COUNTY OF SAN DIEGO
MODEL MUNICIPAL OPERATIONS CENTER

Porous Paving
and
Treatment Train
Water Quality Monitoring Program

FINAL REPORT

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1.0 INTRODUCTION

1.1. *Background*

The concept for this project evolved out of recent Department of General Services (DGS) efforts to strengthen its stormwater program. The DGS is responsible for many highly impervious facilities. As is common in both commercial and industrial districts, vehicle parking areas represent the largest amount of impervious surface at the COC. Parking lots associated with the COC comprise roughly 60 percent of the 35.5 acres of the COC.

The COC is distinguished both as a regional operations facility and by the variety of uses that it contains. These range from office and laboratory buildings to vehicle maintenance and other light-industrial type shops. The broad mix of uses presents the need for a comprehensive strategy to reduce potential stormwater pollutants of concern.

The County of San Diego Department of General Services (DGS) is conducting this project to assess and demonstrate the use of enhanced source control and treatment control best management practices (BMPs) at the County Operations Center (COC).

The project has two major elements. The first is designed to assess the effectiveness of various types of porous pavement in reducing flows and discharge of constituents of concern at the COC. This part of the program focuses on control of pollutants and runoff from parking lots. The second element of the program involves assessment of the effectiveness of two types of structural treatment control devices. These devices provide sequential treatment of stormwater runoff by first removing the gross pollutants through screening and gravity separation and then providing media filtration to further treat the runoff. The sequential treatment process is referred to as a “treatment train”.

The Center for Watershed Protection[1] and others have clearly demonstrated the importance of imperviousness and the functional relationships between impervious surface areas and stream quality. The DGS has initiated a pilot program to evaluate performance of various types of porous pavement as a method to control runoff quantity and quality at the onsite source. As part of this project, the County replaced approximately 64,000 square feet of traditional imperious pavement with three different types of porous paving materials at the COC. The three types of porous paving materials include roughly 7,896 square feet of Eco-Stone concrete pavers, 14,936 square feet of porous concrete, and 41,092 square feet of porous asphalt. An adjacent area consisting of 36,209 square feet of older traditional asphalt has been isolated to serve as a reference site. Engineering design of all porous paving test sites was performed by Cahill Associates, Inc.

The pilot treatment train was installed near the eastern edge of the COC property to provide treatment of the stormwater prior to discharge to the City of San Diego’s municipal storm drain system. The first treatment control device is a Continuous Deflective Separation (CDS) unit designed to remove up to 80% of the suspended solids and 100% of the floatables. This is followed by a Media Filtration System (MFS) that provides filtration through perlite media

[1] Schueler, T.R. and H.K Holland, Editors (2000) The Practice of Watershed Protection: Article 1, Watershed Protection Techniques 1(3):100-111

filters to further reduce the fine fraction of suspended solids. Both systems are manufactured by CDS Technologies.

Determining the effectiveness of the treatment control devices will help guide future installations of BMPs at County facilities and educate DGS project managers as well as contract architects and engineers about treatment control BMPs. The project will also increase the knowledge about treatment control BMPs among municipal officials in the watershed and establish long-term relationships with watershed groups within the San Diego River Watershed, and will provide water quality improvements in the discharges from the COC.

1.2. *Goals and Objectives*

1.2.1. Porous Paving

This element of the study is designed to monitor and evaluate the effectiveness of the three pavement systems in reducing runoff and removing constituents of concern including solids, nutrients and trace metals. Testing the performance of each type of porous pavement entails comparisons of both the quantity and quality of stormwater discharges from each type of pavement with stormwater runoff from the adjacent reference site.

The program is designed to address the following questions:

- ✓ How do normalized[2] stormwater discharges from each treatment type (porous asphalt, porous concrete and pavers) compare to normalized runoff from the reference area by both individual storm events and for the entire storm season.
- ✓ How does water quality of stormwater discharges from each treatment type, measured in terms of flow-rated event mean concentrations, compare to the quality of runoff from the reference area?
- ✓ How do the infiltration basins associated with each of the porous surface treatments impact stormwater discharge hydrographs?
- ✓ How do normalized pollutant loading rates[3] associated with each porous surface treatment compare to those of the adjacent impervious reference area?
- ✓ At what rates do water levels in the infiltration basins of each treatment type change during and between storm events?

1.2.2. Treatment Train

The objective of the element of the program is to evaluate the pollutant removal efficiencies of the treatment technologies. The two different treatment technologies will be assessed individually and as a treatment train. The first treatment control device is a CDS unit. The CDS unit is constructed in-line with an MFS unit to make up the treatment train.

[2] All data are intended to be normalized to a standard unit area to allow comparisons of data from widely differing areas for each of the three porous treatment type.
[3] The normalized loading rate is defined as the mass of each constituent per unit area per inch of rain.

The Mass Balance Approach will be utilized to characterize the removal effectiveness of the CDS unit. The CDS unit is designed to remove trash and litter, vegetative material, and sediments.

The program is designed to address the following questions:

- ✓ What is the total volume of stormwater processed by the CDS unit for individual monitoring events and for the season?
- ✓ What are the mass and general characteristics of solids removed by the CDS unit at the end of the monitoring period?
- ✓ What is the mass of each target pollutant in the sediment portion of the solids removed by the CDS unit?
- ✓ What are the volume and pollutant loads entering the MFS unit, the volume and pollutant loads after treatment and the volume of any overflows within the MFS unit?
- ✓ Does the treated stormwater meet receiving water quality standards?

1.3. *Seasonal Rainfall at the County Operations Center*

The San Diego County Operations Center (COC) is located within Hydrologic Sub-Area 907.11 at an elevation of approximately 415 feet. This region, also known as the Mission San Diego Sub-Area, discharges to the Lower San Diego River. According to the CSU Sacramento, Office of Water Program, Water Quality Planning Tool (http://www.water-programs.com/), this region receives average annual rainfall of 12.7 inches. This is slightly greater than the 10.3 average annual rainfall reported at Lindbergh Field (http://www.sdcwa.org/manage/rainfall-lindbergh.phtml) near the northern end of San Diego Bay.

The San Diego Water Authority maintains an ALERT precipitation gauge near their offices in the COC. Data from this site, known as KEA, are available in near real-time through the California Data Exchange Center (http://cdec.water.ca.gov/). This site also maintains historical records.

The 2006 wet season (October 2005 through May 2006) was a relatively dry period with the majority of rainfall occurring in the latter part of the season (Table 1, Figure 1). Rainfall measured during the 2006 Wet Season (Table 1) at the COC was just 8.15 inches. During the same time period, comparative rainfall at Lindbergh Field was only 5.95 inches.

Table 1. Summary of 2006 Wet Season (October 2005 through May 2006) Rainfall Measured at the Kearny Mesa and Lindbergh Field Precipitation Gauges.

Site	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
Kearny Mesa	0.90	0.04	0.24	0.79	1.34	2.48	1.61	0.75	**8.15**
Lindbergh Field	0.46	0.12	0.25	0.36	1.11	1.36	0.88	1.41	**5.95**

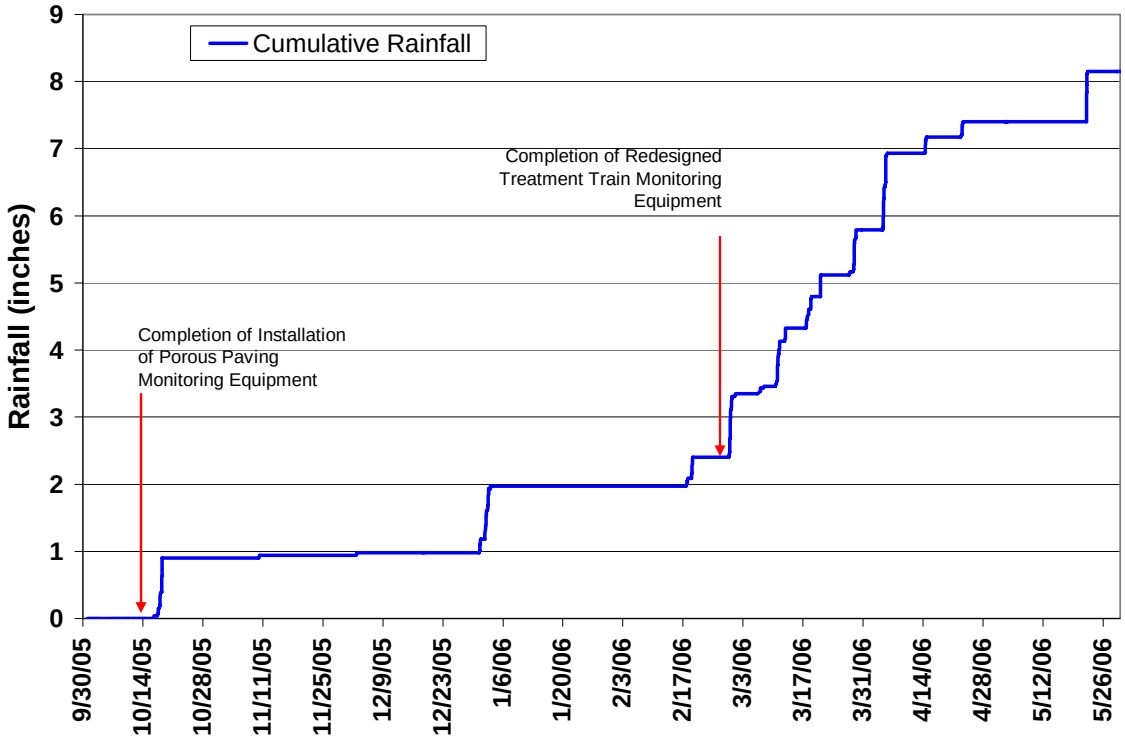

Figure 1. Cumulative Rainfall at the COC during the 2006 Wet Season (data from KEA Rain Gauge)

Initiation of monitoring at the porous paving and treatment sites during the 2005/2006 storm season are noted on Figure 1. Equipment installations at the Porous Paving sites were fully operational in mid October in time for the first event of the season. Some delays were experienced in implementing monitoring at the Treatment Train site due to a need to redesign the monitoring system to facilitate improvements in measuring stormwater flow entering the MFS unit, treated stormwater exiting the system and flow over the internal bypass weir. In addition, the system needed altered to assure that the effluent monitoring system collected only treated water. Further details are provided in Section 3.

2.0 POROUS PAVING

2.1. *Methods*

2.1.1. Site Locations

The County replaced approximately 64,000 square feet of traditional imperious pavement with three different types of porous paving materials at the COC; Eco-Stone concrete pavers, porous asphalt and porous concrete (Figure 4). Eco-Stone concrete pavers were installed in a rectangular form along the northwestern edge of the property line (Figures 2 and 4). As with all sites, including the reference site, the Eco-Stone pavers were isolated by berms to assure that the test sites were completely isolated from runon or runoff. Since some runoff was expected from the pavers, a catch basin was installed at the southwestern end to redirect any runoff from intense events back into the infiltration bed. The monitoring site was established at the southwestern edge of the Eco-Stone pavers (Figure 3).

Figure 2. Eco-Stone Monitoring Area

Porous concrete (14,936 square feet) was installed adjacent to Building 7 (Table 2, Figure 5). The test site largely replaced an existing impervious concrete apron in this region. Porous asphalt formed the largest test site with over an area of 41,092 square feet. The monitoring location for both sites was situated at the corner of Building 7 (Figures 5 and 6). A rain gauge was located on top of the building. A phone line was connected at this site and provided the link to all other sites. Radio modems allowed communication to the Eco-Stone concrete paver site, reference site and Treatment Train equipment located on the east side of the facility at Hazard Way.

Figure 3. Eco-Stone Paver Stormwater Monitoring Site.

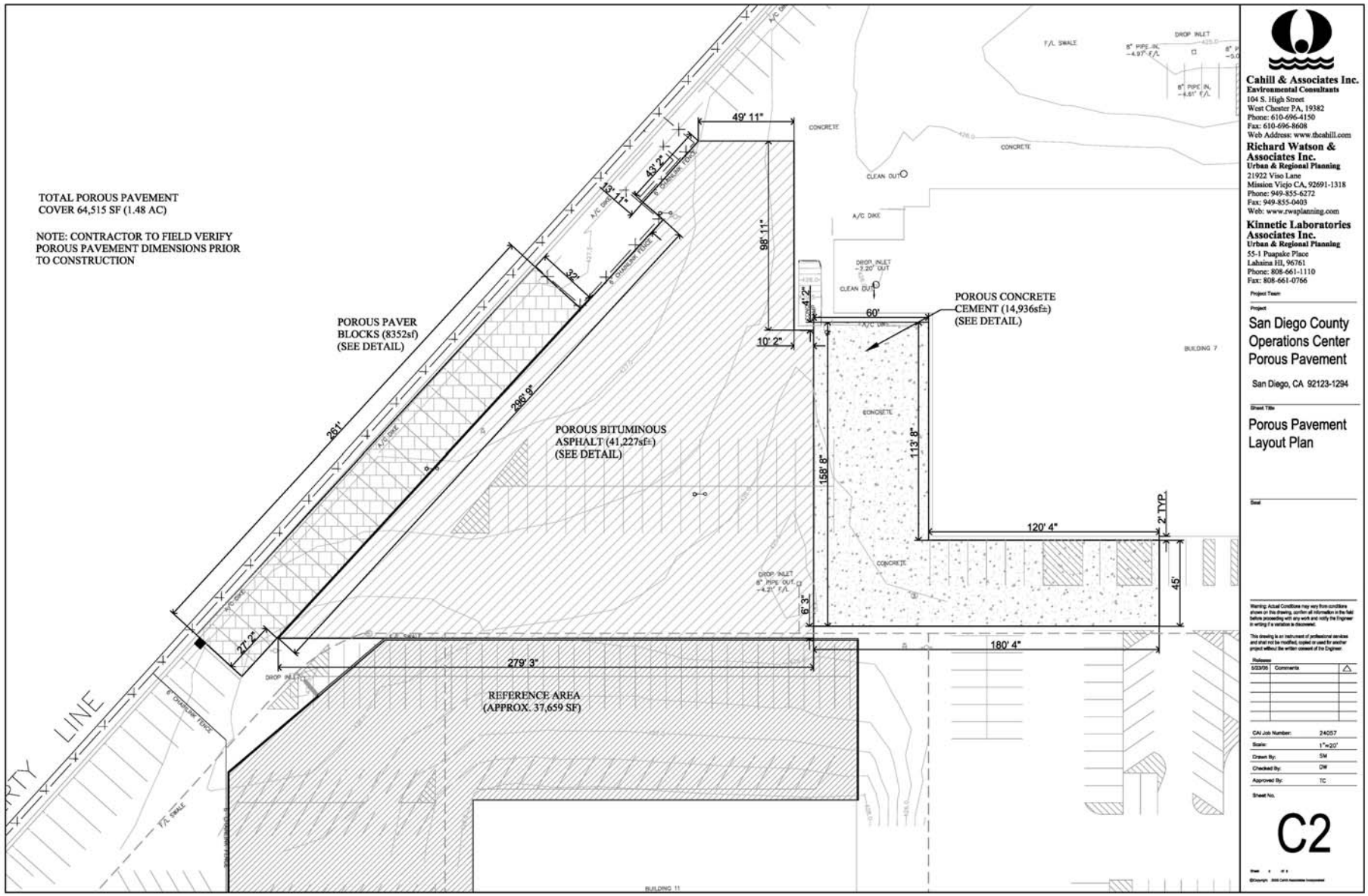

Figure 4. Porous Pavement/Infiltration System Layout (Cahill and Associates)

Table 2. Summary of Reference and Porous Treatment Areas

Site	Area (Sq. Ft.)	Sq. Meters
Reference	36209	3364
Porous Treatments		
Pavers	7896	734
Concrete	14936	1388
Asphalt	41092	3818
TOTAL TREATMENT AREA	**63924**	**5939**

Figure 5. View of Porous Asphalt/Concrete Monitoring Site at Corner of Building 7.

Figure 6. Closeup of Asphalt/Concrete Monitoring Site.

The Reference Area consists of an older, impervious asphalt surface. The cracked asphalt typical of the reference area can be seen in the foreground of Figure 7. The Reference Area monitoring site collects runoff from 36,209 square feet of surface area (Figure 4, Table 2). Runoff is collected in a series of area drains that are connected to a one-foot H-flume (Figure 8). Effluent from the H-Flume discharges to the existing storm drain.

Flow is monitored by a pressure sensor associated with a stilling adjacent to the flume. Stormwater is sampled from the bottom of the last area drain at the head of the flume where turbulence is sufficient to keep most solids well-mixed. This site also has a rain gauge and a solar panel (Figure 7) to maintain battery power for the water sampler, data logger, and communications.

Figure 7. Reference Area Monitoring Sites looking towards the Porous Pavers and Asphalt Test Sites.

Figure 8. One-foot H-Flume at Reference Monitoring Site.

2.1.2. Sample Frequency

Samples of runoff from the COC were collected during the wet season (October 1 through April 30). The monitoring goal was to collect as many storms as possible during the 2005/2006 wet season with a target of six storm events total for the entirety of the project. Storm events were considered viable for monitoring activities if they were predicted to achieve greater than 0.25 inches of rainfall.

2.1.3. Sample Collection and Handling

Monitoring stations were established at locations where subsurface drains exit each of the three test sites and a reference site that drains a similar section of parking areas with standard impervious paving. Access to the discharge pipe is required at each porous pavement monitoring site. All sites were provided with remote monitoring and data-downloading capability. Equipment at each test site consisted of a peristaltic autosampler, a bubbler to measure water depth, a primary control device (e.g. Thel-Mar volumetric weir), a datalogger and controller, a CDMA cellular modem, and steel enclosures. Rain gauges were incorporated into monitoring stations at two of the sites to provide accurate measure of stormwater volumes associated with each site. A San Diego County Flood Control District ALERT rain gauge located just east of Building 2 served as additional backup confirmation.

During construction, a monitoring well was installed by the construction contractor at each of the porous pavement test sites for the purpose of measuring infiltration rates. Pressure sensors were installed in each monitoring well and connected to the datalogger to provide continuous water level records throughout the storm season. Pressure sensors in each monitoring well were referenced to the invert of the pipe entering the monitoring well from the infiltration beds. The monitoring station at the reference site was similar with the exception that a manhole and Thel-Mar volumetric weir were not required. Instead, a 1-foot H-flume was used to measure surface runoff.

Monitoring locations were located at positions where the equipment was able to measure all potential discharges from each type of porous pavement and the reference site. KLI coordinated with the design engineers to assure that each site was designed to allow for accurate measurement of flow from an underlying drain system and suitable configuration for collection of water samples for chemistry. Major design considerations included the size of the discharge pipe, the slope and length of pipe prior to the sampling location, and appropriate access to the pipe.

The automated samplers collected sample aliquots in direct proportion to flow via a peristaltic pumping mechanism. Water samples were pumped through a Teflon/stainless steel intake strainer and Teflon tubing into pre-cleaned and blanked 20-liter borosilicate glass sample bottles. Bottles were kept on ice during the storm event.

Composite sample bottles were subsampled at KLI's Carlsbad facility. Prior to subsampling the composite bottles were placed on a magnetic stir-plate. A pre-cleaned Teflon stir bar was inserted into the bottle and the sample was stirred to ensure homogeneity. The subsample bottles were then delivered to the analytical laboratory for chemistry analyses under appropriate chain of custody procedures.

Flow-weighted composite samples were analyzed for the following constituents: hardness, suspended sediment concentration (SSC), total suspended solids (TSS), chemical oxygen demand (COD), dissolved organic carbon (DOC), total phosphorus, orthophosphate-P, ammonia-N, total Kjeldahl nitrogen (TKN), nitrate-N, and total and dissolved cadmium, copper, lead, and zinc (Table 3).

Table 3. Water Quality Analytical Parameters for the Porous Pavement Water Quality Monitoring Project

Analytical Parameter	Analytical Method	Sample Volume	Containers #, size, type	Preservation (chemical, temperature, light protected)	Maximum Holding Time: Preparation/ analysis
Total Hardness	EPA 130.2	100mL	Plastic or Glass	pH <2, HNO_3, 4ºC	6 Months
SSC	ASTM 2000 D3977-97C	500 mL	Plastic or Glass	4ºC	7 Days
TSS	EPA 160.2	1000 mL	Plastic or Glass	4ºC	7 Days
COD	EPA 410.4	25 mL	Glass	pH <2, H_2S0_4, 4ºC	28 Days
DOC	EPA 415.1	250 mL	Glass	pH <2, H_2S0_4, 4ºC	28 Days
Total Phosphorus	EPA 365.2	300 mL	Plastic or Glass	pH <2, H_2S0_4, 4ºC	28 Days
Orthophosphate-P	EPA 300.0	150 mL	Plastic or Glass	4ºC	48 Hours
Ammonia - N	SM 4500-NH_3-F /EPA 350.3	500 mL	Plastic or Glass	pH <2, H_2S0_4, 4ºC	28 Days
TKN	EPA 351.3	600 mL	Amber Glass	pH <2, H_2S0_4, 4ºC	28 Days
Nitrate - N	EPA 300.0	100mL	Plastic or Glass	4ºC	48 Hours
Total & Dissolved Cadmium	EPA 200.8	250 mL	Plastic	pH <2, HNO_3, 4ºC	6 Months
Total & Dissolved Copper	EPA 200.8	250 mL	Plastic	pH <2, HNO_3, 4ºC	6 Months
Total & Dissolved Lead	EPA 200.8	250 mL	Plastic	pH <2, HNO_3, 4ºC	6 Months
Total & Dissolved Zinc	EPA 200.8	250 mL	Plastic	pH <2, HNO_3, 4ºC	6 Months

Sample bottles were stored and transported on ice, maintaining 4 degrees Celsius (°C) until processed. Sample bottles collected during the storm event were thoroughly homogenized at the KLI Carlsbad facility. The flow-weighted composite samples were then sub-sampled for the project constituents. Chemistry samples were analyzed by ToxScan, Inc. (TSI).

Chemistry samples were labeled with the project name, sample identification number, site location, date and time collected, analyses to be performed, and sample preservatives (if any). Samples were then stored and transported on ice (4 °C) to the analytical laboratory.

2.2. *Results and Discussion*

The following sections summarize the results of 1) monitoring rainfall, runoff and the representativeness of water quality samples, 2) water levels in the infiltration basins in response to each event and 3) characterization of water quality associated with runoff.

2.2.1. Rainfall, Runoff and Sampling Characteristics

The general characteristics of each event are summarized in Tables 4 and 5. Table 4 provides a summary of rainfall during each event. The primary rainfall characteristics described in this table are the duration, total rainfall and maximum rainfall intensity measured during each event. Rainfall intensity is based upon a running evaluation of total rainfall during the previous 15-minute time period expressed in terms of inches per hour. Higher intensity events have more capacity to suspend and transport particulates with the discharges. Information on antecedent conditions identifies the number of days since a rainfall event totaling greater than 0.1 inches as well as the total amount of rainfall associated with that event. Table 5 provides a description of stormwater discharge characteristics for each event such as the duration of flow and total flow volume as well as peak flow rates measured during the event. In addition, information is provided that is useful in assessing the overall quality of the flow-rated composite sample. Sample characteristics of major interest are the number of aliquots taken over the period of the storm, what percentage of the event was include in the flow-rated composite sample and whether the period of peak discharge was effectively represented in the stormwater composite.

Hydrographs are presented for each monitored event (Figures 9 - 14). These plots provide a graphic illustration of the stormwater discharges in relationship to rainfall during each event. These are limited to the six events at the Reference Area since no discharges occurred at any of the porous treatment sites. These clearly show the strong link between rainfall and runoff at this site as well as the sensitivity of this small, impervious area in responding to very small amounts of rain. The responsiveness of this small, impervious area to rainfall is of significance. Rainfall as low as 0.04 inches is sufficient to produce measurable runoff.

Table 4. Rainfall Statistics and Antecedent Conditions for each Monitored Storm Event at the Reference Site.

	Start Rain		End Rain					Antecedent Event	
Event	Date	Time	Date	Time	Duration Rain (hrs:min)	Total Rain (inches)	Max Intensity (inches/hr)	Days since last rainfall	Total Rainfall (inches)
1	10/16/05	15:50	10/18/05	11:10	43:20	0.80	0.84	172	
2[a]	12/31/05	15:25	1/2/06	6:20	38:55	0.51	0.20	74	0.80
2[b]	12/31/05	15:25	1/2/06	16:45	49:20	0.80	0.36	74	N/A
3	2/17/06	23:05	2/19/06	8:15	33:10	0.41	0.48	46	0.51
4	2/27/06	21:10	2/28/06	10:50	13:40	0.84	0.24	10	0.41
5	3/10/06	12:10	3/11/06	17:10	29:00	0.65	0.48	10	0.84
6	3/17/06	17:55	3/18/06	23:15	29:20	0.44	0.32	6	0.65
7[c,d]	3/21/06	1:18	3/21/06	3:07	1:49	0.32	N/A	2	0.44
8[c]	3/28/06	19:45	3/29/06	8:35	12:50	0.59	0.44	7	0.32
9[c]	4/4/06	15:50	4/5/06	7:30	15:40	1.07	0.68	6	0.59
10[c]	4/14/06	10:45	4/15/06	2:25	3:40	0.23	0.12	9	0.68
11[c,d]	4/23/06	0:00	4/23/06	9:00	9:00	0.25	N/A	8	0.23

N/A – Not Applicable

a. Only the first 0.51 inches of rainfall and the associated runoff were sampled for the second event due to a premature termination of internal software associated with the autosampler. Statistics listed under Event 2[a] are for the initial portion of the event represented in the final flow-rated composite sample.

b. Statistics summarized for Event 2[b] represent the entire storm event.

c. Storms monitored only for rainfall and flow.

d. Site was set to collect hourly averages at the time of this event. Intensity data was derived from Kearny Mesa rain gauge.

Table 5. Stormwater Discharge and Sample Quality Assessment for the Reference Site.

	Start Flow		End Flow					Sample Characteristics		
Event	Date	Time	Date	Time	Flow or Discharge Duration (hrs:mins)	Total Flow (cubic feet)	Peak Flow (cfs)	No. of Sample Aliquots Collected	% Storm Capture	Peak Capture
1	10/16/05	16:10	10/18/05	12:05	43:55	2035	0.925	37	100	Yes[c]
2[a]	12/31/05	15:40	1/2/06	7:15	39:35	1281	0.074	41	100	Yes
2[b]	12/31/05	15:40	1/2/06	22:00	54:20	2248	0.344	N/A	N/A	N/A
3	2/17/06	23:35	2/19/06	9:40	34:05	787	0.472	51	100	Yes
4	2/27/06	18:10	2/28/06	12:05	17:55	2221	0.206	73	100	Yes
5	3/10/06	23:10	3/11/06	18:10	19:00	1647	0.470	34	100	Yes
6	3/17/06	18:10	3/19/06	0:45	30:35	950	0.338	62	100	Yes
7[d,e]	3/21/06	02:00	3/21/06	9:00	7:00	594	N/A	N/A	N/A	N/A
8[d]	3/28/06	20:45	3/29/06	9:50	13:05	1611	0.287	N/A	N/A	N/A
9[d]	4/4/06	16:00	4/5/06	8:45	16:45	3322	1.02	N/A	N/A	N/A
10[d]	4/14/06	10:45	4/15/06	3:30	16:45	270	0.072	N/A	N/A	N/A
11[d,e]	4/23/06	1:00	4/23/06	10:00	9:00	346	N/A	N/A	N/A	N/A

N/A – Not Applicable

a. Only the first 0.51 inches of rainfall and the associated runoff were sampled for the second event due to a premature termination of internal software associated with the autosampler. Statistics listed under Event 2[a] are for the initial portion of the event represented in the final flow-rated composite sample.

b. Statistics summarized for Event 2[b] represent the entire storm event.

c. Yes indicates that the period of peak flow was represented in the flow-rated composite sample.

d. Storm events monitored only for rainfall and flow.

e. Data based upon hourly average data. Exact time of peak flow is not available.

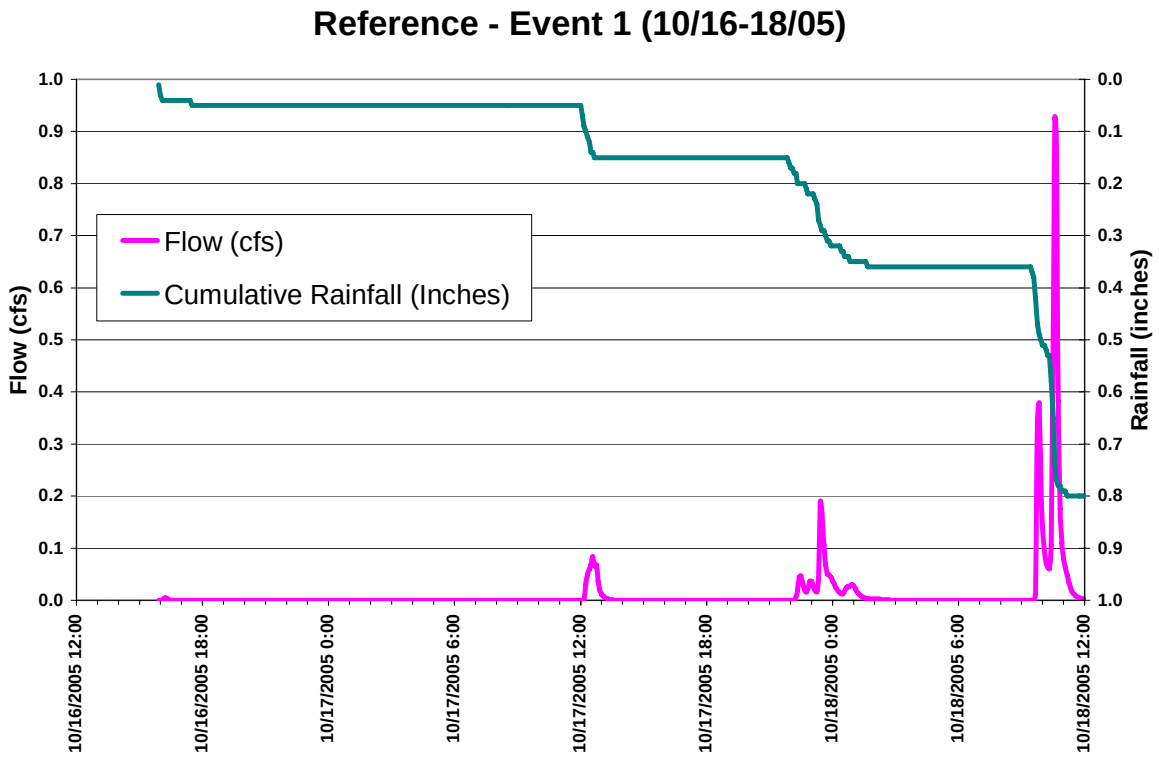

Figure 9. Rainfall and Runoff at the Reference Site during Storm Event 1.

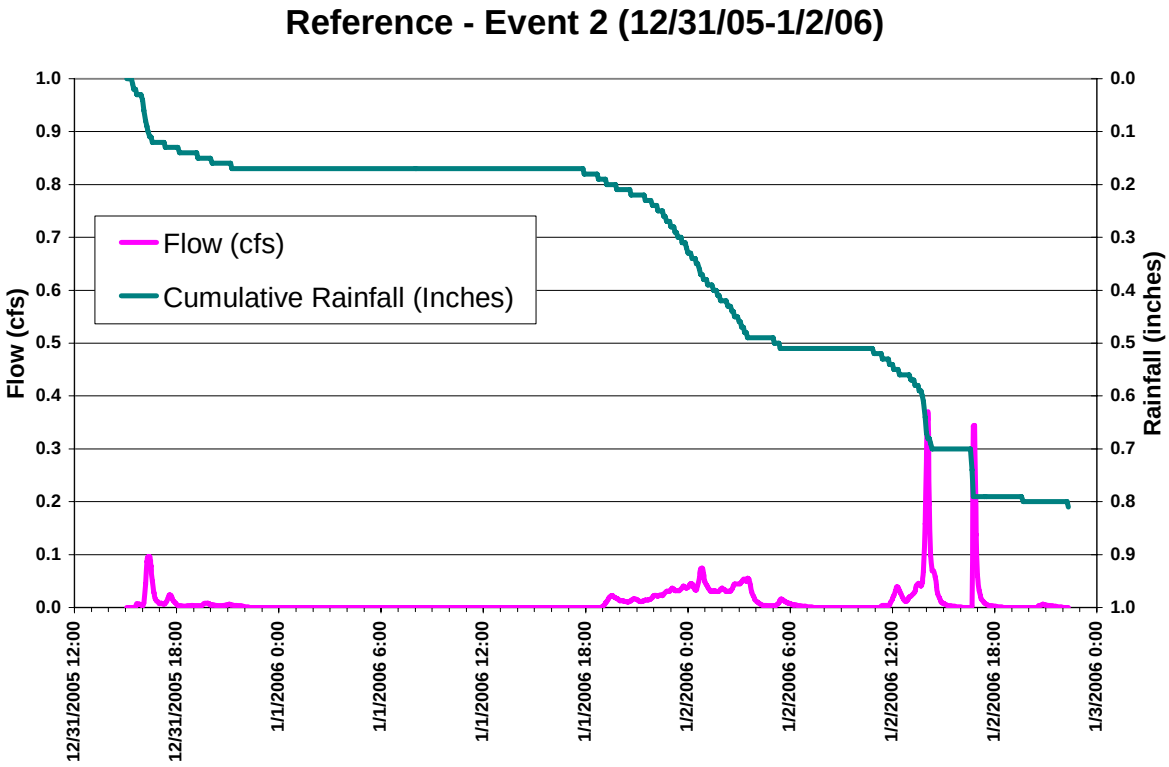

Figure 10. Rainfall and Runoff at the Reference Site during Storm Event 2.

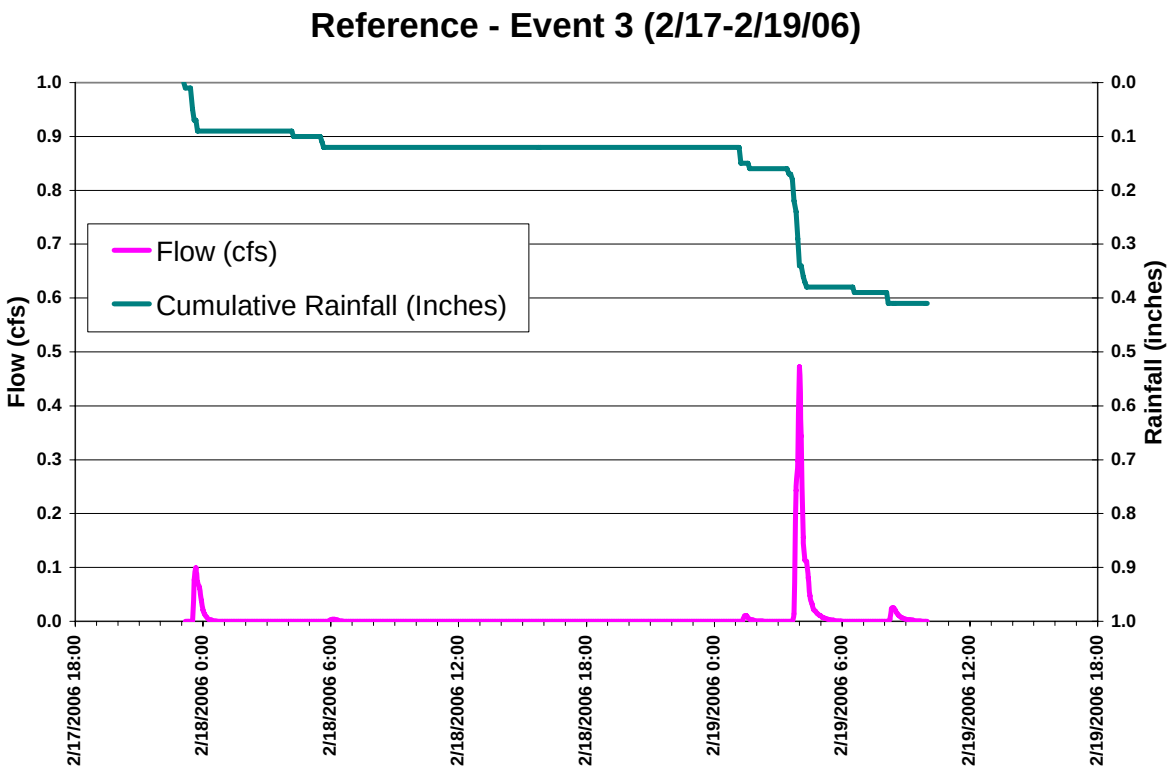

Figure 11. Rainfall and Runoff at the Reference Site during Storm Event 3.

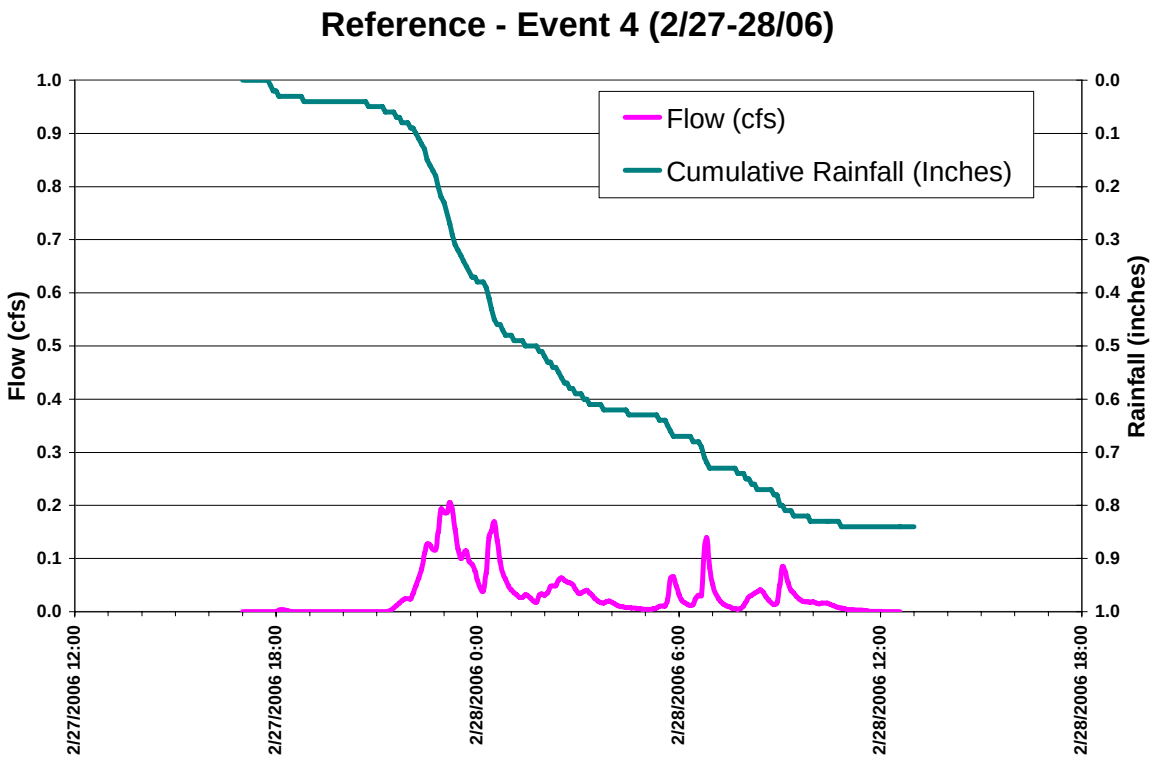

Figure 12. Rainfall and Runoff at the Reference Site during Storm Event 4.

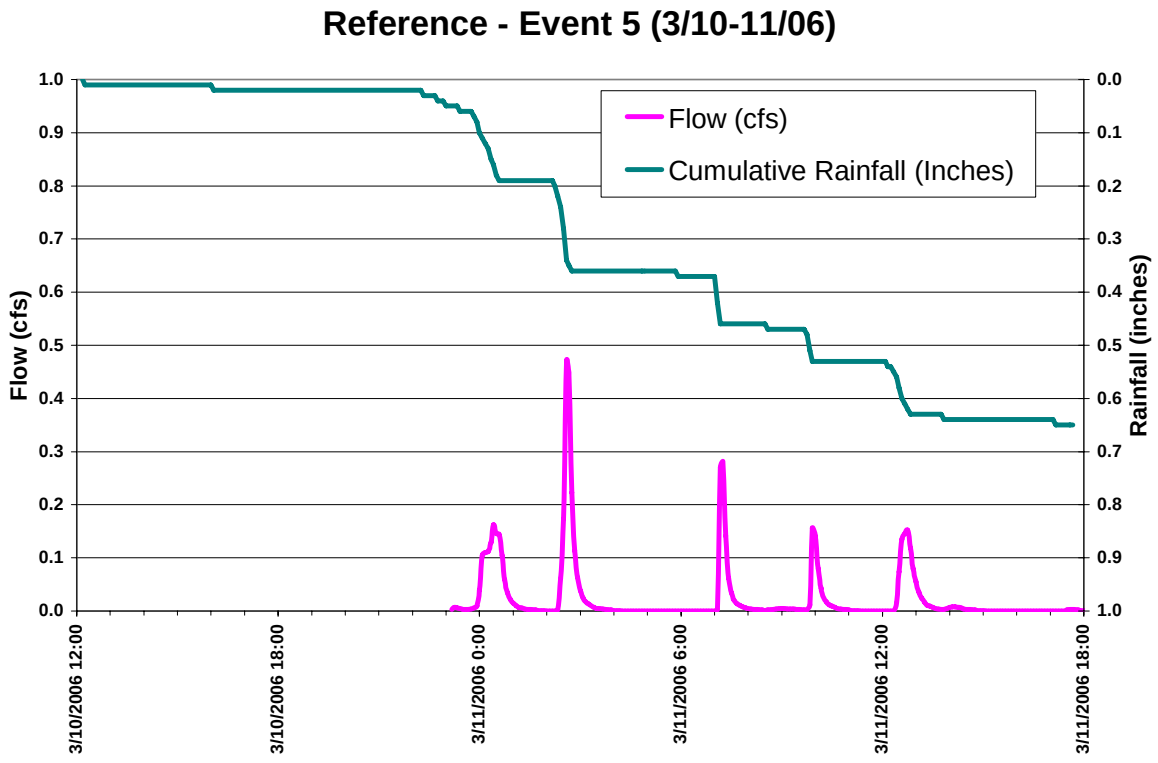

Figure 13. Rainfall and Runoff at the Reference Site during Storm Event 5.

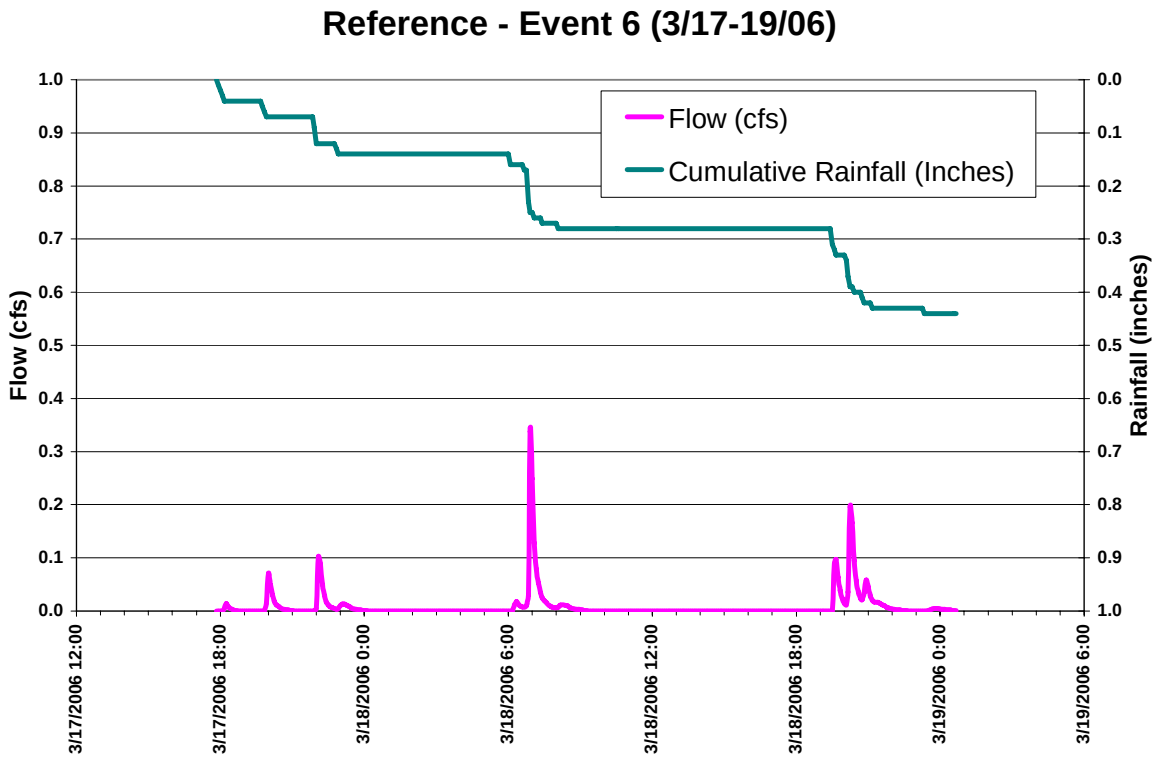

Figure 14. Rainfall and Runoff at the Reference Site during Storm Event 6

2.2.2. Infiltration Basin Monitoring Wells

Water levels in the infiltration beds of all porous pavement treatment sites were continuously monitored throughout the project to determine how the infiltration basins would respond to both individual events and the effects of multiple events throughout the season. Given initial measurements taken with a double-ring infiltrometer during the design phase, it was expected that water levels within the basins might gradually increase due to a series of events due to minimal infiltration rates.

Figures 15 through 22 illustrate changes in water levels versus time for all sites and events where water was detected within the infiltration basins. These figures show rainfall intensity compared against water levels within the infiltration bed monitoring wells. None of the three infiltration basins had a detectable accumulation of water until the fourth storm event of the season in late February, 2006. Prior to this time the cumulative rainfall at the site was between 2.2 and 2.4 inches. Detectable increases in the water levels in the infiltration beds in response to storm events were initially only evident at the porous concrete site. During smaller events such as occurred on March 21, 2006, all water infiltrated without causing detectable increases in water levels in the infiltration basin. Rainfall during this event totaled 0.32 inches over roughly a 2-hour period.

Evidence of water levels increasing within the infiltration basins of the porous pavers and porous asphalt did not occur until an intense, late season storm event on April 4th and 5th, 2006. This event yielded 1.07 inches of rain and reached a maximum intensity of 0.68 inches per hour. Infiltration was slowest at the porous paver site but the maximum water level in the basin only reached 0.15 feet, 0.76 feet below the discharge level. After approximately 15 hours, water was no longer measurable in the infiltration basin. Water levels in the porous asphalt infiltration bed came within 0.2 feet of the discharge level but decreased rapidly. Within 8 hours after water levels peaked at 0.38 feet in the infiltration bed, water levels were no longer measurable. Water in the porous concrete infiltration bed increased to a maximum level of 0.48 feet leaving another 0.44 feet before reaching the level necessary to produce a discharge. Fifteen hours after reaching a level of 0.48 feet, the water level in the porous concrete bed had dropped to zero.

Based upon the April 4th and 5th, 2006 event, infiltration rates for both the porous concrete and asphalt sites were on the order of 0.04 feet per hour or roughly 0.5 inches per hour. Much lower infiltration rates of 0.006 feet per hour (0.08 inches per hour) were observed at the porous paver site. Despite the lower infiltration rates measured at the porous paver site, the fact should not be overlooked that maximum water levels reached in the infiltration basin were minimal leaving a substantial storage volume before discharges would ever occur.

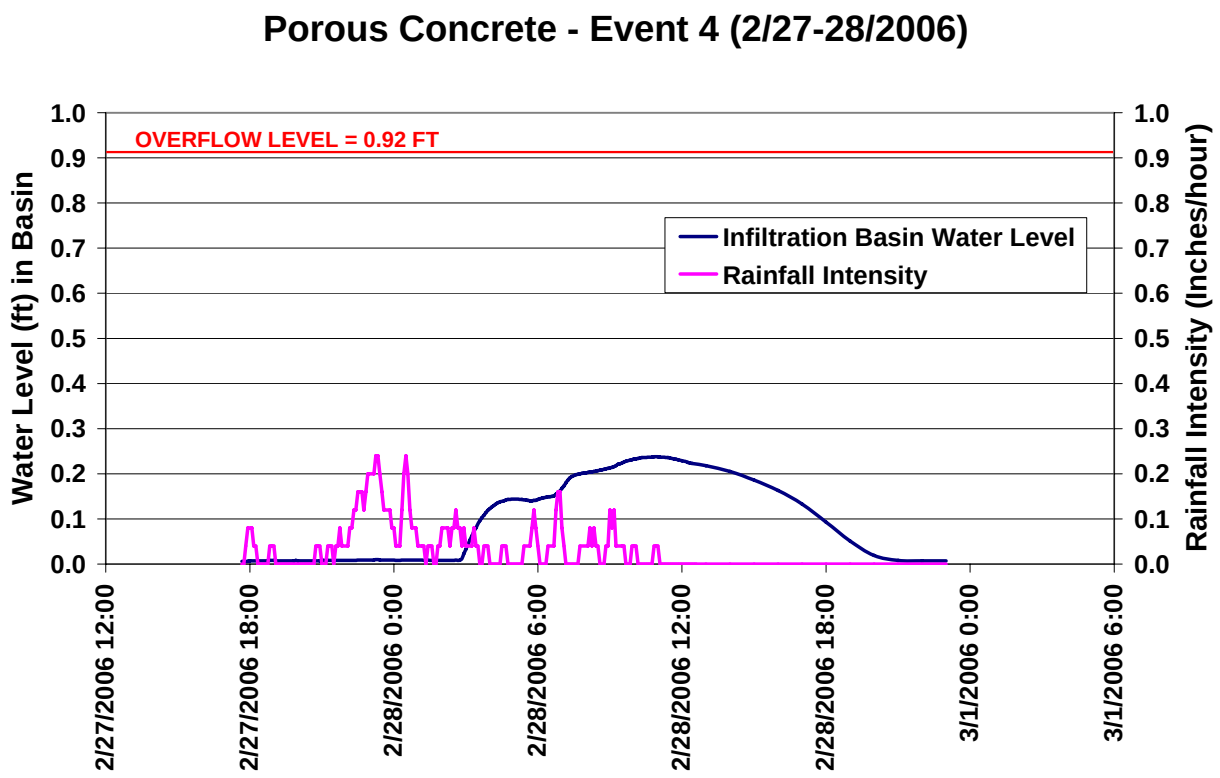

Figure 15. Rainfall Intensity and Response of Water Level in the Infiltration Basin, Porous Concrete – Event 4.

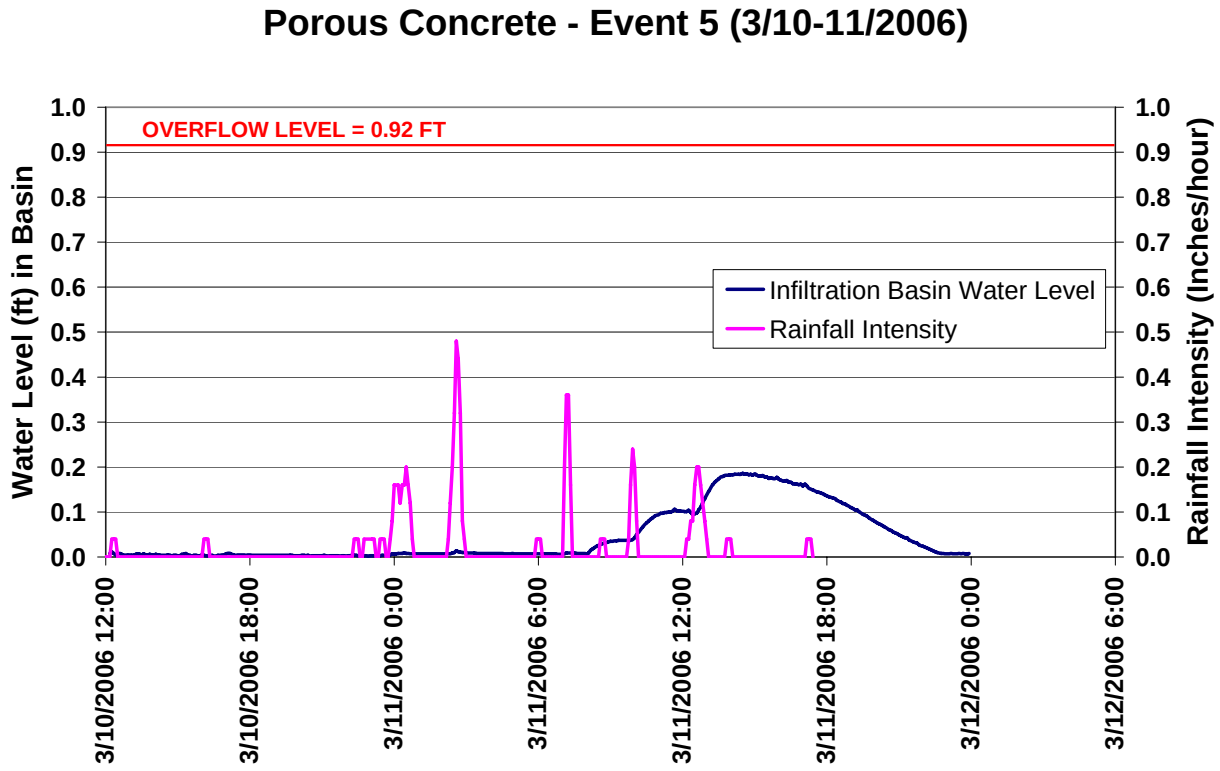

Figure 16. Rainfall Intensity and Response of Water Level in the Infiltration Basin, Porous Concrete – Event 5.

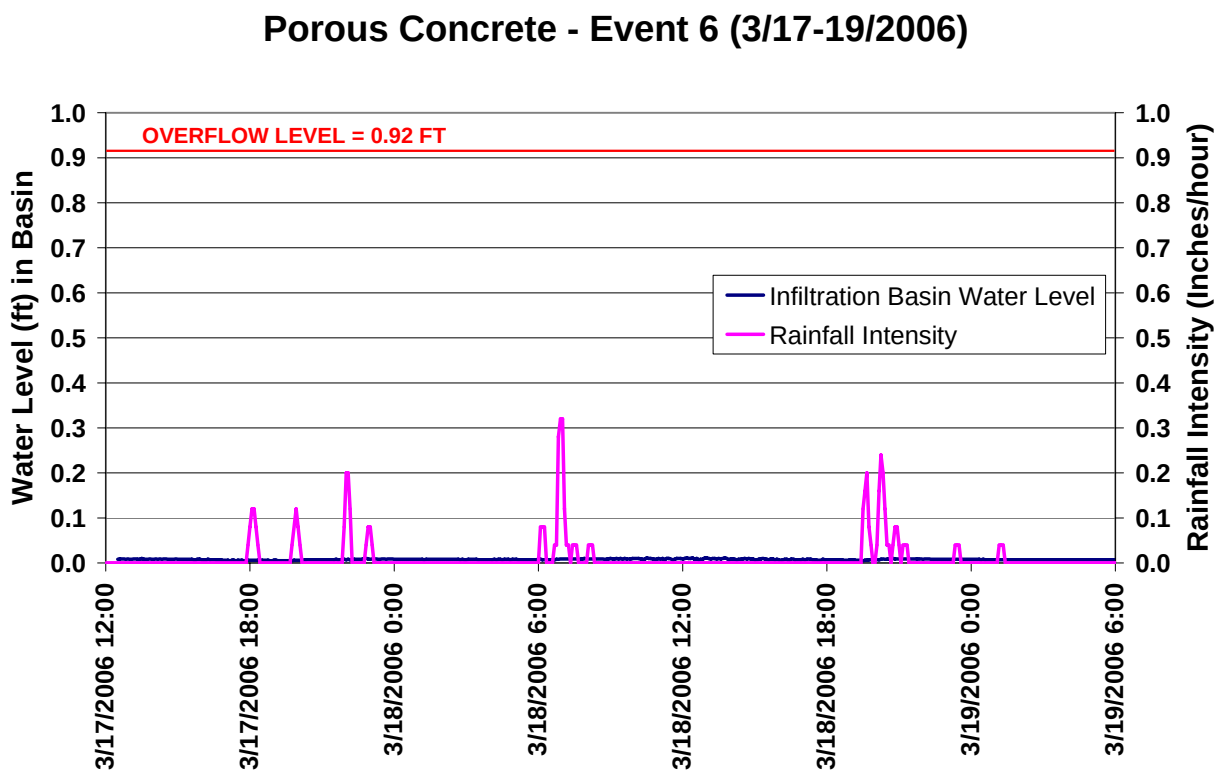

Figure 17. Rainfall Intensity and Response of Water Level in the Infiltration Basin, Porous Concrete – Event 6.

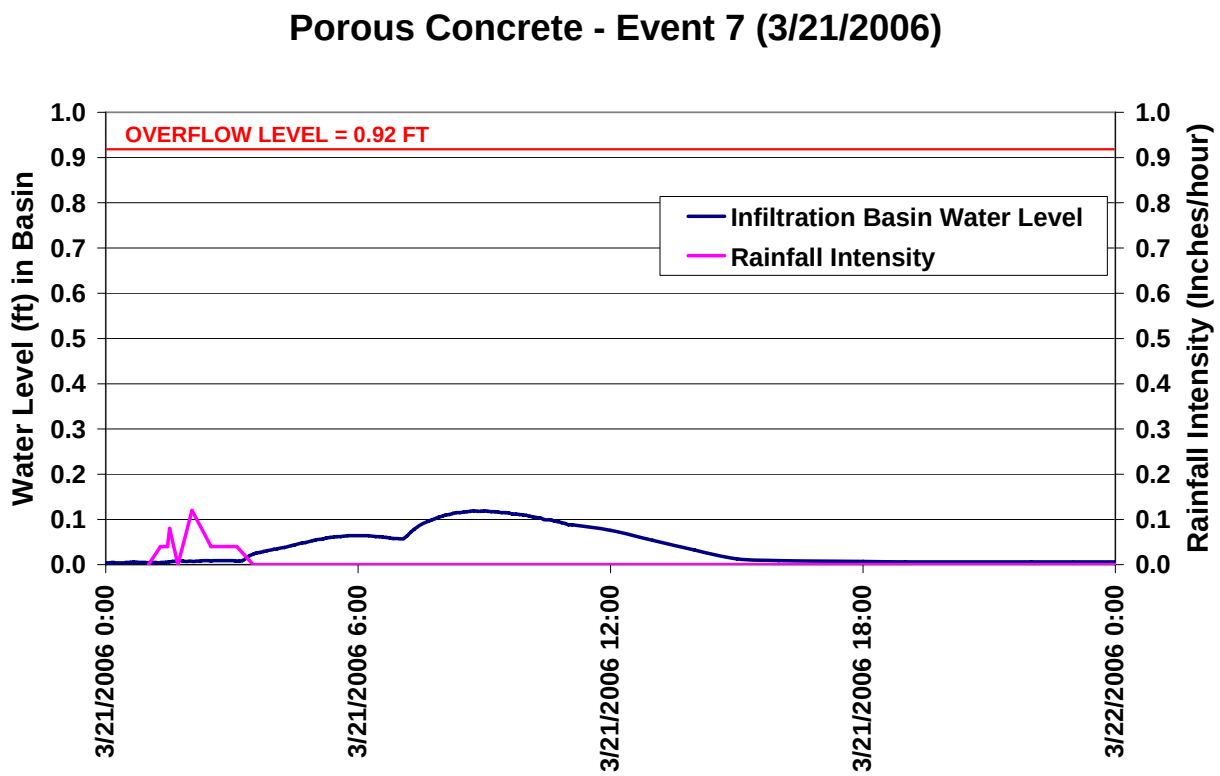

Figure 18. Rainfall Intensity and Response of Water Level in the Infiltration Basin, Porous Concrete – Event 7.

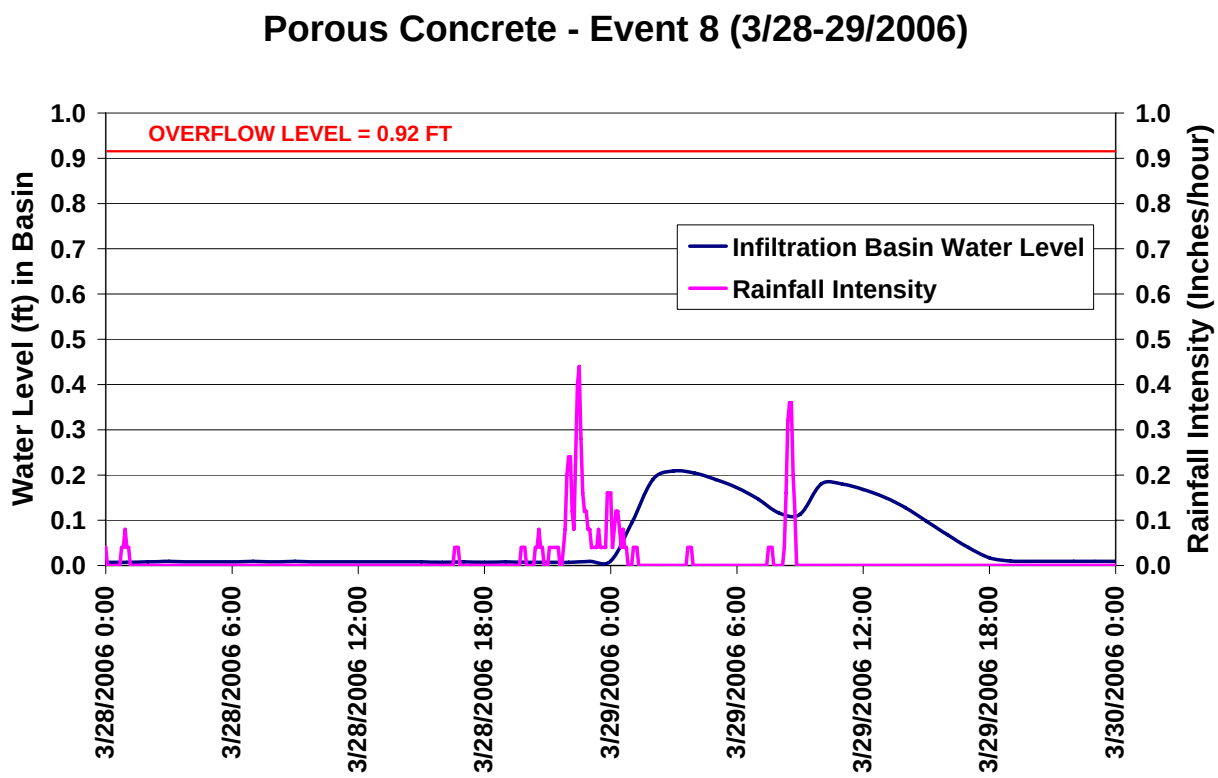

Figure 19. Rainfall Intensity and Response of Water Level in the Infiltration Basin, Porous Concrete – Event 8.

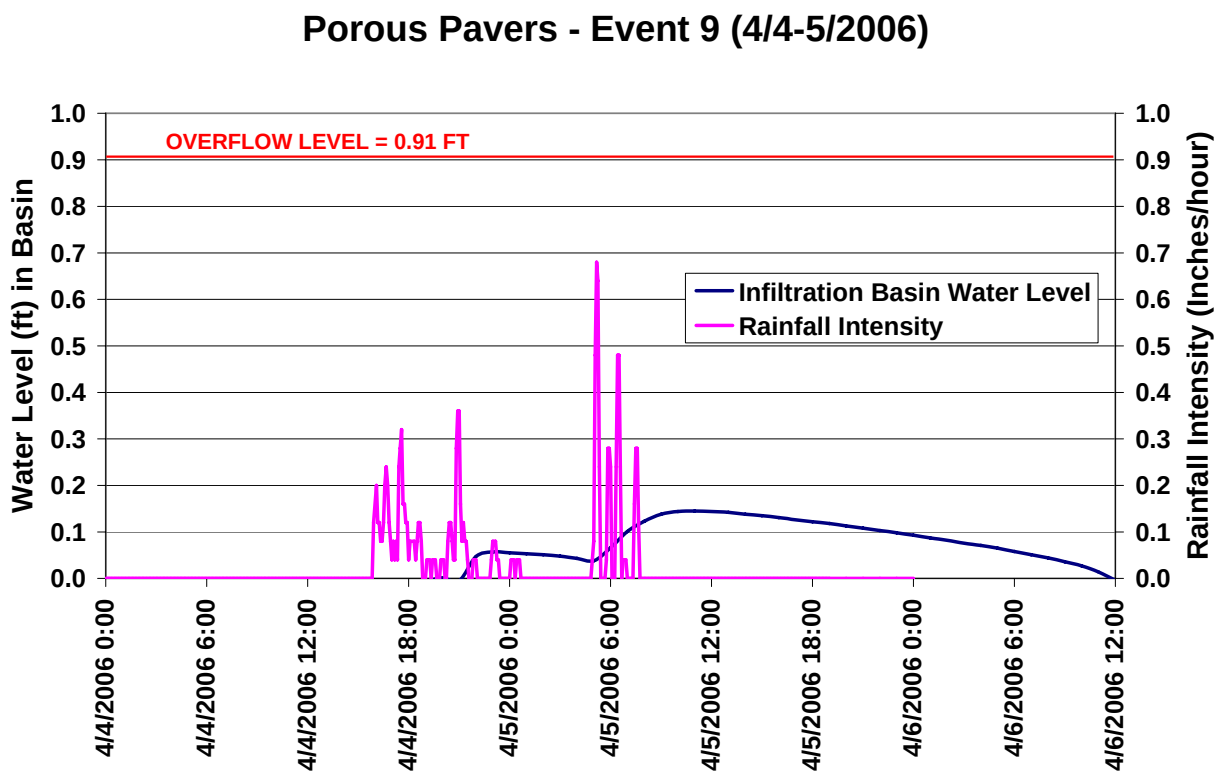

Figure 20. Rainfall Intensity and Response of Water Level in the Infiltration Basin, Porous Pavers – Event 9.

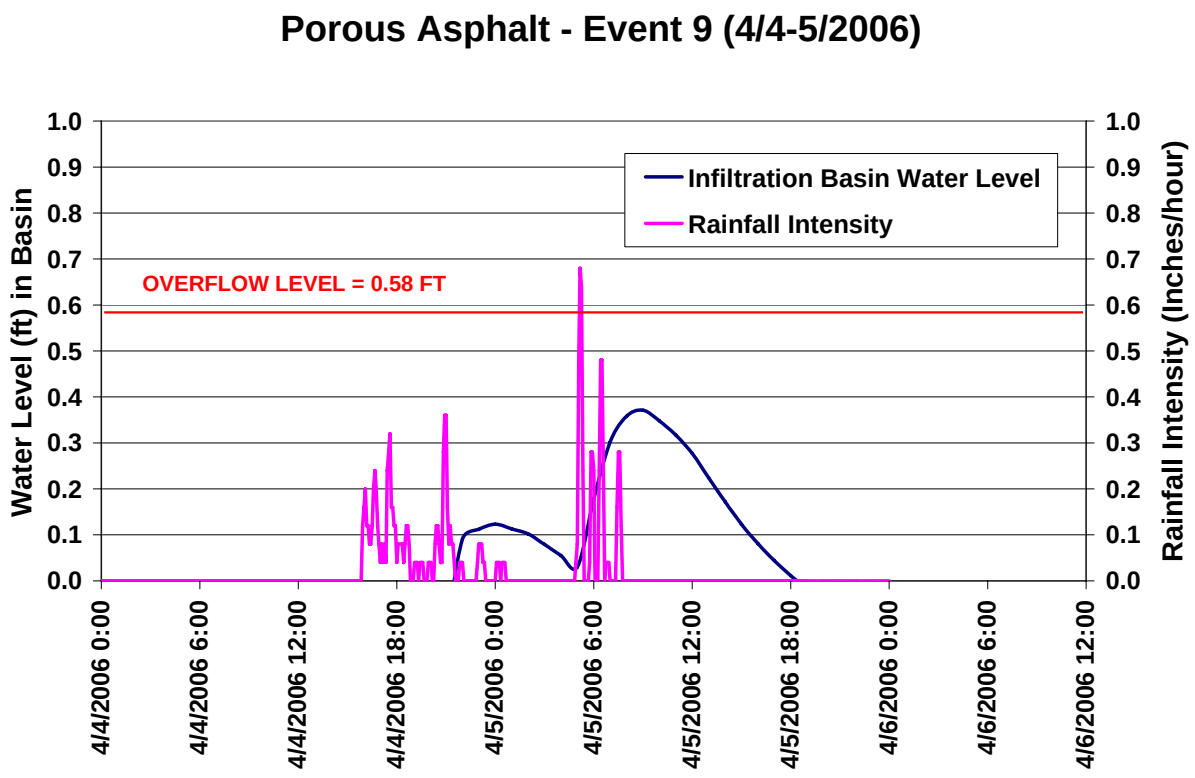

Figure 21. Rainfall Intensity and Response of Water Level in the Infiltration Basin, Porous Asphalt – Event 9.

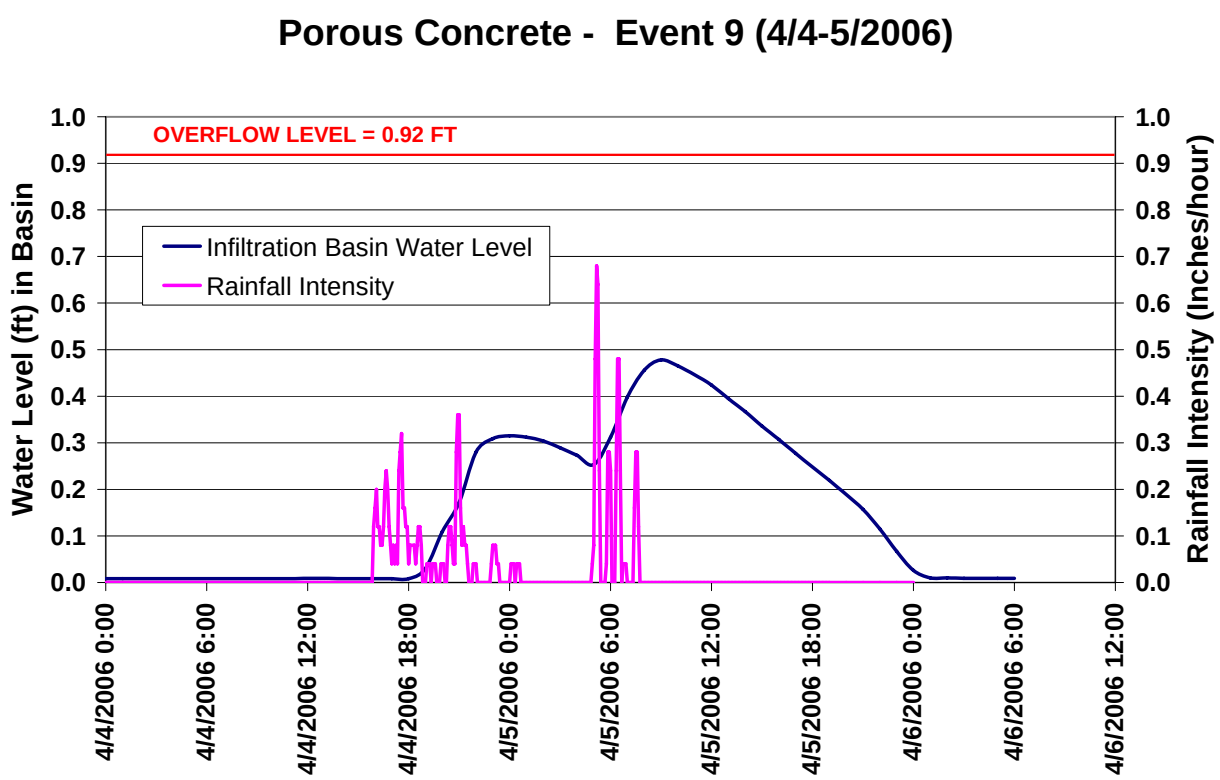

Figure 22. Rainfall Intensity and Response of Water Level in the Infiltration Basin, Porous Concrete – Event 9.

2.2.3. Stormwater Quality and Pollutant Loads

Stormwater quality was measured during six events at the Reference Site. Event Mean Concentrations (EMCs) for each event are summarized in Table 6. Statistical summaries of data for the entire 2005/2006 storm season are presented in Table 7. Pollutant load estimates for the entire storm season are summarized in Table 8 along with estimates of pollutant load reductions achieved at each porous paving test site as a result of effectively retaining and infiltrating 100 percent of rainfall for the season. Table 9 then compares mean runoff quality from the reference site to other studies and to available California Toxics Rule (CTR; USEPA, 2000) acute water quality criteria.

Runoff from the reference site was characterized by very low hardness values (Tables 6 and 7). Average hardness was only 16 mg/L as $CaCO_3$ due to the highly impervious catchment. Rainwater is typically low in hardness. Hardness increases when the runoff is exposed to soils where calcium and magnesium compounds become dissolved. Low hardness values tend to decrease any of the hardness-dependent water quality criteria.

This study used both Suspended Sediment Concentration (SSC) and TSS methods to measure solids present in the runoff. Both tests produced similar results in terms of the total mass of particles in the runoff. The SSC method provided additional information on the size composition. Results (Table 6 and 7) indicate that fine sediments (less than 63 microns) were the dominant size class of particles present in the stormwater discharge. The mean concentration of the coarse fraction (greater than 63 microns) was 10.5 mg/L compared to an average of 51.3 mg/L for the fine fraction (Table 7).

Concentrations of nutrients (Total P, Ortho-P, Ammonia-N, TKN, and Nitrate-N) measured in runoff from the six monitored events were generally highest during the first three events and lowest during the latter three events. This may be indicative of seasonal effects or simply an artifact of the characteristics of the 2005/2006 wet season. Early storms were widely spaced providing time for buildup of nutrients on the parking lot surface. Later storms occurred more frequently (Table 4) with fewer days between event which may have limited the time for buildup of nutrients on the parking lot surface.

Trace metals exhibited substantial variation in ratios of total and dissolved fractions (Table 6). At times, dissolved copper and zinc in the runoff comprised more than 90 percent of the total recoverable concentrations for these metals. During the first four events, between 46 and 77 percent of the cadmium was also in the dissolved form. Since many structural BMPs focus mostly on the particulate fraction, stormwater discharges with a high proportion of the metals in dissolved form would be difficult to address.

All three porous paving BMPs examined were successful in preventing 100 percent of the metals and other contaminants from discharging to the San Diego River through the municipal storm drains. The seasonal mean Event Mean Concentrations (EMC) for runoff from the Reference Area was used to estimate load reductions achieved by each type of porous pavement (Table 8). In addition, the porous pavement prevented the discharge of nearly 34,000 cubic feet of water

that would have been associated with the 8.15 inches of rainfall experienced during the 2005/2006 season.

A comparison of mean EMCs from the reference site (Table 8) was made with the results of studies conducted in similar environments. With a few minor exceptions, the quality of stormwater runoff from the COC Reference Area was very comparable to results from Caltrans Maintenance Yards, Caltrans Park and Ride facilities and a small, highly impervious urban drainage in Long Beach, California. There were no dramatic differences apparent for any constituents although slightly higher mean concentrations of total and dissolved cadmium were evident in runoff from the COC Reference Area. Dissolved concentrations of lead and zinc were also slightly higher in runoff from the Reference Area. With only six events during a single season, the significance of these minor differences cannot be assessed.

The seasonal mean EMCs for three of the four trace metals monitored as part of this program were found to exceed the CTR acute receiving water quality objectives based upon an average hardness of 16 mg/L. Mean concentrations of both dissolved copper and zinc were greater than 5 times the CTR acute criterion. Dissolved cadmium only slightly exceeded the criteria. Although the mean EMC for lead at the Reference Area was high (4.4 µg/L) compared to stormwater runoff from other sites, concentrations did not exceed the CTR acute criterion. These exceedances are largely driven by the extremely low hardness of runoff from the COC Reference Area.

Table 6. Summary of Results of Chemical Analysis of Stormwater Runoff from the Reference Site during Storm Events 1 through 6.

CONSTITUENT	Storm-01 18-Oct-05	Storm-02 02-Jan-06	Storm-03 19-Feb-06	Storm-04 28-Feb-06	Storm-05 12-Mar-06	Storm-06 19-Mar-06
Hardness (mg/L)	18	25	23	9.0	9.0	12
SSC (mg/L)	145.9	16	80.3	22.6	61.5	44.0
>63 microns	34.9	4.5	13.4	2.3	5.0	2.6
<63 microns)	111	11.5	66.9	20.3	56.5	41.4
TSS (mg/L)	160	15	75	22	61	42
COD (mg/L)	130	87	130	59	68	64
DOC (mg/L)	15	23	30	17	8.6	13
Total P (mg/L)	0.54	0.16	0.23	0.17	0.14	0.15
Ortho-P (mg/L)	0.057	0.034	0.034	0.059	0.027	0.040
Ammonia-N (mg/L)	0.62	0.95	0.73	0.40	0.28	0.30
TKN (mg/L)	2.3	2.3	2.5	1.6	1.1	1.2
Nitrate-N (mg/L)	0.55	0.98	1.3	0.44	0.23	0.31
Total Cadmium (ug/L)	1.6	1.3	2.6	0.86	1.8	1.2
Dissolved Cadmium (ug/L)	0.97	1.0	1.2	0.52	0.45	0.53
Total Copper (ug/L)	18	18	38	16	22	36
Dissolved Copper (ug/L)	11	18	20	12	7.7	12
Total Lead (ug/L)	50	17	71	20	74	40
Dissolved Lead (ug/L)	4.6	5.3	6.9	3.8	2.5	3.3
Total Zinc (ug/L)	150	150	390	140	220	170
Dissolved Zinc (ug/L)	140	140	240	110	73	81
Calculated Values[1]						
Oil&Grease$_{(COD)}$ (mg/L)	8.5	6.9	8.5	5.9	6.2	6.1
Oil&Grease$_{(DOC)}$ (mg/L)	4.4	6.6	8.6	4.9	2.6	3.8

1. Kayhanian, M, S. Khan, and M.K. Stenstrom. 2004. A new method to estimate oil and grease event mean concentration in highway runoff. StormCon 2004

Table 7. Statistical Summary of 2006/2007 Event Mean Concentrations for all Constituents Measured in Stormwater Runoff from the Reference Area (n=6)

Constituent	Minimum	Maximum	Mean	Standard Deviation	1st quartile	Median (2nd quartile)	3rd quartile
Hardness (mg/L)	9.0	25	16	7.0	9.8	15	21.8
SSC (mg/L)	16.0	145.9	61.7	47.7	28	52.8	75.6
>63 microns	2.3	34.9	10.5	12.6	3.1	4.8	11.3
<63 microns)	11.5	111	51.3	36.0	25.6	49.0	64.3
TSS (mg/L)	15	160	62.5	52.9	27	51.5	71.5
COD (mg/L)	59	130	89.7	32.6	65	77.5	119.3
DOC (mg/L)	8.6	30	17.8	7.6	13.5	16	21.5
Total P	0.14	0.54	0.23	0.15	0.15	0.17	0.22
Ortho-P (mg/L)	0.03	0.06	0.04	0.01	0.03	0.04	0.05
Ammonia-N (mg/L)	0.28	0.95	0.55	0.27	0.33	0.51	0.70
TKN (mg/L)	1.1	2.5	1.83	0.61	1.30	1.95	2.3
Nitrate-N (mg/L)	0.23	1.3	0.64	0.42	0.34	0.50	0.87
Total Cadmium (ug/L)	0.86	2.6	1.56	0.60	1.23	1.45	1.75
Diss. Cadmium (ug/L)	0.45	1.2	0.78	0.32	0.52	0.75	0.99
Total Copper (ug/L)	16	38	24.7	9.8	18	20	32.5
Diss. Copper (ug/L)	7.7	20	13.5	4.6	11.3	12	16.5
Total Lead (ug/L)	17	74	45.3	24.4	25	45	65.8
Diss. Lead (ug/L)	2.5	6.9	4.4	1.6	3.4	4.2	5.1
Total Zinc (ug/L)	140	390	203	96	150	160	208
Diss. Zinc (ug/L)	73	240	131	61	88	125	140
Calculated Values							
Oil&Grease$_{(COD)}$ (mg/L)	5.90	8.50	7.02	1.20	6.13	6.55	8.10
Oil&Grease$_{(DOC)}$ (mg/L)	2.60	8.60	5.15	2.14	3.95	4.65	6.18

Table 8. Estimated Annual Pollutant Load[1] from the Reference Site and Corresponding Load Reductions due to each Porous Treatment Type.

Constituent	Reference	Pavers	Concrete	Asphalt	Total Kg	Total lbs
	Load (Kg)	Estimated Load Reduction (Kg)				
SSC	29	6.2	12	33	51	111
>63 microns	2.6	0.56	1.1	2.9	4.6	10
<63 microns)	27	5.8	11	30	47	103
TSS	28	6.1	12	32	49	109
COD	42	9.2	17	48	74	163
DOC	8.7	1.9	3.6	9.9	15	34
Total P	0.09	0.020	0.037	0.10	0.16	0.35
Ortho-P	0.02	0.0044	0.0083	0.023	0.035	0.078
Ammonia-N	0.28	0.060	0.11	0.31	0.49	1.1
TKN	1.1	0.23	0.44	1.2	1.9	4.1
Nitrate-N	0.27	0.059	0.11	0.31	0.47	1.0
Total Cadmium	0.00079	0.00017	0.00032	0.00089	0.0014	0.00306
Diss. Cadmium	0.00041	0.000089	0.00017	0.00046	0.00072	0.00158
Total Copper	0.011	0.0024	0.0045	0.012	0.019	0.042
Diss. Copper	0.0065	0.0014	0.0027	0.0074	0.012	0.025
Total Lead	0.024	0.0053	0.010	0.028	0.043	0.095
Diss. Lead	0.0023	0.00050	0.00094	0.0026	0.0040	0.0089
Total Zinc	0.087	0.019	0.036	0.099	0.15	0.34
Diss. Zinc	0.068	0.015	0.028	0.077	0.12	0.26
Calculated Values[2]						
Oil&Grease(COD)	3.6	0.78	1.5	4.0	6.3	14
Oil&Grease(DOC)	2.5	0.55	1.0	2.9	4.5	9.8

1. All load estimates based upon annual rainfall of 8.15 inches measured at the County's Kearny Mesa (KEA) ALERT gauge.
2. Kayhanian, M, S. Khan, and M.K. Stenstrom. 2004. A new method to estimate oil and grease event mean concentration in highway runoff. StormCon 2004.

Table 9. Comparison of Project Reporting Limits with Concentrations found in Runoff from Parking and Maintenance Facilities[1], a Small Residential/Commercial Drainage[2] and Water Quality Criteria.

Analytical Parameter	Project Reporting Limits	COC Parking Lot Reference Site (means)	CTR Acute Freshwater Criteria (based on hardness of 16 mg/L)	Caltrans Maintenance Yards (means)	Caltrans Park and Ride Lots (means)	City of Long Beach Belmont Pump Station (2004-2005 ranges)
Hardness (mg/L)	2.0	16		-	-	15-25
SSC (mg/L)	1.0	61.7		-	-	-
TSS (mg/L)	1.0	62.5		98	61.8	37-130
COD(mg/L)	4.0	89.7		-	-	30-88
DOC(mg/L)	1.0	17.8		17.8	19.8	
Total P (mg/L)	0.05	0.23		0.3	0.4	0.41-0.63
Ortho-P (mg/L)	0.05	0.04		0.2	0.2	0.18-0.36
Ammonia – N (mg/L)	0.1	0.55		-	-	0.1-0.26
TKN (mg/L)	0.1	1.83		1.8	2.6	1.0-1.6
Nitrate – N (mg/L)	0.1	0.64		0.7	0.7	0.33-0.90
Total Cadmium (ug/L)	0.25	1.56		0.8	0.31	0.38-1.1
Diss. Cadmium (ug/L)	0.25	***0.78***	0.6	0.32	0.14	0.074-0.25
Total Copper (ug/L)	1.0	24.7		34.9	16.7	17-49
Diss. Copper (ug/L)	1.0	***13.5***	2.4	13.3	9.0	6.1-10
Total Lead (ug/L)	0.5	45.3		34.3	9.2	15-60
Diss. Lead (ug/L)	0.5	4.4	8.4	2.5	1.2	0.63-1.4
Total Zinc (ug/L)	1.0	203		240	158	110-380
Diss. Zinc (ug/L)	1.0	***131***	25	110	79	31-60

Bolded and Italicized values exceed CTR Acute Criterion. Hardness-based criteria were calculated using the mean hardness of runoff from the 6 events.

1. Caltrans, 2003. Preliminary Report of Discharge Characterization Studies. CTSW-RT-03-023
2. Kinnetic Laboratories, Inc. 2005. City of Long Beach Stormwater Monitoring Report, 2004/2005.

3.0 TREATMENT TRAIN

3.1. *Methods*

3.1.1. Site Conditions

Construction of the Treatment Train at the County Operations Center was completed on February 11, 2005. The Treatment Train (Figure 23) consists of two structural BMPs developed by CDS Technologies. Primary treatment is provided by a Continuous Deflective Separation Pretreatment Unit (CDS Unit). The CDS Unit is a Model PSWC56_40 designed to treat up to 9.0 cfs of stormwater. The CDS unit is intended to remove gross pollutants which include trash, organic debris and coarse particulate matter. Secondary treatment is provided by a CDS Media Filtration System (MFS). The MFS installed at the COC is an MFS 816 containing 42 cartridges and is designed to treat 1.75 cfs of stormwater. The cartridges are designed to use a variety of filtration media. For this study, each cartridge utilized perlite media to filter very fine particulates in the stormwater.

A diversion weir was used to limit flows through the CDS Unit to approximately 7.0 cubic feet per second (cfs) of stormwater runoff. Flows exceeding this magnitude bypass the entire Treatment Train. All water treated by the CDS unit enters another box that serves to split flows to the single MFS unit. Excess flow is redirected back to the main storm drain. Expansion plans are in place to install an additional three media filtration units which would enable all water passing through the CDS unit to receive additional filtration and treatment. At that time the return to the main storm drain will be eliminated.

Originally, flow entering the MFS was controlled by an 8-inch pipe that was intended to prevent flow from exceeding the capacity of the MFS unit. A second internal bypass provides additional protection by assuring that flows through the filter cartridges do not exceed design capacity. Whenever flows exceed the capacity of the cartridges, water in the chamber passes over a weir and discharges downstream of the MFS unit.

Soon after construction was complete, a previous consultant attempted to monitor two storm events. As a result of this effort, several problems were identified that required a re-evaluation of the configuration and monitoring approach. The major issues were primarily related to quantification of the flow regime under less than ideal conditions resulting in part from last minute changes in the configuration of the Treatment Train. An assessment of the flow data from these events determined that data from these events could not be considered valid. A complete reevaluation of the methods was necessary to modify both the Treatment Train and overall monitoring strategy to improve measurement of water quantity and quality. The modified approach resulted from extensive consultation and support from CDS Technologies. The final approach used to instrument and monitor the Treatment Train is described in Section 3.2.

Evaluation of the overall performance of the Treatment Train required accurate measurement of flows at a number of points in the system. Measuring performance of the CDS unit required the ability to continuously monitor the volume of water passing through the system as well as any system bypasses that might occur during periods of high flow. With the MFS unit it was critical to obtain measurements of flows coming into the system, treated stormwater exiting the system and untreated stormwater that flows over the internal bypass weir. The monitoring configuration used to measure these flows and obtain flow-rated composite samples of water entering the MFS and the treated effluent is described below

3.1.2. Monitoring Configuration

Stormwater flows approaching the Treatment Train were measured with an American Sigma Doppler flow sensor. Flow approaching the Treatment Train was monitored continuously throughout the project however, due to the nature of Doppler flow meters, only stormwater flows were quantified. Dry weather flows tend to lack suspended sediments necessary for the sensor to obtain a valid signal. This very characteristic would also mean that dry weather flows are not likely to transport significant loads of gross pollutants that could be removed by the CDS unit. A secondary pressure sensor was used to measure water levels at the face of the diversion weir. Both the Doppler flow measurements and water levels were measured at one-minute intervals and the averages recorded every five to ten minutes. Water levels were then post-processed to calculate bypass flows using the weir equation for a 5.5 foot rectangular weir without end contractions.

The MFS unit required a very advanced monitoring package to effectively measure flow and collect representative samples of the influent and effluent. CDS Technologies was instrumental in providing concepts for alternative approach and implementing the necessary site modifications. Four major modifications were necessary. These included:

- Developing an improved system to limit flow entering the MFS to the design capacity.
- Improve the accuracy of precision of measurements of total flow passing through the unit.
- Enable accurate measurement of water that bypasses the MFS unit over the internal weir.
- Enable access to a location within the MFS unit were only treated water is sampled.

The original design of constricting the MFS inlet to an 8-inch pipe turned out to be a problem. During storm events, hydraulic head would increase to levels that forced excessive quantities of water through the system. To correct this, CDS designed a riser with orifices that provided the necessary control to limit flows to the 1.75 cfs design capacity (Figure 24).

Improvements in the accuracy of total flow measurements was achieved by installation of a 60 degree V-notch weir in the junction box located immediately downstream of the MFS unit. Flow at this location was monitored with a pressure sensor encased in a stilling well.

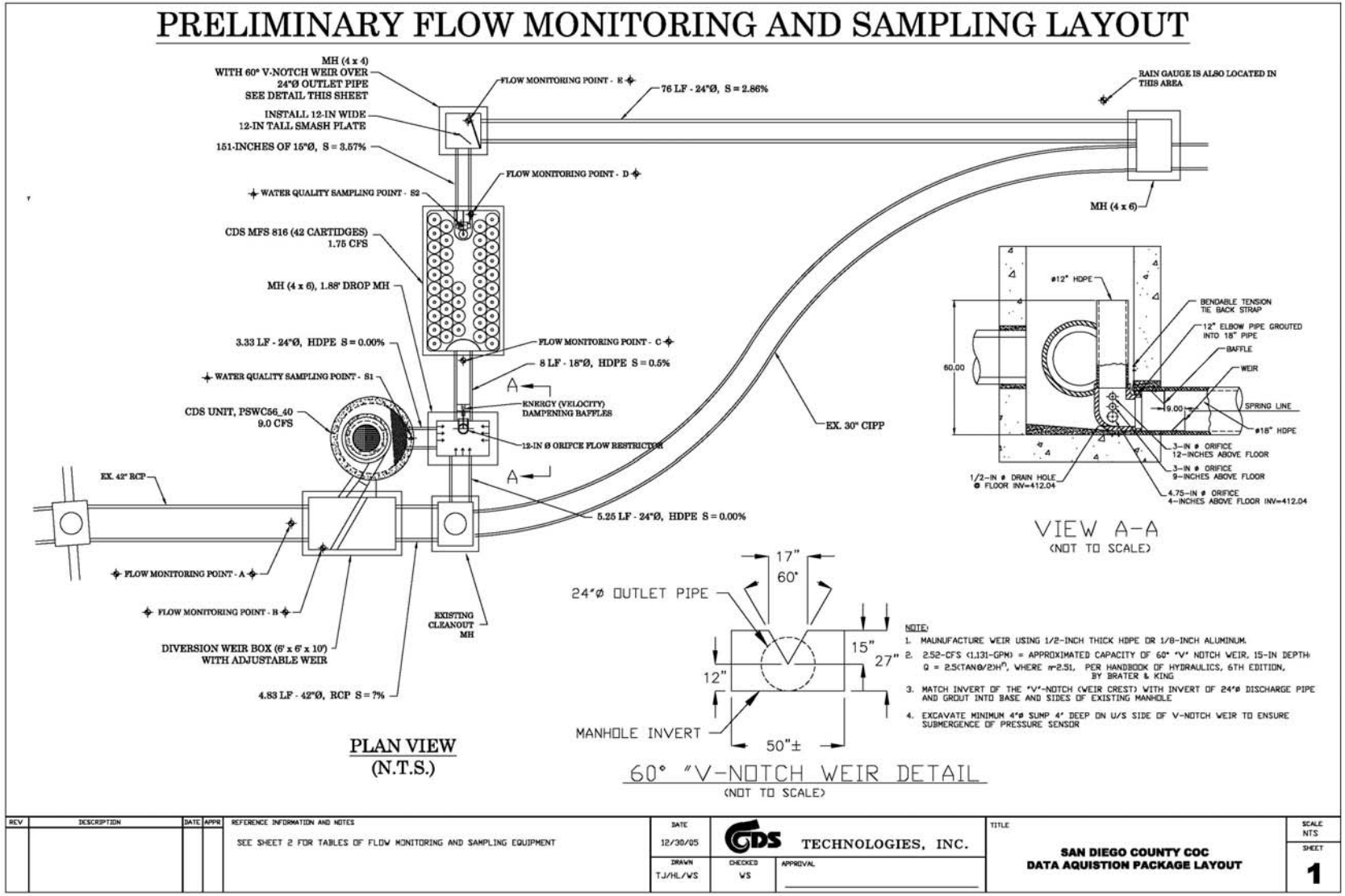

Figure 23. Generalized Plan View of CDS Treatment Train and Monitoring System.

Measurement of internal bypasses required modification of the bypass weir by installation of a 1-foot rectangular weir. A high precision pressure sensor was used to provide water level measurements necessary to calculate flow rates.

The occurrence of bypasses in the system during high flow events results in a blend of treated and untreated stormwater exiting the MFS unit. Evaluation of the performance of the MFS unit required accessing a location in the MFS unit that contained only treated stormwater. CDS provided an additional sampling port just downstream of the filter cartridges before the water mixes with any untreated water that bypassed the system.

Figure 24. Flow Splitting Riser

KLI's standard stormwater monitoring program was modified to enable the flow and sampling to be controlled through a single Campbell Scientific CR-10X. The V-notch weir was used to provide a real-time measure of flow into the MFS. The influent sampler was paced by this measurement. The flow of treated stormwater was calculated based upon the total flow minus flow going over the bypass weir. This flow was used to pace the sampler for the treated effluent. All flow and water sampling data was stored in the datalogger. The entire system was radio linked to the hard-wire telephone line used for the porous pavement monitoring. During storm events, data were downloaded at 15-minute intervals and posted to KLI's internal storm control computer where the information could be readily accessed to monitor progress and performance.

3.1.3. Sample Frequency

Samples of runoff from the COC were collected during the wet season (October 1 through April 30). The monitoring goal was to collect as many storms as possible during the 2005/2006 wet season with a target of at least three storm events total for full chemical characterization. Continuous monitoring of rainfall and flow was conducted once equipment installations were complete. Criteria for storm monitoring were the same as used for the Porous Paving element. Storm events were considered viable for monitoring activities if they were predicted to achieve greater than 0.25 inches of rainfall.

3.1.4. Sample Collection and Handling

Sample collection and handing procedures were also consistent with the Porous Paving element of this program. Composite sample bottles were subsampled at KLI's Carlsbad facility. Prior to subsampling the composite bottles were placed on a magnetic stir-plate. A pre-cleaned Teflon stir bar was inserted into the bottle and the sample was stirred to ensure homogeneity. The subsample bottles were then delivered to the analytical laboratory for chemistry analyses under appropriate chain of custody procedures.

Flow-weighted composite samples were analyzed for the following constituents: hardness, suspended sediment concentration (SSC), total suspended solids (TSS), chemical oxygen demand (COD), dissolved organic carbon (DOC), total phosphorus, orthophosphate-P, ammonia-N, total Kjeldahl nitrogen (TKN), nitrate-N, and total and dissolved cadmium, copper, lead, and zinc. Analytical methods were identical to those used in the Porous Paving study (Section 2.1.3, Table 3).

3.2. *Results and Discussion*

The following sections summarize the results of 1) monitoring rainfall, runoff and the representativeness of water quality samples, 2) water levels in the infiltration basins in response to each event and 3) characterization of water quality associated with runoff.

3.2.1. Rainfall, Runoff and Percent of Stormwater Treated

A total of eight storm events were monitored for rainfall and flow volumes during the 2005/2006 storm season. Flow was monitored through the CDS unit for a ninth event that occurred after the end of the official monitoring season. Monitoring was continued at this site to allow all runoff to be quantified prior to removal and assessment of gross pollutants from the CDS sump. Full analytical testing was conducted on the first three events. All subsequent events that occurred up through the end of the monitoring season on April 30, 2006 were monitored for rainfall and flow.

The major characteristics of each storm event are summarized in Table 10. This includes total rainfall associated with each event, total runoff measured upstream of the treatment train, the volume of water treated by the CDS unit and the volume of water that completely bypassed the treatment train.

Stormwater discharges exceeding 7.0 cfs were intended to bypass the entire Treatment Train. Since the current configuration of the Treatment Train has only a single MFS unit with a design capacity of 1.75 cfs, much of the stormwater treated by the initial CDS unit also had to be redirected around the MFS unit. This condition will be changed during Phase II when three additional media filtration units are installed. Bypasses of the Treatment Train during the nine events (Table 10; Figures 25 through 36) were uncommon and only occurred during brief periods when flow spiked due to particularly intense rainfall. Over the season, 96.5 percent of the stormwater runoff from the COC was treated by the CDS unit. Roughly 33 percent of the water treated by the CDS unit entered the MFS unit (the second phase of the Treatment Train). The remainder was discharged back to the main storm drain and discharged to the municipal storm sewer system.

The MFS unit also experienced internal bypasses that may have been partially influenced by backpressure from the downstream weir. The MFS unit treated 73 percent of the water that entered the system. Overall approximately 25 percent of all stormwater runoff from the COC received full treatment by the CDS and MFS units. A modified control box has now been installed in the MFS unit to provide the ability to make the fine adjustments needed to limit internal bypasses and assure that the design capacity of 1.75 cfs is attained. The three new media filtration units being installed under Phase II of the program will also have the modified control boxes.

During individual storm events, the percent of influent flow to the MFS that was effectively treated ranged from 64 to 95 percent of the water entering the unit. These percentages varied due to differences in duration and intensity of storm events. CDS plans to modify the MFS unit to improve performance of the system prior to the next storm season.

Table 10. Summary of Rainfall and Runoff at the Treatment Train

			CDS			MFS		
Event	Date	Rainfall (inches)	Total Runoff Volume (cf)	Treated Flow (cf)	% Treated	Inflow (cf)	Treated Flow (cf)	% Treated
1	2/27-28/06	0.84	88841	88841	100	35260	-[a]	-[a]
2	3/10-12/06	0.65	72316	71361	98.7	28621	20127	70
3	3/17-19/06	0.44	37721	37721	100	23688	17245	73
4[b]	3/21-22/06	0.35	33082	32205	97.3	13312	8802	66
5[b]	3/28-29/06	0.64	56905	56749	99.7	21494	13808	64
6[b]	4/4-5/06	1.07	122672	111379	90.7	37186	26068	70
7[b]	4/14-15/06	0.23	13366	13366	100	12687	12049	95
8[b]	4/23/06	0.25	17784	17784	100	9259	8158	88
9[b]	5/22/06	0.75	65249	60689	93.0			
TOTAL		**5.22**	**507936**	**490095**	**96.5**	**146247[c]**	**106257**	**73**

a. The amount of bypass could not be quantified during this event due to both a pressure sensor failure and an overflow weir that was too large for accurate assessment of overflows.
b. Storm events monitored for flow and rainfall only.
c. Only storm events 2 through 8 were used for calculation of MFS totals.

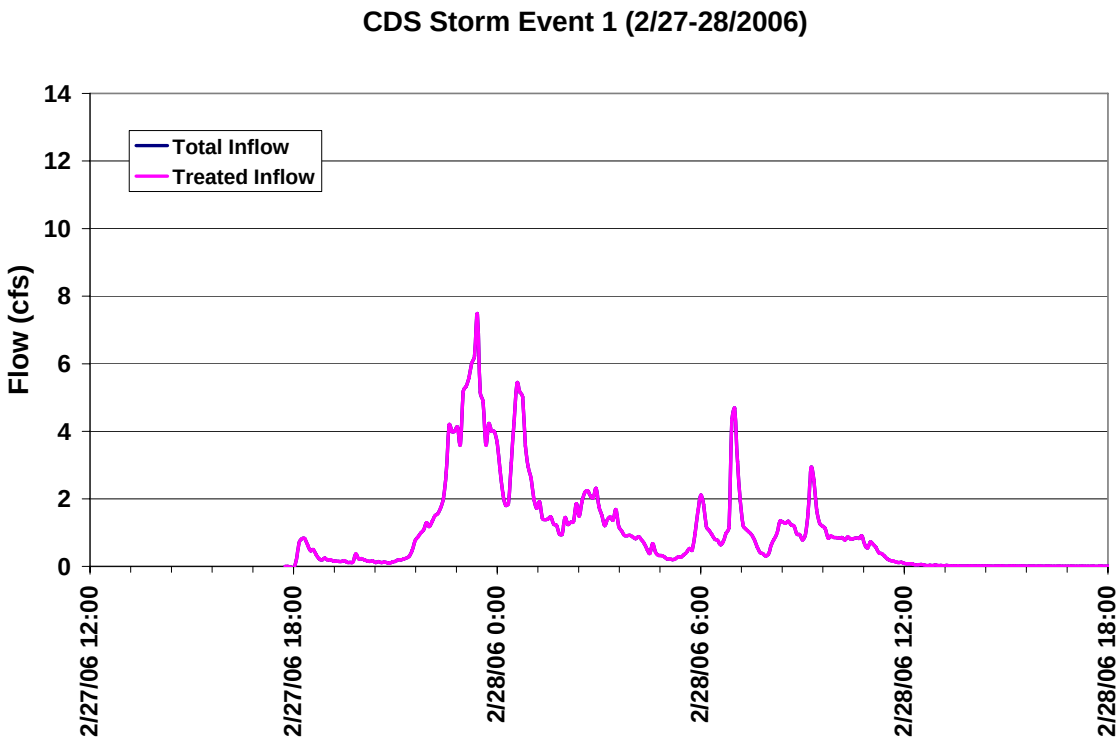

Figure 25. Stormwater Runoff measured upstream of the CDS unit during Event 1. (All stormwater was treated in this event.)

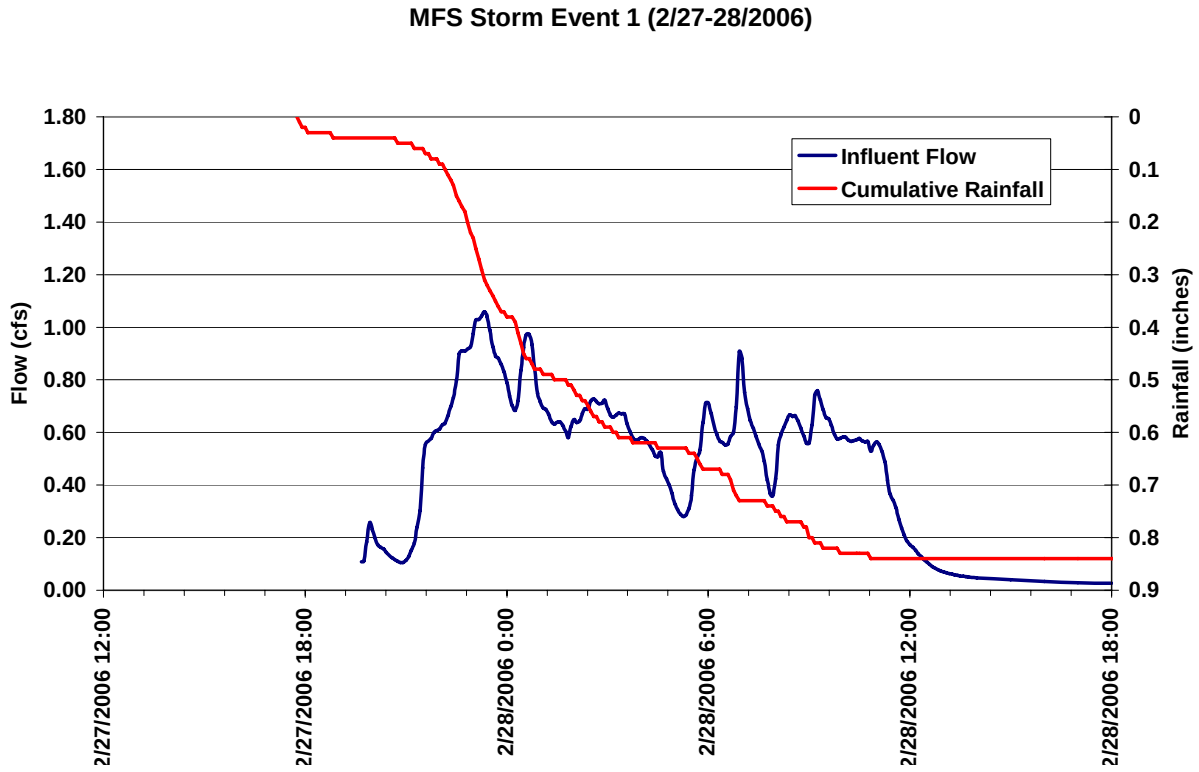

Figure 26. Stormwater flow into the MFS unit and Cumulative Rainfall during Event 1.

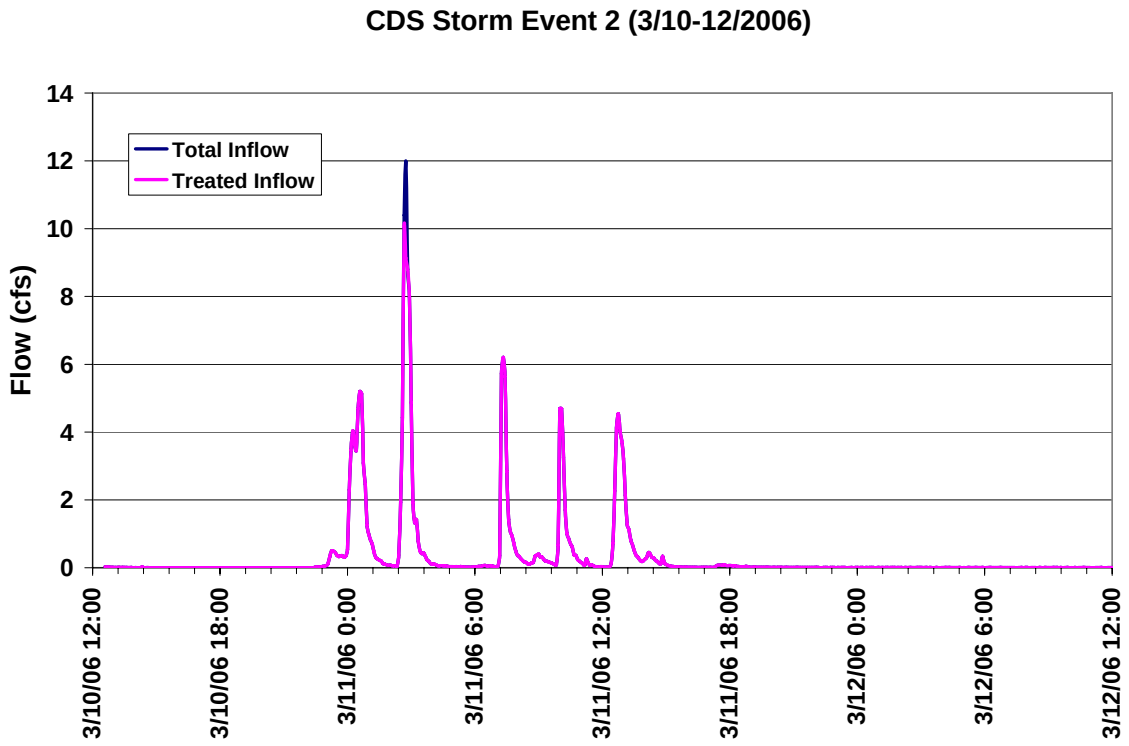

Figure 27. Stormwater Runoff measured upstream of the CDS unit during Event 2.

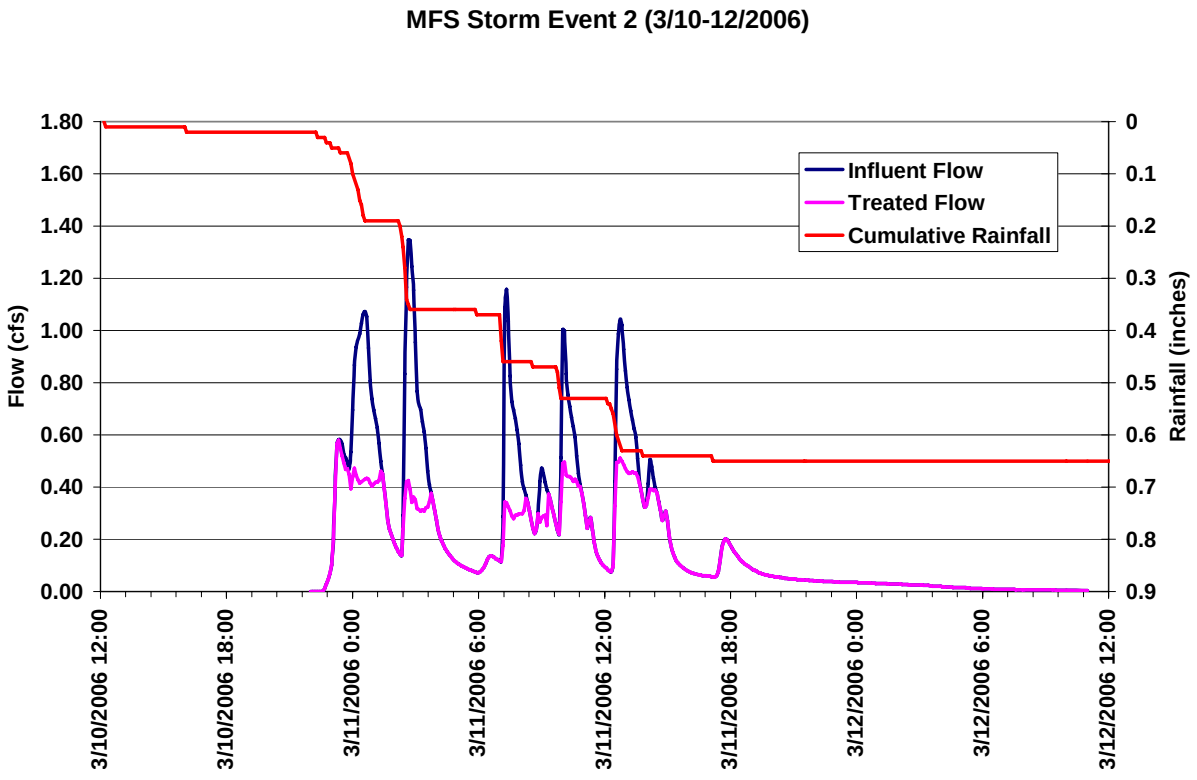

Figure 28. Stormwater flow into the MFS unit, Treated Flow out of the MFS and Cumulative Rainfall during Event 2.

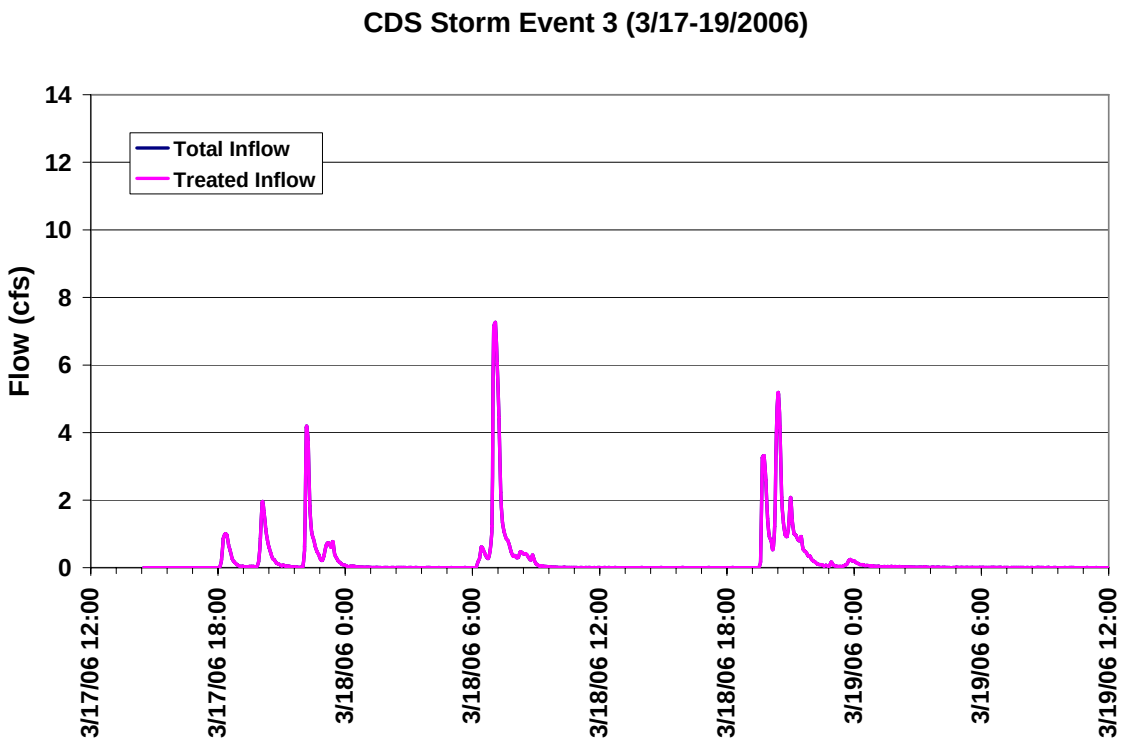

Figure 29. Stormwater Runoff measured upstream of the CDS unit during Event 3. (All stormwater treated in this event.)

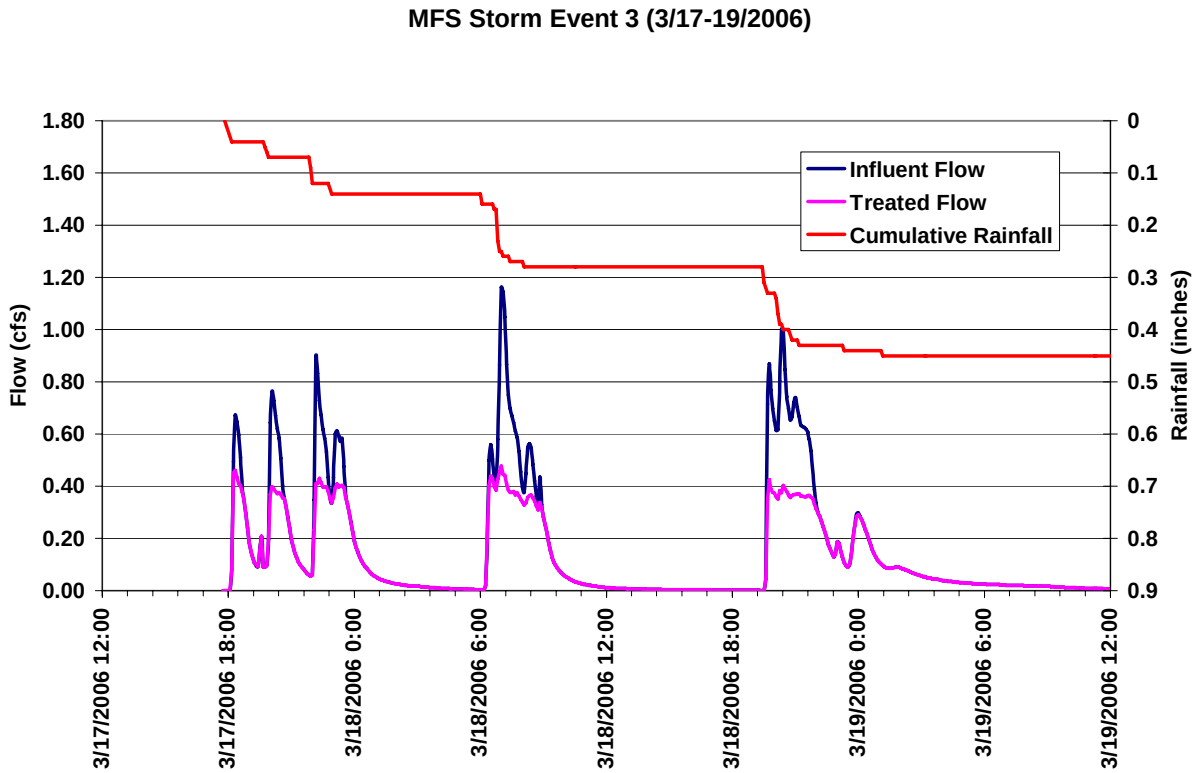

Figure 30. Stormwater flow into the MFS unit, Treated Flow out of the MFS and Cumulative Rainfall during Event 3.

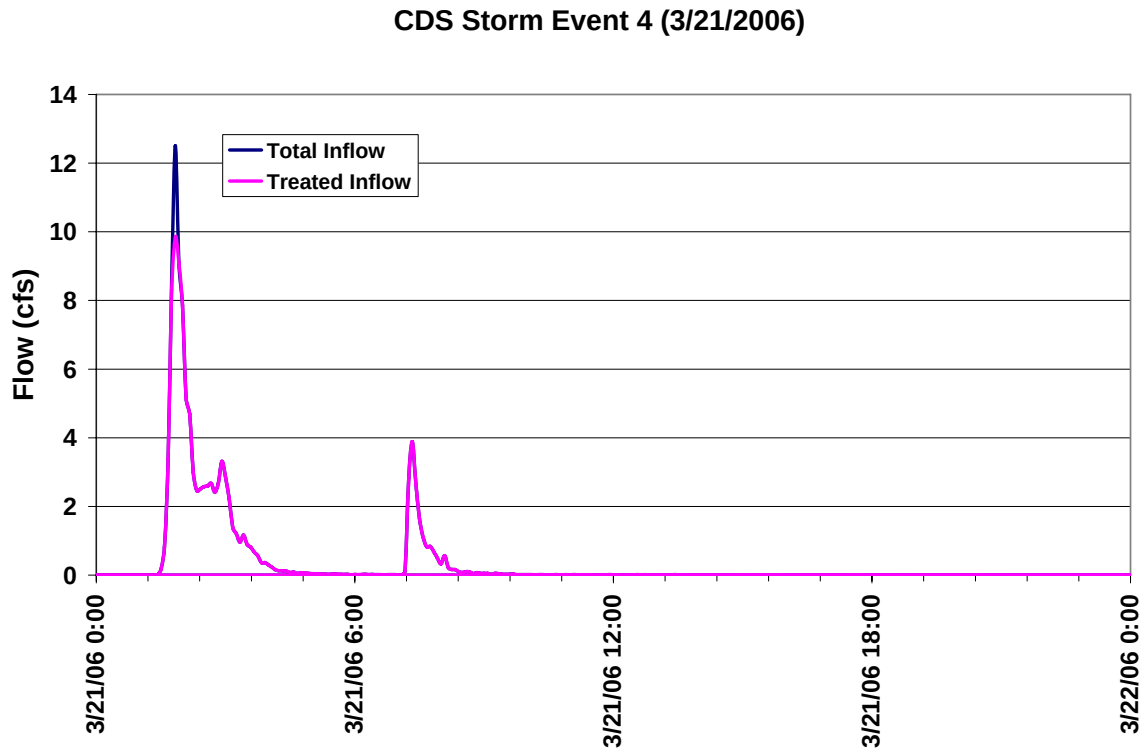

Figure 31. Total Inflow to the Treatment Train and Total Treated Flow directed through the CDS Unit, Event 4.

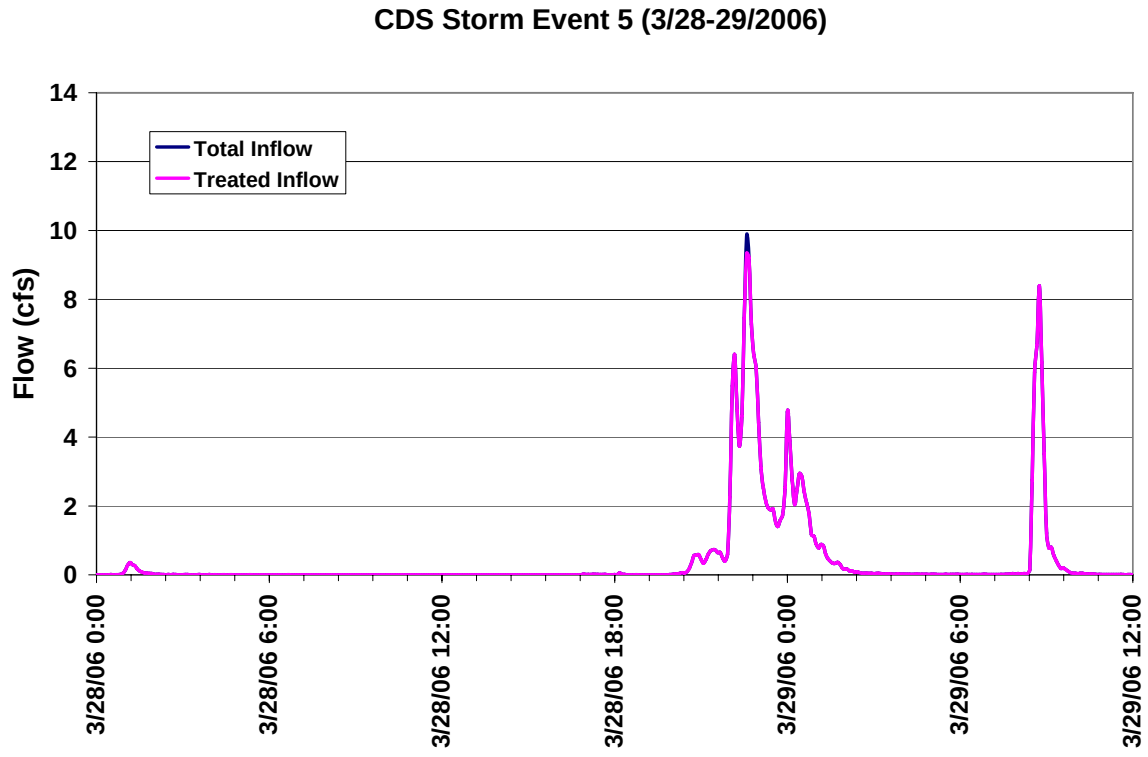

Figure 32. Total Inflow to the Treatment Train and Total Treated Flow directed through the CDS Unit, Event 5.

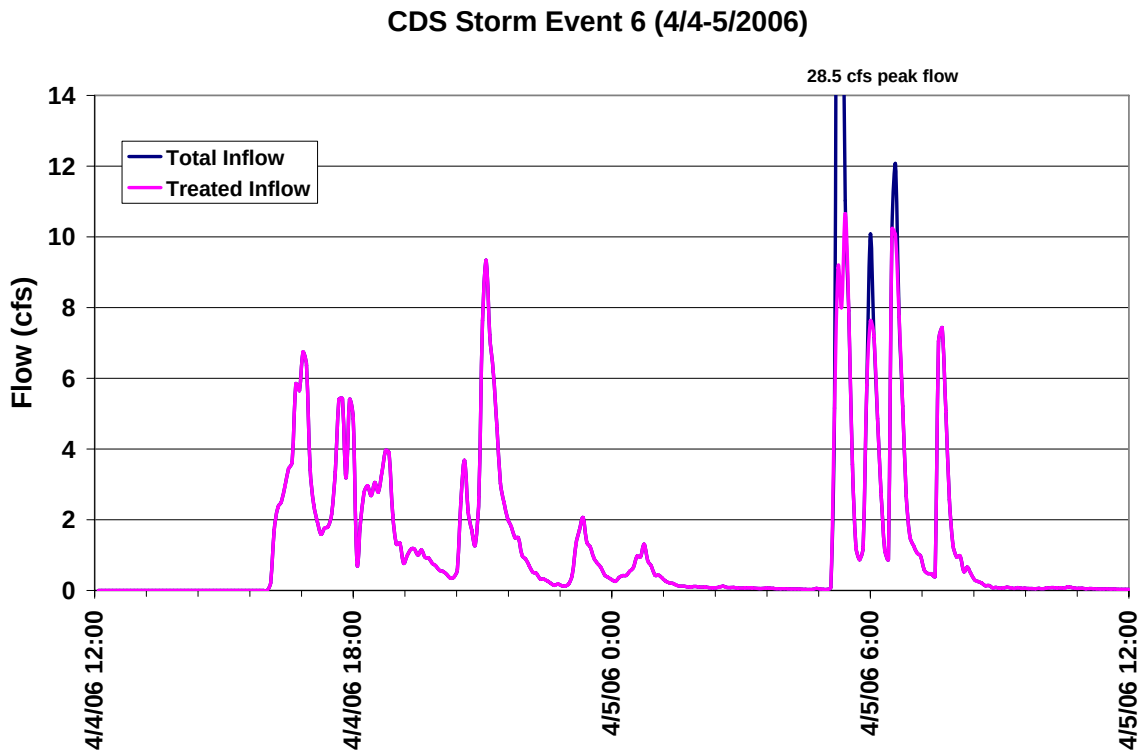

Figure 33. Total Inflow to the Treatment Train and Total Treated Flow directed through the CDS Unit, Event 6.

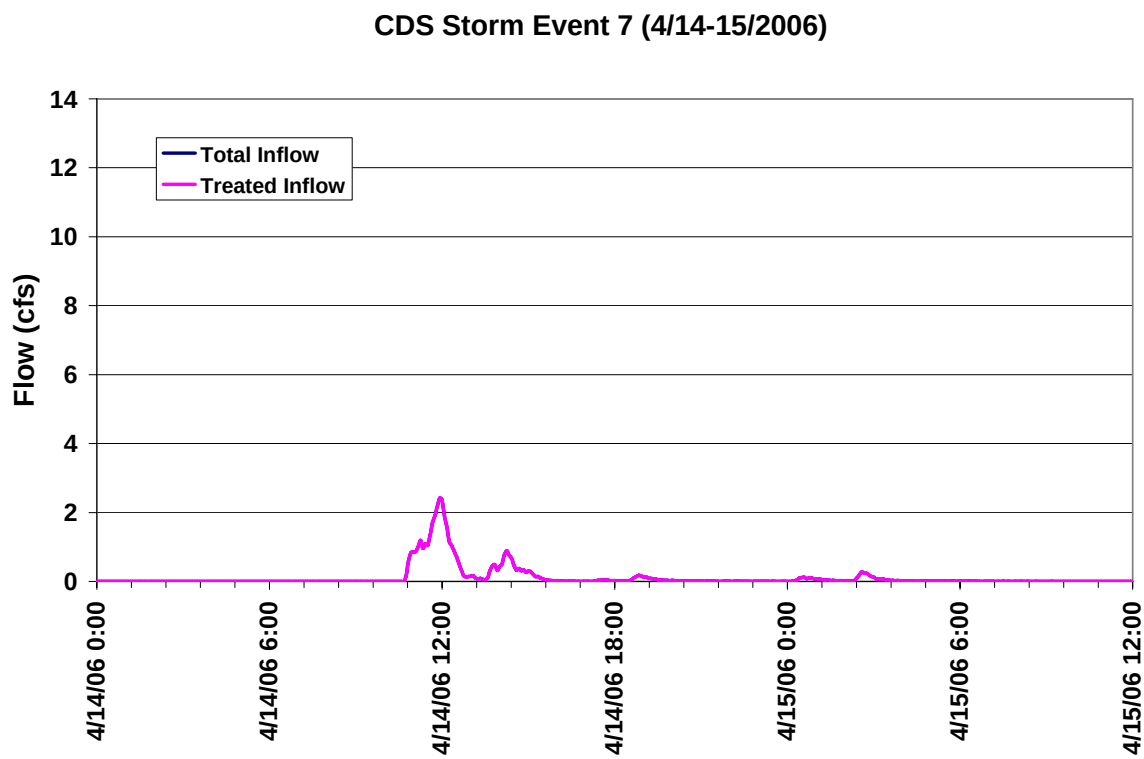

Figure 34. Total Inflow to the Treatment Train and Total Treated Flow directed through the CDS Unit, Event 7. (All stormwater was treated in this event)

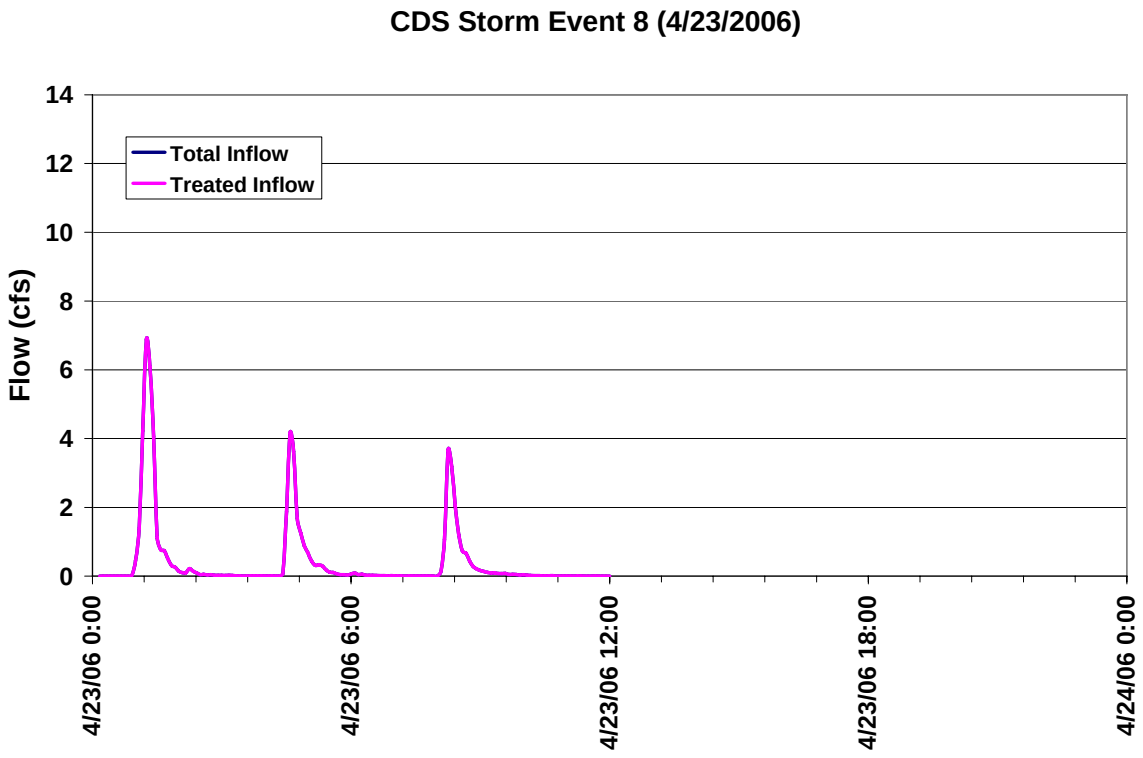

Figure 35. Total Inflow to the Treatment Train and Total Treated Flow directed through the CDS Unit, Event 8. (All stormwater was treated in this event)

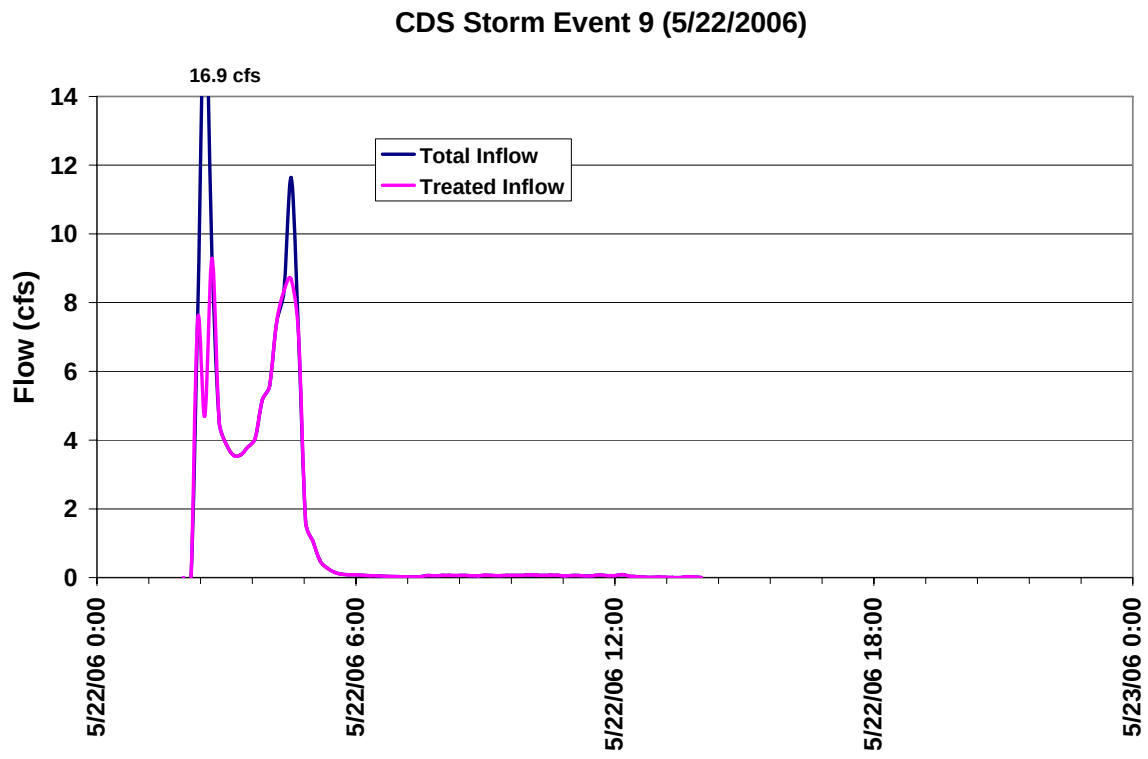

Figure 36. Total Inflow to the Treatment Train and Total Treated Flow directed through the CDS Unit, Event 9.

3.2.2. CDS Gross Pollutant Assessment

This task consists of quantification of gross pollutants and sediments trapped in the sump of the CDS unit over the monitoring period. The CDS unit was cleaned in late February 2006 in conjunction with installation of a new flow metering system to measure flows entering and bypassing the CDS unit. Flow was continuously monitored at this site until June 28, 2006 when the sump was cleaned and the waste material quantified. Over 14 million liters of stormwater resulting from 5.75 inches of rain were treated by the CDS unit during this time period.

A total 259.1 Kg of material was removed (Table 11; Figures 37 and 38). Visual estimates indicated that the material consisted of a 50/50 mix by volume of trash/organic materials and sediments. A subsample of this material was taken and sent to the laboratory for quantitative determination of the relative mass of the trash and other gross pollutants relative to sediments. A #4 sieve (4.75 mm or 3/16 inch) was used as the delineation between gross pollutants and sediments per recommendations from CDS and draft ASCE protocol being developed for assessment of stormwater gross solids (England and Rushton, 2005). Once the relative mass of each fraction was determined, the sediments fraction was analyzed in accordance with the QAPP and SAP.

Figure 37. Material Removed from the CDS Sump after Treating Runoff from 5.75 inches of Rain.

Results of the solids assessment are summarized in Table 11. Sediment removed from the sump consisted of 97.3 percent sand and gravel (Figure 39). Total phosphate –P was the most abundant compound measured in the sump material with an estimate total mass of over 4.5 Kg. Zinc which was the most abundant metal in stormwater runoff from the COC was present in the highest concentrations in the sump sediments.

Figure 38. Closeup of Gross Solids Removed from the CDS sump

Estimates of the equivalent concentrations removed from stormwater were developed by using the total mass of each measured constituent and the total volume of water treated during the 4-month period between cleanouts (Table 12). This very rough approximation was useful in providing a general perspective on effectiveness of the CDS unit. Sediments in the CDS sump were almost entirely in the >63 micron fraction. The equivalent concentration of 9.7 mg/L is roughly equivalent to the >63 micron fraction measured from the Porous Paving Reference Area. If the Reference Area can be considered representative of the entire COC, this would suggest that the CDS was highly effective at removing these larger particles. Similarly, total phosphorus captured in the CDS sump suggested that a large proportion of the phosphorus was collected in the CDS. The estimated mean equivalent concentration of total P was actually greater than the mean seasonal EMC of the reference site. A portion of the phosphorus removed from the sump likely resulted from breakdown of the leaves and other organic matter that comprised roughly half of the material by volume. In contrast, trace metals removed by the CDS appeared to represent a small fraction of the typical concentrations measured both at the Porous Paving Reference area and in the influent to the MFS unit. The masses of copper, lead and zinc collected from the CDS sump were estimated to be on the order of just 1-2 percent of the load that would be expected from the amount of stormwater that was treated. These rough estimates provide interesting insight as to the types of materials and contaminants that are effectively treated by the CDS unit but they are in no way definitive. Further data are necessary based upon more refined methods of quantifying the gross pollutants removed from the sump of the CDS unit.

The removal of gross pollutants by the CDS unit provides the important pretreatment necessary for the MFS unit to function correctly. The MFS unit is intended to provide further treatment of the stormwater by filtration of the finer particulates and contaminants that might be associated with the fine fraction. The following section summarizes data from monitoring conducted on this element of the Treatment Train.

Table 11. Summary Data for the Evaluation of Gross Solids Retained by the CDS Unit.

PARAMETER	VALUE
CDS SUMP TREATMENT STATISTICS	
Total Treated Water Volume (Liters)	14,383,146
Total Rainfall (inches)	5.75
Total Gross Pollutant Removal (Kg – wet)	259.1
Total Sediment (≤4.75 mm; Kg – dry)	139
CDS SUMP SEDIMENT PHYSICAL CHARACTERISTICS	
Sediment Particle Size (percent)	
Gravel	14.6
Sand	82.7
Silt	1.7
Clay	0.97
SEDIMENT CONTAMINANT CONCENTRATIONS	
Percent Solids (% wet weight)	65.1
Oil & Grease (mg/Kg – dry)	4200
TRPH (mg/Kg – dry)	750
Total P (mg/Kg – dry)	33000
TKN (mg/Kg – dry)	1100
Ammonia-N (mg/Kg – dry)	2.3
Total Copper (mg/Kg – dry)	44
Total Lead (mg/Kg – dry)	61
Total Zinc (mg/Kg – dry)	340
SEDIMENT CONTAMINANT MASS (Grams)	
Oil &Grease	584
TRPH	104
Total P	4587
TKN	153
Ammonia-N	0.3
Total Copper	6.1
Total Lead	8.5
Total Zinc	47.3

Table 12. Estimates of Mean Equivalent Stormwater Concentrations removed by the CDS Unit.

EQUIVALENT STORMWATER CONCENTRATIONS	
SSC (mg/L)	9.7
Oil &Grease (mg/L)	0.041
TRPH (mg/L)	0.007
Total P (mg/L)	0.32
TKN (mg/L)	0.011
Ammonia-N (mg/L)	0.00002
Total Copper (µg/L)	0.43
Total Lead (µg/L)	0.59
Total Zinc (µg/L)	3.3

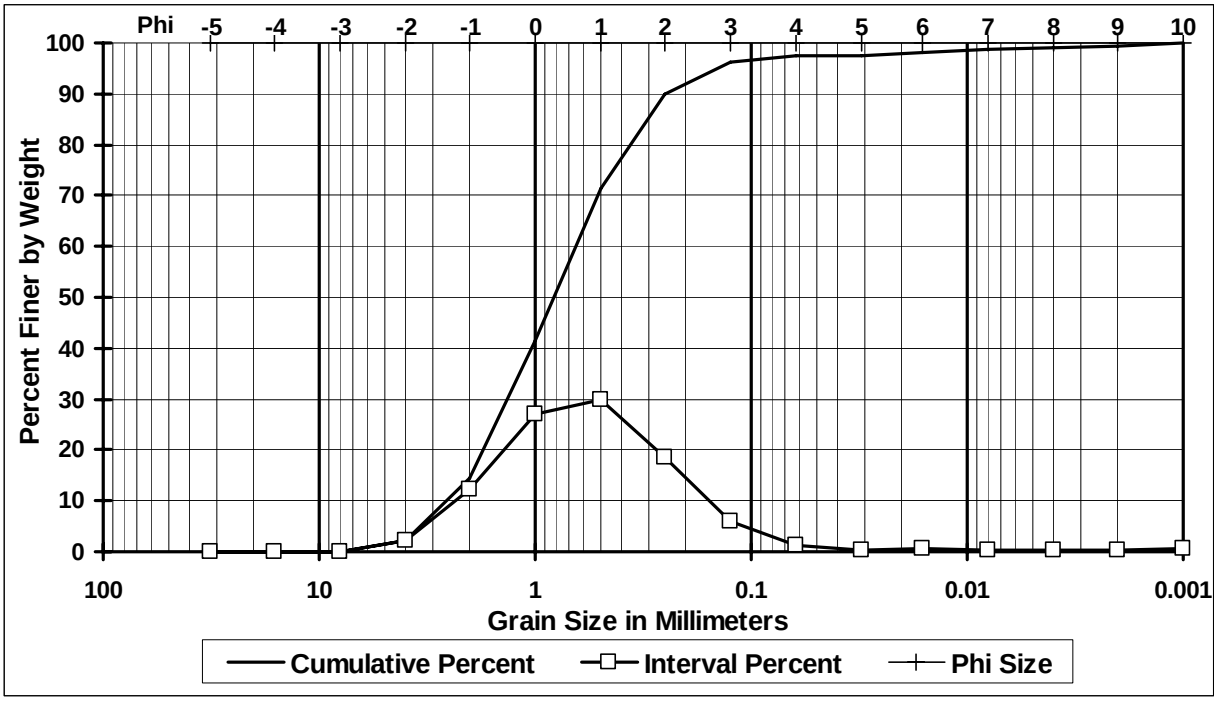

Figure 39. Particle Size Analysis of the Sediment Fraction (>4.75 mm) of Gross Pollutants collected from the CDS Sump.

3.2.3. MFS Water Quality Monitoring

The results of chemical analysis of the MFS influent and effluent are summarized in Table 13. Results from the first three events indicate that the MFS unit was effective in further removing solids from the stormwater. SSC and TSS measured in the effluent from the unit were reduced by 40-75 percent from the concentrations found in the influent. Nearly all particles in the >63 micron size fraction were removed in the final effluent. Residual concentrations of the <63 micron size fraction were ranged from 0.9 to 1.8 mg/L in the effluent. The fine particles (<63 microns) were reduced by 27 to 65 percent in the final effluent.

The effectiveness of the MFS unit in removing solids was also very evident in visual comparisons of flow composited samples of the influent and effluent from the second (Figure 40) and third (Figure 41) storm events. These photographs show the flow composited samples with all sediment suspended by a magnetic stir bar that is used to assure that the samples are well mixed during the subsampling process.

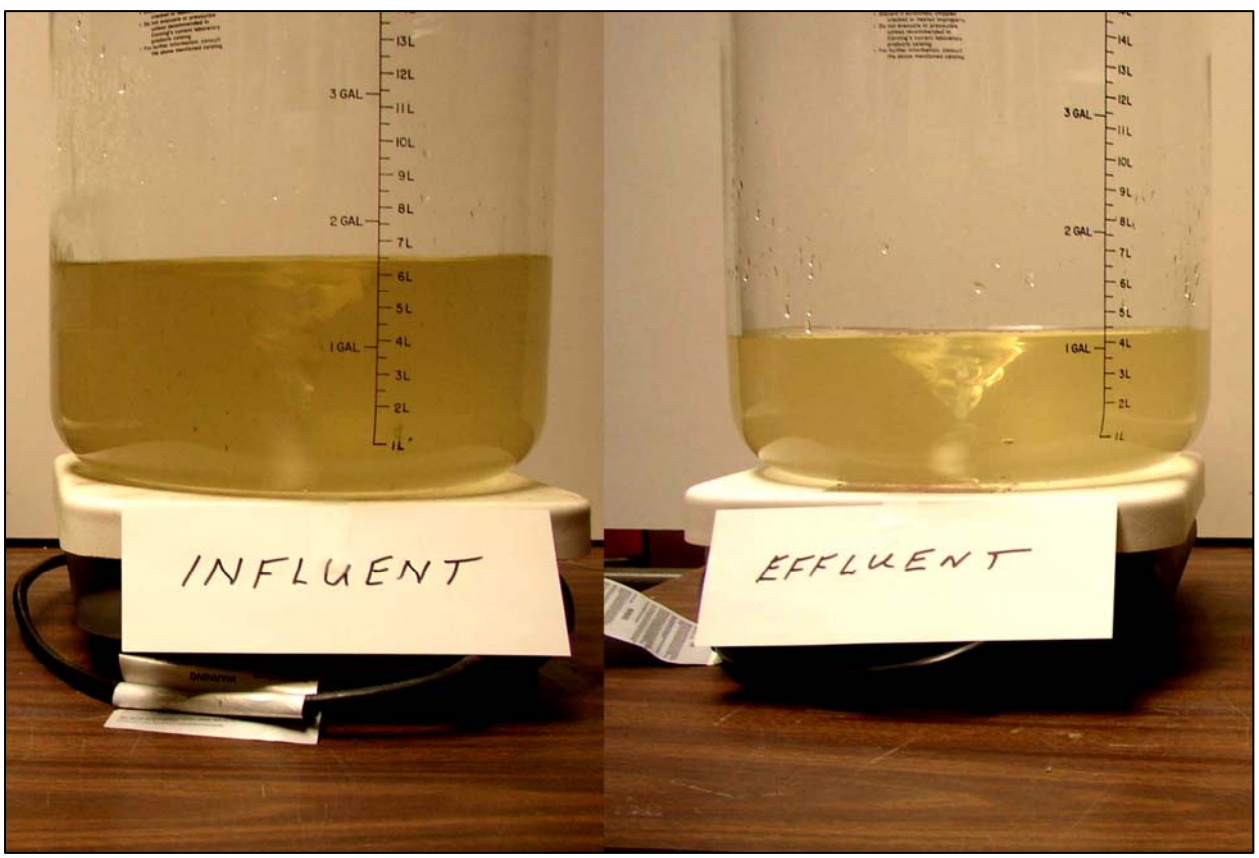

Figure 40. Composite Stormwater Samples from the MFS Influent and Effluent, 12 March 2006

Figure 41. Composite Stormwater Samples from the MFS Influent and Effluent, 19 March 2006.

Stormwater contaminants that are strongly associated with the particulate fraction also demonstrated partial removal. Among the most notable were reductions in total lead and total zinc (Table 13). As expected, concentrations of contaminants that are primarily present in the dissolved form were not affected by the MFS unit. Perlite, the current media being used in the MFS, serves primarily as a filter for fine particles and would only be expected to remove contaminants associated with particles. Expanded testing scheduled to be conducted in 2006/2007 as part of the Phase II Demonstration Project will explore alternative media that have the potential to remove various dissolved contaminants.

Due to the number of storm events, it is not appropriate to conduct a critical examination of the performance of the MFS unit. Ultimately, data will be evaluated using the "effluent probability method" recommended by USEPA/ASCE (2002). This method provides a more robust measure of performance than just reporting efficiency as percent removal. Simple use of percent removal based on the difference between influent and effluent concentrations will always make a BMP that treats stormwater with high concentrations appear to be more efficient than one treating stormwater with low concentrations of contaminants.

Table 13. Summary of Results of Chemical Analysis of Stormwater Runoff from the MFS portion of the Treatment Train during Events 1 through 3.

CONSTITUENT	Influent 28-Feb-06	Treated Effluent 28-Feb-06	Influent 12-Mar-06	Treated Effluent 12-Mar-06	Influent 19-Mar-06	Treated Effluent 19-Mar-06
Hardness (mg/L)	11	12	12	17	11	13
SSC (mg/L)	25.4	16.7	34.2	10.9	31.4	9.1
>63 microns	5.0	1.8	7.4	1.0	7.7	0.9
<63 microns	20.4	14.9	26.8	9.9	23.7	8.2
TSS (mg/L)	23	14	30	9.7	32	8.1
COD (mg/L)	56	43J	40	26	82	26
DOC (mg/L)	13	12	6.0	7.2	7.7	8.3
Total P	0.35	0.21	0.16	0.18	0.16	0.13
Ortho-P (mg/L)	0.10	0.094	0.080	0.11	0.070	0.083
Ammonia-N (mg/L)	0.44	0.48	0.18	0.15	0.23	0.15
TKN (mg/L)	1.6	1.1J	0.68	0.60	0.62	0.53
Nitrate-N (mg/L)	0.62	0.67	0.33	0.51	0.37	0.44
Total Cadmium (ug/L)	0.30	0.28	0.34	0.28	0.33	0.20
Diss. Cadmium (ug/L)	0.20U	0.20U	0.14	0.17	0.15	0.14
Total Copper (ug/L)	28	25	26	20	24	20
Diss. Copper (ug/L)	19	19	12	14	15	16
Total Lead (ug/L)	33	24	53	21	36	16
Diss. Lead (ug/L)	6.3	5.8	3.5	3.1	3.6	3.5
Total Zinc (ug/L)	190	160	200	160	180	140
Diss. Zinc (ug/L)	140	130	110	120	120	120
Calculated Values[1]						
Oil&Grease$_{(COD)}$ (mg/L)	5.8	5.3	5.2	4.7	6.7	4.7
Oil&Grease$_{(DOC)}$ (mg/L)	3.8	3.5	1.8	2.2	2.3	2.5

1. Kayhanian, M, S. Khan, and M.K. Stenstrom. 2004. A new method to estimate oil and grease event mean concentration in highway runoff. StormCon 2004.

U indicates the constituent is a not detected - the value is the reporting limit

J indicates the value is an estimate

Regardless of influent concentrations, an effective structural BMP should produce water of a consistent nature that is not likely to cause or contribute to exceedances of water quality in the receiving waters. Table 14 provides a comparison with water quality criteria specified in the Project QAPP (MEC-Weston, 2004). At the end of the Treatment Train, the final effluent contained consistently low concentrations of sediments and removed various proportions of the total metals. Since concentrations of dissolved metals were not impacted by the Treatment Train, concentrations of both copper and zinc remained elevated and exceeded the water quality criteria used as references. Although the extremely low hardness of the final effluent resulted in very low water quality criteria, dissolved copper would still have exceeded the criteria during all events with hardness values of 100 mg/L.

Table 14. Comparison of Final Effluent from the Treatment Train with available Water Quality Criteria and Guidelines.

CONSTITUENT	Treated Effluent 28-Feb-06	Treated Effluent 12-Mar-06	Treated Effluent 19-Mar-06	Reference Criteria	Source
Hardness (mg/L)	12	17	13		
SSC (mg/L)	16.7	10.9	9.1		
>63 microns	1.8	1.0	0.9		
<63 microns	14.9	9.9	8.2		
TSS (mg/L)	14	9.7	8.1	100 mg/L	Multi-Sector General Permit (USEPA 2000b)
COD (mg/L)	43J	26	26	120 mg/L	Multi-Sector General Permit (USEPA 2000b)
DOC (mg/L)	12	7.2	8.3		
Total P (mg/L)	0.21	0.18	0.13	2 mg/L	Multi-Sector General Permit (USEPA 2000b)
Ortho-P (mg/L)	0.094	0.11	0.083		
Ammonia-N (mg/L)	0.48	0.15	0.15		
TKN (mg/L)	1.1J	0.60	0.53		
Nitrate-N (mg/L)	0.67	0.51	0.44	10 mg/L	Basin Plan (RWQCB 1994)
Total Cadmium (ug/L)	0.28	0.28	0.20		
Diss. Cadmium (ug/L)	0.20U	0.17	0.14	0.5[2]	40 CFR 131 (USEPA 2000a)
Total Copper (ug/L)	25	20	20		
Diss. Copper (ug/L)	***19***	***14***	***16***	2.1[2]	40 CFR 131 (USEPA 2000a)
Total Lead (ug/L)	24	21	16		
Diss. Lead (ug/L)	5.8	3.1	3.5	7.2[2]	40 CFR 131 (USEPA 2000a)
Total Zinc (ug/L)	160	160	140		
Diss. Zinc (ug/L)	***130***	***120***	***120***	22.1[2]	40 CFR 131 (USEPA 2000a)
Calculated Values[1]					
Oil&Grease$_{(COD)}$ (mg/L)	5.3	4.7	4.7		
Oil&Grease$_{(DOC)}$ (mg/L)	3.5	2.2	2.5		

1. Kayhanian, M, S. Khan, and M.K. Stenstrom. 2004. A new method to estimate oil and grease event mean concentration in highway runoff. StormCon 2004.
2. Dissolved metals criteria are CMC (acute values) and are hardness based. Reference criteria were calculated based upon the average hardness of 14 mg/L.

U indicates the constituent is a not detected - the value is the reporting limit
J indicates the value is an estimate
Bold and Italicized values exceed the reference criteria.

4.0 CONCLUSIONS

This program was designed to address a number of specific questions. Each of the major questions is addressed in the following sections.

4.1. *Porous Pavement*

- ✓ How do normalized stormwater discharges from each treatment type (porous asphalt, porous concrete and Eco-Stone pavers) compare to normalized runoff from the reference area by both individual storm events and for the entire storm season.

  No runoff was observed at any of the three porous pavement test sites. Since the intent of normalizing runoff was to standardize the data to unit area, this comparison was not necessary. Although the 2005/2006 storm season was a relatively dry year, the total elimination of runoff from all porous pavement test sites provided strong evidence of the effectiveness of each porous pavement treatment as infiltration methods.

- ✓ How does water quality of stormwater discharges from each treatment type, measured in terms of flow-rated event mean concentrations, compare to the quality of runoff from the reference area?

  The effectiveness of all three porous pavement test sites precludes this comparison since no discharges occurred throughout the season. The mean water quality of runoff from the reference area was compared with runoff from Caltrans maintenance facilities, Caltrans park and ride lots, and a small, highly impervious urban watershed in Long Beach, California. The results of this comparison indicated that runoff from the reference site did not substantially differ from these other studies.

- ✓ How do the infiltration basins associated with each of the porous surface treatments impact stormwater discharge hydrographs?

  One would expect that infiltration facilities would reduce total flow, peak flow and extend the duration of discharge. The complete elimination of discharges from the three sites prevented nearly 34,000 cubic feet of runoff and associated pollutants resulting from 8.15 inches of rain from being discharged to the San Diego River.

- ✓ How do normalized pollutant loading rates associated with each porous surface treatment compare to those of the adjacent impervious reference area?

  The pollutant loading rates for all constituents at all porous pavement treatment sites were zero.

- ✓ At what rates do water levels in the infiltration basins of each treatment type change during and between storm events?

  Water levels in the infiltration beds of all porous pavement treatment sites were not detectable until the fourth storm event of the season in late February, 2006. Detectable increases in the water levels in the infiltration beds in response to storm events were initially only evident at the porous concrete site. During smaller, less intense events such as occurred on March 21, 2006, all water infiltrated without causing detectable increases in water levels in the infiltration basin. This may be due to the layer of scarified soil at the base of the infiltration basins.

  Evidence of water rising in the infiltration basins of the porous pavers and porous asphalt did not occur until an intense, late season storm event on April 4th and 5th, 2006. This event yielded 1.07 inches of rain and reached a maximum intensity of 0.68 inches per hour. Infiltration was slowest at the porous paver site but the maximum water level in the basin only reached 0.15 feet, 0.76 feet below the discharge level. After approximately 15 hours, water was no longer measurable in the infiltration basin. Water levels in the porous asphalt infiltration bed came within 0.2 feet of the discharge level but decreased rapidly. Within 8 hours after water levels peaked at 0.38 feet in the infiltration bed, water levels were no longer measurable. Water in the porous concrete infiltration bed increased to a maximum level of 0.48 feet leaving another 0.44 feet before reaching the level necessary to produce a discharge. Fifteen hours after reaching a level of 0.48 feet, the water level in the porous concrete bed had dropped to zero.

  Based upon the April 4th and 5th, 2006 event, infiltration rates for both the porous concrete and asphalt sites were on the order of 0.04 feet per hour or roughly 0.5 inches per hour. Much lower infiltration rates of 0.006 feet per hour (0.08 inches per hour) were observed at the porous paver site. Despite the lower infiltration rates measured at the porous paver site, the fact should not be overlooked that maximum water levels reached in the infiltration basin were minimal leaving a substantial storage volume before discharges would ever occur.

4.2. *Treatment Train*

The program is designed to address the following questions:

- ✓ What is the total volume of stormwater processed by the CDS unit for the monitoring event and for the season?

  A total of 14,383,146 liters (approximately 11.7 acre feet) of stormwater was treated by the CDS unit during a four month period. This represented 96.5 percent of the runoff from resulting from 5.75 inches of rain.

- ✓ What are the mass and general characteristics of solids removed by the CDS unit at the end of the monitoring period?

  A total 259.1 Kg-wet weight of material was removed from the CDS unit at the end of the monitoring period in June, 2006. Visual estimates indicated that the material consisted

of a 50/50 mix by volume of trash/organic materials and sediments. Sediments, defined as all material less than 4.75 mm, were estimated to total 139 Kg-dry wet. The sediment fraction was strongly dominated by coarse materials. The sediment removed from the sump was 14.6 percent gravel, 82.7 percent sand and only 2.7 percent fines (silt/clay).

- ✓ What is the mass of each target pollutant in the sediment portion of the solids removed by the CDS unit?

  Sediments from the CDS sump contained 4.587 Kg of phosphorus, 0.584 Kg of oil & grease and 0.153 Kg of TKN. Based upon the minute quantity of ammonia-N in the sediments, virtually all of the TKN was organic nitrogen. Relatively small quantities of metals were present in the sediments. The most abundant was zinc with 47.3 grams. Only 6.1 grams of copper and 8.5 grams of lead were associated with the sump sediment.

- ✓ What are the volume and pollutant loads entering the MFS unit, the volume and pollutant loads after treatment and the volume of any overflows within the MFS unit?

  The volume of water entering, bypassing and being fully treated by the MFS unit was accurately quantified during seven events. During this time a total of 146,247 liters of stormwater entered the MFS unit after receiving initial treatment by the CDS unit. Seventy-three percent of this water was effectively treated. Excessive bypasses were caused by a hydraulic imbalance that may have been caused or exacerbated by backpressure from the V-notch downstream of the unit. A modified collection box and gate valve assembly has been installed to correct this imbalance and allow flexibility in modifying or adjusting pressures within to unit to achieve the correct balance.

  Initial data indicate that the MFS unit was effective at removing both residual, coarse sediment that remained after treatment by the CDS unit and the finer (<63 micron) particles. Stormwater contaminants strongly associated with the particulate fraction also demonstrated substantial removal. Total lead and zinc exhibited the greatest reductions. As expected, contaminants that were primarily present in the dissolved form were not notably affected by the MFS.

- ✓ Does the treated stormwater meet receiving water quality standards?

  Sediment in the final effluent was reduced to less than 17 mg/L. All final effluent met the available reference criteria for TSS, COD, total phosphorus, and nitrate. The media being tested was focused on reduction of fine particulates, as a result concentrations of dissolved metals were not reduced by the Treatment Train. Concentrations of both copper and zinc remained elevated and exceeded the benchmark water quality criteria. Although the extremely low hardness of the final effluent resulted in very low water quality criteria, dissolved copper would still have exceeded the criteria during all events with hardness values of 100 mg/L.

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