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Sacramento Stormwater Monitoring Program

Landscape Control Measure Study, 1999-2002

(1500 Expo Parkway)

Prepared for:

County of Sacramento
City of Sacramento
City of Folsom
City of Galt
City of Citrus Heights
City of Elk Grove

STORMWATER POLLUTION SOLUTIONS

SACRAMENTO
STORMWATER
MANAGEMENT PROGRAM

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PURPOSE AND OBJECTIVES

Impervious surfaces, such as parking lots and rooftops, increase both the volume and the peak rate of runoff, and provide sites for traffic-generated residues and airborne pollutants to accumulate and become readily available for wash-off. Various control measures are available for reducing pollutant concentrations and loads in runoff from urban impervious areas. Vegetated swales are being utilized as on-site stormwater quality control measures at various locations in the Sacramento urban area. Swales are listed as recommended treatment control measures in the City/County "Guidance Manual for On-site Stormwater Quality Control Measures" and in the Sacramento "NDMP Stormwater Control Measure Study Work Plan" (LWA, 1996).

This study was designed to evaluate the pollutant removal performance of a vegetated swale. This study is a follow-up to the 1998/99 vegetated landscape study at the SMUD facility (see LWA, 1999a). The current study encompasses three seasons of wet weather monitoring at the Radiological Associates of Sacramento (RAS) facility, at 1500 Expo Parkway in Sacramento. This study was planned as an extended effort (i.e., to include monitoring of at least 10 storm events) under the Sacramento Stormwater Monitoring Program. This is the final report covering the three-year study period, 1999-2002.

The original study objectives were as follows:

1) Characterize the quality of stormwater runoff from a commercial parking lot, as represented by the influent water quality data.

2) Quantify the pollutant removal performance of a representative grassy swale installation in the Sacramento area.

A third study objective was added late in the second monitoring season:

3) Characterize the quality of roof runoff from an on-site commercial building.

At the end of each previous monitoring season, interim status reports were prepared including a statistical summary of the data and monitoring events, a summary of visual observations, and recommendations for modifications to the study based on findings to date (LWA, 2000a; LWA, 2001). For this final report, a summary of the 2001/02 sampling events is provided, in a format similar to the status reports of previous years. Then, summary results for the entire monitoring period (April 2000 through May 2002) are analyzed cumulatively. A total of eleven monitoring events were successfully completed at the RAS swale during this period.

This study provides both quantitative data and relevant observations that can be used in an evaluation of the effectiveness of the selected vegetated landscape control measure. The results of this effectiveness evaluation, in turn, may be used to determine appropriateness of such controls for use within the New Development Management Program (NDMP) element, as part of the Sacramento Stormwater Management Program. All reported data have been input into the Sacramento Stormwater Program's ACCESS database.

STUDY METHODS AND SITE DESCRIPTION

The study site and control measure studied are described below.

Study Location

The grassy swale selected for this study is located in a commercial parking lot operated by RAS. The site is located in the City of Sacramento at 1500 Expo Parkway. Figure 1 shows the location of the study site.

Control Measure Description

A grassy swale is a vegetated, shallow conveyance channel with gentle side-slopes. Treatment occurs as stormwater runoff flows through the dense vegetated lining. A portion of the runoff infiltrates below grade and does not enter the storm drain. Pollutants are removed within the swale by several mechanisms including filtration, sedimentation, adsorption, and infiltration. Once trapped in the swale, pollutants may undergo further conversion through microbial degradation, plant uptake, or evaporation.

In order for the swale to be effective, full grass cover and proper grass height must be maintained. Specific requirements for swale design are outlined in the Guidance Manual for On-site Stormwater Quality Control Measures (Sacramento Stormwater Program, 2000). Grassy swales are "public-domain" systems, to be distinguished from proprietary control measures.

Site Description / Monitoring Locations

The swale monitored for this study was selected in late 1999, with storm-event sampling beginning in April 2000. The swale is located at the south end of the RAS facility parking lot. The swale is approximately 185 feet long with inlet locations on both the east and west ends of the swale. A single outlet is located in the center of the swale (i.e. treatment length from each inlet to the outlet is approximately 90-95 feet). Figure 2 depicts the RAS site with roof runoff, swale inlet, and swale outlet monitoring locations indicated. Photographs of the swale area, presented originally in the 2000/01 Status Report (LWA, 2001), are shown in Figure 3. No modifications have been made to the site since the initial sampling event.

Monitoring of roof runoff from an on-site commercial building was added during the last event of the 2000/01 rainy season (event #6). Samples were collected at the outlet from the downspout where it flowed onto the pavement (see photograph, Figure 4).
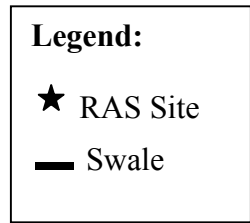
Figure 1. RAS study location.
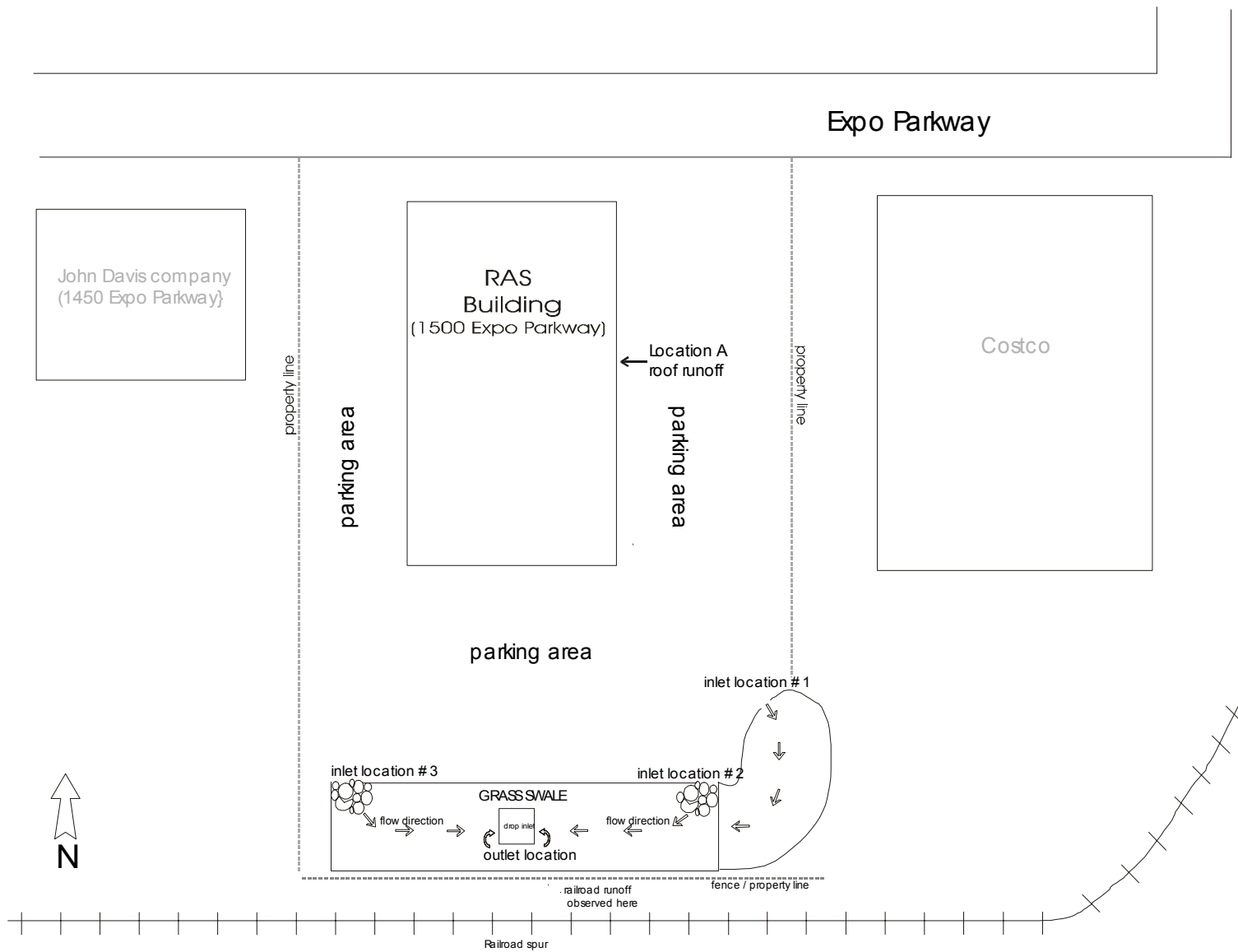
Figure 2. RAS facility site map with sampling stations for inlet, outlet, and roof runoff noted.

Figure 3. Photograph of the RAS vegetated swale during a sampling event.

Figure 4. Photograph of a downspout from the RAS facility. Sampled aliquots were collected at the outlet in the curb.

The following characteristics of the RAS swale site were important factors in the selection of this site for the study:

- The site meets all of the design criteria outlined in the design guidelines (Sacramento Stormwater Program, 2000) with the following exceptions: the east side-slope of the swale near the outlet exceeds the recommended maximum of 3:1, and the calculated retention time of 6.25 minutes is slightly less than the recommended 7-9 minutes.

- The site is in full use, with the parking lot full during normal business hours and never empty (sustaining staff are present 24 hours per day, seven days per week). For this reason, pollutant loadings from this site should be representative of typical parking lot use patterns for similar commercial facilities.

- The swale is located at the rear of the parking lot and therefore monitoring should not cause substantial disruption of traffic or loss of parking spaces.

- The site is well lit and secure. Several street lamps located in the parking lot provided light during sampling activities.

Site/Monitoring Notes

Runoff from inlet #1 does not reach the swale at inlet #2 under normal storm flows; therefore, inlet #1 was not sampled.

Cobbles are in place at each of the inlet locations to act as energy dissipaters and flow spreaders, and to ensure that flows go through the swale without blockage. The vegetation is a perennial fescue/blue grass mix.

A railroad spur runs parallel to the swale on the south side of the property fence, approximately 10-15 feet from the swale edge. A portion of the railroad spur slopes towards the swale. In certain rain events, runoff from the spur could enter the swale and potentially contaminate samples. This additional flow was observed during a portion of Event #3.

Site Maintenance

According to the RAS landscape maintenance schedule:

- All lawn areas are mowed and edged every week between March and November and mowed every two weeks between November and March. Field crews made visual observations during each monitoring event regarding the approximate grass height to ensure that it was within the design guidelines.

- Fertilizer is applied to the swale six times annually and a pre-emergent herbicide is applied twice annually.

- Walkways were blown off and cleared of trash and debris weekly; however, overall sweeping of the parking lots is not performed. Field crews made visual observations of the amount and type of trash and debris in the area and in the swale during each monitoring event.

Study Parameters and Conditions

The sampling protocols and analytical constituents are described below. For complete details of the sample collection and analytical procedures, refer to the original Study Analysis Plan (LWA, 2000b).

Sampling Program

Candidate storms for sampling were those predicted to produce at least 0.2 inches of rainfall within eight hours at the study site. Changing from past practice, professional forecasters were contracted during the 2001/02 rainy season to provide support leading up to and during monitored storm events. This service assisted LWA staff in monitoring approaching storms, as well as tracking on-going storms to assess changes in predicted precipitation totals. A total of 11 storm events were monitored beginning in April 2000.

Runoff from the storm events was monitored at the downspout, and before and after passage through the swale. Swale inlet and outlet composite samples were collected on a flow-proportional basis, using incident rainfall as an analog for runoff volume. Individual sample aliquot volumes were calculated based on the quantity of precipitation forecast (QPF) and assuming sample aliquot collection at an interval of every 0.04 inches of rainfall, so that the total sample aliquots collected would equal the required composite volume needed. Sample aliquots were collected from all inlet locations using a portable peristaltic pump and composited into one inlet sample container. Equal sample volumes were collected from the downspout and outlet locations by placing measuring containers into the sampling stream. A Pyrex pitcher was used for downspout samples. A flexible plastic pitcher was used for outlet samples so that water trickling down the concrete sidewall of the drop structure could be collected. The individual sample aliquots were measured and poured into 20-liter composite carboys.

Grab samples were collected from each location for constituents that transform rapidly, require special preservation, or may adhere to bottles (ammonia, coliform bacteria, and petroleum hydrocarbons). Grab samples were collected directly into individual containers for shipment.

"Clean sampling" techniques were used for the collection of water samples in a way that does not contaminate, lose, or change the chemical form of the analytes of interest. Samples were collected using rigorous protocols, based on EPA Method 1669.

Site Visual Observations

Site observations were made by the field crew before, during, and after each sampling event and noted on the field log. Observations included anything that may potentially impact sample results or that may aid in interpretation of data and/or the collection of samples in future sampling events. Particular attention was paid to the following: runoff to the swale from surrounding properties (especially the railroad spur parallel to the swale), passing of trains during sample collection, leaking vehicles, approximate number of cars parked in the lot, and construction flows (if any) from the westerly adjacent lot.

Analytical Constituents

Removal of total suspended solids, total metals, organic carbon, and oil and other petroleum products were the primary study focus. Samples were analyzed for petroleum hydrocarbons, organophosphate pesticides ("OP" pesticides), nutrients (including ammonia, nitrite/nitrate, TKN, and total phosphorus), BOD, TOC, DOC, and total and fecal coliform, to provide specific

land use runoff data as well as treatment information. Composite and grab samples were analyzed and field measurements were made for several physical and chemical parameters. Table 1 explains the reasoning for analyzing each constituent and parameter. Table 2 lists the sample type, analytical method, and reporting limit for each constituent.

<u>Field-measured Parameters</u>

Turbidity, pH, and electrical conductivity were measured in the field at the time of grab sample collection.

Rainfall amounts and duration for each monitored storm event were also measured during the study.

Data Analysis

Data analysis includes the initial data formatting, statistical comparisons of the data, and a "power analysis" to determine additional monitoring that would be needed to improve the statistical comparisons.

<u>Data Formatting</u>

Precipitation-proportional composite samples as well as grab samples (where required by EPA protocols) were collected at the swale monitoring stations to obtain data representative of the average concentrations of the analytical constituents throughout each monitoring event. The analytical results from the composite samples effectively represent the "event mean concentrations" ("EMCs") for those constituents tested. The time period covered by composite sampling for each event was typically the period of runoff associated with a particular rainfall event. For those constituents for which protocols require grab sample collection, the grab samples were typically collected near peak flow (or mid-event) and the analytical results were then used as an approximation of the EMC.

The data from each sampling event have been fully evaluated for QA/QC and qualified where necessary. The protocols and qualifiers are provided later in this report, in the section "Quality Assurance and Quality Control".

<u>Descriptive Statistics and Non-detected Data Substitution</u>

A programmed data analysis tool (DAT) is used to calculate summary statistics for each site's dataset. The method used to consider non-detected values is typically known as a regression on order statistics (ROS) in the literature. The ROS method develops probability-plotting positions for each data point (censored and uncensored) based on the ordering of the data. A least squares regression line is then fit by regressing the log-transformed values to the uncensored probability plotting positions. The censored data points (non-detects) are assigned values based on their probability plotting positions and the regression line equation. Summary statistics are then calculated based on the uncensored data points and the filled-in censored values. Standard deviation is calculated using a Tukey-Jackknife algorithm, performed by sequentially removing one point from the dataset, running the analysis, and calculating the variance estimators as the average of each of the runs. The criteria for sufficient data to run the DAT are: 1) at least 20% detected data, and 2) at least three unique detected values. Insufficient detected data (IDD) is noted in the summary statistics tables, where necessary.

Table 1. Analytical Constituents

Parameters	Reason for Inclusion

Physical Characteristics
   Electrical Conductivity
   Turbidity
   pH
   Hardness
	Easily measured parameters that help characterize stormwater runoff and provide additional detail for control measure evaluation.

Total suspended solids (TSS)	Common focus of stormwater treatment controls; often used as indicator of removal of other constituents that tend to adsorb onto particulate material.
Total semi- & non-volatile petroleum hydrocarbon extractables	Petroleum-based contaminants are expected to be present in stormwater runoff in parking areas. Additionally, grassy swales have been shown to effectively remove those constituents from stormwater.

Metals (Total recoverable and dissolved)
   Cu
   Pb
   Zn
	Significant total metals removal can be expected to occur in conjunction with sediment removal. These three metals were targeted due to their high priority Target Pollutant classification and common occurrence in urban stormwater runoff.

Nutrients
   Ammonia
   Nitrate
   Nitrite
   Total Kjeldahl nitrogen (TKN)
   Total phosphorus
	Important to characterize because of potential fertilizer use. Also, studies have shown increases in some nutrients after treatment by swales.

Biological oxygen demand (BOD_5)	Valuable to the overall characterization of urban runoff.
TOC/ DOC	Will provide information to support the overall characterization of the discharge.
Fecal and total coliform	Common urban runoff pollutants; indicator parameters.
Organophosphate pesticides	Pesticides commonly found in urban runoff at levels of concern.
Semi- & non-volatile organics	Will provide data on a wide range of organics, including PAHs, components of petroleum products and their break-down products, which are commonly detected in urban runoff at levels of concern.

Table 2. Sample Volume Required and Type of Sample

Constituent	Sample Type	Method[1]	Reporting Limit
OP-Pesticides	Composite	EPA 8141	*
Total Kjeldahl Nitrogen	Composite	EPA 351.3	0.1 (mg/L)
Phosphorus, total	Composite	EPA 365.2	0.1 (mg/L)
Nitrate	Composite	EPA 300.0	0.1 (mg/L)
Nitrite	Composite	EPA 354.1	0.1 (mg/L)
Total Hardness	Composite	EPA 130.2/SM 2340C	5 (mg/L)
Ammonia	Grab or composite[2]	EPA 350.2	0.1 (mg/L)
Semi- & non-volatile petroleum hydrocarbon extractables	Grab	EPA 8015M	*
TOC	Composite	EPA 415.1	1 (mg/L)
DOC	Composite	EPA 415.1	1 (mg/L)
BOD5	Composite	EPA 405.1	3 (mg/L)
TSS	Composite	EPA 160.1/160.2	20 (mg/L)
Coliform, fecal and total	Grab	SM 9221 B&E	2 to 2E6 (MPN/100ml)
Copper (total & dissolved) Lead (total & dissolved) Zinc (total & dissolved)	Composite	EPA 200.8 ICP/MS	0.01 (μg/L) 0.001 (μg/L) 0.02 (μg/L)
Semi & non-volatile organics	Composite	EPA 8270	*

(1) The methods most commonly refer to US EPA methods, except where designated with "SM" which refers to Standard Methods for the Examination of Water and Wastewater.
(2) Ammonia for events #10 and 11 were from composite bottles.
* Reporting limits vary by constituent (see **Appendix B**).

Influent/Effluent Statistical Comparisons

The analyses for comparing sites' data are described in this section.

Calculating Changes in Concentrations
For estimating mean removal efficiencies in the swale and for comparing mean concentrations of constituents in roof runoff to inlet, non-detected data were substituted with values statistically representative of a lognormal distribution of the data, as described above. In cases where the

mean value could not be estimated with filled-in values (i.e., there were insufficient detected data to use the non-detect substitution algorithm), the detection limit was substituted.

Test for Statistical Significance

A test of statistical significance is the accepted statistical procedure used to determine if two monitoring locations are inherently different (i.e., a constituent is removed between the inlet and outlet of a BMP). There are a number of statistical methods available for determining significance. Because the data for the RAS grassy swale are event-based pairs of roof runoff with inlet, and inlet with outlet data, a paired test provides additional statistical power. The data also contain a number of concentrations below the reporting limit. These "non-detect" data reduce the statistical power and significantly complicate performing a paired "t-test". A "signed-rank test" (Wilcoxon) was used to test for statistical significance.

The Wilcoxon signed-rank test considers the numerical difference between sites and the ranks of the absolute values of those differences. However, this test requires the user to provide numerical values for the results reported as non-detects and makes some assumptions about the data variability and skewness. For this study non-detects are conservatively addressed by assuming that their values are equal to the detection limits. The "test statistic" is equal to the sum of the ranks of all the differences that are greater than zero. This test statistic is then used to calculate a p-value. The signed-rank test, unlike the paired t-test, does not make the assumption that the difference in values is normally distributed; an assumption that would be harder to prove given the relatively small number of data points for the RAS swale and assumptions made about the "value" of non-detects. The assumption made to complete the signed-rank test is that values from each site are similarly distributed (i.e., each set of site data has the same variability and skewness) or that their differences (or the logarithmic transformation of their differences) are symmetric around their median. This was assessed visually using boxplots and found to be sufficiently symmetric for the log normal-transformed values for both roof runoff to inlet and inlet to outlet comparisons (figure not shown).

For this analysis, a 95% confidence level was used as the threshold to determine statistical significance in the one-sided sign-rank test. This level corresponds to a probability (p-value) of 0.05 attributed to the null hypothesis. A very low p-value (i.e., p<0.05) corresponds to a low level of confidence in the null hypothesis, which indicates a high level of confidence that the observed differences between the two data sets are not due to chance alone (i.e., that the data sets are in fact significantly different from one another). Alternately, a higher p-value (p>0.05) indicates that there is no statistically significant difference between the data sets.

Power Analysis

A power analysis was performed on constituents with signed rank test p-values between 0.05 and 0.20 to determine the number of samples required for each to achieve a 95% confidence level in the Wilcoxon signed rank test (i.e., to result in a p-value of less than 0.05). The average of all the differences between inlet and outlet concentrations was used to calculate the "effect size" (the expected amount of difference between the data sets). The power analysis was conducted based on a 95% confidence level for rejecting the null hypothesis (described in the section Test for Statistical Significance). The desired power of the tests was set at 80%, where "power" is defined as the probability of rejecting the null hypothesis when it should be rejected (i.e., the probability of detecting a significant decrease in concentration of a constituent between the swale inlet and outlet).

REVIEW OF 2001/02 MONITORING EVENTS

Five rainfall events were monitored successfully at the RAS swale during the most recent (2001-2002) rainy season. These events constitute the 7th through 11th successful monitoring events at this study site. One false start occurred on December 2, 2001. Larry Walker Associates (LWA) staff conducted the fieldwork and provided monitoring management support for all monitoring events. Previous monitoring events have been described in previous status reports (LWA, 2000a; LWA, 2001).

The Permittees were provided with post-event emails, followed by event summary memoranda, briefly describing the monitoring activities. The memos summarized the precipitation received, samples collected and analyses requested, and any problems encountered in the sample collection. Each of the five successful monitoring events for 2001/02 is described separately in this section. This section summarizes the timing, antecedent conditions, samples collected, and any problems encountered for each event. A summary of the precipitation and sample collection characteristics for these events is presented in Table 3.

Table 3. Rainfall, Runoff, and Sampling Characteristics for 2001/02 Wet Weather Events

Rainfall, Runoff, and Sampling Information	Event #7 (October 30, 2001)	Event #8 (December 13, 2001)	Event #9 (January 26, 2002)	Event #10 (March 10, 2002)	Event #11 (May 20, 2002)
Time of first rain[1]	10/30/01 2:59	12/13/01 19:38	1/26/02 3:38	3/9/02 23:37	5/20/02 4:37
Time of last rain	10/30/01 9:00	12/14/01 2:38	1/26/02 6:38	3/10/02 3:36	5/20/02 15:37
Total rain (in.)[2]	0.39	0.67	0.24	0.35	0.83
Time of first sample	10/30/01 7:00	12/13/01 22:05	1/26/02 4:00	3/10/02 1:00	5/20/02 12:50
Time of last sample	10/30/01 9:20	12/14/01 2:30	1/26/02 6:05	3/10/02 3:30	5/20/02 14:35
Total rain captured (in.)[3]	0.22	0.62	0.29	0.43	0.23
Percent storm capture[4]	56	93	121	123	28
Total sampling time	2:20	4:25	2:05	2:30	1:45
Number of aliquots	5	12	6	9	5
Grab time	10/30/01 8:00	12/14/01 1:50	1/26/02 6:10[5]	3/10/02 2:00	5/20/02 14:25
Antecedent Conditions[2]					
Time of last precipitation	9/25/01 0:23	12/9/01 3:50	1/21/02 14:39	3/7/02 12:30	5/20/02 12:17
Time since last precipitation (days)	35.1	4.7	4.5	2.5	On-going
Date of last storm ≥ 0.1 in.	9/25/01 0:23	12/5/01 21:18	1/6/02 7:59	3/7/02 12:30	5/20/02 12:17
Time since last storm ≥ 0.1 in.	35.1	7.9	19.8	2.5	On-going
Date of last storm ≥ 0.25 in.	9/25/01 0:23	12/5/01 21:18	1/5/02 17:57	3/6/02 10:38	5/20/02 12:17
Time since last storm ≥ 0.25 in.	35.1	7.9	20.4	3.5	On-going

(1) All times are in military format, from 0 to 24 hours.
(2) Based on Department of Water Resources rain gauge at Arden Way (see http://cdec.water.ca.gov/cgi-progs/queryF?ARW).
(3) Rainfall measurements were made with an on-site rain gauge.
(4) Percentages greater than 100 are due to the variability in rain gages between the DWR gage and the on-site gage.
(5) Grab was collected just as rain ceased on site.

The monitoring events spanned the entire 2001/02 rainy season, successfully sampling the first and last significant rainfall events of the season. The middle three events were evenly spaced throughout the season, occurring in mid-December, late January, and early March.

Monitoring Event #7: October 30, 2001

The forecast was for 0.25" of precipitation, arriving early Tuesday morning and moving through the Sacramento area over a 3-hour period, followed by overcast and short-term storm conditions throughout the day. The field crew mobilized in time for the main frontal passage; monitoring covered approximately 0.22" of rainfall. Total rainfall from a nearby Department of Water Resources rain gauge at Arden Way was 0.39" (Figure 5).

Figure 5. Rainfall pattern during monitoring event #7 at the RAS swale.

It was estimated that significant flow through the swale did not occur prior to arrival of the field crew at the site. Three composite sample aliquots were collected, comprised of one at the inlets, outlet, and downspout, providing sufficient samples to perform all planned composite analysis. Additionally, grab samples were collected for ammonia, semi- and non-volatile petroleum hydrocarbon extractables, and coliform analyses. LWA staff conducted the fieldwork and provided monitoring management support.

Observations made during the monitoring event are summarized in **Appendix A**. Observations of particular concern included high traffic flow, as this storm/sampling event was during regular business hours. Field measurements were made and recorded as shown in Table 4.

Table 4. Field measurement results from storm event #7

Parameter	Roof Runoff	Swale Inlet	Swale Outlet
pH	9.15	7.5	10.3
Turbidity (NTU)	NA	NA	NA
Electrical Conductivity (uS/cm)	43	28	34.6

NOTE: Field measurements were taken concurrently with grab samples.
NA = Not Available

The types and disposition of samples collected during this event, as well as the disposition of quality assurance and quality control (QA/QC) samples are shown below in Table 5.

Table 5. Sacramento Landscape Control Measure Study Sample Analysis Summary

Event #7: 30-Oct-01													
	Sample	Environmental			QA/QC Samples								
	Type:	Samples			MS/MSD			Field Blank			Field Dupl.		
	Site:	In	Out	Rf	In	Out	Rf	In	Out	Rf	In	Out	Rf
Analysis	**Lab**												
OP Pesticides (EPA 8141)	APPL	R✓	R✓	R✓			R✓						
TKN	CalTest	R✓	R✓	R✓									
Total phosphorus	CalTest	R✓	R✓	R✓									
Nitrate/Nitrite	CalTest	R✓	R✓	R✓									
Ammonia	CalTest	R✓	R✓	R✓									
Total Hardness	CalTest	R✓	R✓	R✓									
Semi- & Non-volatile petroleum hydrocarbons	CalTest	R✓	R✓	R✓			R✓						
TOC	CalTest	R✓	R✓	R✓									
DOC	CalTest	R✓	R✓	R✓									
BOD	SRCSD	R✓	R✓	R✓									
TSS	SRCSD	R✓	R✓	R✓									
Total & Fecal Coliform	SRCSD	R✓	R✓	R✓				R✓					
Copper (dissolved & total recoverable)	FGS	R✓	R✓	R✓			R✓						
Lead (dissolved & total recoverable)	FGS	R✓	R✓	R✓			R✓						
Zinc (dissolved & total recoverable)	FGS	R✓	R✓	R✓			R✓						
Semi- & Non-volatile organics (EPA 625)	CRG	R✓	R✓	R✓			R✓						

"R" = Sample analysis requested.
"✓" = Sample analysis performed.

False Start: December 1, 2001

A significant storm approached from the northwest during the last week of November. In the Sacramento area, forecasts were for rain throughout the weekend (December 1-2). Two distinct fronts were observed off the coast on Friday afternoon, with the first anticipated to enter the valley Saturday afternoon, followed by a second expected front late Sunday.

The storm system was tracked throughout Saturday by the forecasters, but it never concentrated sufficient energy and rainfall. Sacramento did get some rain late Friday night and early Saturday accompanied by high winds but intensity was generally light, and accumulations were marginal.

Late Saturday evening, the forecast models indicated the second – and more substantial – front to get into the Sacramento area Sunday afternoon. However, 0.9 in of rain fell in Sacramento early Sunday morning (5-10 AM), much earlier than expected. Later Sunday morning (8 AM), a crew was mobilized to monitor the swale after forecasters' models still predicted the main front

moving over Sacramento at noon. The crew arrived on site at 10 AM, under clouds and intermittent precipitation, and immediately set up for blank samples (to precede the regular sampling). The main front, however, had already passed. The crew was demobilized approximately 3 hours later after clouds had dispersed. This was the first and only unsuccessful swale event (false start) of the 2001-2002 monitoring season.

Monitoring Event #8: December 14, 2001

The forecast was for at least 0.5" of precipitation, arriving Thursday night and moving through the Sacramento area with strong, cold winds. The field crew mobilized in time for the main frontal passage; monitoring covered approximately 0.62" of rainfall. Total rainfall from a nearby Department of Water Resources rain gauge at Arden Way was 0.67" (Figure 6).

Figure 6. Rainfall pattern during monitoring event #8 at the RAS swale.

It was estimated that significant flow through the swale did not occur prior to arrival of the field crew at the site. Composite sample aliquots were collected at the inlets, outlet and downspout, providing sufficient sample to perform all planned composite analysis. Additionally, grab samples were collected for ammonia, semi- and non-volatile petroleum hydrocarbon extractables, and coliform analyses. LWA staff conducted the fieldwork and provided monitoring management support.

Observations made during the monitoring event are summarized in **Appendix A**. There were no observations of particular concern. Field measurements were made and recorded as shown in Table 6.

Table 6. Field measurement results from storm event #8.

Parameter	Roof Runoff	Swale Inlet	Swale Outlet
pH	7.45	7.7	7.5
Turbidity (NTU)	7.0	39.3	7.5
Electrical Conductivity (uS/cm)	6.0	7.8	12.6

NOTE: Field measurements were taken concurrently with grab samples.

The types and disposition of samples collected during this event, as well as the disposition of QA/QC samples are shown below in Table 7.

Table 7. Sacramento Landscape Control Measure Study Sample Analysis Summary

Event #8: 14 December 2001													
	Sample Type:	Samples			MS/MSD			Field Blank			Field Dupl.		
	Site:	In	Out	Rf	In	Out	Rf	In	Out	Rf	In	Out	Rf
Analysis	Lab												
OP Pesticides (EPA 8141)	APPL	R✓	R✓	R✓								R✓	
TKN	CalTest	R✓	R✓	R✓								R✓	
Total phosphorus	CalTest	R✓	R✓	R✓								R✓	
Nitrate/Nitrite	CalTest	R✓	R✓	R✓								R✓	
Ammonia	CalTest	R✓	R✓	R✓								R✓	
Total Hardness	CalTest	R✓	R✓	R✓								R✓	
Semi- & Non-volatile petroleum hydrocarbons	CalTest	R✓	R✓	R✓								R✓	
TOC	CalTest	R✓	R✓	R✓								R✓	
DOC	CalTest	R✓	R✓	R✓								R✓	
BOD	SRCSD	R✓	R✓	R✓								R✓	
TSS	SRCSD	R✓	R✓	R✓								R✓	
Total & Fecal Coliform	SRCSD	R✓	R✓	R✓				R✓				R✓	
Copper (dissolved & total recoverable)	FGS	R✓	R✓	R✓				R✓				R✓	
Lead (dissolved & total recoverable)	FGS	R✓	R✓	R✓				R✓				R✓	
Zinc (dissolved & total recoverable)	FGS	R✓	R✓	R✓				R✓				R✓	
Semi- & Non-volatile organics (EPA 625)	CRG	R✓	R✓	R✓				R✓				R✓	

"R" = Sample analysis requested.
"✓" = Sample analysis performed.

Monitoring Event #9: January 26, 2002

The forecast was for 0.3" of precipitation, arriving around midnight Friday and moving through the Sacramento area with a cold front in the early morning hours followed by late rain for much of Saturday. The field crew mobilized in time for the main frontal passage; monitoring covered approximately 0.29" of rainfall. Total rainfall between the hours of 3:30 AM and 10:30 AM from a nearby Department of Water Resources rain gauge at Arden Way was 0.24" (Figure 7).
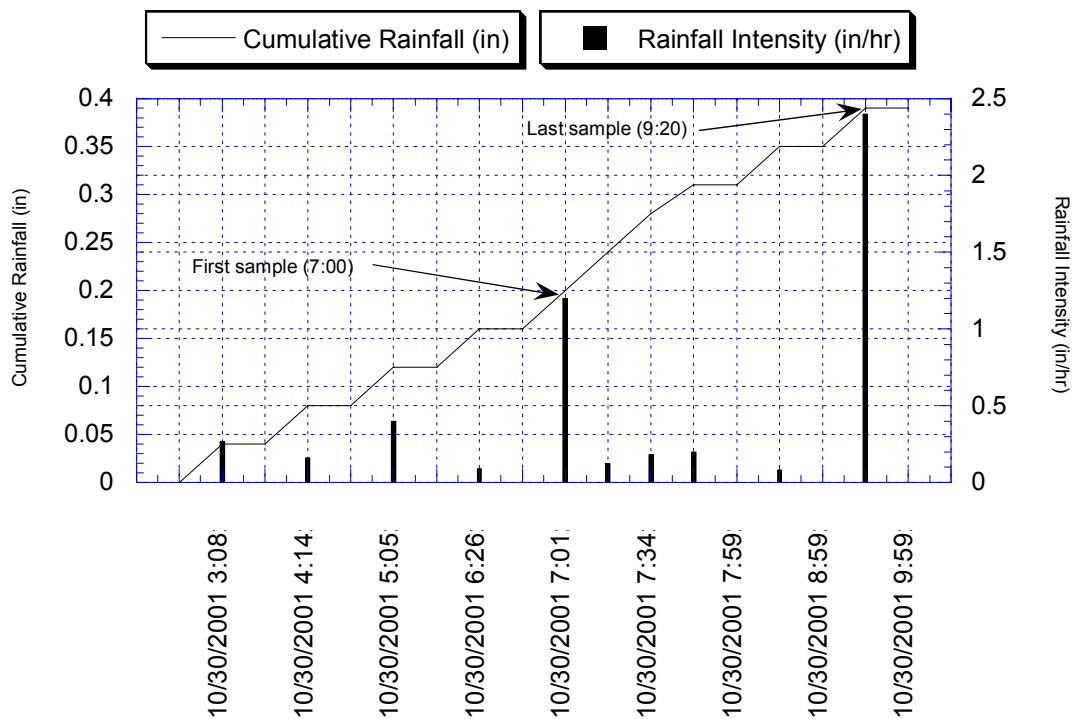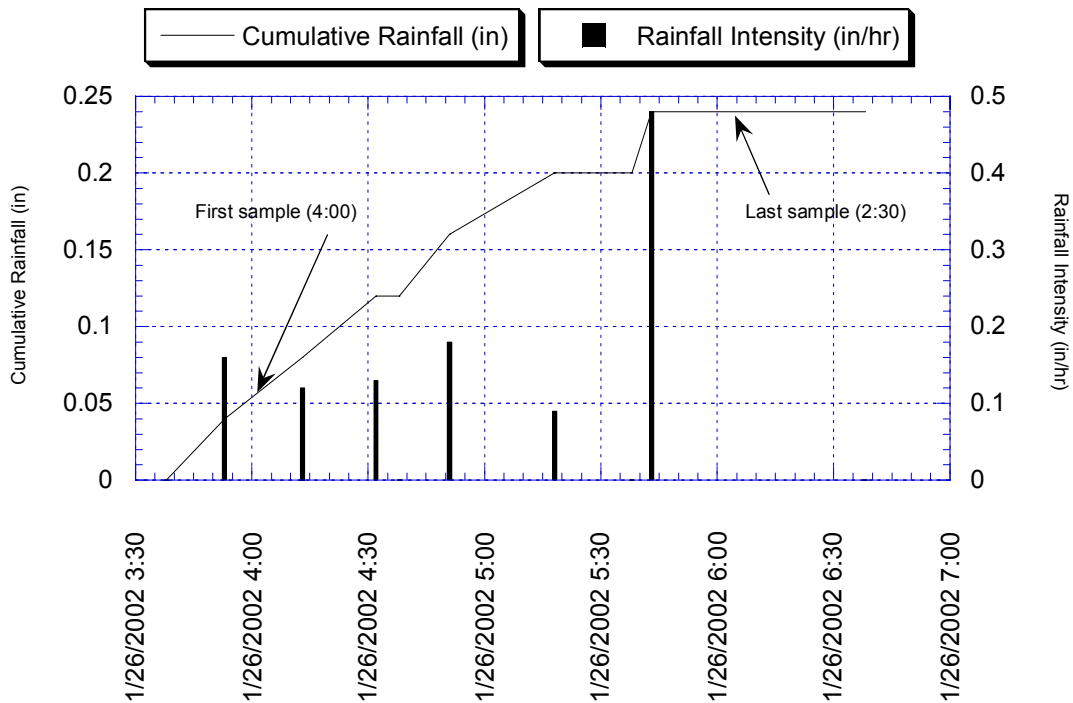
Figure 7. Rainfall pattern during monitoring event #9 at the RAS swale.

It was estimated that significant flow through the swale did not occur prior to arrival of the field crew at the site. Composite sample aliquots were collected at the inlets, outlet and downspout, providing sufficient sample to perform all planned composite analysis. Additionally, grab samples were collected for ammonia, semi- and non-volatile petroleum hydrocarbon extractables, and coliform analyses. Because of high rainfall intensity near the end of the storm, grab samples were delayed until the very end of the runoff period by an urgency to continue collecting composite samples. LWA staff conducted the fieldwork and provided monitoring management support.

Observations made during the monitoring event are summarized in **Appendix A**. The only observation of particular concern was a soapy residue in the inlet water. It appeared to arrive as a plume soon after a night cleaner left the RAS building (perhaps carpet cleaning residue). Field measurements were made and recorded as shown in Table 8.

Table 8. Field measurement results from storm event #9.

Parameter	Roof Runoff	Swale Inlet	Swale Outlet
pH	7.61	NA	NA
Turbidity (NTU)	4.45	10.8	111
Electrical Conductivity (uS/cm)	9.4	17.4	43.5

NOTE: Field measurements were taken concurrently with grab samples.
NA = Not Available

The types and disposition of samples collected during this event, as well as the disposition of QA/QC samples are shown below in Table 9. Samples were not received at the lab within the required holding time for BOD (6 hours) and therefore it was not measured.

Table 9. Sacramento Landscape Control Measure Study Sample Analysis Summary

Event #9: 1/28/02													
	Sample Type:	Samples			QA/QC Samples								
					MS/MSD			Field Blank			Field Dupl.		
	Site:	In	Out	Rf	In	Out	Rf	In	Out	Rf	In	Out	Rf
Analysis	Lab												
OP Pesticides (EPA 8141)	APPL	R✓	R✓	R✓	R✓								
TKN	CalTest	R✓	R✓	R✓									
Total phosphorus	CalTest	R✓	R✓	R✓									
Nitrate/Nitrite	CalTest	R✓	R✓	R✓									
Ammonia	CalTest	R✓	R✓	R✓									
Total Hardness	CalTest	R✓	R✓	R✓									
Semi- & Non-volatile petroleum hydrocarbons	CalTest	R✓	R✓	R✓									
TOC	CalTest	R✓	R✓	R✓									
DOC	CalTest	R✓	R✓	R✓									
BOD	SRCSD	R	R	R									
TSS	SRCSD	R✓	R✓	R✓									
Total & Fecal Coliform	SRCSD	R✓	R✓	R✓					R✓				
Copper (dissolved & total recoverable)	FGS	R✓	R✓	R✓	R✓				R✓				
Lead (dissolved & total recoverable)	FGS	R✓	R✓	R✓	R✓				R✓				
Zinc (dissolved & total recoverable)	FGS	R✓	R✓	R✓	R✓				R✓				
Semi- & Non-volatile organics (EPA 625)	CRG	R✓	R✓	R✓	R✓				R✓				

"R" = Sample analysis requested.
"✓" = Sample analysis performed.

Monitoring Event #10: March 10, 2002

A Pacific trough of low pressure spread clouds across Northern California through the day Saturday, with rain Saturday night continuing into Sunday. Precipitation on Sunday was more organized and continuous than the showery-type rain that affected the area earlier in the week. The forecast was for 0.25" of precipitation, arriving just after midnight. Intensity increased Sunday morning and moved slowly through the Sacramento area. The field crew mobilized in time for the main frontal passage.

Scattered showers ended up being relatively continuous and provided more rain than forecasted. When the composite bottles filled at 0.25", half of the water was discharged from each composite bottle. The bottles were then filled with subsequent aliquots with half of the preceding sample volume. Monitoring covered approximately 0.43" of rainfall. Total rainfall from a nearby Department of Water Resources rain gauge at Arden Way was 0.35" (Figure 8).
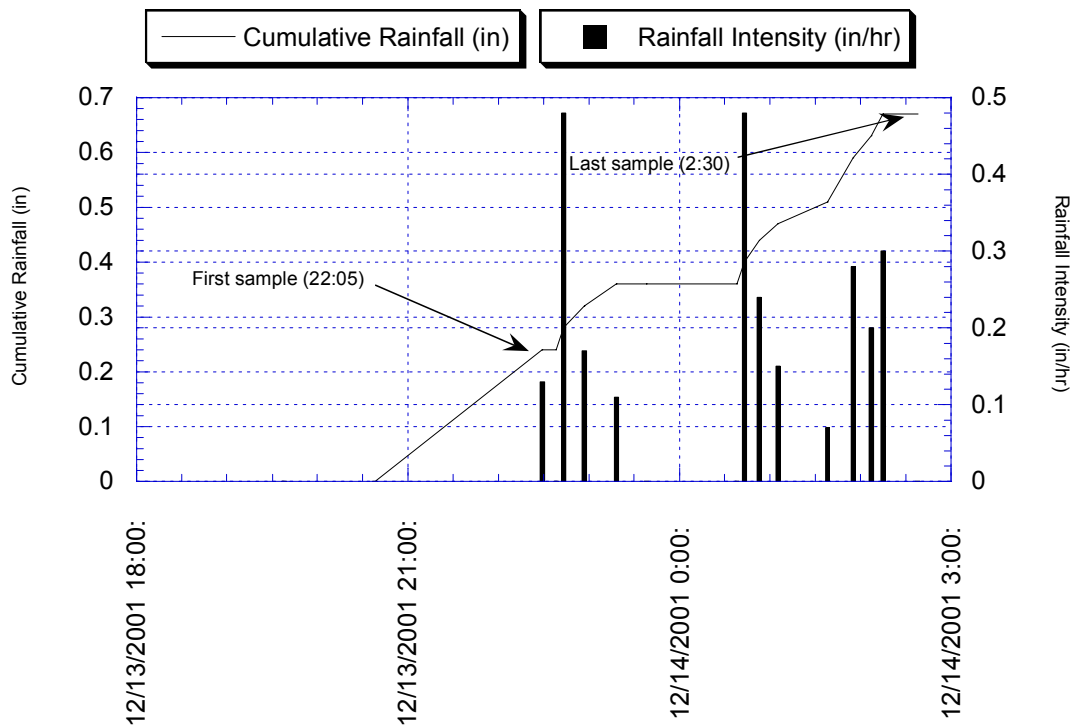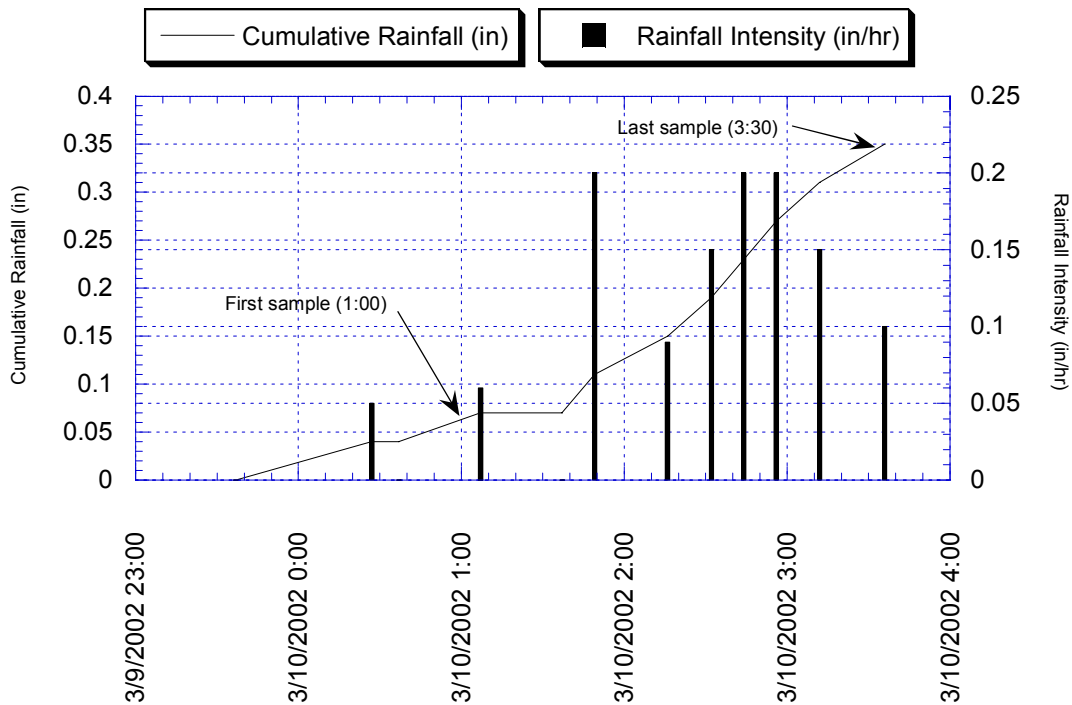
Figure 8. Rainfall pattern during monitoring event #10 at the RAS swale.

Significant flow through the swale did not occur prior to arrival of the field crew at the site. Three composite sample aliquots were collected at the inlets, outlet and downspout (one each), providing sufficient sample to perform all planned composite analysis. Additionally, grab samples were collected for ammonia, semi- and non-volatile petroleum hydrocarbon extractables, and coliform analyses. One ammonia grab bottle was mistakenly used for inlet rather than outlet and thus had to be discarded. As such, there was no outlet *grab* sample analyzed for ammonia. Fortunately, composite samples were analyzed for ammonia at all three locations (plus the duplicate). LWA staff conducted the fieldwork and provided monitoring management support.

Observations made during the monitoring event are summarized in **Appendix A**. Observations of particular concern included the tanker trucks parked on the train tracks and a large GE trailer using half of the parking lot. Field measurements were made and recorded as shown in Table 10.

Table 10. Field measurement results from storm event #10.

Parameter	Roof Runoff	Swale Inlet	Swale Outlet
pH	7.48	7.50	7.39
Turbidity (NTU)	NA	NA	NA
Electrical Conductivity (uS/cm)	5.7	6.9	18.3

NOTE: Field measurements were taken concurrently with grab samples.
NA = Not Available

The types and disposition of samples collected during this event are shown below in Table 11. Note that lab (not field) duplicates were required for QA/QC. APPL labs accidentally broke the

inlet sample bottle (1-L glass) sent to them and therefore could not analyze for OP pesticides at that location.

Table 11. Sacramento Landscape Control Measure Study Sample Analysis Summary

Event #10: 10-March-2002													
	Sample Type:	Samples			QA/QC Samples								
					MS/MSD			Field Blank			Lab Dupl.		
	Site:	In	Out	Rf	In	Out	Rf	In	Out	Rf	In	Out	Rf
Analysis	Lab												
OP Pesticides (EPA 8141)	APPL	R	R√	R√									R√
TKN	CalTest	R√	R√	R√									R√
Total phosphorus	CalTest	R√	R√	R√									R√
Nitrate/Nitrite	CalTest	R√	R√	R√									R√
Ammonia	CalTest	R√	R√	R√									R√
Total Hardness	CalTest	R√	R√	R√									R√
Semi- & Non-volatile petroleum hydrocarbons	CalTest	R√	R√	R√									R√
TOC	CalTest	R√	R√	R√									R√
DOC	CalTest	R√	R√	R√									R√
BOD	SRCSD	R√	R√	R√									R√
TSS	SRCSD	R√	R√	R√									R√
Total & Fecal Coliform	SRCSD	R√	R√	R√									R√
Copper (dissolved & total recoverable)	FGS	R√	R√	R√									R√
Lead (dissolved & total recoverable)	FGS	R√	R√	R√									R√
Zinc (dissolved & total recoverable)	FGS	R√	R√	R√									R√
Semi- & Non-volatile organics (EPA 625)	CRG	R√	R√	R√									R√

"R" = Sample analysis requested.
"✓" = Sample analysis performed.

Monitoring Event #11: May 20, 2002

A Pacific trough of low pressure spread clouds across Northern California Sunday morning. Precipitation on Sunday, unexpected by all forecasting models, was organized and continuous for several hours in the afternoon. Forecasts called for at least as much precipitation arriving Monday. Monday morning (around 4:30 AM) the second wave of precipitation reached downtown Sacramento. Clouds moved swiftly through the Sacramento area from the time of arrival through the early afternoon, producing heavy yet scattered showers. The field crew mobilized in time to sample two distinct rain cells. Monitoring covered approximately 0.23" of rainfall. Total rainfall from a nearby Department of Water Resources rain gauge at Arden Way was 0.83" (Figure 9). The difference in rainfall measured on site versus at Arden Way is indicative of the scattered nature of the storm.
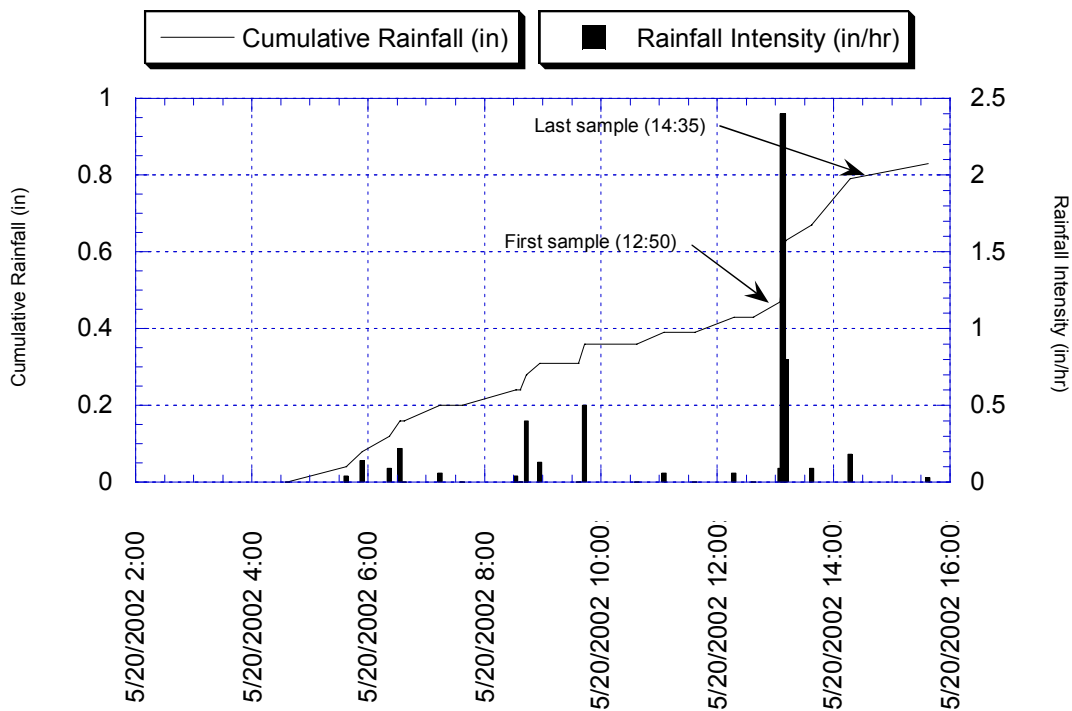
Figure 9. Rainfall pattern during monitoring event #11 at the RAS swale.

A storm cell passing earlier in the day appeared to have produced runoff that passed through the swale, as evident by the sedimentation pattern at the swale inlets and wet soil conditions in grassy areas. However, breaks in the storm preceded the distinct cells monitored on-site and water was not flowing through the swale upon arrival of the sampling crew. Composite sample aliquots were collected at the inlets, outlet and downspout, providing sufficient sample to perform all planned composite analysis. Additionally, grab samples were collected for semi- and non-volatile petroleum hydrocarbon extractables, and coliform analyses. LWA staff conducted the fieldwork and provided monitoring management support.

Observations made during the monitoring event are summarized in **Appendix A**. Observations of particular concern included the tanker trucks parked on the train tracks and a large GE trailer using half of the parking lot. Field measurements were made and recorded as shown in Table 12.

Table 12. Field measurement results from storm event #11.

Parameter	Downspout	Swale Inlet	Swale Outlet
pH	7.00	7.89	7.13
Turbidity (NTU)	NA	NA	NA
Electrical Conductivity (uS/cm)	18.3	19.6	57.8

NOTE: Field measurements were taken concurrently with grab samples.
NA = Not Available

The types and disposition of samples collected during this event are shown below in Table 13. Note that no additional samples were required for QA/QC.

Table 13. Sacramento Landscape Control Measure Study Sample Analysis Summary

Event #11: 20-May-2002													
	Sample Type:	**Samples**			**QA/QC Samples**								
					MS/MSD			**Field Blank**			**Lab Dupl.**		
	Site:	In	Out	Rf	In	Out	Rf	In	Out	Rf	In	Out	Rf
Analysis	**Lab**												
OP Pesticides (EPA 8141)	APPL	R✓	R✓	R✓									
TKN	CalTest	R✓	R✓	R✓									
Total phosphorus	CalTest	R✓	R✓	R✓									
Nitrate/Nitrite	CalTest	R✓	R✓	R✓									
Ammonia	CalTest	R✓	R✓	R✓									
Total Hardness	CalTest	R✓	R✓	R✓									
Semi- & Non-volatile petroleum hydrocarbons	CalTest	R✓	R✓	R✓									
TOC	CalTest	R✓	R✓	R✓									
DOC	CalTest	R✓	R✓	R✓									
BOD	SRCSD	R✓	R✓	R✓									
TSS	SRCSD	R✓	R✓	R✓									
Total & Fecal Coliform	SRCSD	R✓	R✓	R✓									
Copper (dissolved & total recoverable)	FGS	R✓	R✓	R✓									
Lead (dissolved & total recoverable)	FGS	R✓	R✓	R✓									
Zinc (dissolved & total recoverable)	FGS	R✓	R✓	R✓									
Semi- & Non-volatile organics (EPA 625)	CRG	R✓	R✓	R✓									

"R" = Sample analysis requested.
"✓" = Sample analysis performed.

Problems Encountered and Their Resolution

Although the swale outlet structure was designed to be level, runoff water tends to pass principally over the east side of the drain. And although the structure is made of nearly continuous concrete, a noticeable portion of the water seeps through cracks and the structure's open handle. These problems simply presented difficulties for collecting samples, and did not appear to affect the structure's performance. To sample runoff water at the outlet accurately, a plastic pitcher was used instead of the usual type made of Pyrex. To sample runoff water proportionally, water was collected from both sides of the structure for approximately equal portions of *time* (not volume).

Because of infiltration, the outlet did not receive as much water as flowed through the inlets. Not wanting to miss sampling of the first flush of runoff from the parking area, inlet samples were collected during each event as soon as possible after runoff began, even if water had not yet arrived at the outlet. This discrepancy in flow tended to occur only for the first aliquot and when rainfall intensity reduced to a drizzle.

QUALITY ASSURANCE AND QUALITY CONTROL

All data and documentation have been collected and analyzed for accuracy, precision and completeness. The following sections describe quality control performance for each type of quality assurance and quality control (QA/QC) check performed specifically for this study. QA/QC results for the 2001/02 monitoring season are evaluated here to provide some background for the influent and effluent data examined subsequently. QA/QC results for the two earlier monitoring seasons have been reported previously (LWA, 2000a; LWA, 2001). All qualified data are still used in the summary statistics, because we still consider the qualified data point to be our best estimate of the actual concentration.

QA/QC Procedures

The procedures used in the QA/QC analysis performed for the 2001/02 monitoring season data are described in the Data Quality Evaluation Plan (DQEP), included as **Appendix B** to this report. The DQEP includes a discussion of each type of QA/QC parameter examined and includes tables of data quality objectives (DQOs) for spike recovery, relative percent difference (RPD) between duplicate samples, holding times, and reporting limits.

An initial screening of the laboratory data reports is the first step in the QA/QC data evaluation process, and is designed to identify gross omissions, reporting errors, and other general sample handling problems. The detailed QA/QC data evaluation program consists of a review of the results of the laboratory-initiated (internal) QA/QC analyses and field-initiated (external) QA/QC sample analyses.

The review of field-initiated "blind" sample results (field duplicates and field blanks), method blank analyses, and lab duplicate analyses, and the initial screening were performed independent of the laboratory, using laboratory-provided acceptance criteria. Blind samples were submitted to augment the internal laboratory QA/QC, and also provide an assessment of potential contamination during sampling and sample handling prior to laboratory analysis. After identification of out-of-range QA/QC data, qualifications are applied to the affected environmental sample concentrations.

Lab duplicate and matrix spike/duplicate analyses were performed on "normal" runoff samples. Field-generated quality control samples (field blanks and field duplicates) were submitted "blind" to the laboratory. Composite and grab quality control samples were collected according to the schedule shown in (Table 14).

Table 14. 2001-2002 QA/QC Schedule

Location	Event #7	Event #8	Event #9	Event #10	Event #11
Swale Inlet		Field Blank	MS/MSD		
Swale Outlet		Field Dup.	Field Blank		
Roof Downspout	MS/MSD			Lab Dup.	

Table 15 summarizes the success rates of the QA/QC analyses conducted during the 2001/02 monitoring season. The data qualifications used in the results tables and described in the discussion below are described in the DQEP, included as **Appendix B**. The laboratory reports,

including the results of the 2001/02 QA/QC analyses, are reproduced in **Appendix C**. A tabular summary of the 2001/02 QA/QC results is presented in **Appendix D**.

Table 15. Summary of 2001/02 QA/QC Analyses

Constituent	QC Check Type	Number of Observations	Observations within Objectives	Success Rate
Nutrients				
Ammonia	Holding Time	15	15	100%
	Method Blank	15	15	100%
	Field Duplicate	2	2	100%
	Laboratory Control Sample	15	15	100%
	Matrix Spike	12	12	100%
	Matrix Spike Duplicate	4	4	100%
Nitrate	Holding Time	15	15	100%
	Method Blank	15	12	80%
	Field Duplicate	2	2	100%
	Laboratory Control Sample	15	15	100%
	Matrix Spike	15	12	80%
	Matrix Spike Duplicate	5	4	80%
Nitrite	Holding Time	15	12	80%
	Method Blank	15	15	100%
	Field Duplicate	2	2	100%
	Laboratory Control Sample	15	15	100%
	Matrix Spike	15	15	100%
	Matrix Spike Duplicate	5	5	100%
Total Kjeldahl Nitrogen	Holding Time	15	15	100%
	Method Blank	15	15	100%
	Field Duplicate	2	0	0%
	Laboratory Control Sample	15	15	100%
	Matrix Spike	15	15	100%
	Matrix Spike Duplicate	8	8	100%
Total Phosphorus	Holding Time	15	15	100%
	Method Blank	15	15	100%
	Field Duplicate	2	2	100%
	Laboratory Control Sample	15	15	100%
	Matrix Spike	12	9	75%
	Matrix Spike Duplicate	4	4	100%
Conventionals				
BOD$_5$	Holding Time	10	10	100%
	Field Duplicate	2	2	100%
	Laboratory Control Sample	10	7	70%
Fecal Coliform	Holding Time	15	15	100%
	Field Duplicate	2	2	100%
Total Coliform	Holding Time	15	15	100%
	Field Duplicate	2	2	100%
Total Hardness	Holding Time	15	15	100%
	Method Blank	15	15	100%
	Field Duplicate	2	2	100%
	Laboratory Control Sample	15	15	100%
	Matrix Spike	15	15	100%
	Matrix Spike Duplicate	5	5	100%
TOC	Holding Time	15	15	100%
	Method Blank	15	15	100%
	Field Duplicate	2	2	100%
	Laboratory Control Sample	15	15	100%
	Matrix Spike	12	12	100%
	Matrix Spike Duplicate	4	4	100%
DOC	Holding Time	15	15	100%
	Method Blank	15	15	100%
	Field Duplicate	2	2	100%
	Laboratory Control Sample	15	15	100%
	Matrix Spike	15	15	100%
	Matrix Spike Duplicate	5	5	100%
TSS	Holding Time	15	15	100%
	Method Blank	15	15	100%
	Field Duplicate	2	1	50%

Table 15 (continued)

Metals				
Copper, Lead, and Zinc	Holding Time	90	90	100%
	Method Blank	45	45	100%
	Field Blank	36	28	78%
	Field Duplicate	15	13	87%
	Laboratory Duplicate	15	15	100%
	SRM	45	45	100%
	Matrix Spike	45	45	100%
	Matrix Spike Duplicate	15	15	100%
Other/Misc.				
Semi & Non-Volatile Petroleum Hydrocarbon Extractables	Holding Time	60	60	100%
	Method Blank	60	60	100%
	Field Blank	12	12	100%
	Field Duplicate	8	8	100%
	Laboratory Control Sample	24	24	100%
	Matrix Spike	3	3	100%
	Matrix Spike Duplicate	1	1	100%
	Surrogate	15	14	93%
EPA 8141 OP Pesticides	Holding Time	483	483	100%
	Method Blank	477	477	100%
	Field Duplicate	68	68	100%
	Laboratory Control Sample	414	405	98%
	Matrix Spike	90	90	100%
	Matrix Spike Duplicate	30	30	100%
	Surrogate	28	26	93%
EPA 625 Semi & Non-Volatile Organics	Holding Time	924	924	100%
	Method Blank	918	908	99%
	Field Blank	378	314	83%
	Field Duplicate	63	51	81%
	Laboratory Duplicate	65	62	95%
	Matrix Spike	198	182	92%
	Matrix Spike Duplicate	72	70	97%
	Surrogate	120	117	98%

Holding Times

Maximum allowable holding times were met during 2001/02 monitoring for all constituents with a 100% success rate, with the exception of nitrite. The nitrite success rate was 80%, even though samples were always delivered to the analytical laboratories promptly after sample collection. Therefore, the affected samples for nitrite were qualified as holding time exceedance (HT). The holding time exceedances were not excessive, and affected analysis for samples from only one monitoring event.

Field and Method Blanks

Method blanks were analyzed for nearly all constituents monitored. Trace metals such as copper, and lead, nitrate, bis(2-ethylhexyl)phthalate and diethyl phthalate were detected in blank samples. Several sample results for these constituents, specifically results for nitrate, bis(2-ethylhexyl)phthalate and diethyl phthalate, were qualified because the environmental sample results were less than ten times the blank sample result.

Field blanks were submitted for events #8 and #9. Constituents detected in blank samples were 1,4-dichlorobenzene, 1-methylnaphthalene, 2,6-dimethylnaphthalene, 2,6-dinitrotoluene, 2-methylnaphthalene, 2-nitrophenol, benz(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene,

benzo(e)pyrene, benzo(k)fluoranthene, biphenyl, bis(2-ethylhexyl)phthalate, butyl benzyl phthalate, chrysene, copper, lead, zinc, diethyl phthalate, di-n-butyl phthalate di-n-octyl phthalate, fluoranthene, naphthalene, perylene, phenanthrene, and pyrene. Several sample results for all of the above constituents except 1,4-dichlorobenzene and lead were qualified because the environmental sample results were less than ten times the blank sample result for phthalates and common contaminates, less than five times the blank sample result for metals and organics or between five and ten times the blank sample result for metals.

A qualification of either NDB (i.e., result considered not detected at reported environmental concentration) or UL (i.e., result considered an upper limit of true concentration) was assigned to these results as indicated in Tables 16-20. See **Appendix A** and **Appendix C** for additional information regarding these qualifications.

Contamination with the phthalate esters is common and somewhat unavoidable in laboratories. The laboratory makes all efforts to minimize this contamination, but concludes that some contamination is to be expected and accounted for with low-level EPA 625 methods.

Field Duplicates

Field duplicates were collected at the outlet site for event #8 and at the downspout site for event #10 for all constituents. The RPD was out of the acceptable range established by the laboratories for 1-methylnaphthalene, benz(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, fluoranthene, fluorene, lead, naphthalene, phenanthrene, pyrene, total kjeldahl nitrogen, and total suspended solids (TSS). Therefore, the environmental samples associated with these constituents were qualified as estimated (EST).

Laboratory Duplicates

Laboratory duplicates were performed on trace metal samples during every 2001/02 monitoring event and on semi- and non-volatile organic constituents at the outlet site during Event #10. The RPD for 1-methylphenanthrene, fluoranthene, and pyrene was out of the acceptable range as established by the laboratories. Therefore, these constituents were qualified as not reproducible due to laboratory variability (NR).

Laboratory Control Samples and Standard Reference Material

Success rates for laboratory control samples (LCS) and standard reference material equaled 100% for all constituents during 2001/02 monitoring, except BOD_5, demeton, and disulfoton. The percent recovery was lower than the minimum allowable value for BOD_5; therefore, results were qualified as low bias (LB). The percent recovery was lower than the minimum allowable value and the environmental results were not detected above the detection limit for demeton and disulfoton; therefore, results were qualified as rejected (R).

Matrix Spikes

Matrix spikes and matrix spike duplicates were requested of field samples submitted for events #7 and #9. Additional matrix spikes and matrix spike duplicates were performed by the laboratories for all constituents except bacteria, total suspended solids (TSS), and BOD_5. Recovery was outside of the limits set by the laboratories for 2-methylnaphthalene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, fluoranthene, indeno(1,2,3-c,d)pyrene, nitrate, and phosphorus. Recoveries for these constituents were above the highest value in the acceptable range of recoveries established by the laboratories. Results were qualified as having

matrix interference at the high level (MIH) if the constituent was detected in the environmental sample. Recovery for nitrate was below the lowest value in the acceptable range of recoveries and was therefore qualified as having matrix interference at the low level (MIL). Recoveries for anthracene and pentachlorophenol were both below the lowest value in the acceptable range of recoveries but with environmental results less than the detection limit. The environmental samples associated with these matrix spikes were rejected (RMI). Recoveries for all other constituents were within the limits set by the laboratories.

Matrix Spike Duplicates

The RPD was outside of the limits (i.e. above the maximum acceptable level) during 2001/02 for 2-methylnaphthalene, bis(2-ethylhexyl)phthalate, and nitrate. Therefore these constituents were qualified as not reproducible due to MSD variability (NRS). The RPD for all other constituents were within the limits set by the laboratories.

Surrogates

Success rates for surrogates were less than 100% during 2001/02 for 2-fluorophenol (semi-/non-volatile organic), d5-Phenol (semi-/non-volatile organic), o-terphenyl (semi-/non-volatile petroleum hydrocarbon), and triphenylphosphate (OP pesticide). The percent recoveries were above the highest value in the acceptable range of recoveries established by the analytical laboratories. Environmental results associated with these surrogate spikes were qualified as surrogate high bias (SHB).

WATER QUALITY RESULTS FOR 2001/02

Water quality results for five swale monitoring events of the 2001/02 rainy season are presented in this section for the downspout, inlet, and outlet swale locations. Only constituents that were detected or qualified are listed in these tables. Total coliform, fecal coliform, total semi-volatile petroleum hydrocarbons, and ammonia concentrations represent results from grab samples, as required by the analytical method. The other constituents were analyzed from storm-length composite samples created by collecting a fixed composite sample aliquot for each equal rainfall amount, representing an assumed equal runoff flow volume through the swale. Where necessary, the water quality results are qualified with the data qualification codes described previously. Insufficient detected data (explained in section "Descriptive Statistics") for computing summary statistics are noted with "IDD".

Complete laboratory reports for the 2001/02 monitoring season's water quality results are included in **Appendix C**, and the QA/QC results are presented in tabular summary in **Appendix D**. QA/QC results for previous years were presented in annual status reports (LWA, 2000a; LWA, 2001). A comprehensive analysis for the entire study period is provided following this section.

Inlet and Outlet Results

The inlet and outlet sampling results for each event of the most recent rainy season (2001/02) are provided in this section.

Water quality data at the inlet and outlet sites for each of the five swale sampling events of the 2001/02 rainy season are presented in Tables 16-20. Only constituents for which at least one site had a detected value are included here. Similar tables for data collected in previous years' sampling events were presented in annual status reports (LWA, 2000a; LWA, 2001).

Removal efficiencies between inlet and outlet concentrations are presented for each 2001/02 monitoring event in Tables 16-20 as the numerical difference and as the percent change.

Roof Runoff Results

Roof runoff was sampled during each storm event of the 2001/02 rainy season, as recommended in last year's status report (LWA, 2001). The purpose of this monitoring was to gather information about the quality of roof runoff as a contributor to urban runoff discharges.

Water quality data for roof runoff for each of the five swale sampling events of the 2001/02 rainy season are presented in Tables 16-20. Results for the one sampling event in the previous year were presented in the 2000/01 annual status report (LWA, 2001). Because only one additional sampling event (#6, the last one from the previous rainy season) included roof runoff, summary results for roof runoff are only presented in the subsequent cumulative analysis section.

Table 16. Analytical results for event #7 (detected constituents only)[1]

Constituent	Units	Roof Runoff Result	Inlet Result	Outlet Result	Numeric Change (I-O)	% Change (I-O)
Copper, Dissolved	μg/L	6.21	4.55	4.84	0.29	6
Lead, Dissolved	μg/L	0.246	0.591	0.402	-0.19	-32
Zinc, Dissolved	μg/L	132	27.5	14.5	-13	-47
Copper, Total Recoverable	μg/L	7.16	7.93	5.86	-2	-26
Lead, Total Recoverable	μg/L	1.45	4.95	1.53	-3	-69
Zinc, Total Recoverable	μg/L	143	53.3	22.1	-31	-59
Total Coliform	MPN/100mL	23	22,000	8,000	-14,000	-64
Total Suspended Solids (TSS)	mg/L	12	28	11	-17	-61
BOD$_5$	mg/L	97	160	15	-145	-91
Hardness as CaCO$_3$	mg/L	16	6	16	10	167
Carbon, Total Organic	mg/L	49	67	16	-51	-76
Carbon, Dissolved Organic	mg/L	45	58	13	-45	-78
Ammonia as N	mg/L	1.1	0.9	0.4	-1	-56
Nitrate as N	mg/L	0.2[MIL]	0.2[MIL]	0.1[MIL]	-0.1	-50
Nitrite as N	mg/L	0.1	*<0.03	0.03	0	0
Phosphorus, Total	mg/L	1.8	0.2	0.3	0.1	50
Total Kjeldahl Nitrogen	mg/L	0.04	1.3	1.1	-0.2	-15
TPH-Extractable, as Diesel	μg/L	180	180	130	-50	-28
TPH-Extractable, as Motor Oil	μg/L	1,000	1,300	800	-500	-38
Diazinon	μg/L	0.04	0.09	0.1[SHB]	0.01	11
Pentachlorophenol	ng/L	<50	87	*<50[SHB]	-37	-43
1-Methylphenanthrene	ug/L	17	*<2.5	*<2.5	0	0
Acenaphthene	ng/L	<2.5	12	*<2.5	-10	-79
Benz(a)anthracene	ng/L	24	33	*<2.5	-31	-92
Benzo(b)fluoranthene	ng/L	<2.5	90	*<2.5	-88	-97
Benzo(e)pyrene	ng/L	9	31	*<2.5	-29	-92
Benzo(g,h,i)perylene	ng/L	<2.5	40	6	-34	-85
Biphenyl	ng/L	4	*<2.5	*<2.5	0	0
Chrysene	ng/L	21	82	*<2.5	-80	-97
Fluoranthene	ng/L	10	81	25	-56	-69
Indeno(1,2,3-c,d)pyrene	ng/L	<2.5	16	*<2.5	-14	-84
Naphthalene	ng/L	9	*<2.5	*<2.5	0	0
Nitrobenzene	ng/L	<100	236	175	-61	-26
Perylene	ng/L	<2.5	17	*<2.5	-15	-85
Phenanthrene	ng/L	17	64	12	-52	-81
Pyrene	ng/L	<2.5	59	10	-49	-83

(1) See end of Table 20 for footnotes.

Table 17. Analytical results for event #8 (detected constituents only)[1]

Constituent	Units	Roof Runoff Result	Inlet Result	Outlet Result	Numeric Change (I-O)	% Change (I-O)
Copper, Dissolved	µg/L	0.65^{UL}	0.85^{UL}	1.33	0.48	56
Lead, Dissolved	µg/L	0.026	0.086	0.086^{EST}	0	0
Zinc, Dissolved	µg/L	<18.3^{NDB}	<7.36^{NDB}	<6.23^{NDB}	-1	-15
Copper, Total Recoverable	µg/L	1.81	2.32	2.15	-0.17	-7
Lead, Total Recoverable	µg/L	1.42	1.69	0.694	-1	-59
Zinc, Total Recoverable	µg/L	<29^{NDB}	<18.9^{NDB}	<11.1^{NDB}	-8	-41
Total Coliform	MPN/100mL	700	3,000	8,000	5,000	167
Fecal Coliform	MPN/100ml	<20	30	30	0	0
Total Suspended Solids (TSS)	mg/L	8	16	9^{EST}	-7	-44
BOD$_5$	mg/L	NA	NA	10	--	--
Hardness as CaCO$_3$	mg/L	8	*<5	12	7	140
Carbon, Total Organic	mg/L	25	7.8	7.6	-0.2	-3
Carbon, Dissolved Organic	mg/L	18	7.5	4.5	-3	-40
Ammonia as N	mg/L	0.3	0.4	0.3	-0.1	-25
Nitrate as N	mg/L	0.1	0.2	0.1	-0.1	-50
Phosphorus, Total	mg/L	<0.1^{RMI}	*<0.1^{RMI}	0.1^{MIL}	0	0
Total Kjeldahl Nitrogen	mg/L	0.5	0.6	0.8^{EST}	0.2	33
TPH-Extractable, as Diesel	µg/L	<50	80	80	0	0
TPH-Extractable, as Motor Oil	µg/L	300	500	570	70	14
Bis(2-ethylhexyl)phthalate	ng/L	<244^{NDB}	<1,220^{NDB}	<494^{NDB}	-726	-60
Butyl benzyl phthalate	ng/L	<314^{NDB}	<365^{NDB}	<149^{NDB}	-216	-59
Diethyl phthalate	ng/L	<45^{NDB}	<63^{NDB}	<86^{NDB}	23	37
Dimethyl phthalate	ng/L	<10	11	*<10	-1	-9
Di-n-butyl phthalate	ng/L	<32^{NDB}	<89^{NDB}	<80^{NDB}	-9	-10
Di-n-octyl phthalate	ng/L	<10	<109^{NDB}	<20^{NDB}	-89	-82
2-Nitrophenol	ng/L	<675^{NDB}	<490^{NDB}	<269^{NDB}	-221	-45
1-Methylnaphthalene	ng/L	<4.6^{NDB}	<6.1^{NDB}	*<1^{EST}	-5	-84
1-Methylphenanthrene	ng/L	<1	9.3	*<1^{EST}	-8	-89
2-Methylnaphthalene	ng/L	<9^{NDB}	<11.3^{NDB}	*<1^{EST}	-10	-91
Acenaphthene	ng/L	<1	2.8	*<1	-2	-64
Acenaphthylene	ng/L	<1	3.3	*<1	-2	-70
Anthracene	ng/L	<1	1.8	*<1	-1	-44
Benz(a)anthracene	ng/L	<35.7^{NDB}	<13.9^{NDB}	*<1^{EST}	-13	-93
Benzo(a)pyrene	ng/L	<2.4^{NDB}	<10^{NDB}	*<1	-9	-90
Benzo(b)fluoranthene	ng/L	<12.6^{NDB}	<55.2^{NDB}	*<1^{EST}	-54	-98
Benzo(e)pyrene	ng/L	<10.5^{NDB}	<25.5^{NDB}	*<1	-25	-96
Benzo(g,h,i)perylene	ng/L	9.5	43.8	*<1	-43	-98
Benzo(k)fluoranthene	ng/L	<1	<4.9^{NDB}	*<1^{EST}	-4	-80
Biphenyl	ng/L	<3.7^{NDB}	<4.6^{NDB}	*<1	-4	-78
Chrysene	ng/L	<1	22.4^{NDB}	*<1^{EST}	-21	-96
Fluoranthene	ng/L	<9.4^{NDB}	<37.8^{NDB}	*<1^{EST}	-37	-97
Fluorene	ng/L	<1	6.9	13^{EST}	6	88
Indeno(1,2,3-c,d)pyrene	ng/L	<1	15.7	*<1	-15	-94
Naphthalene	ng/L	<13^{NDB}	<17.4^{NDB}	*<1^{EST}	-16	-94
Nitrobenzene	ng/L	53	127	112	-15	-12
Perylene	ng/L	<1	<9.5^{NDB}	*<1	-9	-89
Phenanthrene	ng/L	<32.5^{NDB}	<50.1^{NDB}	*<1^{EST}	-49	-98
Pyrene	ng/L	<8.2^{NDB}	<38.4^{NDB}	*<1^{EST}	-37	-97

(1) See end of Table 20 for footnotes.

Table 18. Analytical results for event #9 (detected constituents only)[1]

Constituent	Units	Roof Runoff Result	Inlet Result	Outlet Result	Numeric Change (I-O)	% Change (I-O)
Copper, Dissolved	µg/L	2.21	2.47	3.41	1	38
Lead, Dissolved	µg/L	0.06	0.34	0.45	0.11	31
Zinc, Dissolved	µg/L	36	80.9	103	22	27
Copper, Total Recoverable	µg/L	3.29	4.9	4.34	-1	-11
Lead, Total Recoverable	µg/L	1.17	3.29	1.74	-2	-47
Zinc, Total Recoverable	µg/L	45.1	135	153	18	13
Total Coliform	MPN/100ml	8,000	800	50,000	49,200	6,150
Fecal Coliform	MPN/100ml	170	*<20	170	150	750
Total Suspended Solids (TSS)	mg/L	6	21	8	-13	-62
Hardness as CaCO$_3$	mg/L	6	*<5	6	1	20
Carbon, Total Organic	mg/L	20	30	15	-15	-50
Carbon, Dissolved Organic	mg/L	14	6.5	9.1	3	40
Ammonia as N	mg/L	0.2	0.4	0.4	0	0
Nitrate as N	mg/L	0.6	0.3	0.7	0.4	133
Phosphorus, Total	mg/L	<0.1	0.1	0.3	0.2	200
Total Kjeldahl Nitrogen	mg/L	0.5	0.9	1.3	0.4	44
TPH-Extractable, as Diesel	µg/L	<50	220[SHB]	530	310	141
TPH-Extractable, as Motor Oil	µg/L	<200	1,500[SHB]	2,100	600	40
Diazinon	µg/L	0.06	*<0.05	*<0.05[SHB]	0	0
Bis(2-ethylhexyl)phthalate	ng/L	<213[NDB]	4990	2,570	-2,420	-48
Butyl benzyl phthalate	ng/L	<403[NDB]	66700	65,500	-1,200	-2
Diethyl phthalate	ng/L	<146[NDB]	<404[NDB]	<868	464	115
Dimethyl phthalate	ng/L	12	*<10	52	42	420
Di-n-butyl phthalate	ng/L	<252[NDB]	<569[NDB]	<766[NDB]	197	35
Di-n-octyl phthalate	ng/L	<10	483	3620	3137	649
2-Nitrophenol	ng/L	197	150[SHB]	249	99	66
4-Nitrophenol	ng/L	111	*<100[SHB]	*<100	0	0
Phenol	ng/L	<100	*<100[SHB]	180	80	80
1-Methylnaphthalene	ng/L	<5.5[NDB]	<9.7[NDB]	<7.4[NDB]	-2	-24
1-Methylphenanthrene	ng/L	8.6	23.9	36.2	12	51
2,6-Dimethylnaphthalene	ng/L	<1	<7.1[NDB]	*<1	-6	-86
2,6-Dinitrotoluene	ng/L	<50	<157[SHB, NDB]	*<50	-107	-68
2-Methylnaphthalene	ng/L	<10.8[MIH, NDB]	<11.8[MIH, SHB, NDB]	<6.2[MIH, NDB]	-6	-47
Acenaphthylene	ng/L	3.1	5.8[SHB]	3.9	-2	-33
Anthracene	ng/L	2.9	7.9[SHB]	6.5	-1	-18
Azobenzene	ng/L	<200	200[SHB]	347	147	74
Benz(a)anthracene	ng/L	<1	6.9[SHB]	*<1	-6	-86
Benzo(a)pyrene	ng/L	<1	10.6[SHB]	*<1	-10	-91
Benzo(b)fluoranthene	ng/L	<1	29.8[SHB]	*<1	-29	-97
Benzo(e)pyrene	ng/L	<1	35.8[SHB]	*<1	-35	-97
Benzo(g,h,i)perylene	ng/L	<1	84.8[MIH, SHB]	*<1	-84	-99
Benzo(k)fluoranthene	ng/L	<1	28.8[MIH, SHB]	*<1	-28	-97
Biphenyl	ng/L	<6.9[NDB]	<7[SHB, NDB]	<8.4[NDB]	1	20
Chrysene	ng/L	<1	49.5[MIH, SHB]	*<1	-49	-98
Fluorene	ng/L	6.8	11[SHB]	7.7	-3	-30
Indeno(1,2,3-c,d)pyrene	ng/L	<1	34.3[MIH, SHB]	*<1	-33	-97
Naphthalene	ng/L	<18.5[NDB]	<25.9[SHB, NDB]	<18.8[NDB]	-7	-27
Nitrobenzene	ng/L	<100	*<100[SHB]	353	253	253
Perylene	ng/L	<1	9.4[SHB]	*<1	-8	-89
Phenanthrene	ng/L	25.2	67.6[SHB]	27.7	-40	-59
Pyrene	ng/L	8.7	74.6[SHB]	16.6	-58	-78

(1) See end of Table 20 for footnotes.

Table 19. Analytical results for event #10 (detected constituents only)[1]

Constituent	Units	Roof Runoff Result	Inlet Result	Outlet Result	Numeric Change (I-O)	% Change (I-O)
Copper, Dissolved	µg/L	0.91	0.99	1.97	1	99
Lead, Dissolved	µg/L	0.03	0.05	0.09	0.03	65
Zinc, Dissolved	µg/L	24.40	9.64	11.3	2	17
Copper, Total Recoverable	µg/L	1.46	2.31	2.68	0.37	16
Lead, Total Recoverable	µg/L	0.521[EST]	1.2	0.69	-1	-43
Zinc, Total Recoverable	µg/L	29.5	22.1	16.3	-6	-26
Total Coliform	MPN/100ml	80	170	1,100	930	547
Fecal Coliform	MPN/100ml	11	*<20	*<20	0	0
Total Suspended Solids (TSS)	mg/L	6	11	7	-4	-36
BOD$_5$	mg/L	25[LB]	10[LB]	7[LB]	-3	-30
Carbon, Total Organic	mg/L	10	5.8	7.3	2	26
Carbon, Dissolved Organic	mg/L	10	3.0	5.5	3	83
Ammonia as N	mg/L	0.3	0.4	0.3	0	-25
Nitrate as N	mg/L	<0.4[NDB]	<0.4[NDB]	<0.6[NDB]	0.2	50
Phosphorus, Total	mg/L	<0.1	*<0.1	0.1	0	0
Total Kjeldahl Nitrogen	mg/L	<0.1[EST]	0.2	0.2	0	0
TPH-Extractable, as Diesel	µg/L	60	140	70	-70	-50
TPH-Extractable, as Motor Oil	µg/L	400	1,100	500	-600	-55
Diazinon	µg/L	0.06	NA	*<0.05	--	--
Bis(2-ethylhexyl)phthalate	ng/L	175[NDB]	1,150	593	-557	-48
Butyl benzyl phthalate	ng/L	594	841	307	-534	-63
Phenol	ng/L	<100	116	*<100	-16	-14
Benz(a)anthracene	ng/L	1.5	3.2	1	-2	-69
Benzo(a)pyrene	ng/L	<1	9.3	*<1	-8	-89
Benzo(b)fluoranthene	ng/L	<1	16.8	6	-11	-64
Benzo(e)pyrene	ng/L	<1	18	2.9	-15	-84
Benzo(g,h,i)perylene	ng/L	<1	24.7	2.8	-22	-89
Benzo(k)fluoranthene	ng/L	<1	10.3	3.2	-7	-69
Chrysene	ng/L	16.9	22.2	6.7	-16	-70
Diethyl phthalate	ng/L	<63[NDB]	<150[NDB]	<86[NDB]	-64	-43
Di-n-butyl phthalate	ng/L	108	141	82	-59	-42
Di-n-octyl phthalate	ng/L	7	79	61	-18	-23
Fluoranthene	ng/L	5.3[NR]	32	10.8	-21	-66
Indeno(1,2,3-c,d)pyrene	ng/L	<1	10.9	*<1	-10	-91
Perylene	ng/L	<1	4.2	*<1	-3	-76
Phenanthrene	ng/L	30.9	39.7	5.8	-34	-85
Pyrene	ng/L	3.1[NR]	26.6	7.6	-19	-71

(1) See end of Table 20 for footnotes.

Table 20. Analytical results for event #11 (detected constituents only)

Constituent	Units	Roof Runoff Result	Inlet Result	Outlet Result	Numeric Change (I-O)	% Change (I-O)
Copper, Dissolved	µg/L	1.86	1.92	2.18	0.26	14
Lead, Dissolved	µg/L	0.09	0.22	0.17	-0.05	-23
Zinc, Dissolved	µg/L	50.6	20.9	21.5	0.6	3
Copper, Total Recoverable	µg/L	3.53	3.55	2.88	-0.67	-19
Lead, Total Recoverable	µg/L	2.27	1.78	1.14	-0.64	-36
Zinc, Total Recoverable	µg/L	80.6	31.4	27.7	-4	-12
Total Coliform	MPN/100ml	170	1,300	22,000	20,700	1592
Fecal Coliform	MPN/100ml	2	240	2,300	2,060	858
Total Suspended Solids (TSS)	mg/L	18	10	11	1	10
BOD$_5$	mg/L	<3	4	*<3	-1	-25
Hardness as CaCO$_3$	mg/L	<5	*<5	24	19	380
Carbon, Total Organic	mg/L	3.8	4.7	5.6	0.9	19
Carbon, Dissolved Organic	mg/L	4.2	4.8	5.4	0.6	13
Ammonia as N	mg/L	0.4	0.4	0.3	-0.1	-25
Nitrate as N	mg/L	0.4	0.4[NRS]	0.5	0.1	25
Phosphorus, Total	mg/L	<0.1	0.3	0.2	-0.1	-33
Total Kjeldahl Nitrogen	mg/L	0.6	0.5	0.3	-0.2	-40
TPH-Extractable, as Diesel	µg/L	130	140	110	-30	-21
TPH-Extractable, as Motor Oil	µg/L	600	800	300	-500	-63
1-Methylphenanthrene	ng/L	23.8	6.5	*<1	-6	-85
Biphenyl	ng/L	<1	*<1	4	3	300
Bis(2-chloroethyl)ether	ng/L	<50	53	*<50	-3	-6
Bis(2-ethylhexyl)phthalate	ng/L	<267[NDB]	10,200	1,370	-8,830	-87
Butyl benzyl phthalate	ng/L	284	614	362	-252	-41
Chrysene	ng/L	58	32	15	-17	-52
Diethyl phthalate	ng/L	<158[NDB]	197	200	3	2
Dimethyl phthalate	ng/L	37	*<5	51	46	920
Di-n-butyl phthalate	ng/L	89	299	271	-28	-9
Di-n-octyl phthalate	ng/L	20	1,860	227	-1,633	-88
Fluoranthene	ng/L	11.3	40.7	25.9	-15	-36
Naphthalene	ng/L	13.4	8.4	12.3	4	46
Phenanthrene	ng/L	34.1	37.1	16.9	-20	-54
Pyrene	ng/L	15.1	30.8	11.7	-19	-62

Footnotes for Tables 16-20 (See **Appendix B** for data qualifier code explanations.):
EST = Estimated
IDD = Insufficient Detected Data
LB = Low Bias
MIH = Matrix Interference High
MIL = Matrix Interference Low
NDB = Not Detected because of a "hit" on Blank sample.
NC = Not Calculated
NR = Not Reproducible due to lab variability.
RMI = Matrix Spike Rejected due to Matrix Interference
R = Rejected
SHB = Surrogate High Bias
UL = Upper Limit of true concentration
* In cases where either the inlet or outlet was reported or qualified as "not detected", the numerical difference and percent change were calculated substituting the effective reporting limit for the "not detected" data. The calculated numerical difference and the percent change represent the minimum value for these constituents.

WATER QUALITY RESULTS – CUMULATIVE ANALYSIS

Summary statistics of the monitoring data at each sampling location (roof runoff, swale inlet, and swale outlet) for the entire monitoring period (1999-2002) are presented first in this section. Where necessary, the water quality results are qualified with the data qualification codes described previously. Constituents which had insufficient detected data (see description of criteria, below) for computing summary statistics are noted with "IDD". Next, results are compared for inlet versus outlet to indicate removal efficiencies by the swale. A power analysis is conducted on constituents that are on the verge of statistical significance. Finally, roof runoff results are assessed.

This cumulative analysis does not focus on inter-annual variability since sampling occurred principally during two seasons (plus one event at the end of the 1999-2000 season).

Summary Statistics for Each Site

Descriptive statistics (min, max, mean, median, standard deviation) summarizing the water quality data for the entire study period's results are presented by monitoring site in Tables 21-23. These summaries cover the results of 11 monitoring events conducted from the 1999-2000 rainy season through the 2001/02 rainy season. All analyzed constituents for which sufficient data are available to estimate mean concentrations or for which the differences in concentrations (discussed next) were statistically significant are included in these tables. Where there were less than three detected data points or less than 20% of the data were detected, the mean and standard deviation columns are noted as having insufficient data detected ("IDD").

The relatively low concentrations in the swale inflow for most constituents should be emphasized. Because many technologies appear to have an "irreducible minimum concentration", lower percent reductions are commonly achieved when influent concentrations are already low.

Table 21. Descriptive statistics for cumulative (1999-2002) inlet data (detected constituents only)

Constituent	Units	# of Data Points	# Non-Detects	Minimum	Maximum	Mean	Median	Standard Deviation
Copper, Dissolved	µg/L	10	0	0.78	5.33	2.36	1.95	1.58
Lead, Dissolved	µg/L	10	0	0.13	0.796	0.323	0.24	0.25
Zinc, Dissolved	µg/L	10	0	7.36	800.9	24.48	18.96	25.04
Copper, Total Recoverable	µg/L	10	0	2.31	7.93	4.99	4.44	2.34
Lead, Total Recoverable	µg/L	10	0	1.2	11.7	3.69	2.94	3.56
Zinc, Total Recoverable	µg/L	10	0	21	135	53.65	42.56	42.86
Total Coliform	MPN/100ml	9	0	170	22,000	4,203	1,415	8548
Fecal Coliform	MPN/100ml	9	4	<2	500	95.99	22.51	191.3
E. Coli	MPN/100ml	3	2	<2	14	IDD	<2	IDD
Total Suspended Solids (TSS)	mg/L	10	0	10	77	24.7	20.38	23.27
BOD$_5$	mg/L	8	1	<5	160	33.32	14.54	65.38
Hardness as CaCO$_3$	mg/L	10	4	<5	10	5.63	5.04	2.76
Carbon, Total Organic	mg/L	10	0	2	67	17.63	9.94	22.18
Carbon, Dissolved Organic	mg/L	9	0	1	58	13.2	6.56	21.17
Ammonia as N	mg/L	10	0	0.2	0.9	0.49	0.45	0.197
Nitrate as N	mg/L	8	2	<0.1	0.4	0.24	0.22	0.11
Nitrate + Nitrite as N	mg/L	2	0	0.1	0.1	0.1	0.1	0
Phosphorus, Total	mg/L	10	4	<0.1	0.3	0.11	0.09	0.091
Total Kjeldahl Nitrogen	mg/L	10	0	0.2	1.3	0.73	0.641	0.36
TPH-Extractable, as Diesel	µg/L	9	1	<63	490	213.99	172.52	158.75
TPH-Extractable, as Motor Oil	µg/L	8	0	500	4,300	1,813	1,412	1,500
Diazinon	µg/L	9	5	<0.05	0.09	0.057	0.055	0.016
Bis(2-ethylhexyl)phthlate	ng/L	9	0	1,150	18,500	6,277	4,436	5,938
Butyl benzyl phthalate	ng/L	9	0	365	66,700	8,036	1,084	31,795
Dibenz(a,h)anthracene	ng/L	10	9	<1	27	IDD	<3.75	IDD
Dibutyl phthalate	ng/L	5	0	83	438	284.8	243.64	154.52
Diethyl phthalate	ng/L	9	0	63	527	284	245.08	145.18
Dimethyl phthalate	ng/L	9	3	<5	105	33.58	19.25	36.56
Di-n-butyl phthalate	ng/L	9	0	83	569	280.22	299	172.56
Di-n-octyl phthalate	ng/L	9	1	<10	3,420	1,021	452.5	1,203
2-Nitrophenol	ng/L	10	5	<100	668	172.31	74.97	237.01
Phenol	ng/L	10	8	<100	197	IDD	<100	IDD
1-Methylnaphthalene	ng/L	9	3	<1	16	5.44	3.89	5.19
1-Methylphenanthrene	ng/L	10	3	<1	23.9	9.01	6.68	7.53
2,6-Dimethylnaphthalene	ng/L	10	7	<1	16	3.7	1.8	6.19
2-Methylnaphthalene	ng/L	5	3	<1	11.8	IDD	<2.5	IDD
Acenaphthene	ng/L	10	8	<1	12	IDD	6	IDD
Acenaphthylene	ng/L	10	5	<1	6	IDD	<5	IDD
Anthracene	ng/L	10	3	<1	18	6.31	4.34	5.84
Benz(a)anthracene	ng/L	10	3	<1	33	9.96	6.57	10.72
Benzo(a)pyrene	ng/L	10	4	<1	71	13.9	7.06	26.84
Benzo(b)fluoranthene	ng/L	10	2	<1	198	51.08	32.01	65.51
Benzo(e)pyrene	ng/L	10	2	<1	130	31.78	20.9	44.40
Benzo(g,h,i)perylene	ng/L	10	3	<1	123	38.25	23.06	41.01
Benzo(k)fluoranthene	ng/L	10	3	<1	54	13.2	7.22	18.2
Biphenyl	ng/L	10	4	<1	22	6.61	4.71	7.02
Bis(2-chloroethyl)ether	ng/L	10	9	<50	53	IDD	<100	IDD
Chrysene	ng/L	10	1	<5	164	52.48	40.48	50.08
Fluoranthene	ng/L	10	0	32	214	83.03	70.22	59.76
Fluorene	ng/L	10	4	32	26	8.63	6.56	8.01
Indeno(1,2,3-c,d)pyrene	ng/L	10	3	<1	89	21.97	13.89	30.2
Naphthalene	ng/L	10	3	<1	46	16.61	13.57	15.31
Nitrobenzene	ng/L	10	8	<50	236	IDD	<100	IDD
Pentachlorophenol	ng/L	10	8	<50	87	IDD	<50	IDD
Perylene	ng/L	10	4	<1	38	9.05	4.96	13.11
Phenanthrene	ng/L	10	0	37.1	223	83.94	71.09	64.08
Pyrene	ng/L	10	0	26.6	173	66.94	57.94	47.33

"IDD" = insufficient data to estimate a mean concentration; substituted detection limit for non-detected values.

Table 22. Descriptive statistics for cumulative (1999-2002) outlet data (detected constituents only)

Constituent	Units	# of Data Points	# Non-Detects	Minimum	Maximum	Mean	Median	Standard Deviation
Copper, Dissolved	μg/L	10	0	1.33	4.84	2.73	2.48	1.32
Lead, Dissolved	μg/L	10	0	0.052	0.469	0.217	0.166	0.164
Zinc, Dissolved	μg/L	10	0	10	103	36.48	27.24	37.24
Copper, Total Recoverable	μg/L	10	0	2.15	6.59	4.02	3.79	1.47
Lead, Total Recoverable	μg/L	10	0	0.689	2.86	1.51	1.39	0.68
Zinc, Total Recoverable	μg/L	10	0	11.1	153	36.48	27.24	54.93
Total Coliform	MPN/100ml	9	0	1,100	90,000	22,544	10,818	32,309
Fecal Coliform	MPN/100ml	9	3	<2	3,000	621.5	47.98	1,230
E. coli	MPN/100ml	3	2	<2	2,300	IDD	<20	IDD
Total Suspended Solids (TSS)	mg/L	10	0	5	28	12.4	10.56	8.4
BOD$_5$	mg/L	9	3	<3	69	21.58	10.17	1.17
Hardness as CaCO$_3$	mg/L	10	1	<5	24	11.62	10.06	6.68
Carbon, Total Organic	mg/L	10	0	4	19	10.55	9.14	5.82
Carbon, Dissolved Organic	mg/L	9	0	4	13	7.06	6.5	3.29
Ammonia as N	mg/L	10	0	0.3	0.4	0.34	0.3	0.052
Nitrate as N	mg/L	8	1	<0.1	0.7	0.3	0.21	0.261
Nitrite	mg/L	8	7	<0.03	0.03	IDD	<0.03	IDD
Nitrate + Nitrite as N	mg/L	2	1	<0.1	0.1	IDD	<0.01	IDD
Phosphorus, Total	mg/L	10	2	<0.1	0.3	0.15	0.125	0.095
Total Kjeldahl Nitrogen	mg/L	10	0	0.3	1.3	0.7	0.606	0.365
TPH-Extractable, as Diesel	μg/L	9	0	70	530	151.22	120.16	186.21
TPH-Extractable, as Motor Oil	μg/L	8	0	300	2,100	822.5	686.67	650.6
Diazinon	μg/L	10	6	<0.05	0.1	0.052	0.047	0.023
Bis(2-ethylhexyl)phthlate	ng/L	9	0	494	5,030	1,923	1,532	1,506
Butyl benzyl phthalate	ng/L	9	0	149	65,500	7,832	894.41	31,220
Diethyl phthalate	ng/L	9	0	86	868	257.11	195.51	290.9
Dimethyl phthalate	ng/L	9	2	<5	55	40.8	38.4	15.55
Di-n-butyl phthalate	ng/L	9	0	80	984	376.56	271	332.38
Di-n-octyl phthalate	ng/L	9	1	<10	3,620	843.66	200.58	1,399
2-Nitrophenol	ng/L	10	5	<100	941	217.73	93.36	328.11
Phenol	ng/L	10	6	<100	299	92.37	59.99	98.02
1-Methylnaphthalene	ng/L	9	7	<1	29	IDD	<5	IDD
1-Methylphenanthrene	ng/L	10	8	<1	36.2	IDD	<5	IDD
2,3,5-Trimethylnaphthalene	ng/L	10	9	<1	33	IDD	<3.75	IDD
2-Methylnaphthalene	ng/L	5	4	<1	6.2	IDD	<1	IDD
Acenaphthene	ng/L	10	9	<1	17	IDD	<3.75	IDD
Acenaphthylene	ng/L	10	8	<1	41	IDD	<5	IDD
Anthracene	ng/L	10	6	<1	23	5.51	2.62	7.95
Azobenzene	ng/L	10	9	<50	347	IDD	<3.75	IDD
Benz(a)anthracene	ng/L	10	7	<1	12	2.22	0.294	5.28
Benzo(a)pyrene	ng/L	10	7	<1	41	6.477	0.769	15.49
Benzo(b)fluoranthene	ng/L	10	4	<1	52	16.43	7.2	20.55
Benzo(e)pyrene	ng/L	10	6	<1	33	6.25	1.53	12.13
Benzo(g,h,i)perylene	ng/L	10	4	<1	37	11.88	7.04	12.73
Benzo(k)fluoranthene	ng/L	10	5	<1	26	6.7	2.48	9.84
Biphenyl	ng/L	10	7	<1	32	4.99	1.19	12.53
Chrysene	ng/L	10	3	<1	60	18.99	11.9	19.63
Fluoranthene	ng/L	10	1	<1	85	34.72	27.12	28.02
Fluorene	ng/L	10	7	<1	41	6.59	1.11	15.64
Indeno(1,2,3-c,d)pyrene	ng/L	10	6	<1	27	11.81	9.89	7.68
Naphthalene	ng/L	10	6	<1	108	15.2	2.07	43.78
Nitrobenzene	ng/L	10	7	<50	353	77.73	31.16	126.79
Phenanthrene	ng/L	10	1	<1	177	37.77	17.01	61.92
Pyrene	ng/L	10	1	<1	62	24.33	17.72	21.28

"IDD" = insufficient data to estimate a mean concentration; substituted detection limit for non-detected values.

Table 23. Descriptive statistics for cumulative (2001-2002*) roof runoff data (detected constituents only)

Constituent	Units	# of Data Points	# Non-Detects	Minimum	Maximum	Mean	Median	Standard Deviation
Copper, Dissolved	μg/L	6	0	0.65	6.21	2.34	1.79	2.38
Lead, Dissolved	μg/L	6	0	0.026	0.246	0.009	0.007	0.096
Zinc, Dissolved	μg/L	6	0	18.3	132	49.6	39.7	51.22
Copper, Total Recoverable	μg/L	6	0	1.46	7.16	3.35	2.93	2.33
Lead, Total Recoverable	μg/L	6	0	0.521	2.27	1.28	1.16	0.642
Zinc, Total Recoverable	μg/L	6	0	29	143	62.82	52.97	48.99
Total Coliform	MPN/100ml	5	0	23	8,000	1,795	280.99	4,711
Fecal Coliform	MPN/100ml	5	2	<2	170	36.94	3.5	36.94
Total Suspended Solids (TSS)	mg/L	6	0	6	18	9.67	8.9	5.12
BOD$_5$	mg/L	4	1	<3	140	67.04	39.64	79.87
Hardness as CaCO$_3$	mg/L	6	2	<5	16	7.31	6.16	5.71
Carbon, Total Organic	mg/L	6	0	3.8	49	18.8	12.92	18.65
Carbon, Dissolved Organic	mg/L	6	0	4.2	45	16.37	12.22	17.57
Ammonia as N	mg/L	6	0	0.2	1.1	0.45	0.383	0.709
Nitrate as N	mg/L	5	0	0.1	0.6	0.34	0.286	0.204
Nitrate + Nitrite as N	mg/L	1	0	0.1	0.1	0.1	0.1	NC
Phosphorus, Total	mg/L	6	5	<0.1	0.1	IDD	<0.1	IDD
Total Kjeldahl Nitrogen	mg/L	6	1	<0.1	1.8	0.702	0.58	0.732
TPH-Extractable, as Diesel	μg/L	6	2	<50	180	93.01	76.6	68.38
TPH-Extractable, as Motor Oil	μg/L	6	1	<200	1,000	454.28	380.86	340.77
Diazinon	μg/L	6	3	<0.05	0.06	IDD	<0.045	IDD
Bis(2-ethylhexyl)phthlate	ng/L	4	0	175	267	224.75	221.9	42.65
Butyl benzyl phthalate	ng/L	5	0	206	594	360.2	337.78	163.78
Diethyl phthalate	ng/L	5	0	45	158	106.4	95.2	51.2
Dimethyl phthalate	ng/L	5	2	<5	37	15.03	10.15	15.64
Di-n-butyl phthalate	ng/L	4	0	89	252	137.75	105	100.54
Di-n-octyl phthalate	ng/L	5	3	<10	20	IDD	<10	IDD
2-Nitrophenol	ng/L	6	4	<100	675	IDD	<100	IDD
4-Nitrophenol	ng/L	6	5	<100	111	IDD	<100	IDD
1-Methylnaphthalene	ng/L	5	4	<1	4.6	IDD	<2.5	IDD
1-Methylphenanthrene	ng/L	6	2	<1	23.8	11.85	9.8	11.8
2-Methylnaphthalene	ng/L	5	3	<1	10.8	IDD	<2.5	IDD
Acenaphthylene	ng/L	6	5	<1	3.1	IDD	<1.75	IDD
Anthracene	ng/L	6	5	<1	2.9	IDD	<1.75	IDD
Benz(a)anthracene	ng/L	6	2	<1	35.7	15.8	4.69	23.52
Benzo(a)pyrene	ng/L	6	5	<1	2.4	IDD	<1.75	IDD
Benzo(b)fluoranthene	ng/L	6	5	<1	12.6	IDD	<1.75	IDD
Benzo(e)pyrene	ng/L	6	4	<1	10.5	IDD	<3	IDD
Benzo(g,h,i)perylene	ng/L	6	5	<1	9.5	IDD	<1.75	IDD
Biphenyl	ng/L	6	3	<1	5	3.63	3.28	2.17
Chrysene	ng/L	6	3	<1	58	17.7	9.27	26.75
Fluoranthene	ng/L	6	5	5.3	11.3	9.23	8.99	2.42
Fluorene	ng/L	6	0	<1	6.8	IDD	<1.75	IDD
Naphthalene	ng/L	6	2	<1	18.5	10.95	10.04	5.33
Nitrobenzene	ng/L	6	5	<50	53	IDD	<75	IDD
Phenanthrene	ng/L	6	0	17	34.1	27.78	27.1	0.756
Pyrene	ng/L	6	1	<2.5	15.1	6.48	4.74	6.2

"IDD" = insufficient data to estimate a mean concentration; substituted detection limit for non-detected values.
* Includes one event near the end of the 2000/01 season, and five events from the 2001/02 season.

Swale Removal Efficiency

Removal efficiency of various pollutants by the swale is a useful metric for comparing treatment alternatives. For a range of influent conditions (flow rate and pollutant concentrations), removal efficiencies may vary significantly, restricting their applicability.

A summary of pollutant removal efficiencies for all eleven swale sampling events during 1999-2002 is presented in Table 24. For each constituent listed in Table 24, p-values are shown to indicate the statistical significance of the difference between inlet and outlet according to the Wilcoxon signed-rank test. For constituents with Wilcoxon test p-values close to 0.05, a one-tail paired t-test was performed as an alternate test of significance. Constituents with p-values less than 0.05 by either test are considered to be significantly different in concentration between inlet and outlet.

Based on the calculated results, the following observations were made:

- Conventional Constituents – Total suspended solids (TSS) were removed moderately well (50% on average). Biochemical oxygen demand (BOD_5) showed no significant change. TOC and DOC both decreased, but the results varied too much ($p > 0.2$) to consider the results statistically significant. Hardness increased 106% between inlet and outlet, possibly caused by rainwater dissolving calcium and magnesium in the swale soil. But at 11.6 mg/L, hardness is still low in the effluent.

- Nutrients – Ammonia decreased 31%, slightly more than nitrate increased (24%), between the inlet and outlet. The increase in nitrate may be attributable to fertilizer use in the swale. Nitrite was never detected. Total Kjeldahl nitrogen (TKN) was not removed. Total phosphorus increased 27% between inlet and outlet, which, like nitrate, may be attributable to fertilizer use.

- Coliform bacteria – Both fecal and total coliform showed significant increases between inlet and outlet in several events. The fecal coliform increase was found on average to be significant ($p = 0.04$) using the one-tail paired t-test. Events #9 and #11 showed the most drastic differences, with outlet concentrations over an order of magnitude higher than inlet concentrations. In general, the poor precision in analytical methods for coliform, based on a logarithmic scale, makes evaluations difficult.

- Metals – Metals removal percentages were generally small to moderate. All total recoverable analyses showed statistically significant decreases between inlet and outlet. Note that total recoverable copper removal was significant ($p = 0.05$) using the one-tail paired t-test. Performance is considered especially good with the low influent concentrations for most metals. Dissolved species showed no significant change or some increase (copper increased by 16%). Relatively low ionic strength runoff water passing through the swale appears to dissolve small amounts of metals from soils.

- Total semi- & non-volatile petroleum hydrocarbon extractables – Motor oil was significantly removed (by 55% on average) in the swale. Diesel concentrations showed no statistically significant change between inlet and outlet.

- Semi- & non-volatile organics – A large number of polyaromatic hydrocarbons (PAHs) decreased significantly between inlet and outlet. No PAHs showed significant increases. This finding indicates that swales are useful control measures for parking areas, where PAHs are commonly discharged. Phthalates were largely unaffected by the swale.

- Organophosphate pesticides – Organophosphate pesticides were generally not found at measurable concentrations in either inlet or outlet samples. The swale appears to have removed both diazinon and Prowl, but results are not statistically significant.

Removal efficiencies for TSS and metals are plotted in comparison to data for other monitored swales in the discussion section "Comparative Data".

Table 24. Removal efficiency estimates for the swale based on cumulative (1999-2002) data (detected constituents only).

Constituent	Units	Inlet Mean	Outlet Mean	Numeric Change	% Change	p-value [1]
Copper, Dissolved	µg/L	2.36	2.73	0.37	16	0.011
Lead, Dissolved	µg/L	0.32	0.217	-0.106	-33	0.055[3]
Zinc, Dissolved	µg/L	24.48	36.48	12	49	0.193[3]
Copper, Total Recoverable	µg/L	4.97	4.02	-1	-19	0.0844[2]
Lead, Total Recoverable	µg/L	3.69	1.51	-2	-59	0.003
Zinc, Total Recoverable	µg/L	53.65	36.48	-17	-32	0.006
Total Coliform	MPN/100ml	4,203	22,544	18,341	436	0.010
Fecal Coliform	MPN/100ml	96	621.5	526	547	0.054[2]
Total Suspended Solids (TSS)	mg/L	24.7	12.4	-12	-50	0.010
BOD$_5$	mg/L	33.32	21.58	-12	-35	0.250
Hardness as CaCO$_3$	mg/L	5.63	11.62	6	106	0.014
Carbon, Total Organic	mg/L	17.63	10.55	-7	-40	0.419
Carbon, Dissolved Organic	mg/L	13.2	7.06	-6	-47	0.495
Ammonia as N	mg/L	0.49	0.34	-0.150	-31	0.019
Nitrate as N	mg/L	0.242	0.3	0.058	24	0.300
Phosphorus, Total	mg/L	0.12	0.15	0.032	27	0.250
Total Kjeldahl Nitrogen	mg/L	0.73	0.7	-0.030	-4	0.406
TPH-Extractable, as Diesel	µg/L	213.99	151.22	-63	-29	0.104[3]
TPH-Extractable, as Motor Oil	µg/L	1,813	822.5	-990	-55	0.018
Diazinon	µg/L	0.057	0.052	-0.005	-9	0.327
Prowl	µg/L	0.123	0.1	-0.023	-19	>.99
Bis(2-ethylhexyl)phthlate	ng/L	6,277	1,923	-4,353	-69	>.99
Butyl benzyl phthalate	ng/L	8,036	7,832	-204	-3	0.157[3]
Diethyl phthalate	ng/L	284	257.11	-27	-9	0.157[3]
Dimethyl phthalate	ng/L	33.58	40.8	7	22	0.337
Di-n-butyl phthalate	ng/L	280.22	376.56	96	34	0.157[3]
Di-n-octyl phthalate	ng/L	1,022	843.66	-178	-17	0.062[3]
2,6-Dimethylnaphthalene	ng/L	3.7	3.15	-1	-15	>.99
Anthracene	ng/L	6.3	5.51	-1	-13	0.118[3]
Benz(a)anthracene	ng/L	9.96	2.22	-8	-78	0.025
Benzo(a)pyrene	ng/L	13.9	6.48	-7	-53	0.032
Benzo(b)fluoranthene	ng/L	51.08	16.43	-35	-68	0.025
Benzo(e)pyrene	ng/L	31.78	6.25	-26	-80	0.019
Benzo(g,h,i)perylene	ng/L	38.25	11.88	-26	-69	0.025
Benzo(k)fluoranthene	ng/L	13.26	6.7	-7	-49	0.088[3]
Biphenyl	ng/L	6.6	4.99	-2	-24	0.306
Chrysene	ng/L	54.49	18.99	-36	-65	0.018
Fluoranthene	ng/L	83.03	34.72	-48	-58	0.003
Fluorene	ng/L	8.63	6.59	-2	-24	0.232
Indeno(1,2,3-c,d)pyrene	ng/L	22.0	11.81	-10	-46	0.025
Naphthalene	ng/L	18.61	15.2	-3	-18	0.088[3]
Perylene	ng/L	9.06	3.15	-6	-65	0.022
Phenanthrene	ng/L	84.0	37.77	-46	-55	0.003
Pyrene	ng/L	66.94	24.33	-43	-64	0.003

(1) Shaded cells indicate statistically significant change.
(2) p<0.05 using one-tail paired t-test.
(3) Power analysis conducted on these constituents with nearly statistically significant changes (0.05<p<0.2).

Power Analysis Results

The data for several constituents were on the verge of statistical significance (as noted in Table 24), with t-test p-values from 0.05 to 0.20. These data were analyzed using "post hoc" power analysis to determine how many total data points would be needed to achieve statistical significance (i.e., to achieve a p-value below 0.05, given the known characteristics of the influent and effluent data sets), as described in the earlier section, "Power Analysis".

Table 25 shows the power analysis projections of total numbers of data points needed before statistical significance is expected, given data characteristics similar to those presently available for the tested data sets. The power analysis results project that three constituents (anthracene, benzo(k)flouranthene, and di-n-octyl phthalate) would require 1-2 years of additional monitoring (assuming three to five events per year) to achieve significance. Two constituents (THP-extractable as diesel and naphthalene) would require five to 12 additional years. Butyl benzyl phthalte, diethyl phthalate, dissolved lead, di-n-butyl phthalate, and dissolved zinc would require many additional years of monitoring before acquiring sufficient data for statistical significance.

Table 25. Power analysis results for constituents on the verge of statistical significance.

Constituent	p-value	n (existing)	#>0	#<0	n (needed)	n (additional)
Anthracene	0.118	10	6	1	11	1
Benzo(k)fluoranthene	0.088	10	6	1	11	1
Butyl benzyl phthalate	0.157	9	6	3	37	28
Diethyl phthalate	0.157	9	6	3	37	28
Di-n-butyl phthalate	0.157	9	4	5	>100	>100
Di-n-octyl phthalate	0.062	9	7	1	11	2
Lead, Dissolved	0.055	10	6	3	37	27
Naphthalene	0.088	10	5	2	27	17
TPH-Extractable, as Diesel	0.104	9	6	2	20	11
Zinc, Dissolved	0.193	10	5	5	>100	>100

Roof Runoff Contributions

A summary of pollutant contributions from roof runoff for all eleven swale sampling events during 1999-2002 is presented in Table 26. This analysis assumes that rainfall contributes pollutants equally to roofs and parking lots. The swale inlet samples consist of runoff from both the parking lot and the roofs. A comparison of the roof runoff data with the swale inlet data can therefore provide an indication of the relative magnitude of the contribution of roof runoff to the overall runoff from the site. In Table 26, p-values are shown to indicate the statistical significance of the difference between roof runoff and inlet according to the Wilcoxon signed-rank test. Constituents with p-values less than 0.05 are considered to be significantly different in concentration. Because additional runoff – not from the roof – contributes to the runoff volume at the inlet, decreases in concentration between the roof runoff and inlet implies dilution from other runoff areas, not removal between the downspout and the swale inlet. Increases in concentration between roof runoff and inlet samples indicate that parking areas generate greater proportions of the overall runoff load than roofs.

Table 26. Roof runoff contributions to pollutant concentrations based on event mean concentrations (detected constituents only).

Constituent	Units	Roof Runoff Mean	Inlet Mean	Numeric Difference	% Difference	p-value [1]
Copper, Dissolved	μg/L	2.34	2.36	0.02	1	0.124
Lead, Dissolved	μg/L	0.089	0.32	0.234	263	0.014
Zinc, Dissolved	μg/L	49.6	24.48	-25	-51	0.058
Copper, Total Recoverable	μg/L	3.35	4.97	2	48	0.014
Lead, Total Recoverable	μg/L	1.28	3.69	2	188	0.037
Zinc, Total Recoverable	μg/L	62.82	53.65	-9	-15	0.232
Total Coliform	MPN/100ml	1,795	4,203	2,409	134	0.173
Fecal Coliform	MPN/100ml	36.94	96	59	160	0.297
Total Suspended Solids (TSS)	mg/L	9.67	24.7	15	155	0.023
BOD$_5$	mg/L	67.04	33.32	-34	-50	0.233
Hardness as CaCO3	mg/L	7.31	5.63	-2	-23	0.137
Carbon, Total Organic	mg/L	18.8	17.63	-1	-6	0.173
Carbon, Dissolved Organic	mg/L	16.37	13.2	-3	-19	0.058
Ammonia as N	mg/L	0.45	0.49	0.04	9	0.040
Phosphorus, Total	mg/L	0.1	0.12	0.018	18	0.090
Total Kjeldahl Nitrogen	mg/L	0.702	0.73	0.028	4	0.104
TPH-Extractable, as Diesel	μg/L	93.02	213.99	121	130	0.022
TPH-Extractable, as Motor Oil	μg/L	454.28	1,813	1,358	299	0.014
Bis(2-ethylhexyl)phthlate	ng/L	224.75	6,277	6,052	2693	0.022
Butyl benzyl phthalate	ng/L	360.2	8,036	7,676	2131	0.022
Diethyl phthalate	ng/L	106.4	284	178	167	0.022
Dimethyl phthalate	ng/L	15.03	33.58	19	123	0.358
Di-n-butyl phthalate	ng/L	120.25	274.5	154	128	0.040
Di-n-octyl phthalate	ng/L	11.4^{IDD}	1,022	1,010	8862	0.022
Benzo(b)fluoranthene	ng/L	3.85^{IDD}	51.08	47	1227	0.022
Benzo(e)pyrene	ng/L	4.58^{IDD}	31.78	27	594	0.022
Benzo(g,h,i)perylene	ng/L	3.33^{IDD}	38.25	35	1049	0.034
Benzo(k)fluoranthene	ng/L	1.92^{IDD}	13.26	11	591	0.034
Biphenyl	ng/L	3.63	6.60	3	82	0.495
Chrysene	ng/L	17.70	54.49	37	208	0.037
Fluoranthene	ng/L	9.23	83.03	74	800	0.014
Indeno(1,2,3-c,d)pyrene	ng/L	1.92^{IDD}	21.97	20	1046	0.034
Naphthalene	ng/L	10.95	18.61	8	70	0.233
Phenanthrene	ng/L	27.78	83.95	56	202	0.014
Pyrene	ng/L	6.48	66.94	60	933	0.014

(1) Shaded cells indicate statistically significant change.
 "IDD" = insufficient data to estimate a mean concentration; substituted detection limit for non-detected values.

Mean concentrations in roof runoff were significantly lower than mean concentrations at the inlet for most constituents. The general trend was for concentrations to increase as runoff flowed across the parking area, as expected. Percent changes in concentrations for the following constituents are noted:

- Metals – Total and dissolved zinc concentrations decreased substantially from the roof runoff to inlet, although the differences were not statistically significant. This finding is not

surprising because the RAS facility's roof is galvanized (zinc alloy coated). Copper and lead concentrations increased significantly through the parking area.

- Coliform bacteria – Both fecal and total coliform showed large (160% and 134%, respectively) increases between roof runoff and inlet, but varied too much to confirm the statistical significance of those results.

- Conventional Constituents – Biochemical oxygen demand (BOD_5) was substantially higher (50%) in roof runoff than at the inlet. Carbon (both total and dissolved fraction) was also higher in roof runoff than at the inlet. The higher values in roof runoff may be attributable to airborne organic material and bird droppings on the roof. Higher TSS concentrations at the inlet were presumably from larger particulate material generated in the parking areas (i.e., larger than could be carried by winds to rooftops).

- Nutrients – Total Kjeldahl nitrogen (TKN) and ammonia concentrations were almost identical in roof runoff and at the inlet site. Total phosphorus concentrations at both locations were often below the analytical detection limit.

- Semi- & non-volatile organics – The majority of polyaromatic hydrocarbons (PAH) increased significantly between roof runoff and inlet, with the exceptions of biphenyl and naphthalene. This result confirms the general understanding that automobile use is a dominant source of PAHs.

These results indicate that for most constituents parking lot runoff carries higher pollutant concentrations than roof runoff. No constituent exhibited a statistically significant decrease between the roof runoff sampling site and the swale inlet. This assessment of roof runoff concentrations is of a more general interest and is not directly related to performance of the swale.

Qualitative Evaluation of Study Results

Observations of the grassy swale at the RAS study site during several storm events provided valuable information regarding the capability of the swale to effectively treat stormwater runoff.

In addition to reducing pollutant concentrations in runoff entering storm drains, a grassy swale also reduces the volume of runoff (Rushton, 2002). As runoff water passes through the grassy swale, a portion of it infiltrates into the soil. This reduction in volume of water discharged is a major advantage of low impact designs (more closely approximating pre-development conditions). For this study, runoff volumes at the inlet and outlet to the swale were not measured, due to practical limitations related to the physical configuration of the inlet and outlet monitoring sites. Because of this study condition, it is not possible to calculate load reductions, only concentration reductions. Therefore, the comparative ability of the swale to remove pollutants by infiltrating stormwater cannot be quantified. At the SMUD swale site monitored previously, flows were clearly reduced by passage through the swale (LWA, 1999a).

Maintenance of the swale was much improved during the 2001/02 rainy season compared to previous years (see recommendation in the 2000/01 status report). The swale appeared to be well maintained during all 2001/02 sampling events. Although minor channeling was observed on occasion, in general the grass was healthy and full. Maintenance by ground crews was generally good. There were never large amounts of litter, and the grass was always healthy and trimmed.

Observations related to number of parked cars and traffic present during the monitoring events were also made and are recorded in the field logs (**Appendix A**).

An additional qualitative advantage of swales is that they do not create stagnant water, breeding ground for mosquitoes and other water-related disease vectors.

Sediment samples from a set of swales in Florida (Rushton, 2002) indicate that almost all of the metals were sequestered in the top one inch of soil, near the inlet end of the swales. Nitrogen, and to a certain extent phosphorus, increased in the swales' sediments.

COMPARATIVE DATA ANALYSIS

In general, grassy swales are effective at removing constituents associated with particulates, especially total suspended solids (TSS), total recoverable metals, and organic carbon. Removal rates for nutrients, dissolved metals, pesticides, and bacteria are variable. Increases in nitrate levels have been observed in several vegetated landscape control measure studies conducted by others (LWA, 1998).

Of particular interest for the RAS swale are the high PAH removal efficiencies (50%-80%). PAH removal efficiencies are not commonly reported in national literature. Oil and grease (sometimes measured as total petroleum hydrocarbons) are removed effectively by swales and do have some comparative data. Often, because petroleum products are largely in particulate form, TSS is used as a surrogate. But results here indicate that PAHs are on average removed more than TSS.

The RAS grassy swale removal efficiencies are compared here to summary results for similar swales monitored both in California and nationwide for several constituents. For TSS, for which a larger amount of data have been reported, the grassy swale's removal efficiency is also compared to removal efficiencies by several other control measures.

Comparative Swale Data Sources

Data for grassy swale sites in California and nationwide have been collected for this comparison.

Caltrans Sites

Six biofiltration swales in southern California were studied by Caltrans to examine the benefits of retrofitting various structural BMPs into existing infrastructure (Caltrans, 2002). General siting criteria for the swales included drainage areas less than one hectare, slopes no greater than 5%, and a seasonally high water table at least 2 feet below grade. Each of these swales treated runoff from highways (90-95% impervious area). Irrigation was provided at each site to help establish vegetation. A mix of plant species tended to establish naturally, in contrast to the monoculture grass found in the RAS swale. Data are available for TSS, nutrients (nitrogen and phosphorus), total and dissolved metals (copper, lead, and zinc), petroleum hydrocarbons (oil, gasoline, and diesel), and fecal coliform. Removals were found highest for metals and lowest (outflow > inflow) for phosphorus.

Reported removal efficiencies for TSS are approximately 50%. Metals removal rates were 50%-77% for both total and dissolved forms of copper, lead, and zinc. Total nitrogen, nitrate, and total Kjeldahl nitrogen were all highly variable, but were removed on average. Total and dissolved phosphorus concentrations increased markedly (over 100%) through the swales. P-values reported in these studies portray similar variability to that reported here. Only constituents with significant changes ($p < 0.05$) are included in the figures presented for comparison.

National BMP Database

A review of data submitted to a national BMP database[1] can be informative. This database is increasing in size rapidly, from 71 BMP study reports in 1999 to 198 reports in mid-2002. Of that total, 41 are in California (more than from any other state). There are 21 reports for BMPs of the same type ("Biofilter – Grassy Swale"); however, only seven sites with less than six-hectare

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[1] See http://www.bmpdatabase.org

drainage areas reported both inflow and outflow concentrations (as event mean values) for at least two storms. It is this subset of the data that is used in the comparisons described here.

Reported removal efficiencies for TSS are in the range 18-93% for six sites. Metals removal rates were reported for three to seven sites (depending on the constituent), with general decreases at all sites of 22-66%. No data are available for PAHs or other constituents of interest. To evaluate the comparative value of the datasets for each constituent, the linear regression of the inlet-outlet data was used only if the regression coefficient (r^2) was greater than 0.5. P-values were not reported with the database.

Sacramento Performance Data Summary

LWA (1999b) reported comparative data for swales around the country. These data represent summary results from eight different studies, at multiple swale sites for each study. Sufficient data to provide regression curves (removal efficiency versus inlet concentration, shown below) are available only for TSS and total zinc.

Comparison to Other Grassy Swales

Removal efficiencies for TSS and metals (total and dissolved copper, total and dissolved lead, and total zinc) for the RAS swale are compared to removal rates reported elsewhere (Table 27). The Caltrans and National BMP Database figures were computed from reported data. From these sources, only constituents with significant changes at the RAS swale are included. LWA, ASCE, and USEPA reported generalized removal efficiencies as guides for design. The RAS swale appears to perform similarly to swales elsewhere in the US for removal of TSS, petroleum hydrocarbons, and metals.

Table 27. Constituent removal efficiencies (in percent) for the RAS swale compared to swale data reported elsewhere

Source	TSS	Oil & Grease	Total Copper	Total Lead	Total Zinc	Dissolved Copper	Dissolved Lead
RAS	50	55[1]	19	59	32	-16	33
Caltrans	50	51[1]	63	69	77	50	61
LWA (1999b)[2]	72	62	37	39	49	10	NA
NBMPDB[3]	57	NA	33	66	29	22	30
ASCE[4]	60	62[5]	2	15	16	NA	NA
USEPA[6]	81	49	51	67	71	NA	NA

"NA" = Data are not available.
(1) Measured as THP-Oil.
(2) Average from eight different swale study sites evaluated in Sacramento Structural Controls Investigation.
(3) National BMP Database, available on-line at http://www.bmpdatabase.org
(4) American Society of Civil Engineers (2001). "Guide for Best Management Practice (BMP) Selection in Urban Developed Areas", 51 pp.
(5) Reported as "Hydrocarbons".
(6) USEPA (1999). Office of Water. September 1999. "Storm Water Technology Fact Sheet: Vegetated Swales." (EPA-832-F-99-006). http://www.epa.gov/owm/mtb/vegswale.pdf"

<u>Removal Efficiency as a Function of Inlet Concentration</u>

Paired inlet and outlet results for the RAS swale were converted into removal efficiencies as a function of inlet concentrations. These individual points (one per sampling event) are compared to removal efficiency curves regressed from data summarized above from the Sacramento Structural Controls Investigation (LWA, 1999b), the BMP Pilot Study Program (Caltrans, 2002), and the National BMP Database data in Figures 10-13. The RAS swale tended to perform well for TSS removal, although inlet concentrations were generally lower than reported elsewhere. For example, average inflow TSS concentration in the National BMP Database is 70 mg/L. The RAS swale generally performed as well as or better than swales elsewhere in the US for total metals removal, although inlet concentrations tended to be lower than reported elsewhere.

Figure 10. TSS removal efficiency versus inlet concentrations for the RAS swale. Efficiency curves for Caltrans study sites in California and aggregate data from the Sacramento Comparative Study (which includes some Caltrans sites' data) are also shown.
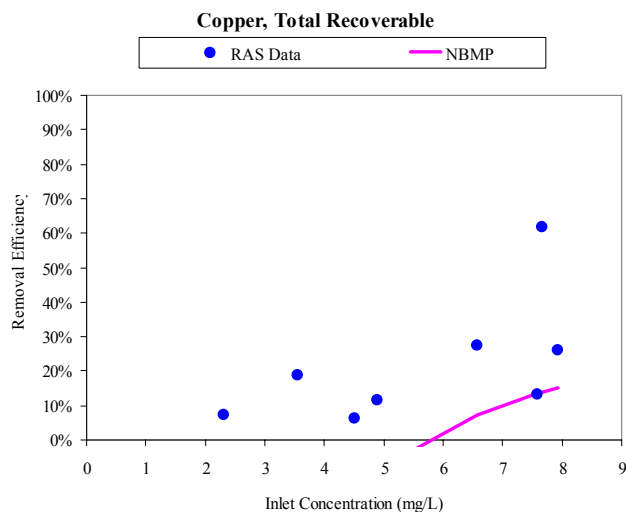
Figure 11. Total recoverable copper removal efficiency versus inlet concentrations for the RAS swale. An efficiency curve for National BMP Database records is shown.

Lead, Total Recoverable
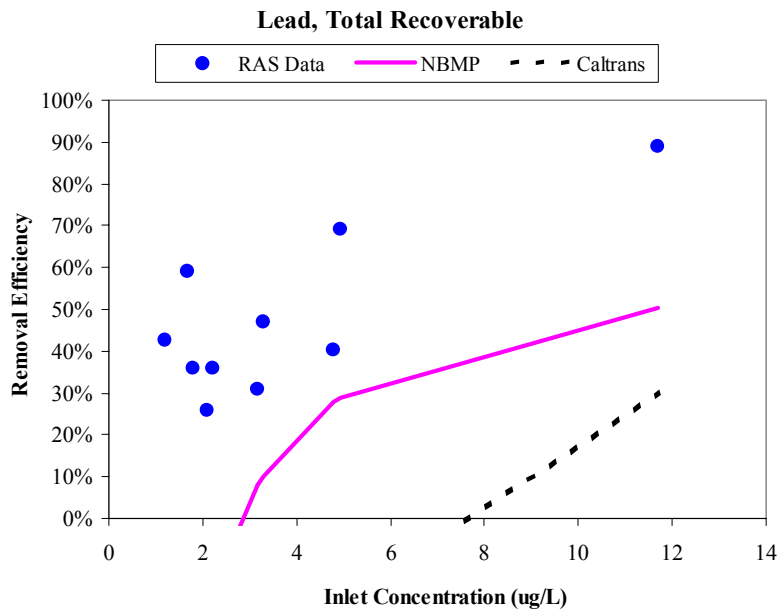
Figure 12. Total recoverable lead removal efficiency versus inlet concentrations for the RAS swale. Efficiency curves for National BMP Database records and Caltrans study sites' data are shown.

Zinc, Total Recoverable
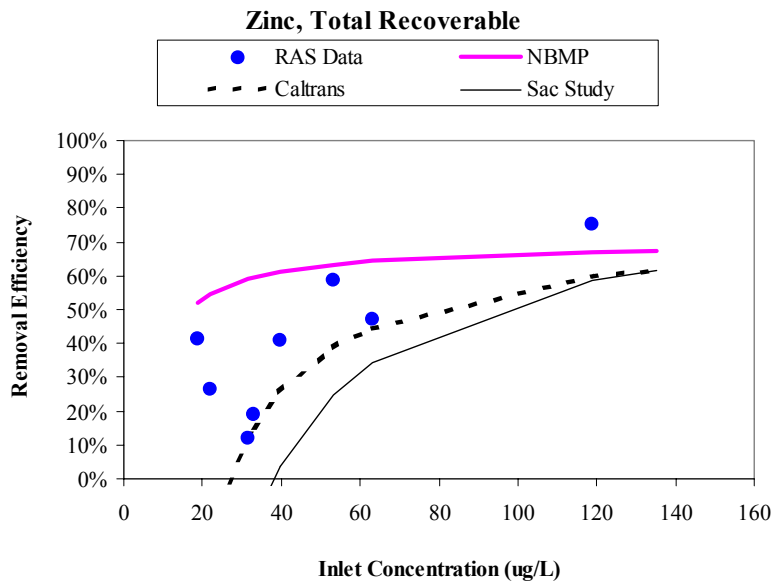
Figure 13. Total recoverable zinc removal efficiency versus inlet concentrations for the RAS swale. Efficiency curves for National BMP Database records and for aggregate data from the Sacramento County Comparative Study (which includes some sites also reported in the other two datasets).

Comparison to Other Stormwater Control Measures

Figure 14 indicates TSS removal efficiency of the RAS swale relative to several other common structural control measures. The comparison data for this figure are from Caltrans BMP study sites monitored throughout California (Caltrans, 2002). The line labeled "CP Line" is a line of comparative performance, which has been used previously by the Sacramento Stormwater Permittees to compare BMP removal efficiencies for TSS (LWA, 1999b). The expectation is that data points must fall above and to the left of the line, loosely defined as acceptable performance. The line was developed from an evaluation of the performance data of several treatment systems studied in western Washington. Results from that analysis are considered applicable here because of regional similarities in rainfall characteristics and TSS concentrations.

As shown in Figure 14, comparative results indicate that the RAS swale TSS removal rates are relatively good. Interestingly, the opposite conclusion would be drawn if comparing the Caltrans swale data to the CP Line. However, it is also apparent that the range of inlet TSS concentrations at the RAS swale is relatively low compared to typical concentrations found in rainfall runoff at other sites.

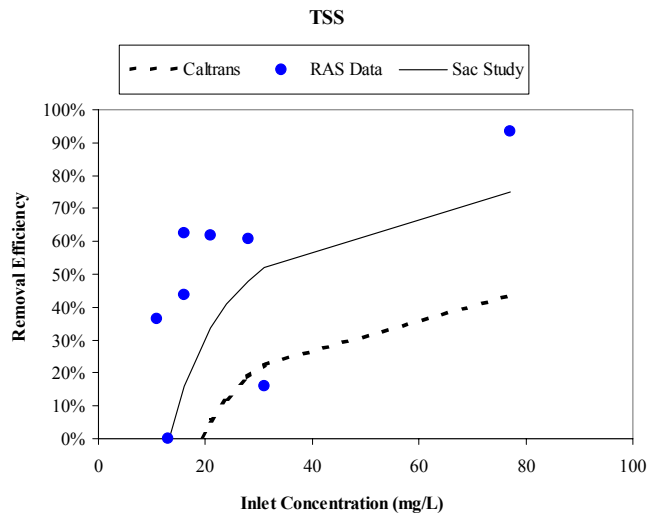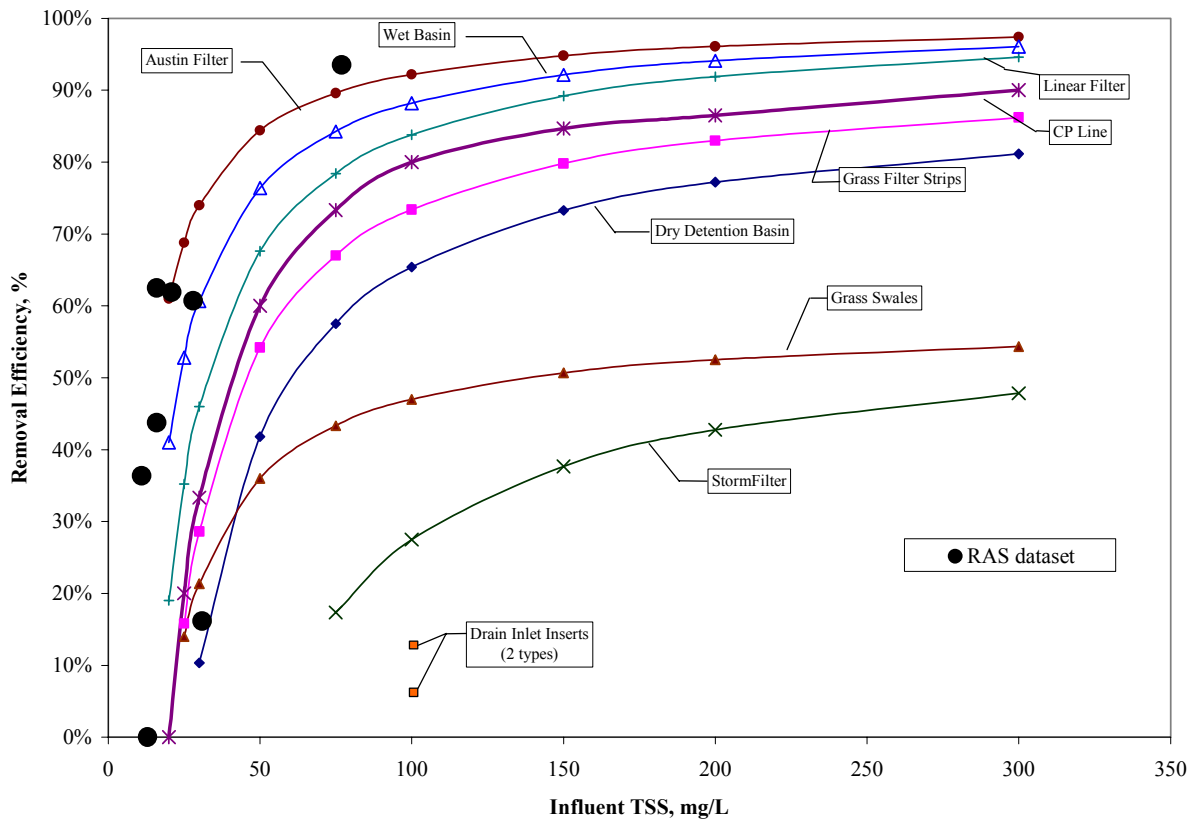**Figure 14. TSS removal efficiency versus inlet concentrations for the RAS swale. Efficiency curves for Caltrans control measures monitored throughout California are shown for comparison.**

CONCLUSIONS

From the quantitative and qualitative evaluation of the RAS swale, the following conclusions are drawn.

Grassy Swale Treatment Efficiency

Removal efficiencies are separated by relative levels:

- Substantial removal – Polyaromatic hydrocarbons (PAH) are removed by up to 80% through the swale. This may be attributable to adsorption onto grass leaves and organic soil particles.

- Moderate removal – TSS was removed by 50%, consistent with findings elsewhere. Total recoverable metals were removed by 19% to 59%, attributed to sediment being filtered out of the water. Ammonia was removed by 31%. Motor oil (TPH-extractable) was removed by 55% through the swale. This finding is useful since grassy swales are often sited near vehicle use areas (such as at this RAS site).

- No removal or apparent contribution – Dissolved metals were not removed in the swale, attributed to the short residence time of water in the swale not allowing dissolved metals to partition onto settleable solids. Total and fecal coliform increased by more than a factor of four as runoff passed through the swale, attributable to coliform present in the soil and possibly to bird droppings. Hardness increased through the swale, but outlet concentrations are still low and not of concern. Except for ammonia, nitrogen and phosphorus were not removed by the swale. Increases in nutrients are potentially caused by fertilizer application in the swale.

Pollutant removal efficiencies from this site should be representative of grassy swale performance for runoff from typical parking lot use patterns for commercial facilities in the Sacramento area.

Power Analysis

Power analysis showed that the number of additional monitoring samples required to demonstrate statistical significance was often large. As many constituents did exhibit statistically significant differences between inlet and outlet over the course of this study, continued monitoring, at least in the near-term, would probably add little to our understanding of the pollutant removal effectiveness of this swale.

Comparisons to Other Sites and Other Control Measures

TSS removal rates by grassy swales are relatively good compared to other structural control measures. However, the comparison is limited by the range of inlet concentrations for TSS experienced at the RAS site, which are relatively low compared to typical concentrations found in rainfall runoff at other sites.

Oil and grease are reduced to approximately half of their inlet concentration at the RAS swale as well as at other sites nationwide. Although an important finding in the RAS dataset is the effective removal of PAHs (~80%), comparative data from other studies are not available.

For most swales, total metals concentrations are moderately reduced (19%-59%), consistent with findings at the RAS site.

Roof Runoff Contribution

The measured pollutant concentrations in roof runoff were generally lower than those found at the inlet to the swale, with a few exceptions. The zinc alloy coated rooftop of the RAS building appears to contribute zinc to roof runoff. BOD, hardness, TOC and DOC all were marginally higher in rainfall runoff from the roof than from the drainage area as a whole (as sampled at the swale inlets). The majority of polyaromatic hydrocarbons (PAH) increased significantly between roof runoff and the inlet to the swale from the parking area, confirming the general understanding that automobile use is a dominant source of PAHs.

RECOMMENDATIONS

It was recommended in the 2000/01 status report (LWA, 2001) that runoff from the railroad spur be sampled at least once. However, runoff from this area was never observed during this past monitoring season. It is recommended that any future monitoring sites be reconfigured, if necessary, to prevent lateral runoff into the swale.

It was also recommended in the 2000/01 status report (LWA, 2001) that nitrate and nitrite be analyzed as a sum rather than separately. The main concern was the short holding time (48 hours) for the individual analyses, compared to a much more attainable holding time for the sum (28 days). Nitrite was not detected in any samples. However, the practice was continued and not all holding times were met.

Where soils contain any degree of clay or humus, the earth is a powerful filter that can protect receiving waters from urban contamination. It takes only a few inches of soil to trap and accumulate oils, metals, and nutrients. As long as the infiltrating runoff contains only the common, mostly biodegradable, constituents from residential and commercial development, then it is within most soil's treatment capacity. To estimate that capacity of a site, incorporate the ability to calculate load reductions by:

- Measuring flow rates into and out of the swale, to quantify pollutant load reductions. Flumes or weirs with automatic data loggers would be required because of the rapid changes in runoff flow rate.

- Sampling sediments before and after the monitoring period, to quantify the soil's long-term capacity for adsorbing and degrading pollutants.

Costs have not been assessed in this report. If the Permittees wish to evaluate costs of various stormwater control measures, information on land value, construction costs, and maintenance requirements would need to be collected. It is recommended to conduct such an assessment before developing long-term BMP use recommendations. The maintenance and vegetative integrity of the RAS swale were appropriate and therefore should be useful for developing unit costs.

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APPENDICES A-E

APPENDIX A. VISUAL OBSERVATION CHECKLISTS (EVENTS #7-11)

The same checklists for previous years' events have been reported in status reports (LWA, 2000; LWA, 2001).

Table A-1. Visual Observations Checklist for Monitoring Event #7: October 30, 2001

Field crew: LWA	**Date:** 10/30/01	**Event No.:** 7 **Location:** RAS swale
Observation	**Time**	**Notes/Comments**
SWALE		
Grass height (recently mowed, approx. height)	9:45AM	Recently mowed, some clippings picked up in outlet samples
Overall condition of grass	"	Good cover, healthy
Flow patterns and channelization in the swale	"	Only short distances in mower tracks
Sediment build-up at inlets or throughout swale	"	Minimal, sand and larger particles only
Debris or other pollutants in swale	"	No debris, petroleum residue on water surface
Other observations	"	--
SURROUNDING AREAS		
Runoff from railroad spur (amount, is it entering swale?)	10:00 AM	none
Trains passing during monitoring	"	none
Approximate number of vehicles in parking area	"	20 up to 80 as business opened
Noticeable leaking vehicles	"	none
Traffic (cars coming and going during monitoring)	"	Scattered traffic as business opened, but not noticed near sampling location
Sediment, debris, garbage, other pollutants in parking area	"	none
Other observations	"	--

Table A-2. RAS Site Visual Observations Checklist for Monitoring Event #8: December 14, 2001

Field crew: SAM, JL		Date: 14-Dec-01	Event No.: 8
Observation	**Time**	**Notes/Comments**	
SWALE			
Grass height (recently mowed, approx. height)	11 PM	Slightly high	
Overall condition of grass	"	good	
Flow patterns and channelization in the swale	"	even, but more flow on east side	
Sediment build-up at inlets or throughout swale	"	Leaves at stilling basin	
Debris or other pollutants in swale	"	minimal	
Other observations	"	none	
SURROUNDING AREAS			
Runoff from railroad spur (amount, is it entering swale?)	2:30 AM	None	
Trains passing during monitoring	"	None	
Approximate number of vehicles in parking area	"	None in back area, ~10 in side lot	
Noticeable leaking vehicles	"	none	
Traffic (cars coming and going during monitoring)	"	Minimal, 3rd shift crew	
Sediment, debris, garbage, other pollutants in parking area	"	Leaves	
Other observations	"	none	

Table A-3. RAS Site Visual Observations Checklist for Monitoring Event #9: January 26, 2002

Field crew: SAM, YO, JL	Date: 1/28/02	Event No.: 9
Observation	**Time**	**Notes/Comments**
SWALE		
Grass height (recently mowed, approx. height)	3:50 AM	Medium to tall
Overall condition of grass	"	Fair, some yellowing
Flow patterns and channelization in the swale	"	minimal
Sediment build-up at inlets or throughout swale	"	some sand and debris
Debris or other pollutants in swale	"	Soap residue and organic debris
Other observations	"	--
SURROUNDING AREAS		
Runoff from railroad spur (amount, is it entering swale?)	3:50 AM	None
Trains passing during monitoring	"	None
Approximate number of vehicles in parking area	"	One (ours)
Noticeable leaking vehicles	"	None
Traffic (cars coming and going during monitoring)	"	None
Sediment, debris, garbage, other pollutants in parking area	"	None
Other observations	"	--

Table A-4. RAS Site Visual Observations Checklist for Monitoring Event #10: March 10, 2002

Field crew: SAM, YO, JL	Date: 3-10-02		Event No.: 10
Observation	Time	Notes/Comments	
SWALE			
Grass height (recently mowed, approx. height)	Midnt.	Medium height	
Overall condition of grass	"	Excellent	
Flow patterns and channelization in the swale	"	None	
Sediment build-up at inlets or throughout swale	"	Minimal	
Debris or other pollutants in swale	"	None	
Other observations	"	--	
SURROUNDING AREAS			
Runoff from railroad spur (amount, is it entering swale?)	Midnt.	Minimal	
Trains passing during monitoring	"	Tanker cars parked along swale	
Approximate number of vehicles in parking area	"	2 (field crew)	
Noticeable leaking vehicles	"	None	
Traffic (cars coming and going during monitoring)	"	1	
Sediment, debris, garbage, other pollutants in parking area	"	Cigarette butts, scattered leaves	
Other observations	"	A large GE trailer with a refrigeration system was in the parking lot.	

Table A-5. RAS Site Visual Observations Checklist for Monitoring Event #11: May 20, 2002

Field crew: SAM, YO		Date: 5-20-02	Event No.: 11
Observation	**Time**	**Notes/Comments**	
SWALE			
Grass height (recently mowed, approx. height)	3:30 PM	High – needs cutting	
Overall condition of grass	"	Very healthy	
Flow patterns and channelization in the swale	"	No rivulets	
Sediment build-up at inlets or throughout swale	"	Minimal	
Debris or other pollutants in swale	"	Minor trash (wrappers, etc.)	
Other observations	"	--	
SURROUNDING AREAS			
Runoff from railroad spur (amount, is it entering swale?)	3:30 PM	None	
Trains passing during monitoring	"	None	
Approximate number of vehicles in parking area	"	Full lot (during business hours)	
Noticeable leaking vehicles	"	None	
Traffic (cars coming and going during monitoring)	"	2/hour	
Sediment, debris, garbage, other pollutants in parking area	"	Small leaves	
Other observations	"	--	

Appendix B.
2001/02 DATA QUALITY EVALUATION PLAN

APPENDIX B.
2001/02 DATA QUALITY EVALUATION PLAN

This data quality evaluation plan (DQEP) describes the process by which data produced by the Sacramento Stormwater Monitoring Program are evaluated. Data quality evaluation is a multiple step process used to identify any errors, inconsistencies, or other problems potentially associated with monitoring program data. A data quality evaluation plan provides a reference point from which a program-consistent quality assurance/ quality control (QA/QC) evaluation can be performed. The plan described here generally follows the program implemented and reported during the 1995-1999 monitoring period.

The overall data evaluation process includes three major components. The initial screening step occurs promptly when the data are received from the laboratory. This step is intended to identify sample handling and analysis problems that can still be corrected within analytical hold times. The technical data evaluation step includes a detailed assessment of reported QA/QC data including both externally (field-initiated) and internally (lab-initiated) generated data. This detailed, task-intensive step includes the evaluation components in Figures 1 (lab-initiated data) and Figure 2 (field-initiated data). The DQEP is a detailed description of this technical review and is based on EPA guidance documents[1] and requirements set forth by the monitoring program management team. The acceptance criteria for some of the QA/QC checks (allowable spike recovery, maximum relative percent difference, etc.) are program "constants" each monitoring year. This is sometimes done using historical lab performance, but always stays within EPA guidelines. The final element of the overall process is the data reporting step. All data collected throughout the monitoring year are reported in the Annual Data Report and in the annually updated database.

Once the data quality evaluation has identified any chronic or significant QA/QC inconsistencies, a request to verify and explain the exceedances is sent to the laboratory. These issues are also reviewed and discussed in a narrative form in the QA/QC section of the annual data report.

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[1] Environmental Protection Agency. February 1994. *USEPA Contract Laboratory Program National Functional Guidelines for Inorganic Data Review.* (EPA-540/R-94-013)
Environmental Protection Agency. December 1994. *USEPA Contract Laboratory Program National Functional Guidelines for Organic Data Review* (EPA-540/R-94-090)
Environmental Protection Agency. April 1995. *Guidance on the Documentation and Evaluation of Trace Metals Data Collected for Clean Water Act Compliance Monitoring* (EPA-821/B-95-002)

INITIAL SCREENING

The initial screening process occurs when the laboratory reports are received, following each monitored storm event, and after the pre-season QA/QC sampling. It is important to check the reported data as soon as possible after the storm event to identify gross errors committed in the sampling, analysis, or reporting process. To ensure that the corrective measures are completed before the holding time has elapsed the laboratory must report results in a timely fashion and these results must be reviewed immediately upon receipt to allow for re-analysis of questionable (out-of-range) results. The initial screening includes the following checks:

√   Completeness. All laboratory analyses specified in the sampling plan should be requested on the chain of custody forms. All laboratory analyses should likewise be performed as specified in the chain of custody forms. QA/QC analyses should also be checked for completeness. A review of chain of custody forms is necessary to check that this documentation was properly filled out by the field crew and the laboratory check-in attendant.

√   Detection Limits. Detection limits should meet or be lower than the levels agreed upon prior to laboratory submission.

√   Reporting Errors. On occasion laboratories commit typographical errors or send incomplete results. Reported concentrations that appear out of range or inconsistent are indicators of laboratory reporting problems that should be investigated when detected. Examples of this would be a dissolved concentration greater than the corresponding total recoverable concentration or a constituent concentration orders of magnitude different than the same constituent for other events.

Irregularities found in the initial screening process should immediately be reported to the laboratory for clarification or correction. The initial screening process can identify and correct errors that would otherwise cause problems further along in the data evaluation process, or later if the data are used for higher-level analyses. Moreover, reanalysis of out-of-range values can increase confidence in the integrity of questionable data.

TECHNICAL DATA EVALUATION

The QA/QC process flow chart, Figures 1 and 2, depicts the checks necessary to completely assess data quality. The entire set of QA/QC data necessary for a complete technical data evaluation is provided by the laboratories. Certain elements are available by special request as they are not part of a laboratory's standard report deliverables. The technical QA/QC review process is established in the DQEP, in part, for consistency, however, the data evaluator must rely on professional judgment for consideration of "special cases" where data evaluation information apparently conflict. Such cases are documented in the narrative discussion included in the annual data report.

The criteria used for each of these components are listed in Tables 1 through 6 at the end of this section, for each method and type of constituent analyzed. Each table contains a field for constituent name, reported detection limit (MDL, quantitation limit or reporting limit), acceptable spike range, maximum allowable relative percent difference (MAV RPD), and holding time.

Detection limits for this project are reported by the laboratories as a method detection limit (MDL), a practical quantitation limit (PQL) or a reporting limit (RL). The MDL is performed according to the protocol established in 40 CFR, Part 136, Appendix B and should be reported only when the laboratory is performing calibration curves at levels in the range of the reported MDL. The PQL and RL are laboratory defined detection level terms. They are calculated as a multiple of the MDL based on the laboratory's comfort level and historical performance. They are limits that the principal analyst feels can be achieved on a routine basis for a specific type of matrix. These reporting detection levels are typically 1-10X the MDL, and is generally at least 3X the MDL[2]. For example, the PQL is established by the laboratory based on historical laboratory performance, background constituents, instrument noise, and matrix effects for the sample.

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[2] Agriculture & Priority Pollutants Laboratories, Inc. February 1996. *Quality Assurance Program Plan.*

1. Holding time compliance? — no → **Qualify results as estimated if holding time variance allowed, or reject results. Proceed to next step.**

yes ↓

2. Are Method blanks ND or within project specs? — no → Are sample results ND? — no → Are sample results <10x (phthalates & common contaminants) or <5x (semi- & non-volatiles & metals*) blank concentration? — no → **No qualification. Proceed to next step.**

yes (Are sample results ND?) ↓ **No qualification. Proceed to next step.**

yes (blank concentration) ↓ **Qualify associated detected environmental sample results as "NDB". Proceed to next step.**

yes (Method blanks) ↓

3. Are Lab duplicate RPDs within project specs? — no → Are measured differences between samples less than the reporting limit? — no → **Qualify sample results as estimates due to analytical variability. Proceed to next step.**

yes (measured differences) ↓ **No qualification. Proceed to next step.**

yes (Lab duplicate RPDs) ↓

4. Are MS recoveries within project specs? — no → **If MS result is >UL, qualify detected associated environmental sample results as estimates due to matrix interference. If MS result is <LL, qualify associated environmental sample results as estimates due to matrix interference and consider rejecting associated environmental sample data below detection based on other supporting QA/QC data.**

yes ↓

5. Are MSD RPDs within project specs? — no → **Qualify sample results as estimates due to matrix interfernce. Proceed to next step.**

yes ↓

6. LCS & ERS recoveries within project specs? — no → **If spike recovery result is >UL, qualify associated environmental sample results above detection levels as estimates due to high analytical bias. If spike recovery result is <LL or more than half of recoveries are outside acceptability limits, qualify associated detected environmental sample results as estimates due to low analytical bias and reject associated environmental sample data below detection.**

yes ↓

No qualification. Proceed to field-initiated QA/QC data evaluation.

*Environmental results between 5x and 10x the blank concentration are qualified as "an upper limit on the true concentration" and the data user should be cautioned.

Figure 1. Technical Data Evaluation for Lab-Initiated QA/QC Samples

7. Are field blanks ND? → **no** → Are sample results ND? → **no** → Are sample results <10x (phthalates & common contaminants) or <5x (semi- & non-volatiles & metals*) blank concentration? → **no** → No qualification. Proceed to next step.

Are field blanks ND? → **yes**

Are sample results ND? → **yes** → No qualification. Proceed to next step.

Are sample results <10x... blank concentration? → **yes** → Qualify associated detected environmental sample results as "NDB". Proceed to next step.

8. Are field duplicate RPDs within project specs? → **no** → Are measured differences between samples less than the Reporting Limit? → **no** → Qualify sample results as estimates due to analytical variability. Proceed to next step.

Are field duplicate RPDs within project specs? → **yes**

Are measured differences between samples less than the Reporting Limit? → **yes** → No qualification. Proceed to next step.

9. Do overall QC results indicate systematic problems? → **yes** → Make additional data qualifications as necessary matrix, method, etc. Qualified data should be noted and reported.

Do overall QC results indicate systematic problems? → **no** → No limitation on use of unqualified data. Qualified data should be noted and reported.

*Environmental results between 5x and 10x the blank concentration are qualified as "an upper limit on the true concentration" and the data user should be cautioned.

Figure 2. Technical Data Evaluation for Field-Initiated QA/QC Samples

Contamination Checks

Contamination of samples is assessed using method/reagent blanks (Figure 1, step #2) and field/equipment blanks (Figure 2, step #1). Blanks are prepared using reagent grade deionized water and tested using analytical procedures identical to those used for the environmental samples. The conditions under which the blanks are prepared follow, as closely as possible, the conditions in the field or laboratory, as appropriate for the type of blank.

A *method (or reagent) blank* is prepared and analyzed for every batch of samples (typically once per event for all three discharge characterization sites). A detected concentration or "hit" is an indication of contamination in the analytical process. Such hits have frequently occurred in this project in the EPA 625 analysis for phthalates. Phthalates are commonly associated with plasticides, a ubiquitous set of compounds in modern life and the laboratory setting. Efforts by the laboratory to identify and remediate the sources of contamination have not been completely successful and values are consistently reported at a baseline levels above the quantitation limit.

Equipment blanks, collected prior to the monitoring year, are used to identify contamination introduced by the sampling equipment (Teflon tubing, silicone tubing, and the overall sampling unit). Blank concentrations reported above the detection limit are assessed and acted upon using the guidelines listed in the bulleted items below. Concentrations reported above the detection limit for the common organic contaminants (phthalates, benzoic acid and certain phenols) do not need to be considered further if the reported concentration is less than 10x the detection limit. This cutoff is not statistically derived, and is used to account for analytical variability around the low detection limits reported by the laboratory and the presence of these constituents as common laboratory contaminants. Selection of this cutoff is based on a review of historical laboratory performance. Blank concentrations reported above the detection limit for the mercury samples analyzed by Frontier Geosciences do not need to be considered further if the reported concentration is less than 10x the detection limit. Blank water provided by Frontier Geosciences contains up to approximately 1 ng/L of mercury (the detection limit is 0.1 ng/L nominally). Equipment blanks for metals other than mercury should be investigated further if a concentration is reported above the detection limit.

Equipment blank hits should be investigated using the actions listed below.

- Request that the laboratory confirm the reported results against lab bench sheets or other original analytical instrument output. Any calculation or reporting errors should be corrected and reported by the laboratory in an amended laboratory report.

- If the previous step does not identify improperly reported results, the laboratory should be asked to identify any possible sources of contamination in the lab.

- If no laboratory contamination is identified, a note should be introduced into the text stating that the equipment blank results indicate that the sampling equipment may have introduced contamination. When practical, remedial measures should be taken to eliminate field contamination, including tubing cleaning and replacement or introduction of new, "cleaner" equipment.

Bottle rinse blanks are performed by the laboratory, prior to the monitoring year, and should be handled, for QA/QC purposes, in the same manner as equipment blanks.

A *field blank* is prepared in the field, using procedures that simulate the actual field sampling procedures. A hit reported in a field blank indicates that contamination has occurred at some point during the field sampling or analytical procedures. When a method blank is reported as "not detected" and the corresponding field blank is reported at concentrations greater than the detection limit, the contamination has likely been introduced in the field. Additionally, if the pre-season equipment blank result for the constituent in question was reported at a concentration above the detection limit, the equipment might have introduced the contamination. Field observations and input from lab personnel can be useful in confirming contamination source identification.

Accuracy Checks

The laboratory performs internal accuracy checks by analyzing a "spike" of known concentration and comparing their results with the known concentration. Laboratories calculate percent recovery using the following formula:

$$R = 100\% * [(C_s - C) \div s] \qquad \{1\}$$

$$\text{where,} \quad R = \text{percent recovery}$$

$$C_s = \text{spiked sample concentration}$$

$$C = \text{sample concentration (for spiked matrices)}$$

$$s = \text{concentration equivalent of spike added}$$

Matrix spike analysis (Figure 1, step #4) involves the introduction of a known spike in the original environmental sample "matrix" (sample solution), and is a measure of the accuracy of the recovery performance of the laboratory. To perform this analysis, the laboratory generally requires an additional volume of sample. Matrix interference can lead to recovery problems and raised detection limits. Re-analysis is the first corrective action once matrix interference problems are identified, but reanalysis is only possible when sufficient sample volume is available.

Laboratory control spike (LCS) and standard reference material (SRM) analyses (Figure 1, step #6), are batch checks for recovery of a known concentration of a standard solution, used to assess the accuracy of the entire recovery process from preparation of the sample to analysis. LCS samples are analyzed in the same manner as the environmental samples. SRMs are spiked samples prepared by a third party laboratory. SRMs are only necessary if chronic LCS recovery problems are noted, or if they are used by the lab in place of LCSs. Typically, laboratories perform SRMs on a quarterly basis or for constituents whose in-house preparation of spikes is difficult or expensive.

Surrogate matrix spikes, considered along with LCS spikes in Figure1, step #6, are used as a check on the extraction process for organic compounds. Surrogate recovery uses organic compounds other than the constituent being tested for, but with similar chemical characteristics. The surrogate used is easier to distinguish from other compounds and can be more accurately extracted and recovered.

Laboratory accuracy results and percent recovery calculations for each type of accuracy check should be delivered by the laboratory and screened by the data reviewer upon receipt.

Precision Checks

Precision is the measurement of the difference between samples (environmental and QA/QC) that are presupposed to be collected and analyzed in the same manner. The relative percent difference (RPD) is used to measure the difference between these replicate samples. The RPD is calculated from field duplicate, lab duplicate, and matrix spike duplicate data as follows:

$$RPD = 100\% * |R_1 - R_2| \div [(R_1 + R_2) \div 2] \qquad \{2\}$$

$$\text{where,} \qquad RPD = \text{relative percent difference}$$

$$R_1 = \text{replicate sample \#1}$$

$$R_2 = \text{replicate sample \#2}$$

Laboratory duplicates (Figure 1, step #34) are samples split in the laboratory to measure the precision, as relative percent difference (RPD), of the laboratory analysis and the storm composite sample splitting.

Field duplicates (Figure 2, step #8), in the case of grab samples, are sampled one directly after the other in the field and submitted to the laboratory as separate samples. Composite duplicates are prepared in the staging area (Sacramento Regional Wastewater Treatment Plant) along with the preparation of the environmental composite-based samples during splitting of the storm composite sample. Both composite-based and grab-based field duplicates provide a measure of the concentration variability introduced by field and laboratory procedures. Composite-based field duplicates also provide a measure of the precision of the storm composite sample splitting process. In combination with lab duplicates, field duplicates allow some separation of the sources of analytical variability (e.g. field and lab procedures).

Matrix spike duplicate (MSD) analysis (Figure 1, step #5), checks the precision of the MS recovery. Ideally, triple the normal sample volume is available for the analysis of a matrix spike and a matrix spike duplicate. As with field duplicates, the additional QA/QC volume is collected at the same time as the environmental sample, and the additional composite sample volume is poured off of the storm composite sample in the staging area, along with the environmental sample.

RPDs between duplicated samples are calculated by the data reviewer. This calculation should be done immediately following receipt of the laboratory results. Generally, laboratories will perform the reanalysis for the laboratory-initiated duplicates (laboratory and matrix spike duplicates) that are significantly out-of-range on the first analysis run. The results of the reanalysis should be presented in laboratory report form or in a case narrative prepared by the laboratory.

Table 1. QA/QC Criteria for Laboratory Reporting of Analytical Concentrations: Metals (Total Recoverable & Dissolved)

Constituent	Method	Units	Minimum Reporting Limit	LCS Recovery LL	LCS Recovery UL	Spike Recovery LL	Spike Recovery UL	MAV RPD	Holding Time [1]
Arsenic	HG-AFS	µg/L	0.3	80	120	80	120	20	6 months
Cadmium	ICP-MS	µg/L	0.02	80	120	80	120	20	6 months
Chromium	ICP-MS	µg/L	0.2	80	120	80	120	20	6 months
Copper	ICP-MS	µg/L	0.5	80	120	80	120	20	6 months
Iron	ICP-MS	µg/L	5	80	120	80	120	25	6 months
Lead	ICP-MS	µg/L	0.3	80	120	80	120	20	6 months
Nickel	ICP-MS	µg/L	0.5	80	120	80	120	20	6 months
Zinc	ICP-MS	µg/L	0.4	80	120	80	120	25	6 months

[1] Dissolved samples should be filtered and preserved ASAP. Total recoverable samples should be preserved ASAP.

Table 2. QA/QC Criteria for Laboratory Reporting of Analytical Concentrations: Conventional, Grab Sampled & Miscellaneous Constituents

	Method	Units	Minimum Reporting Limit	LCS Recovery LL	LCS Recovery UL	Spike Recovery LL	Spike Recovery UL	MAV RPD	Holding Time
CONVENTIONAL AND MISCELLANEOUS CONSTITUENTS									
BOD_5	EPA 405.1	mg/L	1	85	115	NA	NA	20	2 days
Hardness as $CaCO_3$	EPA 130.2/ SM 2340C	mg/L	1	90	110	80	120	10	6 months
Nitrate as N	EPA 300	mg/L	0.15	80	120	80	120	10	28 days
Nitrite as N	EPA 300	mg/L	0.15	80	120	80	120	10	28 days
Total Phosphorus	EPA 365.3	mg/L	0.02	80	120	80	120	20	28 days
TDS	EPA 160.1	mg/L	20	80	120	NA	NA	20	7 days
TSS	EPA 160.2	mg/L	5	80	120	NA	NA	20	7 days
DOC	EPA 415.1	mg/L	1	80	120	80	120	20	28 days
TOC	EPA 415.1	mg/L	1	80	120	80	120	20	28 days
Cyanide	EPA 335.2	µg/L	3	80	120	80	120	20	14 days
Diazinon	ELISA	µg/L	0.010	60	140	---	---	21	2 days
Chlorpyrifos	ELISA	µg/L	0.025	60	140	---	---	25	2 days
GRAB SAMPLED CONSTITUENTS									
Ammonia	EPA 350.2	mg/L	0.05	80	120	80	120	20	28 days
Total & Fecal Coliform	SM 9221	MPN/100 mL	2	---	---	---	---	---	6 hours
Mercury [1]	EPA 1631 CV-AFS	ng/L	~0.05			80	120	30	

[1] The mercury analysis reporting, performed by Frontier Geosciences, does not include a discussion of acceptable limits. However, each laboratory report contains a case narrative regarding sample handling and QA/QC problems. The criteria presented for mercury are not based on published guidelines, but indicate "alarm" values when the laboratory should provide a satisfactory discussion or reanalyze the sample.

Table 3. QA/QC Criteria for Laboratory Reporting of Analytical Concentrations: Base/Neutral & Acid Extractables (EPA 625)

Constituent	Reporting Limit (µg/L)	LCS/Spike Recovery LL	LCS/Spike Recovery UL	RPD MAV	Holding Time Extraction	Holding Time Analysis
1,2,4-Trichlorobenzene*	0.05	39	100	22	7 days	40 days
1,2-Dichlorobenzene	0.05			30	7 days	40 days
1,3-Dichlorobenzene	0.05			30	7 days	40 days
1,4-Dichlorobenzene*	0.05	36	100	28	7 days	40 days
2,4,5-Trichlorophenol	0.05			30	7 days	40 days
2,4,6-Trichlorophenol	0.05			30	7 days	40 days
2,4-Dichlorophenol	0.05			30	7 days	40 days
2,4-Dimethylphenol	0.1			30	7 days	40 days
2,4-Dinitrophenol	0.25			30	7 days	40 days
2,4-Dinitrotoluene*	0.05	24	100	38	7 days	40 days
2,6-Dinitrotoluene	0.05			30	7 days	40 days
2-Chloronaphthalene	0.05			30	7 days	40 days
2-Chlorophenol*	0.1	27	123	40	7 days	40 days
2-Methylnaphthalene	0.05			30	7 days	40 days
2-Methylphenol	0.1			30	7 days	40 days
2-Nitroaniline	0.1			30	7 days	40 days
2-Nitrophenol	0.1			30	7 days	40 days
3,3'-Dichlorobenzidine	0.1			30	7 days	40 days
3-Nitroaniline	0.1			30	7 days	40 days
4,6-Dinitro-2-methylphenol	0.5			30	7 days	40 days
4-Bromophenyl phenyl ether	0.05			30	7 days	40 days
4-Chloro-3-methylphenol*	0.05	23	100	42	7 days	40 days
4-Chloroaniline	0.25			30	7 days	40 days
4-Chlorophenyl phenyl ether	0.05			30	7 days	40 days
4-Methylphenol	0.1			30	7 days	40 days
4-Nitroaniline	0.1			30	7 days	40 days
4-Nitrophenol*	0.25	10	100	50	7 days	40 days
Acenaphthene*	0.05	46	118	31	7 days	40 days
Acenaphthylene	0.05			30	7 days	40 days
Anthracene	0.05			30	7 days	40 days
Benzo(a)anthracene	0.05			30	7 days	40 days
Benzo(a)pyrene	0.1			30	7 days	40 days
Benzo(b)fluoranthene	0.05			30	7 days	40 days
Benzo(ghi)perylene	0.1			30	7 days	40 days
Benzo(k)fluoranthene	0.05			30	7 days	40 days
Benzoic acid	0.5			30	7 days	40 days
Benzyl alcohol	0.5			30	7 days	40 days
Bis(2-chloroethoxy)methane	0.5			30	7 days	40 days
Bis(2-chloroethyl)ether	0.5			30	7 days	40 days

Table 3 (cont'd). QA/QC Criteria for Laboratory Reporting of Analytical Concentrations: Base/Neutral & Acid Extractables (EPA 625)

Constituent	Reporting Limit (µg/L)	LCS/Spike Recovery LL	LCS/Spike Recovery UL	RPD MAV	Holding Time Extraction	Holding Time Analysis
Bis(2-chloroisopropyl)ether	0.15			30	7 days	40 days
Bis(2-ethylhexyl)phthalate	0.05			30	7 days	40 days
Butyl benzyl phthalate	0.05			30	7 days	40 days
Carbazole	0.1			30	7 days	40 days
Chrysene	0.05			30	7 days	40 days
Di-n-butyl phthalate	0.1			30	7 days	40 days
Di-n-octyl phthalate	0.05			30	7 days	40 days
Dibenzo(a,h)anthracene	0.1			30	7 days	40 days
Dibenzofuran	0.05			30	7 days	40 days
Diethyl phthalate	0.05			30	7 days	40 days
Dimethyl phthalate	0.05			30	7 days	40 days
Fluoranthene	0.05			30	7 days	40 days
Fluorene	0.05			30	7 days	40 days
Hexachlorobenzene	0.05			30	7 days	40 days
Hexachlorobutadiene	0.1			30	7 days	40 days
Hexachlorocyclypentadiene	0.1			30	7 days	40 days
Hexachloroethane	0.1			30	7 days	40 days
Indeno(1,2,3-cd)pyrene	0.1			30	7 days	40 days
Isophorone	0.25			30	7 days	40 days
N-Nitrosodiphenylamine	0.5			30	7 days	40 days
N-Nitrosodipropylamine*	0.5	41	116	38	7 days	40 days
Naphthalene	0.05			30	7 days	40 days
Nitrobenzene	0.25			30	7 days	40 days
Pentachlorophenol*	0.25	9	103	50	7 days	40 days
Phenanthrene	0.05			30	7 days	40 days
Phenol*	0.1	12	110	42	7 days	40 days
Pyrene*	0.05	26	127	31	7 days	40 days

*The laboratory has selected this constituent for spike analysis. For all other constituents acceptable RPD value have been determined by the QA/QC program manager using EPA guidelines.

Table 4. QA/QC Criteria for Laboratory Reporting of Analytical Concentrations: Carbamate Pesticides (EPA 632)

Constituent	Units	Quantitation Limit	LCS/Spike Recovery LL	LCS/Spike Recovery UL	RPD MAV	Holding Time Extraction	Holding Time Analysis
Aldicarb*	µg/L	0.40	22	146	25	7 days	40 days
Aminocarb	µg/L	0.40			25	7 days	40 days
Barban	µg/L	3.5			25	7 days	40 days
Benomyl (Carbendazim)*	µg/L	0.40			25	7 days	40 days
Bromacil*	µg/L	0.40	58	111	25	7 days	40 days
Carbaryl*	µg/L	0.07	40	131	25	7 days	40 days
Carbofuran*	µg/L	0.07	44	128	25	7 days	40 days
Chloropropham	µg/L	3.5			25	7 days	40 days
Chloroxuron	µg/L	0.40			25	7 days	40 days
Diuron*	µg/L	0.40	57	133	25	7 days	40 days
Fenuron	µg/L	0.40			25	7 days	40 days
Fluometuron*	µg/L	0.40	66	158	25	7 days	40 days
Linuron*	µg/L	0.07	53	135	25	7 days	40 days
Methiocarb*	µg/L	0.40	42	129	25	7 days	40 days
Methomyl*	µg/L	0.07	37	113	25	7 days	40 days
Mexacarbate	µg/L	3.5			25	7 days	40 days
Monuron*	µg/L	0.40	55	134	25	7 days	40 days
Neburon*	µg/L	0.40	55	132	25	7 days	40 days
Oxamyl	µg/L	0.40			25	7 days	40 days
Propachlor	µg/L	3.5			25	7 days	40 days
Propham	µg/L	3.5			25	7 days	40 days
Propoxur	µg/L	0.40			25	7 days	40 days
Siduron	µg/L	0.40			25	7 days	40 days
Tebuthiuron*	µg/L	0.40	67	109	25	7 days	40 days

*The laboratory has selected this constituent for spike analysis. For all other constituents acceptable RPD value have been determined by the QA/QC program manager using EPA guidelines.

Table 5. QA/QC Criteria for Laboratory Reporting of Analytical Concentrations: Organochlorine Pesticides (EPA 8081)

Constituent	Units	Quantitation Limit	LCS/Spike Recovery LL	LCS/Spike Recovery UL	RPD MAV	Holding Time Extraction	Holding Time Analysis
4,4'-DDE	µg/L	0.05			25	7 days	40 days
4,4'-DDT*	µg/L	0.05	47	118	19	7 days	40 days
4,4'-TDE/DDD	µg/L	0.05			25	7 days	40 days
Aldrin*	µg/L	0.05	30	99	31	7 days	40 days
Chlordane	µg/L	0.05			25	7 days	40 days
Dieldrin*	µg/L	0.05	45	122	14	7 days	40 days
Endosulfan I	µg/L	0.05			25	7 days	40 days
Endosulfan II	µg/L	0.05			25	7 days	40 days
Endosulfan Sulfate	µg/L	0.05			25	7 days	40 days
Endrin*	µg/L	0.05	61	133	18	7 days	40 days
Endrin aldehyde	µg/L	0.05			25	7 days	40 days
Endrin ketone	µg/L	0.05			25	7 days	40 days
Heptachlor*	µg/L	0.05	28	125	26	7 days	40 days
Heptachlor epoxide	µg/L	0.05			25	7 days	40 days
Methoxychlor	µg/L	0.05			25	7 days	40 days
Toxaphene	µg/L	1			25	7 days	40 days
alpha-BHC	µg/L	0.05			25	7 days	40 days
beta-BHC	µg/L	0.05			25	7 days	40 days
delta-BHC	µg/L	0.05			25	7 days	40 days
gamma-BHC*	µg/L	0.05	19	132	16	7 days	40 days

*The laboratory has selected this constituent for spike analysis. For all other constituents acceptable RPD value have been determined by the QA/QC program manager using EPA guidelines.

Table 6. QA/QC Criteria for Laboratory Reporting of Analytical Concentrations: Organophosphorus Pesticides (EPA 8141)

Constituent	Units	Quantitation Limit	LCS/Spike Recovery LL	LCS/Spike Recovery UL	RPD MAV	Holding Time Extraction	Holding Time Analysis
Azinphosmethyl	µg/L	1.0			25	7 days	40 days
Bolstar	µg/L	0.10			25	7 days	40 days
Chlorpyrifos	µg/L	0.05			25	7 days	40 days
Coumaphos	µg/L	0.10			25	7 days	40 days
Def	µg/L	0.10			25	7 days	40 days
Demeton	µg/L	0.20			25	7 days	40 days
Diazinon*	µg/L	0.05	57	130	21	7 days	40 days
Dichlorvos	µg/L	0.20			25	7 days	40 days
Dimethoate	µg/L	0.10			25	7 days	40 days
Diphenamid	µg/L	0.10			25	7 days	40 days
Disulfoton*	µg/L	0.10	47	117	22	7 days	40 days
Ethion*	µg/L	0.10	65	134	20	7 days	40 days
Ethoprop	µg/L	0.10			25	7 days	40 days
Fensulfothion	µg/L	0.20			25	7 days	40 days
Fenthion	µg/L	0.10			25	7 days	40 days
Malathion	µg/L	0.40			25	7 days	40 days
Merphos	µg/L	0.10			25	7 days	40 days
Methyl trithion	µg/L	0.20			25	7 days	40 days
Mevinphos	µg/L	0.70			25	7 days	40 days
Naled	µg/L	0.50			25	7 days	40 days
Parathion, ethyl	µg/L	0.10			25	7 days	40 days
Parathion, methyl*	µg/L	0.10	55	164	24	7 days	40 days
Phorate*	µg/L	0.10	22	96	24	7 days	40 days
Phosalone	µg/L	0.10			25	7 days	40 days
Prometon	µg/L	0.10			25	7 days	40 days
Prowl	µg/L	0.10			25	7 days	40 days
Ronnel	µg/L	0.10			25	7 days	40 days
Simazine	µg/L	0.50			25	7 days	40 days
Trichloronate	µg/L	0.10			25	7 days	40 days
Trifluralin	µg/L	0.10			25	7 days	40 days

*The laboratory has selected this constituent for spike analysis. For all other constituents acceptable RPD value have been determined by the QA/QC program manager using EPA guidelines.

Application of Qualifications

Comparing the QA/QC data against the QA/QC acceptance criteria identifies out-of-range QA/QC samples. Translating the QA/QC results into qualifications of environmental data requires identifying the relationships of QA/QC data to the environmental sample results. These relationships are presented in Table 7. Beginning with the 1996/97 monitoring year the qualification application process was completed using a "program" written in a database software system. This automated process uses the information in Table 7, the QA/QC database, and the constituent database, to produce the qualified constituent database which includes the qualification "codes" listed in the "qualification" column of Table 7. The qualifiers developed for the Sacramento Stormwater Monitoring Program are a more detailed subset of the EPA qualifiers also listed in Table 7.

Justification of these qualification application relationships is based on the design of the entire QA/QC program for the Sacramento Stormwater Monitoring Program. For instance, in an ideal world of unlimited resources all QA/QC checks would be run for every monitoring site and all constituents. To minimize laboratory analytical costs the checks are rotated from site to site from one monitored storm event to the next based on a schedule published in the *Sampling Plan*[3] before the start of the storm monitoring season.

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[3] Larry Walker Associates. November 1999. *Sacramento Stormwater Monitoring Program: Discharge Characterization Monitoring 1999-2000 Sampling Plan.* Prepared for the Sacramento Stormwater Permittees

Table 7. Application of Qualifiers to Environmental Data Based on Out-of-Range QA/QC Checks

QA/QC Type	Out-of-Range Test Result	Qualification	EPA Qualifier	Qualification Application Sampling Location	Qualification Application Constituent
METHOD BLANK	"Hit" on blank. Associated environmental sample is detected and is less than 5x (10x for phthalates) the blank concentration.	"NDB" Result considered not detected at reported environmental concentration.	UJ	All	One to One (when dissolved metal blanks are not available, use TR metal blanks)
	"Hit" on a metals analysis blank. Associated environmental sample is detected and is between 5x and 10x the blank concentration.	"UL" Result considered an upper limit of true concentration and data users are cautioned when using the result for comparison to water quality objectives.	J	All	*Metals Only* One to One (when dissolved metal blanks are not available, use TR metal blanks)
FIELD BLANK	"Hit" on blank. Associated environmental sample is detected and is less than 5x (10x for phthalates) the blank concentration.	"NDB" Result considered not detected at reported environmental concentration.	UJ	All	One to One (dissolved metals use TR metal blanks)
	"Hit" on a metals analysis blank. Associated environmental sample is detected and is between 5x and 10x the blank concentration.	"UL" Result considered an upper limit of true concentration and data users are cautioned when using the result for comparison to water quality objectives.	J	All	*Metals Only* One to One (dissolved metals use TR metal blanks)
PRE-SEASON BLANKS	Considered only as indicator of potential contamination problems that need to be corrected prior to the monitoring season (see discussion in text).	-	-	-	-
LCS & SRM	Out of range value on laboratory QA/QC report. Recovery is outside of limits set forth in data quality evaluation plan. This can be set by project managers or the lab acceptable ranges can be adopted.	"LB"-Low Bias or "HB"-High Bias "R" – Reject if <LL or more than half or recoveries are outside limits and environmental sample result is ND	J or R	All	One to One
MATRIX SPIKE	Out of range value on laboratory QA/QC report. Recovery is outside of limits set forth in data quality evaluation plan. This can be set by project managers or the lab acceptable ranges can be adopted.	"MI" - Matrix Interference "R" – Reject considered if <LL and environmental sample result is ND	J or R	All	One to One
MATRIX SPIKE DUPLICATE	Relative percent difference (RPD) is greater than maximum allowable value. RPD is set forth in data quality evaluation plan. This can be set by project managers or the lab acceptable ranges can be adopted.	"NRS" - Not reproducible due to MSD variability.	J	Site specific	One to One

Table 6 (cont'd). Application of Qualifiers to Environmental Data Based on Out-of-Range QA/QC Checks

QA/QC Type	Out-of-Range Test Result	Qualification	EPA Qualifier	Qualification Application	
				Sampling Location	Constituent
LAB DUPLICATE	<u>Relative percent difference (RPD) is greater than maximum allowable value</u>. RPD is set forth in data quality evaluation plan. This can be set by project managers or the lab acceptable ranges can be adopted.	"NR"- Not reproducible due to lab variability.	J	Site specific	One to One
FIELD DUPLICATE	<u>Relative percent difference (RPD) is greater than maximum allowable value</u>. RPD is set forth in data quality evaluation plan. This can be set by project managers or the lab acceptable ranges can be adopted.	"EST" - Estimated	J	Site specific	One to One
SURROGATE [1]	<u>Out of range value</u> on laboratory QA/QC report. Recovery is outside of limits set forth in QA/QC criteria tables. This can be set by project managers or the lab acceptable ranges can be adopted.	"SLB" - Surrogate Low Bias "SHB" - Surrogate High Bias, or "SRB" Surrogate Recovery Bias if both cases are present for the batch examined.	J, UJ, or R	All	All
HOLDING TIME	The difference between the time/date of analysis and the time/date of sampling is greater than the EPA prescribed holding time (as included in QA/QC criteria tables).	"HT" - Holding time exceedance may have compromised constituent recovery.	J or UJ when non-detect	Site Specific	One to One
BACTI DUPLICATE SAMPLES	Considered as an indicator of potential out-of-range values.	-	-	-	-

[1] EPA recommends data qualification based on surrogate recovery results as follows:

"Estimated value" (J) when the associated environmental sample result is detected and at least two surrogate recoveries are below the lower limit or above the upper limit or if the associated environmental sample result is detected and the surrogate recovery is <10%.

"Estimated detection limit" (UJ) if the associated environmental result is below the detection level and at least two surrogate recoveries are between 10% and the acceptable lower limit.

"Rejected" (R) if the associated environmental result is below the detection level and the surrogate recovery is <10%.

Application by Monitoring Site

Qualification is applied to all sites (batch application) when a QA/QC check done on a sample from a preselected site is outside of the acceptable criteria, and the QA/QC check involves blank or spike analysis. Data qualification is applied to the environmental data from only the site generating the QA/QC sample (one-to-one application) when the QA/QC check involves duplicate analysis. This procedure, as outlined in Figure 1, applies one-to-one (site-specific) data qualification for QA/QC checks that assess the sub-sampling (e.g. splitting off of samples for duplicate analysis) and applies a batch data qualification for all other QA/QC checks. The rationale for this is based on the presumption that the sub-sampling process is site dependent. The actual matrix type is similar, but the effectiveness of the sample splitting is dependent more on sample handling than on laboratory analytical performance. Spike and blank analyses represent laboratory analytical performance more generally, and should be applied to all sites as a batch. Field blank results from one monitoring site are applied to all three monitoring sites because field procedures are very similar at all three sites (same tubing type, same autosampler (ISCO), grab and composite samples are collected in a similar fashion, etc.).

Application by Analysis Method/Constituent

The constituent qualified for an out-of-range QA/QC check is the constituent that failed the check, with one exception. Concentrations of the compounds used for surrogate spikes are not reported (or of interest) in the environmental sample concentration report. Therefore, a one-to-one relationship with the environmental sample constituents is impossible. In this case, if a surrogate spike recovery is out-of-range, all constituents in that method are qualified.

Data qualification is limited to the constituents spiked in the case of organic analysis (EPA 625, EPA 632, EPA 8081, EPA 8141, MTBE, and ELISA) matrix and laboratory control sample spikes. Only a limited number of constituents from the method list are spiked into the sample for recovery. Without additional information, such as an obvious extraction problem for a sample, it is inappropriate to apply matrix or laboratory control sample spike qualification to constituents that are not actually spiked. In the case of matrix or laboratory control sample spikes, only the out-of-range constituents that were spiked are qualified.

DQEP FUTURE MODIFICATIONS

This document summarizes the process used to assess the quality of environmental concentration data reported for the Sacramento Stormwater Discharge Characterization Monitoring Program. In fact, the process will change as laboratory analytical methods advance and the concentration data set grows. The QA/QC process should then be flexible enough to allow for improvements, but with enough structure to focus work effort and minimize ambiguity.

APPENDIX C. LABORATORY REPORTS (EVENTS #7-11)

(pdf format not available. See original document.)

APPENDIX D. LABORATORY RESULTS (EVENTS #7-11)

(pdf format not available. See original document.)

APPENDIX E. QA/QC RESULTS (EVENTS #7-11)

(pdf format not available. See original document.)