those obtained in the recently completed Caltrans BMP Retrofit Pilot Study in southern California that included an assessment of the performance of vegetated buffer strips. The buffer strips in the pilot study were engineered and operated specifically for water quality improvement. These sites also had a very rigorous operation and maintenance protocol that kept grass height and coverage within strict requirements. However, the improvement in water quality was no better than that observed in this study of standard roadside shoulders.

Based on evaluation of the data collected during the 2-year monitoring study it was found that a minimum vegetative cover of about 65% is required for concentration reduction to occur, although a rapid decline in performance occurs below about 80%. Concentration reductions consistently occur for TSS and total metals and frequently for dissolved metals. Concentration increases consistently for dissolved solids and occasionally for organic carbon. Nutrient concentrations were generally unchanged by the buffer strips.

A substantial load reduction is evident for all constituents even those that exhibit no change in concentration because of the low runoff coefficients at all of the sites. At sites with greater than 80% vegetation coverage, the following buffer widths result in irreducible minimum concentrations for those constituents whose concentrations decrease:

- 4.2 meters for slopes less than 10% (Redding)
- 4.6 meters for slopes greater than 10% and less than 35% (Sacramento)
- 9.2 meters for slopes between 35% and 50% (Cottonwood)

At sites with less than 80% coverage, the following buffer widths result in irreducible minimum concentrations:

- No data for slopes less than 10%
- 10 meters for slopes greater than 10% (San Onofre, San Rafael)

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1.0 Introduction

1.1 General

The Roadside Vegetated Treatment Sites (RVTS) Study was a two-year water quality monitoring project undertaken to evaluate the removal of storm water contaminants by existing vegetated slopes adjacent to freeways. The objective of this study was to determine if standard roadway design requirements result in buffer strips with treatment equivalent to those specifically engineered for water quality performance. Variables such as length, slope, vegetation density, and hydraulic loading were evaluated by studying the runoff through existing vegetated slopes at four locations in northern California and four locations in southern California. At each location, concrete channels, approximately 30 m long, were constructed to capture freeway runoff after it passes through existing biofilter strips of varying lengths (see Figure 1). The length of the biofilter strip is defined as the distance from the edge of pavement to the collection channel. The quantity and quality of the runoff in the biofilter strip was compared to freeway runoff collected at the edge of pavement. Collection channels were covered to eliminate measurement of flow generated from incidental rainfall and diluting the runoff from the road and test strips. Table 1 describes the RVTS test sites. Figure 2 shows the locations of the RVTS test sites. Table 2 presents the characteristics of the RVTS biofilter strip test sites and parameters used for the design of the collection systems. Photos of the RVTS biofilter siting, construction and monitoring can be found in Appendix E.

1.2 Monitoring Period

The monitoring period occurred over two wet seasons, generally from October to April 2001-2002 and 2002-2003. Monitoring of the RVTS sites began shortly after the completion of construction of the collection systems and installation of the monitoring equipment. The first monitoring event occurred on October 30, 2001, at San Rafael, and the last event occurred on April 15, 2003 at sites within northern and southern California. This report provides findings of the study based on the data collected during the 2-year monitoring period.

1.3 Project Locations

1.3.1 Site 1 – Sacramento, District 3

The RVTS biofilter strips are located along the I-5 northbound between Laguna Boulevard and Pocket Road at KP 21.7 in the City of Sacramento, Sacramento County in Caltrans District 3. The first 3 m of the site slope 2.2 percent from the edge of pavement followed by a 22.5 percent slope, which continues to the edge of the right-of-way. Each collection system consists of a 28-m long concrete V-ditch, constructed parallel to the northbound lanes of I-5. The V-ditches are positioned 1.1, 4.6, 6.6, and 8.4 m from the edge of pavement and adjacent to the edge of pavement (baseline). Figure 1 shows a schematic of the collection system. Photographs of each of the test sites are included in Appendix E.

Table 1. RVTS Test Sites

Site No.	Caltrans Statewide Site ID	Location	Freeway	Kilopost (Post Mile)	County	Latitude	Longitude	Caltrans District	Regional Board	Avg Annual Rainfall mm (in.)	Avg Annual Daily Trips (AADT)
1	3-213 3-214 3-215 3-216 3-217	City: Sacramento *Northbound between Pocket and Laguna Exits*	I-5	21.7 (13.5)	Sacramento	38º 26.65’	121º 29.45’	3	5b	437 (17.2)	75,000
2	2-201 2-202	City: Cottonwood *Southbound near Cottonwood Exit*	I-5	2.4 (1.5)	Shasta	34º 46.98’	137º 26.97’	2	5a	1001 (39.4)	38,500
3	2-203 2-204 2-205 2-206	City: Redding *Eastbound near Old Oregon Trail/Shasta College Exist*	SR-299	42.0 (26.0)	Shasta	34º 59.19’	137º 32.4’	2	5a	1001 (39.4)	11,800
4	4-213 4-214	City: San Rafael *Northbound at St. Vincent on-ramp*	I-101	24.0 (15.0)	Marin	38º 1.53’	122º 32.27’	4	2	912 (35.9)	151,000
5	12-225 12-226 12-227 12-228 12-229	City: Yorba Linda *Eastbound between Weir Canyon Road and SR-241 Exits*	SR-91	24.0 (15.0)	Orange	33º 52.23’	117º 44.18’	12	8	358 (14.1)	226,000
6	12-230 12-231 12-232 12-233	City: Irvine *Northbound at Sand Canyon Ave off-ramp*	I-405	4.0 (2.5)	Orange	33º 39.43’	117º 46.58’	12	8	325 (12.8)	237,000
7	8-201 8-202 8-203 8-204 8-205	City: Moreno Valley *Eastbound at Fredrick St. on-ramp*	SR-60	22.0 (14.0)	Riverside	33º 56.48’	117º 16.38’	8	8	262 (10.3)	106,000
8	11-204 11-205 11-206 11-207	City: San Onofre *Northbound near Basilone Exit*	I-5	113.3 (70.4)	San Diego	33º 22.81’	117º 34.12’	11	9	262 (10.3)	124,000

a Source: Western Regional Climate Center

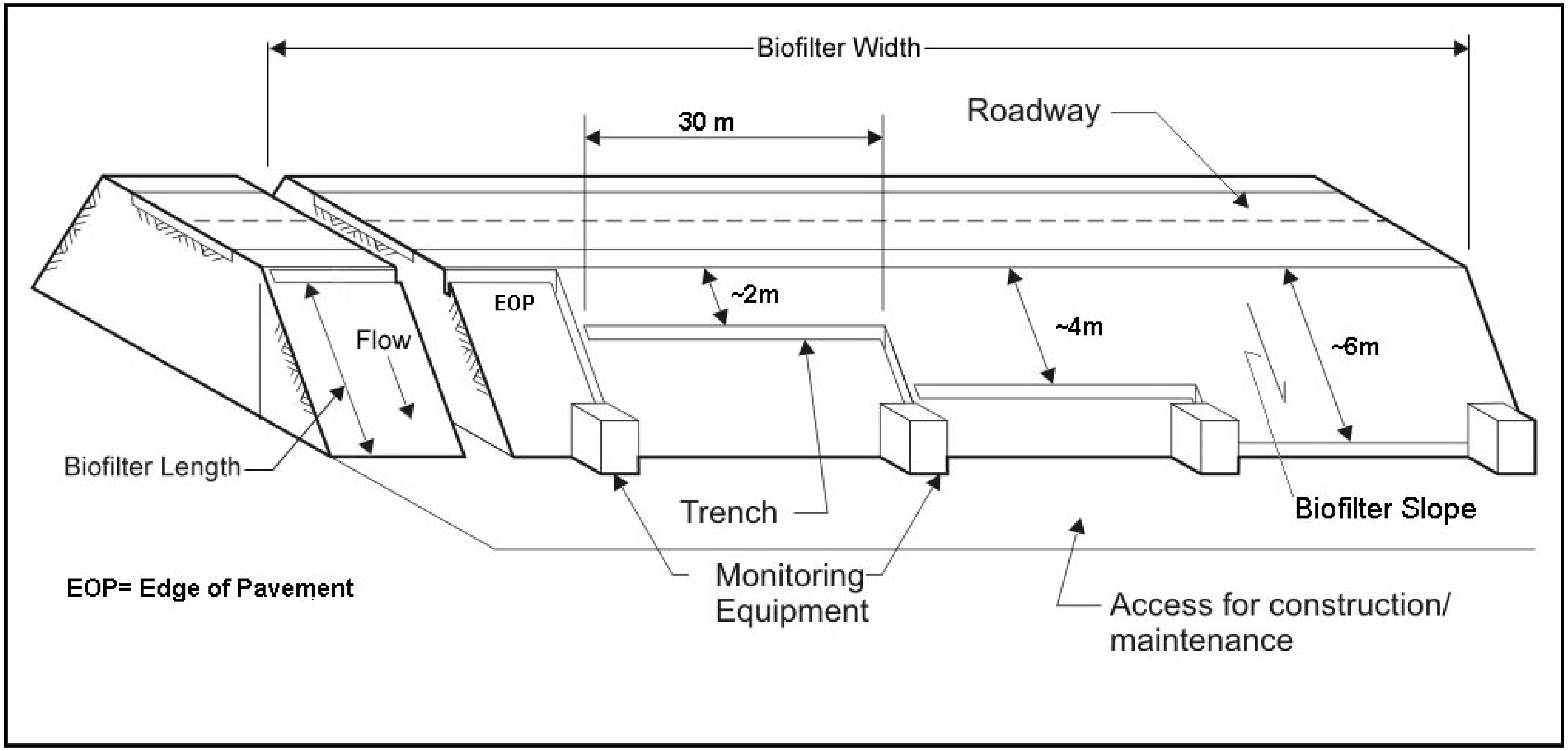

Figure 1. Schematic of Test Site

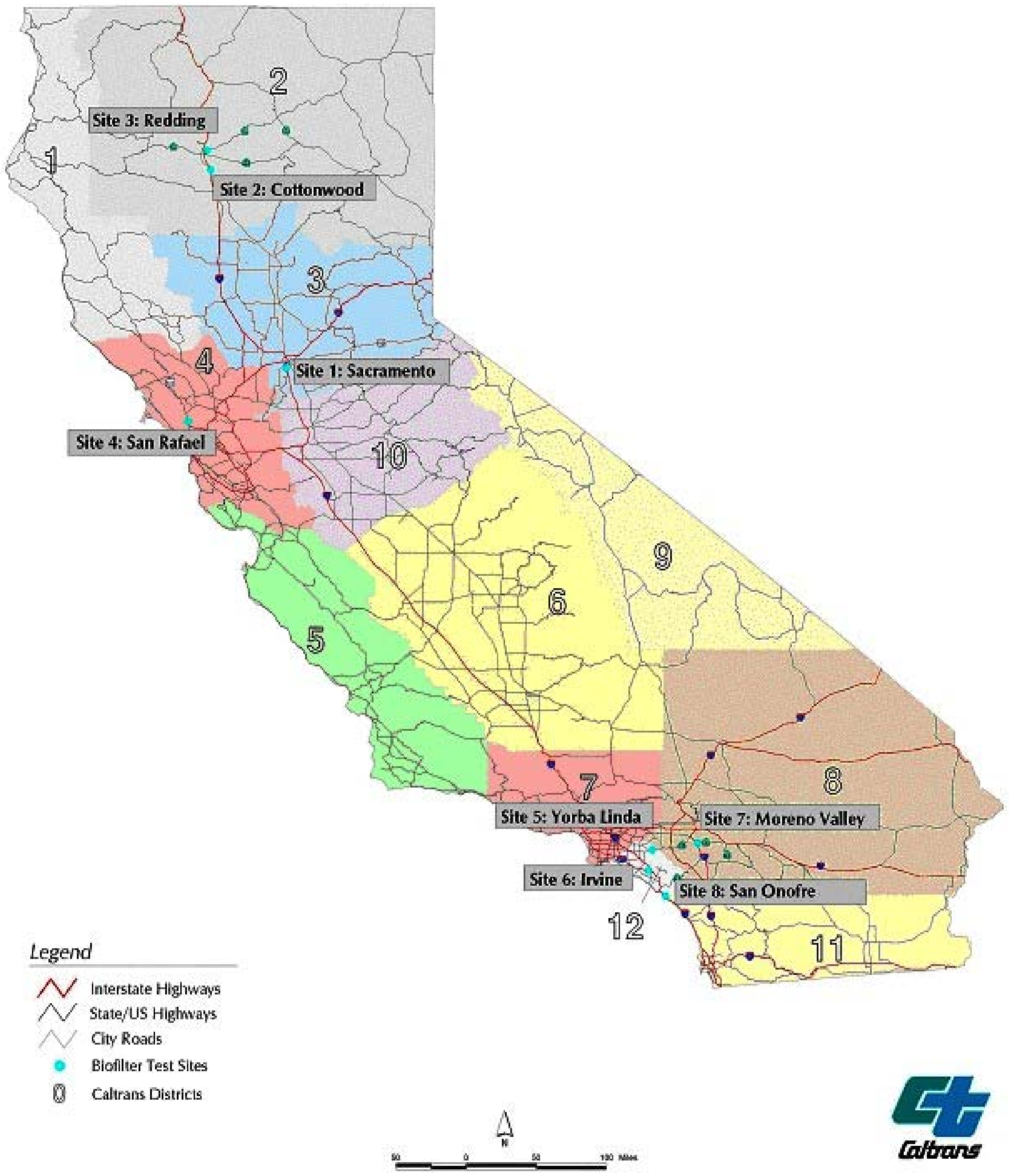

Figure 2. RVTS Biofilter Test Site Map

1.3.2 Site 2 – Cottonwood, District 2

The RVTS biofilter strip is located along the I-5 southbound at the Gas Point Road exit in the City of Cottonwood, County of Shasta at KP 2.4 located in Caltrans District 2. The site has a 50-percent slope. The collection system consists of a 27.5-m long concrete V-ditch, constructed parallel to the southbound lanes of I-5. The V-ditch is positioned 9.3 m from the edge of pavement and adjacent to the edge of pavement (baseline).

1.3.3 Site 3 – Redding, District 2

The RVTS biofilter strips are located along the SR-299 eastbound between Churn Creek Road and Old Oregon Trail/Shasta College exits in the City of Redding, County of Shasta at KP 42.0. This site is located in Caltrans District 2. The site has a 10-percent slope. The collection systems consist of 26.5-m long concrete V-ditches, constructed parallel to the eastbound lanes of SR-299. The V-ditches are positioned 2.2, 4.2, and 6.2 m from the edge of pavement and adjacent to the edge of pavement (baseline).

1.3.4 Site 4 – San Rafael, District 4

The RVTS biofilter strip is located along the US-101 northbound before the St Vincent Road exit at KP 24.0 in the City of San Rafael, County of Marin in Caltrans District 4. The site has a 50-percent slope. The collection system consists of a 21-m long concrete V-ditch, constructed parallel to the northbound lanes of US-101. The V-ditch is positioned 9.3 m from the edge of pavement and adjacent to the edge of pavement (baseline).

1.3.5 Site 5 – Yorba Linda, District 12

The RVTS biofilter strips are located along the SR-91 eastbound, between Weir Canyon and SR-241 exits in the City of Anaheim, County of Orange at KP 24.0. This site is located in Caltrans District 12. The site has a 14-percent slope. The collection system consists of a 30-m long concrete V-ditches, constructed parallel to the eastbound lanes of SR-91. The V-ditches are positioned 2, 4, 7.6 and 13 m from the edge of pavement and adjacent to the edge of pavement (baseline).

1.3.6 Site 6 – Irvine, District 12

The RVTS biofilter strips are located along the I-405 northbound at the Sand Canyon exit in the City of Irvine, County of Orange at KP 4.0 in Caltrans District 12. The site has an 11-percent slope. The collection systems consist of 19-m long concrete V-ditches, constructed parallel to the northbound lanes of I-405. The V-ditches are positioned 3, 6, and 13 m from the edge of pavement and adjacent to the edge of the pavement (baseline).

1.3.7 Site 7 – Moreno Valley, District 8

The RVTS biofilter strips are located along the SR-60 eastbound just before the Frederick exit in the City of Moreno Valley, County of Riverside at KP 22.0 located in Caltrans District 8. The site has a 13-percent slope. The collection system consists of 24-m long concrete V-ditches, constructed parallel to the eastbound lanes of SR-60. The V-ditches are positioned 2.6, 4.9, 8.0 and 9.9 m from the edge of pavement and adjacent to the edge of pavement (baseline).

1.3.8 Site 8 – San Onofre, District 11

The RVTS biofilter strips are located along the I-5 northbound before the Basilone exit in the County of San Diego, County of San Diego at KP 113.3 located in Caltrans District 11. The site has an 8- to 16-percent slope. The collection systems consist of 24-m long concrete V-ditches, constructed parallel to the northbound lanes of I-5. The V-ditches are positioned 1.3, 5.3 and 9.9 m from the edge of pavement and adjacent to the edge of pavement (baseline).

Table 2. Characteristics of RVTS Test Sites

Site	System	Collection Ditch Design Rainfall Intensity [a] (mm/hr)	Slope	Drainage Area [b] (m^2)	Strip Length (m)	Strip Width (m)	Hydrologic Soil Type [c]
Sacramento		38.9					D
	System 1		EP	362	0.0	22.5	
	System 2		5%	390	1.1	22.5	
	System 3		33%	478	4.6	22.5	
	System 4		33%	549	6.6	22.5	
	System 5		33%	580	8.4	22.5	
Cottonwood		58.9					C
	System 1		EP	755	0.0	27.5	
	System 2		52%	546	9.3	27.5	
Redding		60.7					C
	System 1		EP	295	0.0	26.5	
	System 2		10%	372	2.2	26.5	
	System 3		10%	425	4.2	26.5	
	System 4		10%	478	6.2	26.5	
San Rafael		43.4					C/D
	System 1		EP	1324	0.0	21.5	
	System 2		50%	2919	8.3	21.5	
Yorba Linda		48.5					B
	System 1		EP	910	0.0	30	
	System 2		14%	1080	2.3/1.4 [d]	30	
	System 3		14%	1160	5.4/4.4 [d]	30	
	System 4		14%	1090	7.6	30	
	System 5		14%	1843	13.0	30	
Irvine		55.4					B
	System 1		EP	368	0.0	19	
	System 2		11%	486	3.0	19	
	System 3		11%	419	6.0	19	
	System 4		11%	873	13.0	19	
Moreno Valley		38.1					C
	System 1		EP	370	0.0	24	
	System 2		13%	460	2.6	24	
	System 3		13%	520	4.9	24	
	System 4		13%	610	8.0	24	
	System 5		13%	670	9.9	24	
San Onofre		57.2					B/C
	System 1		EP	638	0.0	24	
	System 2		8%	560	1.3	24	
	System 3		10%	700	5.3	24	
	System 4		16%	840	9.9	24	

[a] Rainfall Intensity based upon 10-year 15-min event.

[b] Drainage Area includes road and test strip area.

[c] United States Department of Agriculture, Soil Conservation Service and Forest Service, 1993.Soil Survey of Sacramento County (1993), Shasta County (1967), Marin County (1985), Orange County and Western Part of Riverside County (1978), San Diego Area (1973), California

[d] Strip Length varies (lengths provided at ends of the test plots)

2.0 Hydrology

The sections that follow describe the RVTS site hydrological characteristics as observed during the monitored storm events of the 2001/2002 and 2002/2003 wet weather seasons.

2.1 Precipitation During the Wet Season

The normal seasonal rainfall for the southern California sites ranges from 262 mm to 358 mm. The normal seasonal rainfall for the northern California selected sites ranges from 437 mm to 1000 mm. Generally, most precipitation falls between November 1 and April 30 in both northern and southern California. Between October 2001 and April 2002, approximately 100 mm (4.0 in.) of precipitation fell in southern California and approximately 840 mm (33.0 in.) of precipitation fell in northern California. Between October 2002 and April 2003, approximately 250 to 350 mm (10 to 14 in.) of precipitation fell in southern California and approximately 300 to 910 mm (12 to 36 in.) of precipitation fell in northern California. Figure 3 shows a comparison of total rainfall at each test site compared to average annual rainfall.

The number of sampling events ranged from nine at Yorba Linda in southern California to 26 sampling events at the San Rafael site in northern California. Table 3 summarizes the number of samples obtain at each test site.

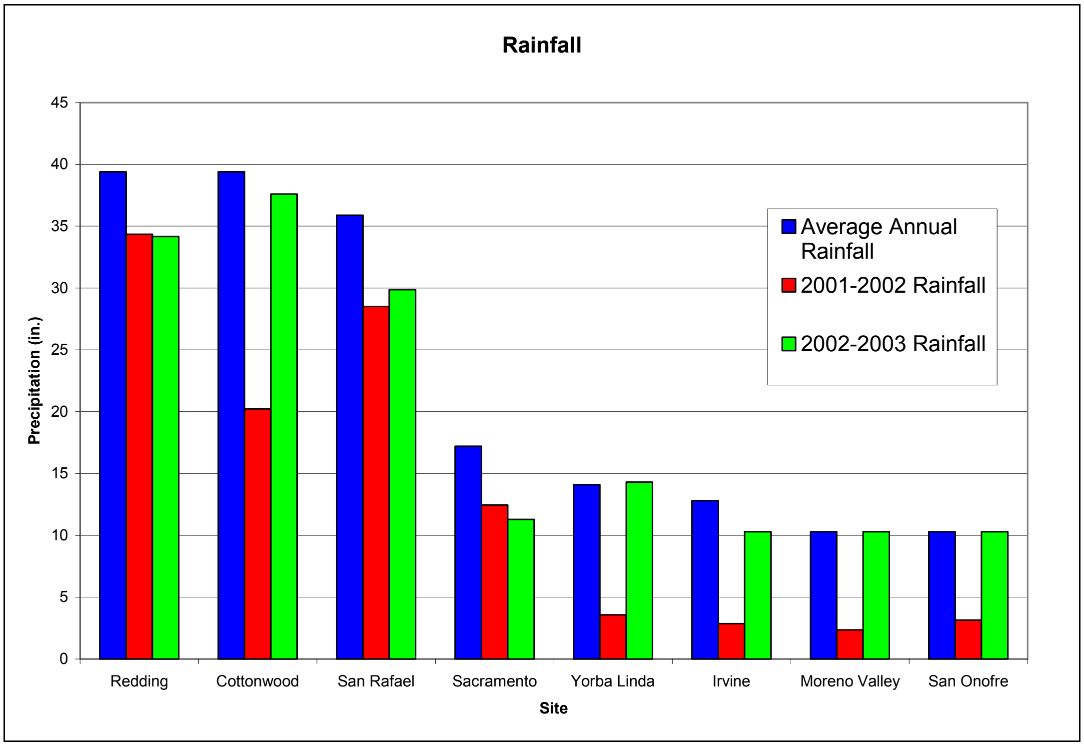

Figure 3. Annual Rainfall at Test Sites

Table 3. Number of Successfully Sampled Storms

Site	System No.	Length m	2001-2002	2002-2003	Total
Sacramento	1	0.0	16	5	21
Sacramento	2	1.1	15	5	20
Sacramento	3	4.6	13	2	15
Sacramento	4	6.6	11	2	13
Sacramento	5	8.4	13	2	15
Cottonwood	1	0.0	14	7	21
Cottonwood	2	9.3	13	4	17
Redding	1	0.0	14	7	21
Redding	2	2.2	11	7	18
Redding	3	4.2	13	5	18
Redding	4	6.2	11	6	17
San Rafael	1	0.0	18	5	23
San Rafael	2	8.3	16	4	20
Yorba Linda	1	0.0	3	9	12
Yorba Linda	2	2.3/1.4	2	8	10
Yorba Linda	3	5.4/4.4	1	9	10
Yorba Linda	4	7.6	2	4	6
Yorba Linda	5	13.0	0	4	4
Irvine	1	0.0	7	5	12
Irvine	2	3.0	1	5	6
Irvine	3	6.0	0	1	1
Irvine	4	13.0	0	4	4
Moreno Valley	1	0.0	1	7	8
Moreno Valley	2	2.6	1	7	8
Moreno Valley	3	4.9	1	7	8
Moreno Valley	4	8.0	1	7	8
Moreno Valley	5	9.9	1	7	8
San Onofre	1	0.0	8	8	16
San Onofre	2	1.3	4	8	12
San Onofre	3	5.3	2	8	10
San Onofre	4	9.9	0	6	6
Total			**213**	**175**	**388**

EP - Edge of Pavement

2.2 Precipitation During the Monitored Events

Precipitation during each storm event was characterized by total rainfall, duration of rainfall, days since last rainfall and antecedent rainfall. Precipitation characteristics for each monitored event are provided in Appendix B. Most sampled storm events were preceded by at least 24 hr without rainfall, meeting the minimum required antecedent dry period. The desired minimum required antecedent dry period for the study is 72 hr.

2.3 Storm Water Runoff During Monitored Events

Monitoring was designed to isolate rainfall events and the runoff created by those events. For information on the monitoring equipment and methods, refer to the RVTS Sampling Analysis Plan (Caltrans, 2001 and Caltrans, 2002).

A summary of the runoff measured at each monitoring station in conjunction with each storm event is provided in Appendix B. Hydrographs for each storm event at each system are provided in Appendix A (Enclosed CD-ROM). These hydrographs also show when the individual aliquots of each composite sample were collected.

The highway drainage areas at each RVTS site are relatively small and impervious. This results in quick response times at the edge of pavement system in relation to the arrival of rain and fluctuations in rainfall intensity. For the most part, the RVTS biofilter strips responded in a delayed manner to the inlet flow, and in some cases, there was a lack of response due to infiltration.

Flow monitoring was conducted during each monitored storm event and continually throughout the storm season at each of the RVTS biofilter strips. Flow was measured using bubbler flow meters in conjunction with trapezoidal flumes. During several events, particularly in southern California, flow did not discharge through the biofilter strips due to infiltration.

3.0 Analytical Results

3.1 Assessment of Quality Assurance/Quality Control Results

Overall, data quality met program objectives during the two years of monitoring. The 2001/2002 monitoring effort resulted in 5,727 chemical measurements. Of these, 220 values (3.8 percent) required data qualifications. Forty-two of the 220 values (0.7 percent) were rejected data points due to evidence of either presence of worms in the samples or nitric acid contamination from the bottle cleaning process. One hundred forty-nine (2.6 percent) data points were assigned "J" values (value estimated). The majority of the "J" qualifiers were attributable to holding-time violations for nutrients and a low bias on accuracy of the TOC and DOC measurements. TDS was the only commonly found contaminant in equipment blanks. The presence of TDS in equipment blanks resulted in elevation of detection limits for 10 percent of the measured values. The 2002/2003 monitoring effort resulted in 6,232 chemical measurements. Data quality review indicates that laboratory results met the overall quality objectives of the program. All constituent results are appropriate for use in the RVTS performance evaluation. Any constituent reported as non-detect (Numerical Qualifier "<") received an Overall qualification of "U" in the absence of laboratory quality control qualification. Refer to Appendix D for the QA/QC data assessment.

3.2 Water Quality Procedures

A laboratory certified under the California Environmental Laboratory Accreditation Program (ELAP) conducted the storm water analyses. The analyses were performed in accordance with methods and procedures outlined in the Sampling Analysis Plans (Caltrans, 2001 and 2002), the Guidance Manual: Stormwater Monitoring Protocols (Caltrans, 2000) and as specified by applicable EPA methods. The laboratory analyses performed and the methods and reporting limits used on the storm water composite samples are listed in Table 4. Analytical results are summarized in Appendix C.

Table 4. Analytical Methods Summary

Analyte	Analytical Procedure	Reporting Limits
Conventionals		
Hardness as $CaCO_3$	EPA 130.2	1 mg/L
TDS	EPA 160.1	1 mg/L
TSS	EPA 160.2	1 mg/L
Conductivity	EPA 120.1	0.1 umho/cm
Temperature	EPA 170.1	0.1 °C
pH	EPA 150.1	0.1 units
TOC	EPA 415.1	1 mg/L
DOC	EPA 415.1	1 mg/L
Nutrients		
Ammonia	EPA 350.3	0.1 mg/L
Nitrate as Nitrogen (NO_3-N)	EPA 300.0	0.5 mg/L
TKN	EPA 351.3	0.1 mg/L
Total Phosphorus	EPA 365.2	0.03 mg/L
Dissolved Orthophosphate	EPA 365.2	0.01 mg/L
Metals (Total and Dissolved)		
Arsenic	EPA 206.3	0.5 µg/L
Cadmium	EPA 200.8	0.2 µg/L
Chromium	EPA 200.8	1 µg/L
Copper	EPA 200.8	1 µg/L
Iron [a]	EPA 236.1	1 µg/L
Lead	EPA 200.8	2 µg/L
Nickel	EPA 200.8	5 µg/L
Zinc	EPA 200.8	10 µg/L

[a] Iron is being tested at the District 2 sites only.

4.0 RVTS Biofilter Strip Performance Evaluations

The performance of each of the vegetated shoulders was evaluated in terms of the changes in concentration for constituent commonly found in highway runoff and the load reduction caused by infiltration of stormwater into these areas. Each of these elements is described in detail in the following sections.

4.1 Changes in Constituent Concentrations

The results of the chemical monitoring program were analyzed statistically using a multi-tiered approach. The first statistical treatment applied to the dataset was the construction of skeletal boxplots for the identification of outliers. Observations that fell beyond 1.5 * (Inter-quartile range) were examined individually, and either retained or discarded on the basis of physical location and precedent. As with any outlier determination, the judgment of the analysts plays a key role in this process. A full listing of eliminated points can be found in Appendix C. An example of a typical discarded point would be a value 10 or more standard deviations above its mean as well as the means of any preceding or subsequent samples. Note that for a Gaussian distribution 95.4% of all observations fall within plus or minus 2 standard deviations from the sample mean. Therefore, it is assumed that observations substantially beyond plus or minus 2 standard deviations are affected by any number of error sources commonly found in environmental sampling and analysis.

The next step in the data analysis was the determination of parameter-specific summary statistics for each length at each sample location. Arithmetic mean, median, range, standard deviation, and coefficient of variation were initially calculated. In general, the minimum variance unbiased estimator (MVU) is viewed as the best indicator of a population's mean if its coefficient of variation < 1.2 (Gilbert, 1987). Accordingly, the coefficients of variation were examined, and found to be generally below the 1.2 threshold. In cases where the coefficient of variation < 1.2 and the underlying distribution is either normal or lognormal, the arithmetic mean is the most accurate indicator of the population's mean (Koch and Link, 1980). Therefore the arithmetic mean can be accepted as a satisfactory estimate for the population means for each of the constituents in our dataset.

Step three in this investigation was the application of analysis of variance (ANOVA) to the dataset. The purpose of this is to determine whether statistically significant differences exist between levels of contaminants at different lengths within the BMP locations, and whether steady state concentrations were achieved at any length away from the edge of pavement.
The edge of pavement concentrations for all constituents at each site were compared to average highway runoff quality (Caltrans, 2003a) to determine if the runoff being treated at these test sites was representative. Average concentrations at 6 of the 8 sites were within one standard deviation of the average concentration for highway runoff. Table 5 summarizes the concentrations at each

site compared to mean highway runoff. Edge of pavement concentration at Moreno Valley exceeded the statewide average for dissolved zinc. At Irvine, the average concentration was exceeded for arsenic (total and dissolved), dissolved copper, and dissolved nickel. Consequently, it can be concluded that the vast majority of the runoff being treated at the test sites is similar to Caltrans runoff statewide.

There are a number of possible measures of performance of stormwater BMPs. The two most common measures report performance as removal efficiency (i.e., a percentage change between the influent and effluent quality) or focus on the effluent quality achieved. A boxplot of observed TSS data at Sacramento is presented in Figure 4 and suggests that an irreducible minimum concentration occurs that is relatively insensitive to concentrations at the edge of pavement. Consequently, the primary comparison among the sites in this report will focus on determining the minimum concentration for each site and the distance at which it firsts becomes manifest.

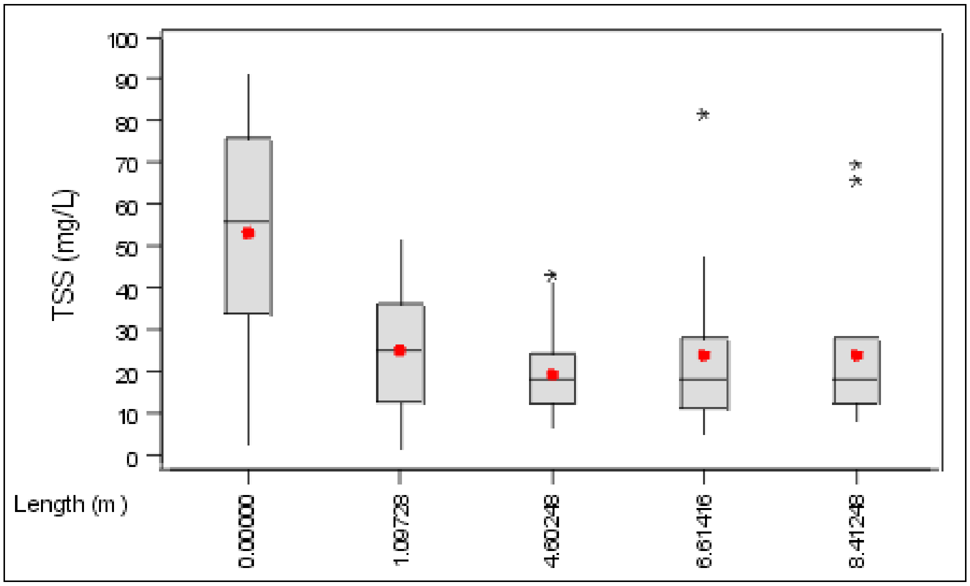

Figure 4. Boxplot of TSS EMCs at Sacramento

Table 5. Concentrations for Each Location Compared to Mean Highway Runoff

Parameter	Mean[a]	Std Dev	Sacramento	Cottonwood	Redding	San Rafael	Irvine	Moreno Valley	San Onofre	Yorba Linda
DOC	19.8	29.0	8.3	11.5	5.3	15.4	37.1	26.4	28.5	18.4
TOC	21.0	28.0	8.9	12.2	8.3	17.0	39.9	31.0	31.4	20.2
TDS	177.6	563.0	63.9	76.3	30.8	76.0	343.3	67.4	117.7	70.5
TSS	147.3	310.7	63.0	95.2	47.7	84.8	130.8	74.7	105.7	120.9
NO3	1.1	2.0	0.6	1.1	0.5	2.8	2.7	0.9	1.5	0.9
Ortho P	0.1	0.2	0.2	0.1	0.03	0.1	0.3	0.2	0.1	0.1
TKN	2.3	2.4	1.7	1.9	1.3	3.1	3.7	3.6	2.5	2.3
Total P	0.4	0.7	0.4	0.2	0.1	0.2	0.5	0.6	0.4	0.3
Dissolved As	1.06	1.53	0.9	0.7	0.7	0.6	6.8	1.6	1.5	1.2
Total As	1.99	2.43	1.5	0.9	0.7	0.8	9.8	6.6	3.7	3.8
Dissolved Cd	0.24	0.37	0.3	0.3	0.2	0.2	0.4	0.2	0.4	0.3
Total Cd	0.84	1.37	0.6	0.8	0.4	0.6	1.6	0.4	1.3	0.1
Dissolved Cr	2.9	3.8	14.6	1.5	1.3	2.8	6.4	3.2	3.9	3.2
Total Cr	9.3	10.6	18.2	4.3	1.7	5.3	12.1	5.2	7.5	7.1
Dissolved Cu	15.2	16.4	4.1	12.0	2.8	16.3	35.5	25.5	25.9	17.0
Total Cu	48.1	412.5	13.2	33.1	5.8	37.7	84.4	37.6	59.4	43.2
Dissolved Ni	4.5	5.6	2.3	3.2	2.2	4.0	11.3	5.8	7.5	5.0
Total Ni	11.4	17.3	4.0	4.5	2.7	7.0	17.6	7.2	64.6	13.1
Dissolved Pb	5.4	25.7	1.0	1.4	1.0	1.2	11.7	2.6	16.4	5.6
Total Pb	62.6	164.5	4.5	14.4	3.5	15.4	86.2	8.5	67.1	23.7
Dissolved Zn	72.2	115.3	14.8	41.4	15.8	43.5	79.8	261.4	77.9	137.6
Total Zn	208.3	223.4	74.3	130.9	39.0	119.7	290.3	351.2	279.5	329.8

It is also noteworthy that the relationship between width of the RVTS and resulting constituent concentrations are nonlinear. The TSS concentration changes very rapidly at first and then stabilizes at an average of about 20 mg/L. Other constituents whose concentrations decrease exhibit a similar tendency.

The following tables contain the summary statistics (arithmetic mean, range, and standard deviation) of the monitoring data collected at each of the RVTS sites. The rows have been color coded to indicate whether the observed concentrations (at various distances from the edge of pavement (EOP)) exhibit statistically significant increases (shown in red) or decreases (shown in green) in concentration. If the colored cell is located at the far right then the lowest/highest concentration occurs at the greatest distances from the edge of pavement. If multiple cells are colored, such as for TSS in Table 6, then the lowest concentration occurs at the distance of the first colored cell (4.2 m) and no further statistically significant change occurs at greater distances. Constituents in rows with no colored cells did not exhibit any statistically significant change in concentration at the test site.

Summary statistics of the monitoring data for Sacramento are presented in Table 6. For the constituents exhibiting a statistically significant decrease in concentration, the lowest concentration for all is achieved within 4.6 meters and those that increase again achieve their highest concentration at the most distant monitoring site. One significant difference at this site is that the concentration of arsenic, both total and dissolved, increases consistently across the RVTS resulting in concentrations that are much greater than at EOP, indicating that the soil at that site is a likely source of arsenic. No change in nutrient concentrations could be demonstrated at this site and this is typical for the other sites as well.

Table 6. Summary Statistics of EMCs at Sacramento

Constituent	**EOP Mean Range Std. Dev.**	**1.1 m Mean Range Std. Dev.**	**4.6 m Mean Range Std. Dev.**	**6.6 m Mean Range Std. Dev.**	**8.4 m Mean Range Std. Dev.**
Specific Conductivity (µmhos/cm)	89 33 - 265 51	89 34 - 181 40	107 46 - 145 34	133 36 - 240 51	193 35 - 365 98
Hardness (mg/L)	31 2 - 46 10	33 23 - 49 7	45 16 - 110 24	53 24 - 160 42	79 20 - 200 61
TSS (mg/L)	53 2 - 92 24	25 1 - 52 14	19 6 - 43 11	24 5 - 82 21	24 8 - 70 19
TDS (mg/L)	64 32 - 170 33	57 1 - 120 31	99 49 - 150 33	135 82 - 250 45	153 58 - 300 92
TOC (mg/L)	8.7 2 - 21 5.4	11 3 -23 6.2	13 5 - 25 5.9	13 3 - 30 7.9	16 2 - 32 9.1
DOC (mg/L)	8.6 4 - 23 5.2	9.7 1 - 19 5.2	13 5 - 25 5.1	13 4 - 26 7.0	15 2 - 24 7.1

Constituent	**EOP** **Mean** **Range** **Std. Dev.**	**1.1 m** **Mean** **Range** **Std. Dev.**	**4.6 m** **Mean** **Range** **Std. Dev.**	**6.6 m** **Mean** **Range** **Std. Dev.**	**8.4 m** **Mean** **Range** **Std. Dev.**
Total As (µg/L)	1.1 0.6 - 1.6 0.28	1.3 0.7 - 2.4 0.49	3.5 0.9 - 8.1 2.0	4.1 1 - 11 3.7	4.5 0.7 - 13 4.0
Total Cd (µg/L)	0.53 0.2 - 1.6 0.37	0.36 0.2 - 0.8 0.20	0.25 0.2 - 0.9 0.18	0.64 0.2 - 1.8 0.52	0.31 0.2 - 1.1 0.24
Total Cr (µg/L)	17 1 - 49 13	17 2 - 63 18	21 3 - 71 23	29 5 - 76 25	21 5 - 66 19
Total Cu (µg/L)	12 3 - 26 6.4	8.5 2 - 16 4.2	6.3 2 - 19 3.9	6.0 2 - 13 3.1	6.0 3 - 10 2.5
Total Pb (µg/L)	4.0 0.5 - 8.8 2.7	2.2 1.0 - 4.6 1.3	1.6 1.0 - 6.0 1.4	1.5 1.0 - 3.9 0.88	1.3 1.0 - 3.9 0.77
Total Ni (µg/L)	3.9 2.0 - 7.8 1.7	3.0 2.0 - 4.6 0.84	2.7 2.0 - 5.8 0.98	3.5 2.0 - 7.4 1.6	3.4 2.0 - 7.8 1.5
Total Zn (µg/L)	65 5 - 170 41	34 8 - 65 17	26 10 - 100 22	30 7 - 63 18	21 5 - 67 17
Dissolved As (µg/L)	0.84 0.5 - 2.4 0.42	1.1 0.6 - 3.4 0.63	2.6 0.7 - 6.3 1.8	3.4 0.7 - 8.3 2.7	3.7 0.5 - 10 3.5
Dissolved Cd (µg/L)	0.25 0.2 - 0.5 0.09	0.24 0.2 - 0.5 0.09	0.25 0.2 - 1.0 0.21	0.32 0.2 - 0.9 0.22	0.24 0.2 - 0.6 0.11
Dissolved Cr (µg/L)	14 1 - 54 13	14 2 - 56 16	18 1 - 63 19	24 1 - 59 21	14 1 - 40 12
Dissolved Cu (µg/L)	4.0 1.4 - 11 2.4	4.3 1.0 - 10 2.5	3.5 1.0 - 9.3 2.1	3.4 1.0 - 11 2.7	4.2 1.0 - 9.8 2.7
Dissolved Pb (µg/L)	1.0 none 0.0	1.0 1.0 - 1.4 0.09	1.0 1.0 - 1.4 0.10	1.0 none 0.0	1.0 none 0.0
Dissolved Ni (µg/L)	2.3 2.0 - 4.3 0.58	2.4 2.0 - 3.7 0.58	2.2 2.0 - 2.7 0.27	2.7 2.0 - 6.7 1.4	2.9 2.0 - 4.8 0.99
Dissolved Zn (µg/L)	14 5 - 40 11	17 5 - 41 13	12 5 - 29 8.3	8.5 5 - 28 6.9	7.9 5 - 23 6.1
NO3-N (mg/L)	0.44 0.1 - 1.2 0.35	0.35 0.07 - 0.72 0.21	0.25 0.02 - 0.72 0.23	0.45 0.08 - 0.87 0.26	0.46 0.1 - 1.6 0.44
TKN (mg/L)	1.7 0.7 - 4.3 1.1	1.5 0.5 - 2.9 0.61	1.5 0.8 - 3.3 0.68	1.8 1.1 - 3.6 0.74	1.5 0.7 - 2.7 0.57
Total P (mg/L)	0.40 0.03 - 1.7 0.37	0.27 0.03 - 0.62 0.14	0.35 0.09 - 0.60 0.15	0.34 0.08 - 1.1 0.28	0.26 0.08 - 0.55 0.15
Dissolved P (mg/L)	0.17 0.03 - 0.41 0.11	0.21 0.08 - 0.45 0.12	0.25 0.05 - 0.43 0.12	0.17 0.03 - 0.37 0.12	0.17 0.03 - 0.44 0.14

Table 7 presents the results of the statistical analysis at Redding. Performance at this site is very similar to that observed at Sacramento despite the differences in the physical characteristics of the two sites. However more constituents are observed to change concentration at the Redding site. The RVTS in Redding cause significant reduction of the EMCs of TSS and many of the metals. Removal of the total form of the metals is generally more consistent than the dissolved forms. Note that for the constituents showing a reduction in concentration, an irreducible minimum concentration occurs for all constituents by 4.2 meters and no further reduction occurs at greater distances. A number of constituents exhibit increases including dissolved solids, organic carbon, and phosphorus. The concentrations of each of these constituents continuously increases across the width of the vegetated area, achieving the highest observed concentrations at the furthest monitoring point from EOP. Based on this assessment 4.2 meters may be the optimum width for the RVTS since the lowest concentration for those constituents has been achieved and less increase would be observed for the others.

Table 7. Summary Statistics of EMCs at Redding

Constituent	EOP Mean Range Std. Dev.	2.2 m Mean Range Std. Dev.	4.2 m Mean Range Std. Dev.	6.2 m Mean Range Std. Dev.
Specific Conductivity (µmhos/cm)	36 9 - 226 49	69 20 - 139 31	58 9 - 88 19	78 40 - 170 38
Hardness (mg/L)	14 2 - 44 11	37 14 - 64 14	32 2 - 62 12	41 20 - 72 14
TSS (mg/L)	49 8 - 260 55	26 1 - 220 50	5.0 1 - 22 5.2	10 1 - 54 15
TDS (mg/L)	27 1-150 35	47 6 - 96 28	42 6 - 90 25	79 6 - 190 53
TOC (mg/L)	7.3 1 - 23 6.2	12 2 - 29 8.9	11 3 - 20 5.6	19 8 - 33 8.7
DOC (mg/L)	6.3 2 - 25 5.7	11 3 - 25 6.9	9.7 3 - 19 5.5	20 5 - 86 19
Total As (µg/L)	0.68 0.5 - 1.0 0.24	0.79 0.5 - 1.2 0.27	0.64 0.5 - 1.0 0.23	0.76 0.5 - 1.7 0.34
Total Cd (µg/L)	0.41 0.2 - 1.2 0.32	1.2 0.2 - 9.4 2.5	0.21 0.2 - 0.3 0.02	0.44 0.2 - 2.0 0.50
Total Cr (µg/L)	1.8 1 - 5.4 1.2	1.4 1 - 3.1 0.72	1.2 1 - 2.4 0.35	1.1 1 - 1.9 0.28
Total Cu (µg/L)	5.8 1.5 - 18 4.1	4.6 1.5 - 18 3.9	2.4 1 - 4.9 1.2	4.5 1.2 - 16 3.5
Total Fe (µg/L)	505 50 - 1700 480	205 32 - 730 182	68 25 - 150 34	131 25 - 277 91
Total Pb (µg/L)	3.5 1 - 13	4.0 1 - 13	1.4 1 - 5.5	1.8 1 - 6.1

Constituent	**EOP** **Mean** **Range** **Std. Dev.**	**2.2 m** **Mean** **Range** **Std. Dev.**	**4.2 m** **Mean** **Range** **Std. Dev.**	**6.2 m** **Mean** **Range** **Std. Dev.**
	2.9	3.8	1.2	1.6
Total Ni (µg/L)	2.7 2 - 7 1.3	2.5 2 - 6.9 1.2	2.1 2 - 4.1 0.5	2.6 2 - 6 1.0
Total Zn (µg/L)	39 7 - 130 30	12 6 - 25 6.2	10 5 - 32 7.1	20 5 - 110 28
Dissolved As (µg/L)	0.67 0.5 - 1.0 0.24	0.69 0.5 - 1.0 0.25	0.64 0.5 - 1.0 0.23	0.70 0.5 - 1.0 0.25
Dissolved Cd (µg/L)	0.23 0.2 - 0.76 0.13	0.38 0.2 - 2.4 0.56	0.2 none 0.0	0.22 0.2 - 0.57 0.09
Dissolved Cr (µg/L)	1.28 1 - 3.6 0.68	1.1 1 - 1.6 0.17	1.1 1 - 2 0.25	1.0 1 - 1.4 0.11
Dissolved Cu (µg/L)	2.8 1 - 12 2.8	1.9 1 - 4.1 1.0	1.8 1 - 4.1 1.0	2.6 1 - 6.7 1.7
Dissolved Fe (µg/L)	164 25 - 753 206	149 25 - 470 135	85 25 - 300 78	106 25 - 510 117
Dissolved Pb (µg/L)	1.0 1 - 1.4 0.09	1.0 1 - 1.3 0.07	1.0 none 0.0	1.0 none 0.0
Dissolved Ni (µg/L)	2.2 2 - 4.3 0.57	2.3 2 - 6.1 0.98	2.2 2 - 3.7 0.46	2.4 2 - 5.1 0.83
Dissolved Zn (µg/L)	16 6 - 50 11	13 5 - 43 13	8.2 5 - 26 5.4	12 2 - 51 13
NO3-N (mg/L)	0.45 0.10 - 1.2 0.37	0.30 0.08 - 0.9 0.25	0.22 0.03 - 0.8 0.22	0.20 0.04 - 0.56 0.17
TKN (mg/L)	1.32 0.38 - 5.2 1.1	0.87 0.26 -2.0 0.50	0.84 0.27 - 1.9 0.40	1.2 0.49 - 3.6 0.80
Total P (mg/L)	0.14 0.03 - 0.67 0.18	0.09 0.03 - 0.26 0.07	0.10 0.03 - 0.31 0.07	0.17 0.03 - 0.61 0.17
Dissolved P (mg/L)	0.04 0.003 - 0.24 0.06	0.06 0.011 - 0.25 0.07	0.05 0.02 - 0.12 0.03	0.07 0.03 - 0.24 0.05

Summary statistics for the San Rafael site are presented in Table 8. Since monitoring only occurred at a single distance from the edge of pavement (8.3 meters), the colored cells indicate only if there was a significant increase or decrease across this distance. The data is not sufficient to determine if an equilibrium concentration was achieved. Since the average concentration of TSS at 8.3 meters is very similar to that observed at Sacramento (19 mg/L at San Rafael vs. 24 mg/L at Sacramento) it is likely that little additional change would be expected with greater distances. Constituents showing decreases include TSS, most of the metals, and nitrate. Like the previously described sites, concentrations in dissolved salts generally increase.

Table 8. Summary Statistics of EMCs at San Rafael

Constituent	**EOP** **Mean** **Range** **Std. Dev.**	**8.3 m** **Mean** **Range** **Std. Dev.**
Specific Conductivity (µmhos/cm)	94 22 - 460 95	168 39 - 378 83
Hardness (mg/L)	28 15 - 64 11	110 59 - 180 35
TSS (mg/L)	70 5 - 210 50	19 1 - 38 11
TDS (mg/L)	71 10 - 290 60	142 80 - 230 47
TOC (mg/L)	16 5 - 41 10	13.5 3 - 33 9.4
DOC (mg/L)	14.5 4 - 34 9.4	13.3 3 - 32 8.2
Total As (µg/L)	0.79 0.5 - 2.8 0.49	1.1 0.5 - 2.9 0.65
Total Cd (µg/L)	0.60 0.2 - 1.7 0.35	0.23 0.20 - 0.35 0.05
Total Cr (µg/L)	5.8 2 - 36 7.0	4.2 1 - 10 2.5
Total Cu (µg/L)	38 7 - 82 19	6.6 1 - 16 3.4
Total Pb (µg/L)	14.5 1 - 45 11	2.7 1 - 11 2.7
Total Ni (µg/L)	7.2 3 - 14 2.8	3.2 2.0 - 5.5 1.1
Total Zn (µg/L)	123 33 - 330 69	25 6 - 110 26

Constituent	EOP Mean Range Std. Dev.	8.3 m Mean Range Std. Dev.
Dissolved As (µg/L)	0.64 0.5 - 1.0 0.22	0.91 0.5 - 2.2 0.49
Dissolved Cd (µg/L)	0.24 0.20 - 0.47 0.07	0.21 0.20 - 0.30 0.02
Dissolved Cr (µg/L)	2.1 1.0 - 8.5 1.6	3.3 1.0 - 8.3 2.1
Dissolved Cu (µg/L)	16 5 - 34 6.7	3.8 1.0 - 7.8 1.9
Dissolved Pb (µg/L)	1.2 1.0 - 2.7 0.45	1.0 1.0 - 1.3 0.07
Dissolved Ni (µg/L)	3.8 2.0 - 9.6 1.9	2.5 2.0 - 4.3 0.75
Dissolved Zn (µg/L)	43 8 - 79 18	10 5 - 36 7.4
NO3-N (mg/L)	1.9 0.1 - 4.6 1.2	0.61 0.08 - 2.2 0.48
TKN (mg/L)	2.3 0.6 - 4.7 1.1	1.2 0.6 - 4.8 0.94
Total P (mg/L)	0.21 0.04 - 0.81 0.17	0.13 0.03 - 0.31 0.08
Dissolved P (mg/L)	0.07 0.01 - 0.49 0.10	0.06 0.02 - 0.19 0.04

Summary statistics for Cottonwood are presented in Table 9. Like San Rafael, the colored cells indicate only if there was a significant increase or decrease across the RVTS. The data is not sufficient to determine if an equilibrium concentration was achieved. However, at 9.2 meters, the concentration of TSS dropped to an average of 19 mg/L, which is again similar to the irreducible concentration at Sacramento of 24 mg/L. One would therefore not expect to observed additional reduction at greater distances. Those constituents exhibiting statistically significant changes in concentration are generally the same as those in the previously described RVTS.

Table 9. Summary Statistics of EMCs at Cottonwood

Constituent	**EOP** **Mean** **Range** **Std. Dev.**	**9.2 m** **Mean** **Range** **Std. Dev.**
Specific Conductivity (µmhos/cm)	55 23 - 140 29	89 44 - 180 43
Hardness (mg/L)	24 4 - 82 17	33 16 - 72 14
TSS (mg/L)	88 26 - 260 69	19 4 - 50 14
TDS (mg/L)	34 1 - 88 25	85 32 - 180 44
TOC (mg/L)	12 3 - 51 10	12 2 - 25 5.2
DOC (mg/L)	12 3 - 50 9.7	11 3 - 25 5.2
Total As (µg/L)	0.86 0.5 - 1.6 0.30	0.68 0.5 - 1.2 0.25
Total Cd (µg/L)	0.84 0.2 - 2.9 0.57	0.27 0.20 - 0.80 0.17
Total Cr (µg/L)	4.2 1.3 - 9.5 2.1	2.4 1.0 - 7.6 1.9
Total Cu (µg/L)	33 8 - 85 19	8.6 3 - 33 7.7
Total Fe (µg/L)	1627 66 - 3580 963	1016 50 - 2120 732
Total Pb (µg/L)	11 0.5 - 54 12	3.0 1.0 - 9.5 2.6
Total Ni (µg/L)	5.5 2 - 11 2.7	3.9 2.0 - 6.3 1.3
Total Zn (µg/L)	127 17 - 310 72	22 5 - 120 32

Constituent	**EOP Mean Range Std. Dev.**	**9.2 m Mean Range Std. Dev.**
Dissolved As (µg/L)	0.68 0.5 - 1.0 0.24	0.65 0.5 - 1.1 0.24
Dissolved Cd (µg/L)	0.27 0.20 - 0.78 0.16	0.21 0.20 - 0.40 0.05
Dissolved Cr (µg/L)	1.6 1.0 - 4.1 0.96	1.5 1.0 - 4.2 1.0
Dissolved Cu (µg/L)	12 4 - 33 7.6	5.2 2 -16 3.8
Dissolved Fe (µg/L)	172 22 - 949 229	476 50 - 1100 367
Dissolved Pb (µg/L)	1.4 1.0 - 5.8 1.1	1.3 1.0 - 3.6 0.78
Dissolved Ni (µg/L)	3.2 2.0 - 8.9 1.8	3.0 2.0 - 4.9 0.84
Dissolved Zn (µg/L)	40 6 - 84 21	12 5 - 52 14
NO3-N (mg/L)	0.81 0.1 - 3.4 0.78	1.4 0.1 - 5.2 1.3
TKN (mg/L)	1.9 0.8 - 4.6 0.98	1.9 0.7 - 7.4 1.7
Total P (mg/L)	0.19 0.03 - 0.85 0.23	0.15 0.03 - 0.67 0.19
Dissolved P (mg/L)	0.05 0.01 - 0.28 0.06	0.05 0.01 - 0.29 0.07

Summary statistics for San Onofre are presented in Table 10. This site is typical of the southern California sites with the abundant presence of gophers. The gopher mounds were often located adjacent to the runoff collection ditches, which allowed the loose sediment to be mobilized and sampled. Additionally, increased infiltration in this test segment was enhanced by the gopher burrows. No statistically significant reductions in TSS concentrations were observed. Nevertheless, reductions in most metal species were apparent, indicating that highway runoff treatment is occurring. Most of the sediment collected at various distances could be gopher derived and not entirely represent the material washed from the road surface.

For many of the constituents which decline in concentration there is no statistically significant difference in concentration beyond 1.3 meters. Nevertheless, for many of these the lowest observed concentration occurs at 9.9 meters. Unfortunately, the sample size at this distance is small (n = 6), so the statistical test do not have much power. Consequently additional sampling is likely to indicate that the distance needed to obtain equilibrium concentrations is closer to 10 meters than 1.3 meters.

Table 10. Summary Statistics for San Onofre

Constituent	**EOP Mean Range Std. Dev.**	**1.3 m Mean Range Std. Dev.**	**5.3 m Mean Range Std. Dev.**	**9.9 m Mean Range Std. Dev.**
Specific Conductivity (µmhos/cm)	112 13 - 280 73	151 14 - 390 122	141 19 - 356 90	145 23 - 356 79
Hardness (mg/L)	43 18 - 86 20	39 16 - 98 26	39 18 - 82 20	28 22 - 82 5.6
TSS (mg/L)	104 12 - 206 58	66 7 - 150 51	50 11 - 140 40	90 18 - 216 83
TDS (mg/L)	118 16 - 360 95	131 10 - 360 124	112 40 - 278 66	90 14 - 278 39
TOC (mg/L)	31 8 - 84 24	25 9 - 73 18	30 11 - 86 22	29 11 - 86 17
DOC (mg/L)	28 7 - 82 22	23 7 - 66 17	26 7 - 77 20	27 10 - 77 16
Total As (µg/L)	1.9 1.0 - 3.9 0.82	2.8 1.0 - 6.1 1.8	5.9 1 - 13 3.4	3.0 1 - 13 0.90
Total Cd (µg/L)	1.3 0.2 - 2.7 0.73	0.51 0.2 - 1.8 0.44	0.35 0.20 - 0.89 0.23	0.40 0.2 - 10 0.21
Total Cr (µg/L)	7.3 3 - 16 3.0	7.8 2 - 23 5.5	5.2 3 - 12 2.7	8.6 6 - 12 2.3
Total Cu (µg/L)	58 13 - 110 28	31 9 - 75 19	26 10 - 46 13	18 8 - 46 7.3

Constituent	**EOP** **Mean** **Range** **Std. Dev.**	**1.3 m** **Mean** **Range** **Std. Dev.**	**5.3 m** **Mean** **Range** **Std. Dev.**	**9.9 m** **Mean** **Range** **Std. Dev.**
Total Pb (µg/L)	68 15 - 190 46	34 8 - 100 26	41 11 - 110 33	41 3 - 110 28
Total Ni (µg/L)	12 2 - 29 7.2	5.5 2 - 12 3.2	4.6 2 - 10 2.6	4.9 2 - 10 2.0
Total Zn (µg/L)	265 46 - 510 142	81 20 - 160 47	78 21 - 250 73	57 20 - 250 30
Dissolved As (µg/L)	1.5 0.7 - 4.5 0.90	2.3 1.0 - 5.2 1.6	5.9 1 - 15 4.4	3.0 1 - 15 1.5
Dissolved Cd (µg/L)	0.42 0.20 - 0.90 0.22	0.28 0.20 - 0.65 0.16	0.21 0.20 - 0.30 0.03	0.27 0.2 - 10 0.10
Dissolved Cr (µg/L)	3.6 1.4 - 7.7 1.5	4.6 2 - 10 2.4	3.3 1.7 - 5.4 1.3	5.2 4 - 10 2.4
Dissolved Cu (µg/L)	26 9 - 54 13	19 7 - 58 14	17 8 - 39 8.6	12 6 - 39 4.5
Dissolved Pb (µg/L)	16 3 - 75 20	8.5 1 - 21 6.2	11 3 - 24 6.8	14 1 - 32 11
Dissolved Ni (µg/L)	7.4 2 - 18 4.7	4.2 2.0 - 9.0 2.3	3.5 2.0 - 7.3 1.9	3.3 2 - 10 0.94
Dissolved Zn (µg/L)	77 27 - 170 41	33 5 - 85 22	32 16 - 58 13	34 15 - 64 17
NO3-N (mg/L)	1.5 0.2 - 4.6 1.4	1.6 0.2 - 5.7 1.8	0.72 0.1 - 1.9 0.61	0.60 0.1 - 10 0.68
TKN (mg/L)	1.8 0.4 - 4.2 1.2	2.0 0.1 - 5.2 1.6	1.6 0.6 - 2.7 0.94	1.7 1 - 10 0.52
Total P (mg/L)	0.35 0.03 -1.2 0.27	0.57 0.2 - 1.5 0.37	0.83 0.3 - 1.8 0.46	0.78 0.6 - 10 0.17
Dissolved P (mg/L)	0.11 0.03 - 0.36 0.10	0.37 0.06 - 1.4 0.35	0.67 0.3 - 1.6 0.39	0.59 0.4 - 10 0.17

Table 11 presents the summary statistics of the monitoring data at Irvine. No summaries are provided for the 6 meter distance since only a single sample was collected at this point over the two year sampling period. The lack of samples was due to the extreme amount of infiltration which occurred in the vegetated area, there was only one occasion where sufficient volume was collected for analysis. The infiltration in this test segment was enhanced by the large number of gopher burrows adjacent to the collection system. The statistical tests indicate no significant decrease in constituent concentrations beyond 3 meters; however, this is somewhat misleading. For each of the constituents showing decreases, concentrations were lower at 13 meters than 3, but the sample size was so small at 13 meters (n = 4) that the tests have very little discriminating power. Note that the average TSS concentration at 13 meters is about 25 mg/L, which was the irreducible minimum at several of the northern California sites. It is likely that additional numbers of samples would prove that equilibrium concentrations (for all constituents with decreasing concentrations) occur beyond 3 meters.

Table 11. Summary Statistics for Irvine

Constituent	EOP Mean Range Std. Dev.	3.0 m Mean Range Std. Dev.	6.0 m Mean Range Std. Dev.	13.0 m Mean Range Std. Dev.
Specific Conductivity (µmhos/cm)	164 83 - 316 71	172 66 - 362 116	NA	128 90 - 175 43
Hardness (mg/L)	67 34 - 113 27	61 26 - 125 34	NA	56 36 - 76 18
TSS (mg/L)	127 40 - 320 86	52 8 - 110 36	NA	25 14 - 38 11
TDS (mg/L)	164 1 - 350 96	135 44 - 292 85	NA	104 65 - 166 45
TOC (mg/L)	39 13 - 94 27	31 10 - 92 31	NA	21 14 - 34 8.9
DOC (mg/L)	36 9 - 90 26	26 9 - 73 24	NA	17 9 - 29 8.6
Total As (µg/L)	9.6 4 - 16 4.5	6.0 2.6 - 9.2 2.9	NA	3.9 2.5 - 5.5 1.4
Total Cd (µg/L)	1.6 0.5 - 3.3 0.75	0.72 0.2 - 1.2 0.42	NA	0.43 0.2 - 1.1 0.45
Total Cr (µg/L)	12 7 - 19 4.0	10 3 - 21 6.2	NA	4.4 4.0 - 4.7 0.31
Total Cu (µg/L)	84 37 - 130 27	41 11 - 74 25	NA	12 8 - 17 4.0
Total Pb (µg/L)	85 27 - 210 51	23 5 - 45 14	NA	4.8 2.7 - 6.3 1.5

Constituent	**EOP** **Mean** **Range** **Std. Dev.**	**3.0 m** **Mean** **Range** **Std. Dev.**	**6.0 m** **Mean** **Range** **Std. Dev.**	**13.0 m** **Mean** **Range** **Std. Dev.**
Total Ni (µg/L)	17 6 - 31 7.9	8.3 3 - 15 4.9	NA	2.7 2.0 - 3.5 0.62
Total Zn (µg/L)	286 110 - 480 113	99 40 - 200 57	NA	25 15 - 34 8.3
Dissolved As (µg/L)	6.7 2 - 14 3.5	4.2 1.2 - 8.7 2.9	NA	3.3 2.4 - 5.3 1.4
Dissolved Cd (µg/L)	0.41 0.20 - 0.80 0.20	0.38 0.20 - 0.90 0.30	NA	0.20 none 0.00
Dissolved Cr (µg/L)	6.4 4 - 12 2.5	4.6 1.0 - 8.4 2.8	NA	3.5 2.8 - 4.3 0.66
Dissolved Cu (µg/L)	35 15 - 75 18	19 5 - 50 17	NA	9.6 7 - 13 2.6
Dissolved Pb (µg/L)	11 2 - 38 12	3.8 1.0 - 7.4 2.6	NA	2.0 1.3 - 2.6 0.62
Dissolved Ni (µg/L)	11 3 - 27 6.7	5.1 2 - 14 4.5	NA	2.4 2.0 - 3.4 0.67
Dissolved Zn (µg/L)	80 40 - 170 36	36 13 - 94 31	NA	20 13 - 26 6.0
NO3-N (mg/L)	2.6 0.7 - 5.2 1.6	1.5 0.2 - 4.4 1.6	NA	0.21 0.10 - 0.27 0.08
TKN (mg/L)	3.6 0.9 - 8.0 2.0	2.8 0.5 - 9.0 3.2	NA	1.0 0.7 - 1.7 0.45
Total P (mg/L)	0.48 0.2 - 1.0 0.26	0.70 0.4 - 1.3 0.40	NA	0.65 0.4 - 1.1 0.34
Dissolved P (mg/L)	0.22 0.03 - 0.49 0.15	0.37 0.04 - 1.1 0.38	NA	0.35 0.03 - 0.75 0.30

Summary statistics for the Yorba Linda RVTS are presented in Table 12. This site is similar to Irvine in the large number of gophers living in the test sections and the very small sample size (n = 4 at 13 m). Consequently, the data at this site is relatively hard to interpret. Of the constituents that decrease, only dissolved zinc achieves a stable minimum concentration, while the lowest concentration for the other constituents is observed at the furthest monitoring location. The EMCs for dissolved and total arsenic are significantly different between the EOP and the 13 meter width; however, because of the small sample size and lack of trend for any of the intermediate values, arsenic is not indicated to have any trend in Table 12.

Table 12. Summary Statistics for Yorba Linda

Constituent	EOP Mean Range Std. Dev.	1.8 m Mean Range Std. Dev.	4.9 m Mean Range Std. Dev.	7.6 m Mean Range Std. Dev.	13.0 m Mean Range Std. Dev.
Specific Conductivity (µmhos/cm)	69 5 - 160 51	77 3 - 190 67	85 16 - 208 60	65 18 - 95 29	106 85 - 149 30
Hardness (mg/L)	32 16 - 57 13	37 20 - 64 15	41 26 - 74 16	35 28 - 49 7.7	47 42 - 58 7.7
TSS (mg/L)	114 24 - 221 73	222 47 - 670 189	119 28 - 400 115	124 19 - 330 116	42 15 - 108 45
TDS (mg/L)	68 19 - 149 44	87 8 - 190 58	67 1 - 182 49	91 20 - 150 49	80 44 - 124 34
TOC (mg/L)	20 9 - 48 13	21 3 - 44 13	24 8 - 57 16	24 9 - 50 16	21 11 - 32 8.8
DOC (mg/L)	18 7 - 43 11	18 1 - 37 12	21 8 - 48 14	22 7 - 50 16	18 8 - 28 8.3
Total As (µg/L)	1.6 1.0 - 2.7 0.57	2.0 1.0 - 3.0 0.69	1.8 1.0 - 3.5 0.78	1.6 1.1 - 2.1 0.42	2.4 1.8 - 2.9 0.48
Total Cd (µg/L)	1.1 0.3 - 3.0 0.69	1.1 0.4 - 3.5 0.93	0.63 0.2 - 1.5 0.42	0.56 0.2 - 1.4 0.44	0.25 0.20 - 0.40 0.10
Total Cr (µg/L)	7.1 3 - 19 4.5	10 5 - 21 5.3	7.9 3 - 19 4.4	4.9 2.9 - 7.9 1.9	4.7 2.8 - 8.6 2.6
Total Cu (µg/L)	43 16 - 100 22	44 25 - 85 19	31 9 - 77 20	16 7 - 26 7.2	10 7 - 14 3.7
Total Pb (µg/L)	23 4 - 45 11	29 17 - 47 11	24 8 - 55 16	19 7 - 42 15	7.3 3 - 17 6.5
Total Ni (µg/L)	6.6 0.5 - 12 3.5	9.9 5 - 22 5.7	7.0 2 - 17 4.6	4.7 2.4 - 8.1 2.4	3.5 2.4 - 6.4 1.9
Total Zn (µg/L)	321 94 - 640 208	224 95 - 550 154	105 31 - 250 69	54 21 - 96 29	33 20 - 58 17
Dissolved As (µg/L)	1.2 0.7 - 2.2 0.49	1.3 0.7 - 3.1 0.68	1.2 0.9 - 2.1 0.43	1.9 0.9 - 5.6 1.8	1.9 1.7 - 2.1 0.18

Constituent	**EOP** **Mean** **Range** **Std. Dev.**	**1.8 m** **Mean** **Range** **Std. Dev.**	**4.9 m** **Mean** **Range** **Std. Dev.**	**7.6 m** **Mean** **Range** **Std. Dev.**	**13.0 m** **Mean** **Range** **Std. Dev.**
Dissolved Cd (µg/L)	0.34 0.2 - 1.0 0.23	0.23 0.20 - 0.40 0.07	0.25 0.20 - 0.50 0.11	0.20 none 0.00	0.35 0.20 - 0.60 0.19
Dissolved Cr (µg/L)	3.2 1.2 - 9.6 2.3	4.2 1.8 - 9.5 2.6	3.6 1.0 - 9.4 2.4	3.0 1.4 - 4.9 1.5	2.4 1.5 - 3.6 0.88
Dissolved Cu (µg/L)	17 6 - 38 11	15 6 - 31 7.8	17 6 - 47 13	9.3 6 - 14 3.1	6.9 5.2 - 8.3 1.5
Dissolved Pb (µg/L)	5.2 1 - 12 4.0	4.3 1.0 - 9.0 2.6	4.5 1 - 11 3.0	2.9 1.0 - 7.4 2.4	2.2 1.0 - 4.3 1.5
Dissolved Ni (µg/L)	5.0 2 - 11 3.3	3.6 2.0 - 7.6 2.0	3.7 2.0 - 8.8 2.4	2.6 2.0 - 3.3 0.55	2.2 2.0 - 2.5 0.26
Dissolved Zn (µg/L)	139 31 - 490 135	39 5 - 83 26	40 11 - 140 39	17 11 - 24 4.6	21 11 - 31 8.4
NO3-N (mg/L)	0.83 0.1 - 2.2 0.67	1.8 0.4 - 6.0 1.7	1.3 0.3 - 3.9 1.2	0.84 0.2 - 2.0 0.70	0.26 0.14 - 0.41 0.11
TKN (mg/L)	2.2 0.9 - 4.9 1.4	2.4 0.8 - 5.0 1.2	1.9 0.7 - 3.8 1.1	1.7 0.4 - 3.7 1.3	1.3 0.8 - 2.3 0.70
Total P (mg/L)	0.26 0.18 - 0.46 0.09	0.40 0.24 - 0.99 0.23	0.40 0.19 - 0.65 0.16	0.54 0.2 - 1.2 0.38	0.67 0.5 - 1.2 0.34
Dissolved P (mg/L)	0.06 0.03 - 0.16 0.04	0.06 0.03 - 0.13 0.03	0.19 0.03 - 0.43 0.13	0.31 0.03 - 0.67 0.25	0.51 0.38 - 0.81 0.21

Table 13 presents the summary statistics for Moreno Valley. This site differs from the other sites mainly in the extremely low level of vegetation coverage, less than 25% at even the best test section. Not unexpectedly, the concentration of only a single constituent, dissolved zinc, decreased. Only three other constituents exhibited a significant increase in concentration, so for the majority of parameters no consistent trend was observed.

Table 13. Summary Statistics for Moreno Valley

Constituent	EOP Mean Range Std. Dev.	2.6 m Mean Range Std. Dev.	4.9 m Mean Range Std. Dev.	8.0 m Mean Range Std. Dev.	9.9 m Mean Range Std. Dev.
Specific Conductivity (µmhos/cm)	55 16 - 107 31	99 22 - 263 88	77 20 - 202 57	78 18 - 166 52	67 17 - 163 47
Hardness (mg/L)	39 16 - 97 26	43 24 - 80 23	35 18 - 79 19	39 24 - 74 17	33 14 - 64 16
TSS (mg/L)	71 11 - 257 81	161 34 - 680 213	330 56 - 1300 419	280 77 - 538 167	626 50 - 2600 812
TDS (mg/L)	66 26 - 110 34	100 16 - 230 74	81 14 - 172 52	81 12 - 163 54	59 8 - 100 38
TOC (mg/L)	31 9 - 96 30	33 9 - 83 26	30 9 - 90 27	31 9 - 85 27	26 9 - 73 22
DOC (mg/L)	26 8 - 88 27	28 9 - 72 22	29 9 - 87 27	27 8 - 81 25	24 8 - 71 21
Total As (µg/L)	1.8 1.0 - 4.1 1.1	2.1 1.6 - 2.8 0.42	2.5 1.6 - 4.3 0.93	3.4 1.9 - 7.1 1.7	2.2 1.2 - 3.1 0.60
Total Cd (µg/L)	0.38 0.20 - 0.83 0.20	0.39 0.2 - 1.1 0.30	0.48 0.2 - 1.2 0.36	0.42 0.20 - 0.88 0.25	0.83 0.2 - 3.3 1.1
Total Cr (µg/L)	5.2 3.0 - 8.0 1.6	6.9 3 - 11 2.8	8.9 4 - 19 5.4	12 5 - 27 7.2	12 5 - 27 7.6
Total Cu (µg/L)	38 16 - 100 27	36 20 - 72 18	37 14 - 71 19	32 18 - 53 12	40 21 - 67 15
Total Pb (µg/L)	8.4 4 - 13 3.2	12 4 - 32 8.8	16 5 - 42 13	16 6 - 31 9.0	27 6 - 52 17
Total Ni (µg/L)	7.3 3 - 23 6.6	7.7 4 - 15 3.7	8.1 3 - 15 4.1	7.9 4 - 13 2.9	10 5 - 17 4.4
Total Zn (µg/L)	349 150 - 800 237	184 62 - 640 188	196 44 - 630 190	191 79 - 510 139	404 120 - 1800 570
Dissolved As (µg/L)	1.6 1.0 - 3.8 0.94	1.6 1.1 - 2.6 0.47	2.0 1.5 - 3.9 0.88	2.0 1.0 - 2.5 0.47	1.4 1.0 - 2.3 0.45
Dissolved Cd (µg/L)	0.24 0.20 - 0.40 0.07	0.20 none 0.00	0.21 0.20 - 0.30 0.04	0.20 none 0.00	0.20 none 0.00

Constituent	EOP Mean Range Std. Dev.	2.6 m Mean Range Std. Dev.	4.9 m Mean Range Std. Dev.	8.0 m Mean Range Std. Dev.	9.9 m Mean Range Std. Dev.
Dissolved Cr (µg/L)	3.2 1.9 - 5.1 1.1	3.5 2.1 - 6.6 1.5	4.8 2 - 12 3.0	4.4 2.6 - 6.3 1.5	3.5 1.9 - 5.6 1.2
Dissolved Cu (µg/L)	26 11 - 87 25	24 12 - 61 16	23 14 - 62 16	19 10 - 40 9.3	18 10 - 39 9.5
Dissolved Pb (µg/L)	2.6 1.0 - 5.5 1.4	2.0 1.0 - 3.4 0.79	3.0 1.0 - 3.9 0.89	3.4 1.0 - 5.8 1.3	3.0 1.0 - 6.3 1.7
Dissolved Ni (µg/L)	6.0 2 - 21 6.2	5.2 3 - 14 3.9	5.4 3 - 12 3.5	4.6 2.7 - 8.3 1.9	4.3 2.8 - 7.0 1.7
Dissolved Zn (µg/L)	261 99 - 700 206	55 29 - 140 36	49 18 - 120 31	53 25 - 94 21	56 21 - 110 28
NO3-N (mg/L)	0.94 0.3 -3.6 1.1	1.1 0.4 - 2.5 0.77	1.1 0.5 - 2.7 0.72	0.88 0.3 - 1.9 0.59	0.65 0.2 - 1.6 0.48
TKN (mg/L)	3.7 1 - 13 4.0	3.5 1.4 - 8.0 2.3	3.8 1.2 - 9.1 2.9	4.8 2 - 13 4.0	4.6 2 - 14 4.3
Total P (mg/L)	0.57 0.1 - 2.3 0.72	0.52 0.2 - 1.1 0.30	0.69 0.2 - 1.8 0.58	0.48 0.09 - 0.84 0.25	0.80 0.5 - 1.1 0.26
Dissolved P (mg/L)	0.18 0.03 - 0.54 0.20	0.26 0.03 - 0.69 0.24	0.27 0.03 - 0.86 0.30	0.27 0.04 - 0.72 0.25	0.28 0.05 - 0.81 0.30

A summary of the shortest length observed to produce a constant (best) effluent quality for all constituents that decrease in concentration is presented in Table 14. For the sites with relatively few samples (Irvine and San Onofre) the distance presented is where the lowest concentrations are observed rather than where no statistical difference was demonstrated.

Table 14. Shortest Effective Width for each RVTS

Site	Distance (m)
Redding	4.2
Sacramento	4.6
San Rafael	8.3*
Cottonwood	9.2*
San Onofre	9.9
Irvine	13
Yorba Linda	13
Moreno Valley	Not Effective

*shortest distance monitored

4.2 *Effect of Vegetation Density and Type on Performance*

Vegetation plays a very important role in the concentration reduction in buffer strips by slowing the velocity of runoff, stabilizing the slope, and stabilizing accumulated sediment in the root zone of the plants. Consequently, the nature of the vegetation could be an important factor in determining the reduction in concentration observed.

A vegetation assessment was conducted at all the RVTS sites on a quarterly basis to characterize the vegetation condition of the test sites. The vegetation is characterized by percent vegetation cover/density, height, plant species composition, and observation on maintenance. Vegetation assessment was conducted at all sites during each season over the duration of the study. Table 15 shows the schedule on when the vegetation assessments were conducted. The vegetation assessment reports can be found in Appendix F (Enclosed CD-ROM).

Table 15. Vegetation Assessment Schedule

Assessment Period	Season	Time Conducted
First Quarter (Initial Assessment)	Winter	January – February 2002
Second Quarter	Spring	April –May 2002
Third Quarter	Summer	July-August 2002
Fourth Quarter	Fall-Winter	December 2002-January 2003
Final Assessment	Spring	April 2003

A typical stratified random sampling design was adopted to monitor vegetation in the biofilter test plots. A transect tape was placed along the entire length of the concrete collection channel for each test plot. The tape was started on either the western most end or the southern most end (depending on orientation of the roadway). Orientation of the tape was kept consistent regardless of the direction of flow in the channels. Measuring tapes were pulled taut and staked in place.

A second tape was placed perpendicular to the first tape every 5 m along the length of the first tape. The second tape extended from the concrete collection channel toward the end of vegetation at the roadway edge. Measurements of vegetation were taken every 2 m along the second tape, as width of each plot allowed. The vegetation was measured using quarter square-meter quadrants (0.5 m X 0.5 m). Quadrants were centered on the meter measure of the first tape. A number was randomly selected as the designated position along the sampling interval of the second tape (12 cm). This number was used for all sampling performed in the Winter of 2002. For each quadrant, total percent vegetation was visually estimated. Additionally, the percent of cover from grass species and from broadleaf species was estimated. The tallest plant (grass or broadleaf species) was recorded, and an average height of all plants in the quadrant was estimated. Heights lower than 10 cm were aggregated. Finally, plant species were recorded for each quadrant at the taxonomic level allowed by prevailing phenology. Table 16 shows the vegetation coverage during the winter, spring, summer, and winter season vegetation assessments.

The average vegetation coverage for the sites exceeds 65%. The only exception is Moreno Valley where the density averages about 15%. Due to the lack of concentration reduction at Moreno Valley, it can be concluded that 15% coverage is definitely insufficient for effective operation. Other sites had substantial reduction in concentrations with coverage just exceeding 65%, so based on this data a minimum of 65% coverage should be recommended. However, additional research at other sites could result in adjusting this threshold downward.

Table 16. Vegetation Coverage and Height

Site (m)	Winter 2002		Spring 2002		Summer 2002		Winter 2003		Spring 2003	
	Total Cover (%)	Height (cm)	Total Cover (%)	Height (cm)	Total Cover (%)	Height (cm)	Total Cover (%)	Height (cm)	Total Cover (%)	Height (cm)
Sacramento 1.1	97.4	14.0	94.4	14.4	98.2	13.6	80.0	5.0	86.6	32.8
Sacramento 4.6	93.1	6.6	93.0	22.7	80.5	13.6	68.3	6.0	92.6	34.4
Sacramento 6.6	95.7	11.2	94.4	27.3	95.7	11.4	80.2	7.3	94.5	43.7
Sacramento 8.4	91.1	10.5	95.6	32.3	97.2	14.7	75.2	6.6	92.0	42.7
Cottonwood 9.3	70.2	12.3	80.7	30.7	77.7	20.9	63.7	6.9	84.0	38.9
Redding 2.2	83.0	5.0	89.5	26.6	86.2	14.8	89.7	6.3	93.2	28.3
Redding 4.2	92.1	8.6	97.6	34.0	84.1	14.8	67.9	4.8	92.6	31.3
Redding 6.2	71.0	8.0	93.0	39.6	83.9	14.2	70.4	5.6	94.1	28.6
San Rafael 8.3	83.2	16.0	87.3	35.7	92.7	31.4	72.7	10.5	86.5	32.4
Yorba Linda 2.3	61.7	12.5	81.6	27.5	61.7	4.0	39.2	5.0	86.0	40.5
Yorba Linda 5.0	85.8	13.3	89.9	27.5	78.2	4.8	75.6	7.0	95.3	21.2
Yorba Linda 7.6	82.5	11.7	76.1	36.3	60.3	3.9	78.9	6.7	95.2	18.4
Yorba Linda 13.0	81.5	15.3	88.5	31.3	73.7	5.8	58.6	7.9	91.0	27.8
Irvine 3.0	71.3	13.8	96.0	25.5	57.5	9.3	55.8	7.1	95.0	43.0
Irvine 6.0	64.4	14.4	78.7	10.7	65.0	9.0	45.6	5.6	-	-
Irvine 13.0	60.0	12.8	73.4	11.8	65.7	7.2	49.8	6.5	89.0	59.0
Moreno Valley 2.6	1.0	3.0	1.8	3.2	3.0	0.3	6.4	0.4	22.8	2.7
Moreno Valley 4.9	14.0	3.5	18.4	3.6	16.2	2.1	16.6	0.9	28.8	2.6
Moreno Valley 8.0	23.3	3.25	25.6	3.2	13.0	1.0	24.4	0.6	41.3	6.1
Moreno Valley 9.9	22.6	4.6	21.2	4.3	7.7	0.7	21.4	0.6	38.4	3.5
San Onofre 1.3	92.0	10.0	73.2	11.0	84.0	27.4	75.6	6.7	80.0	13.6
San Onofre 5.3	82.7	8.3	69.5	14.0	69.4	18.0	73.6	6.1	85.5	24.1
San Onofre 9.9	79.2	9.4	70.3	12.2	60.5	16.2	66.4	4.9	87.7	27.4

Redding and Sacramento have average vegetation coverage exceeding 80% and moderate slopes yet achieved irreducible minimum concentrations within 5 meters. Sites in southern California such as Irvine, Yorba Linda, and San Onofre have similar slopes and vegetation coverages of 75% or less and achieve minimum concentrations in 10 meters. This suggests that performance declines rapidly as vegetation coverage declines below 80%.

Vegetation type and relative quantity is similar at all the California sites. Non-native grasses (Italian rye and brome grasses) dominate and comprise 65% to 100% of the vegetative cover type. Consequently, there is little basis for relating type of ground cover to performance. Average vegetation height varied between 11 and 22 cm, and was not correlated with performance. The vegetation at Redding, which produced runoff with the lowest constituent concentrations, consisted of 73% grasses with an average height of about 15 cm. This height is near the conventional recommendation for vegetated stormwater controls.

Performance of existing vegetated areas adjacent to highways was also reported (Barrett et al., 1998)_. Two sites were monitored in the Austin, Texas area, which had substantially different types of vegetation (shown in Table 17). Despite vegetation differences, average TSS concentrations discharged from the two sites were very similar, 21 mg/L at US 183 and 29 mg/L on Loop 1. These concentrations are similar to those observed in the RVTS study, again suggesting that vegetation type alone is not an important factor in performance. This conclusion is reinforced by the results of the studies on engineered biostrips described more fully later. The average minimum concentration of TSS observed at these sites, which had a monoculture of salt grass was about 27 mg/L.

Table 17. Vegetation Composition of the Highway Medians in Austin, Texas

Species Name	U.S. 183 (%)	Loop 1 (%)
Bermuda grass	1	30
Illinois Bundleflower	1	30
Meadow Dropseed	0	19
Little Bluestem	0	10
Florida Palpalum	0	7
Indiangrass	0	2
Prairie Buffalo grass	76	<1
Cedar Sage	6	0
Texas Frogfruit	2	0
Bare ground	14	2

4.3 Infiltration and Load Reduction

Each length of the buffer strip was evaluated for the amount of infiltration that occurred based on all events during the study period. Figure 5 and Figure 6 show the amount of infiltration at each site. The amount of infiltration increases as the runoff flows through greater distances of vegetation.

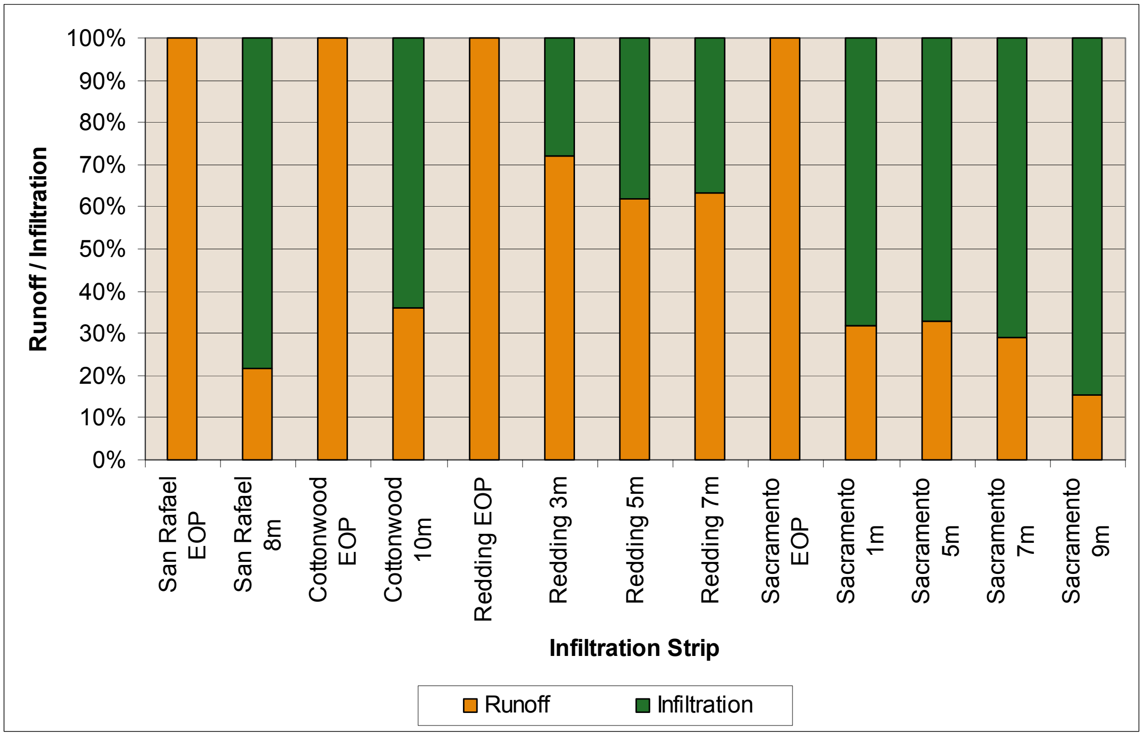

Figure 5. Infiltration Verses Distance for Northern California RVTS Biofilters

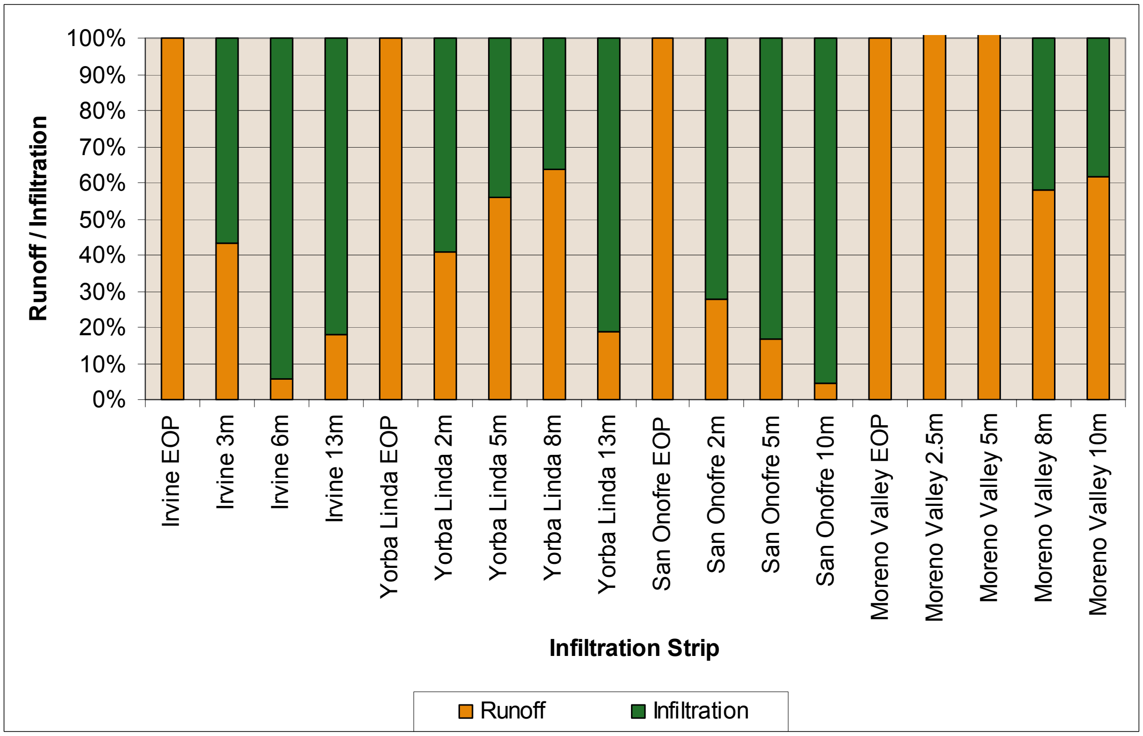

Figure 6. Infiltration Verses Distance for Southern California RVTS Biofilters

The load reduction for selected constituents is shown in Table 18. Reduction is calculated from the edge of pavement concentration at each site, the terminal concentration, and the runoff coefficient at the lengths shown in Table 14. In general, infiltration is responsible for a greater portion of the load reduction than the change in concentration. Only Moreno Valley which was ineffective at reducing concentrations and which had a relatively high runoff coefficient (about 50%) did not have substantial load reductions for all constituents.

Table 18. Total Load Reduction at Minimum Effective Width

Site	TSS	Copper	Lead	Zinc
Redding	97	76	84	90
Sacramento	85	83	87	87
San Onofre	77	88	83	92
San Rafael	96	98	98	97
Cottonwood	96	95	95	97
Irvine	97	98	99	99
Yorba Linda	94	96	95	98
Moreno Valley	-450	46	-63	68

4.4 Effect of Gophers on RVTS Performance

The test sites at three of the four southern California RVTS sites were overwhelmed with gopher activities affecting stormwater sampling results. Gopher activities created exposed dirt mounds within the test strips and along the edges of the collection ditches resulted in increased TSS concentrations (see Figure 7). Sites with gopher activities include: Irvine, Yorba Linda, and San Onofre. The fourth site, Moreno Valley, is likely too dry to support gophers.

Gopher activities should not necessarily be interpreted as causing low pollutant removal, but mainly causing difficulties with storm sampling and analysis. Observations have shown that gopher activities within the test strips enhanced infiltration of runoff, thus enhancing pollutant removal.

Figure 7. Gopher Activity at Edge of Collection Ditch at Irvine

4.5 Comparison with Retrofit Pilot Program Results

Caltrans recently completed a study in southern California that included an assessment of the performance of vegetated buffer strips. Three sites, I-605/91, Altadena, and Carlsbad, were constructed and monitored for this study. Each of the strips had a slope of less than 5%, abundant gophers, vegetation consisting initially of salt grass, and coverage of at least 90%. The sites were all eight meters wide. These sites also had a very rigorous operation and maintenance protocol that kept grass height and coverage within strict requirements as described in the study final report (Caltrans, 2003b).

Figure 8 presents a boxplot that compares discharge concentrations for TSS at the pilot sites as well as for selected RVTS study sites. Eliminated from the plot are Redding, which performed significantly better all other sites, and San Onofre and Yorba Linda, which performed significantly worse for sediment removal. The remaining sites are not significantly different. This indicates that many existing vegetated areas along highways have performance comparable to systems engineered and operated specifically for water quality improvement.

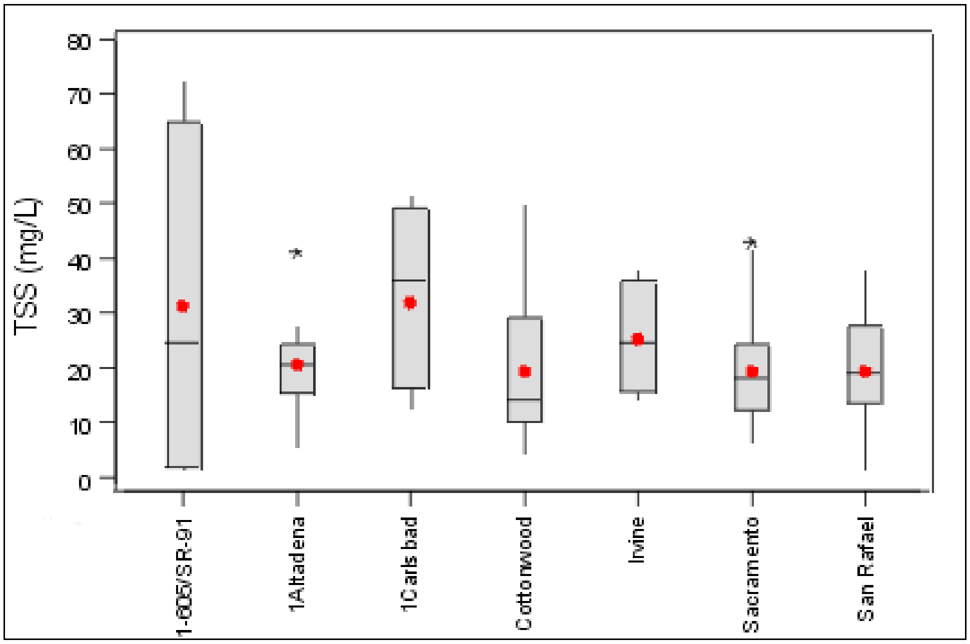

Figure 8. Comparison of TSS EMC at Pilot and Selected RVTS Sites

4.6 Regression Analysis of Monitoring Data

Multiple (stepwise) regression was performed with the monitoring data from the RVTS biofilter strips. Initially five predictors were used strip length, slope, grass coverage, peak discharge and influent concentration. These five predictors gave counterintuitive results, indicating that the steeper slopes resulted in lower effluent concentrations and that wider buffer strips increased concentrations compared to narrow ones.

There were several factors that lead to the disappointing results. The two steepest sites (San Rafael and Cottonwood) outperformed sites at some locations with much flatter slopes (San Onofre and Yorba Linda). Additionally sites with lower average vegetation density (Irvine) performed much better than sites with higher coverage (San Onofre) even though both suffered about the same gopher damage.

5.0 Soils Investigation

Soil evaluations were performed on the RVTS to derive relationships between soil characteristics and the runoff coefficient. The detailed report of the soils investigation is provided in Appendix G (Enclosed CD_ROM). A summary of the results of the investigation is provided in Table 19.

5.1 Runoff Coefficient

The runoff coefficient "C" is the factor that is directly associated with infiltration. Runoff coefficient can be defined as the ratio of stormwater runoff volume to rainfall total over a given time period. The average runoff coefficient was calculated for each of the biofiltration strips using data that was collected during the study period (October 1, 2001 through April 15, 2003). Each data set (i.e., rainfall total and runoff volume) from the successfully monitored storms was used. Additionally, data sets from non-monitored storms that appeared to be reasonable were also used. Table 20 summarizes the factors that were used and to calculate the runoff coefficient and the resulting value.

5.2 Infiltration Rate

Infiltration rate measurements were performed at three locations (near the edge-of-pavement, at the strip's centroid, and near the concrete collection channel) within each of the 23 biofiltration strips using a Turf-Tec Infiltrometer. Several trends observed include:

- Northern California RVTS infiltrated faster than Southern California RVTS.
- Comparisons between sieve analyses and the infiltration rates showed that coarser gravel near the edge of the pavement often caused faster infiltration
- The Sacramento RVTS had the most homogeneous soils
- Cottonwood and San Rafael RVTS, the two steepest slopes, had the highest infiltration rates due to higher gravel and rock fragment percentages in the soil.
- Moreno Valley RVTS had the lowest infiltration rates due to the area being situated on cut soils that consistently had very high dry densities and high percentages of relative compaction.

5.3 Soil Properties

Understanding local soil properties and site characteristics is critical for many aspects of the RVTS evaluation. Soil properties and site characteristics are important because they control many of the hydrologic and sediment aspects of stormwater. RVTS predominantly treat stormwater runoff by filtration and infiltration. This section focuses on the affects that soil properties and site characteristics have on infiltration, which are directly associated with stormwater runoff volume.

Described below are several soil evaluations that were performed on the RVTS. The purpose of these evaluations was to derive relationships between soil characteristics and the runoff coefficient. Additionally, the hydraulic residence times (i.e., flow travel time through the biofiltration strips) were estimated and used to derive a relationship with the runoff coefficient. A discussion of site characteristics including biofiltration strip width, slope inclination, and vegetative cover are discussed in other sections of this report and were also used to derive similar relationships. Table 20 summarizes these characteristics for each of the 23 biofiltration strips

Storm Water Runoff Coefficient

Annual stormwater runoff volume can be estimated using the following simple model:

$$V=PCA/12$$

Where:

V = annual stormwater runoff volume (ft^3)
P = annual rainfall (in)
C = runoff coefficient
A = tributary area (ft^2)

The runoff coefficient "C" is the factor that is directly associated with infiltration. Runoff coefficient can be defined as the ratio of stormwater runoff volume to rainfall total over a given time period. The average runoff coefficient was calculated for each of the biofiltration strips using data that was collected during the study period. Each data set (i.e., rainfall total and runoff volume) from the successfully monitored storms was used. Additionally, data sets from non-monitored storms that appeared to be reasonable were also used.

Soil Texture Measurement

Near surface (top 2- inches) soil texture was determined for each of the 23 RVTS biofiltration strips by collecting a representative soil sample and performing a sieve analysis using ASTM D 422-63 - *Standard Test Method for Particle Size Analysis of Soils*. The representative soil sample consisted of a composite sample taken from the four corners and centroid of each biofiltration strip. Results were used to help classify the soil using the Unified Soil Classification System. More importantly, the results were used to determine the percentage of gravel, sand, and fines (silt and clay) that exist in each biofiltration strip; these results were used to evaluate the relationship of these different-size soil and rock materials with the runoff coefficient. Results of near surface (top 2- inches) soil texture measurements are shown in Appendix G.

Soil Compaction Measurement and Soil Classification

Soil compaction was determined in situ at each of the 23 biofiltration strips using ASTM D 2922-91 – *Standard Test Methods for Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth)*. This test method determines the total or wet density of soil and soil-rock mixtures by the attenuation of gamma radiation where the cylindrical probe containing the source and detector is lowered to desired test depths. The dry density is calculated by dividing the wet density of the soil by its moisture content. Soil moisture measurements are discussed in section 6. Following the removal of vegetation cover and smoothing of the soil to create a flat surface, density tests were taken at 5 locations (four corners and centroid) and at three different depths (2-, 6-, and 12- inches) within each of the 23 biofiltration strips. The dry density was recorded during each density test.

To determine the percent relative compaction of each density test, a composite sample was collected at each of the eight RVTS and tested at a soils laboratory to determine its maximum dry density and optimum moisture content. Laboratory compaction was performed using ASTM D 1557-91—*Test method for Laboratory Compaction Characteristics of Soil using Modified Effort (56,000 ft-lbf/ft3 (2,700 kN-m/m3))*. The composite sample was collected by digging with a geologic pick and collecting a hand-sample of the upper six inches of soil from each of the five test locations and mixing it with similarly collected samples from the other biofiltration strips of the RVTS (if a RVTS had multiple biofiltration strips). During the collection of each composite sample, the upper six inches of soil was visually classified using the Unified Soil Classification System, and the different soil horizons were measured with a tape measure and recorded. Percent relative compaction of each density test was calculated by dividing the dry density recorded during each density test by the maximum dry density determined at the soils laboratory.

Results of soil compaction measurements, average dry densities and average relative compaction percentages are summarized in Appendix G These dry densities and relative compaction percentages were averaged for only the 8 density tests taken at the 12- inch depth below the smoothed ground surface. Data from the 12-inch tests was used for the averages because density testing at this depth is often the standard during the testing of earthwork operations. Furthermore, a 12- inch test gives a more accurate assessment of the overall compaction of the soil since the nuclear gauge is measuring the density and moisture of an entire cubic foot of soil rather than a smaller volume of soil. One observed trend from the density testing was that the averaged dry densities and percent relative compactions were often the highest for the narrowest biofiltration strips due to a higher percentage of gravel relative to wider strips. The exception to this trend was the Moreno Valley RVTS, which was composed of homogeneous decomposed granitic cut soils (often coarse grained sandy material) that consistently had high dry densities and high percent relative compaction.

Soil Moisture Measurement

Soil moisture was determined *in situ* at each of the 23 biofiltration strips using ASTM D 3017–88 - *Standard Test Method for Water Content of Soil and Rock in Place by Nuclear Methods (Shallow Depth)*. The method determines the water content of soil by the thermalization or slowing of fast neutrons where the neutron source and thermal neutron detector are lowered to desired test depths. Moisture contents were tested at 5 locations (four corners and centroid) and at three different depths (2-, 6-, and 12-inches) within each of the 23 biofiltration strips. Results of soil moisture contents are summarized in Appendix G.

Table 19. Average Runoff Coefficient and Relevant Soil and Site Characteristics at RVTS

Site/System	Average Runoff Coefficient	Average Strip Length (m)	Slope (%)	Average Vegetative Cover (%)	Est. Hydraulic Residence Time (min)	Relative Compaction(%)	Dry Density (lb/ft^3)	Infiltration Rate (in/hr)	Porosity (%)	Gravel (%)	Sand (%)	Silt/Clay(%)
Sacramento System 2	0.31	1.1	2	93	5	93.5	121.6	2.96	29.2	51.8	36.9	11.3
Sacramento System 3	0.32	4.6	33	84	5	81.2	105.6	2.68	38.5	31.9	36.5	31.6
Sacramento System 4	0.28	6.6	33	92	6	79.7	103.6	2.35	39.6	32.5	36.5	31.0
Sacramento System 5	0.15	8.4	33	90	8	78.4	101.9	3.14	40.6	39.2	35.8	25.0
Cottonwood System 2	0.19	9.3	52	73	7	85.8	111.5	3.50	33.3	44.0	41.6	14.4
Redding System 2	0.57	2.2	10	80	5	93.9	129.3	1.89	27.1	39.6	48.8	11.6
Redding System 3	0.31	4.2	10	85	7	93	128.9	3.34	27.3	47.2	42.5	10.3
Redding System 4	0.45	6.2	10	87	8	88.6	122.6	4.15	30.8	34.7	52.8	12.5
San Rafael System 2	0.13	8.3	50	84	7	78.8	107.1	9.29	35.9	40.6	38.6	20.8
Irvine System 2	0.39	3.3	11	70	5	88.4	108.7	1.54	34.0	24.9	59.9	15.2
Irvine System 3	0.05	6.0	11	63	8	84.7	104.9	1.65	36.3	16.7	59.5	23.8
Irvine System 4	0.16	13.0	11	62	12	87.6	107.8	0.92	34.6	20.1	46.5	33.4
Yorba Linda System 2	0.37	1.9	14	61	4	89.2	114.7	1.26	33.4	28.1	53.4	18.5
Yorba Linda System 3	0.51	4.9	14	82	6	82.5	106.0	0.87	38.5	25.3	53.5	21.2
Yorba Linda System 4	0.58	7.6	14	74	8	87.7	112.7	1.57	34.6	17.2	60.6	22.2
Yorba Linda System 5	0.17	13.0	14	76	12	86.8	111.6	1.81	35.2	34.2	49.6	16.2
Moreno Valley System 2	**0.95**	2.6	13	3	1	90.7	123.4	0.72	28.9	20.3	61.5	18.2
Moreno Valley System 3	**0.95**	4.9	13	16	2	93.3	126.6	0.57	27.0	29.7	53.0	17.3
Moreno Valley System 4	0.48	8.0	13	22	2	92.9	125.8	0.94	27.5	16.5	59.1	24.4
Moreno Valley System 5	0.51	9.9	13	18	3	93.9	127.3	1.04	26.6	13.7	70.2	16.1
San Onofre System 2	0.45	1.3	8	81	3	95.9	122.7	2.25	27.4	19.0	63.8	17.2
San Onofre System 3	0.27	5.3	10	74	7	88.5	114.7	1.25	32.2	27.1	56.8	16.1
San Onofre System 4	0.07	9.9	16	69	9	85.3	108.3	0.75	36.0	21.7	55.7	22.6

Notes:

Bold results indicate runoff coefficient was adjusted from greater than 1.0 to reflect site condition.

Table 20. Average Runoff Coefficient Values and Factors

Site/System	Total Rain[1] (mm)	Total Flow[1] Volume (L)	Tributary Area (ha)	Average Runoff Coefficient
Sacramento System 2	2210.814	269358	0.0390	0.31
Sacramento System 3	2113.278	321547	0.0478	0.32
Sacramento System 4	1762.758	273839	0.0549	0.28
Sacramento System 5	1744.978	150925	0.0580	0.15
Cottonwood System 2	5003.034	530036	0.0546	0.19
Redding System 2	6643.100	1405100	0.0371	0.57
Redding System 3	5684.016	737900	0.0424	0.31
Redding System 4	6463.288	1384627	0.0477	0.45
San Rafael System 2	1389.380	536492	0.2918	0.13
Irvine System 2	462.534	87182	0.0486	0.39
Irvine System 3	1036.828	20580	0.0419	0.05
Irvine System 4	1177.798	163221	0.0873	0.16
Yorba Linda System 2	477.774	191293	0.1080	0.37
Yorba Linda System 3	557.022	331058	0.1160	0.51
Yorba Linda System 4	468.630	296841	0.1090	0.58
Yorba Linda System 5	439.42	139797	0.1843	0.17
Moreno Valley System 2	442.976	298403	0.0460	0.95
Moreno Valley System 3	489.966	358188	0.052	0.95
Moreno Valley System 4	517.906	151108	0.0610	0.48
Moreno Valley System 5	570.738	196515	0.0670	0.51
San Onofre System 2	471.932	117783	0.0560	0.45
San Onofre System 3	471.932	90251	0.0700	0.27
San Onofre System 4	451.612	25027	0.0840	0.07

Notes:

Bold results indicate runoff coefficient was adjusted from greater than 1.0 to reflect site condition.

[1] Monitored and reasonable non-monitored storm data was used.

6.0 Empirical Observations

Empirical observations were taken during each storm event at each RVTS biofilter test site. Field crews assessed BMP operations at the beginning, middle and end of a storm event. Traffic, weather and sufficient light sometimes limited these observations.

Observations generally provided information on the following:

- Present meteorological characteristics
- Rainfall (start times and intensity indication)
- Hydrologic and hydraulic characteristics (flowing and/or standing water, channelization)
- Water level
- Edge-of-pavement conditions (problems affecting performance)
- Evidence of debris (organic or trash), scouring, resuspension or erosion
- Description of amount and location of sediment accumulation
- Water quality appearance (visual)
- Vegetation condition
- Collection ditch conditions (problems affecting performance)
- Structural condition of facility

A summary of pertinent empirical observations for the 2001/2002 and 2002/2003 seasons is presented in Appendix H. The most significant observations affecting strip performance were gopher activities and the lack of vegetation at several southern California strips, notable erosion at the Moreno Valley strips, long-lasting seepage flows from several of the northern California strips, and storm water infiltration at all strips. Numerous smaller-scale observations occurred periodically at all sites throughout the storm season (Appendix H).

7.0 Site Maintenance (Caltrans)

Since the goal of the study is to determine the performance of existing vegetated areas, no special care to the biofilter test sites were performed by the study team. Caltrans Maintenance Manual Chapter 2 states "Vegetation should be controlled where necessary for fire prevention, safety, and reduction of noxious weeds. Removal of vegetation is generally restricted to a narrow band adjacent to shoulder edges and that necessary to provide sight distance and protection of highway appurtenances such as guardrails and signs."

Each district prepares an annual plan for vegetation control. The districts identify Vegetation Management units that encompass highway segments with similar terrain, vegetation and neighboring land use characteristics. Vegetation control strategies for each segment are developed by identifying characteristics and making decisions on the degree of fire risk and the consequences. The minimum vegetation control necessary to provide adequate fire prevention is implemented while not compromising safety or integrity of the highway surface. Typically, this requires mowing the site twice per year. A summary of noted maintenance activities at the sites is summarized in Table 21.

Table 21. Summary of Site Maintenance (2001/2002 and 2002/2003)

Site	System No.	Test Site ID	Strip Length (m)	Maintenance Activity	Approx. date of Maintenance
Sacramento	System1	3-213	0.0	None noted	-
	System2	3-214	1.1	Vegetation mowed ~6 in.	3-25-02
	System3	3-215	4.6	Vegetation mowed ~6 in. (portion of test strip)	3-25-02
	System4	3-216	6.6	None noted	-
	System5	3-217	8.4	None noted	-
Cottonwood	System1	2-201	0.0	None noted	-
	System2	2-202	9.3	None noted	-
Redding	System1	2-203	0.0	Notice of herbicide use given by District 2 Strips appeared to be recently mowed	3-6-02 12-13-03 1-21-03
	System2	2-204	2.2	Strips appeared to be mowed	12-13-03 1-21-03
	System3	2-205	4.2	Strips appeared to be mowed	12-13-03 1-21-03
	System4	2-206	6.2	Strips appeared to be mowed	12-13-03 1-21-03
San Rafael	System1	4-213	0.0	Firebreak was regraded by monitoring crew to eliminate tire ruts causing bypass	1-3-02

Site	System No.	Test Site ID	Strip Length (m)	Maintenance Activity	Approx. date of Maintenance
				Site was observed to be mowed	2-15-03
	System2	4-214	8.3	Site was observed to be mowed	2-15-03
Irvine	System1	12-230	0.0	Firebreak was partially bladed by Caltrans crew. Later regraded by monitoring crews to eliminate bypass	1-30-02
	System2	12-231	3.0	None noted	-
	System3	12-232	6.0	None noted	-
	System4	12-233	13.0	None noted	-
Yorba Linda	System1	12-225	0.0	None noted	-
	System2	12-226	2.3/1.4	None noted	-
	System3	12-227	5.4/4.4	None noted	-
	System4	12-228	7.6	None noted	-
	System5	12-229	13.0	None noted	-
Moreno Valley	System1	8-201	0.0	Test site was bladed by CT, soil stabilizer applied by study team	10-1-01 12-5-01
	System2	8-202	2.6	Test site was bladed by CT, soil stabilizer applied by study team	10-1-01 12-5-01
	System3	8-203	4.9	Test site was bladed by CT, soil stabilizer applied by study team	10-1-01 12-5-01
	System4	8-204	8.0	Test site was bladed by CT, soil stabilizer applied by study team	10-1-01 12-5-01
	System5	8-205	9.9	Test site was bladed by CT, soil stabilizer applied by study team	10-1-01 12-5-01
San Onofre	System1	11-204	0.0	None noted	-
	System2	11-205	1.3	Vegetation mowed to <6"	3-25-02
	System3	11-206	5.3	Vegetation mowed to <6"	3-25-02
	System4	11-207	9.9	Vegetation mowed to <6"	3-25-02

8.0 Summary of Findings

Based on evaluation of the data collected during the 2-year monitoring study, a summary of findings are summarized below:

- A minimum vegetative cover of about 65% is required for concentration reduction to occur, although a rapid decline in performance occurs below about 80%.
- Concentration reductions consistently occur for TSS and total metals and frequently for dissolved metals.
- Concentration increases consistently for dissolved solids and occasionally for organic carbon.
- Nutrient concentrations were generally unchanged by the buffer strips.
- Vegetation species and height was similar at most sites and no effect on performance was observed.
- A substantial load reduction is evident for all constituents even those that exhibit no change in concentration because of the low runoff coefficients at all of the sites.
- At sites with greater than 80% vegetation coverage, the following buffer widths result in irreducible minimum concentrations for those constituents whose concentrations decrease:
    - 4.2 meters for slopes less than 10% (Redding)
    - 4.6 meters for slopes greater than 10% and less than 35% (Sacramento)
    - 9.2 meters for slopes between 35% and 50% (Cottonwood)
- At sites with less than 80% coverage, the following buffer widths result in irreducible minimum concentrations:
    - No data for slopes less than 10%
    - 10 meters for slopes greater than 10% (San Onofre, San Rafael)
- Study sites with sufficient vegetation and not overrun by gophers produced an effluent quality that was equal to or better than that observed from vegetated buffer strips engineered and operated specifically for water quality improvement.
- Comparison of results to a recently completed Caltrans the BMP Retrofit Pilot Study in southern California that included an assessment of the performance of vegetated buffer strips shows that many existing vegetated areas along highways have performance comparable to systems engineered and operated specifically for water quality improvement

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9.0 References

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Appendix A:

HYDROGRAPHS

(See Attached CD)

Appendix B:

RAIN AND FLOW DATA FOR ALL EVENTS

Appendix C:

CHEMISTRY DATA 2001-2003

Appendix D:

QA/QC SUMMARY REPORTS (LDD OUTPUTS)

2002-2003 REPORT (YET TO BE INCLUDED)

Appendix E:

SITE PHOTOGRAPHS

Appendix F:

VEGETATION ASSESSMENT REPORTS

(SEE ATTACHED CD)

Appendix G:

SOIL INVESTIGATION REPORTS

(SEE ATTACHED CD)

Appendix H:

EMPIRICAL OBSERVATIONS