CATCHBASIN STORMFILTER PERFORMANCE EVALUATION REPORT

Prepared by
Seattle Public Utilities

March 5, 2012

This page intentionally left blank.

Table of Contents

1 SUMMARY

From February 2009 through September 2011, Seattle Public Utilities (SPU) conducted a performance evaluation of the Stormwater Management StormFilter® (StormFilter) in two CatchBasin StormFilter™ (CBSFs) stormwater treatment systems configured with zeolite-perlite-granular activated carbon (ZPG™) cartridges installed in West Seattle, Washington. The monitoring work was performed to fulfull a portion of the City of Seattle's monitoring requirements contained in Section S8.F of the 2007 National Pollutant Discharge Elimination System (NPDES) Municipal Stormwater Permit (Permit) and was performed in accordance with criteria in the Permit and the Department of Ecology's (Ecology) "Technical Guidance Manual for Evaluating Emerging Stormwater Treatment Technologies: Technology Assessment Protocol - Ecology" ("TAPE," Ecology 2008 and revised 2011).

This report summarizes findings from this study based on analyses of water quality, rainfall and flow data. A total of 37 stormwater events were sampled between both of the monitored CBSF units, which exceeded the required maximum storm event number of 35 required pursuant to the Permit and TAPE. Because the maximum sample number has been achieved, this study is considered complete and SPU has fulfilled its monitoring obligation pursuant to Permit.

1.1 Water Quality Performance

The water quality treatment performance of the CBSF units was evaluated by comparing influent to effluent concentrations. For the effluent locations, only treated (not bypassed) stormwater was sampled so the water quality evaluation considers stormwater that received full treatment by the units. TAPE specifies screening criteria based on influent concentrations for total suspended solids (TSS), total phosphorus and dissolved copper and zinc. Removal rates for those four parameters are calculated using the TAPE screening criteria and discussed below. TAPE also lists performance goals for these four parameters; however, since this study was conducted to fulfill Permit requirements and not to certify stormwater treatment technology, the performance of the two CBSFs evaluated will not be directly compared to the TAPE treatment goals. Results for the three additional parameters required by the Permit which do not have TAPE screening criteria (orthophosphate, total copper and total zinc) are summarized in the body of this report.

Statistical tests were performed to test for significant differences in influent and effluent concentrations for all seven permit-required water quality parameters with a 95 percent confidence limit. The Permit's statistical power goal of 75-80 percent was met for three of the seven parameters (TSS, total copper and total zinc). Though the minimum power goal was not achieved for the remaining four water quality parameters (total phosphorus, orthophosphate, dissolved copper and dissolved zinc), greater than 35 samples were collected and consequently the Permit monitoring requirement was met.

For samples with influent total suspended solids (TSS) concentrations exceeding 100 milligrams per liter (mg/L), removal rates averaged 72 percent with a lower 95 percent confidence limit of 63 percent. For samples with influent TSS concentrations below 100 mg/L, effluent concentrations averaged 20 mg/L with an upper 95 confidence limit of 24 mg/L.

For samples with influent total phosphorus concentrations ranging from 0.1 to 0.5 mg/L, removal rates averaged 30 percent with a lower 95 percent confidence limit of 20 percent.

For samples with influent dissolved copper concentrations ranging from 5 to 20 micrograms per liter (µg/L), removal rates averaged -17 percent with a lower 95 percent confidence limit of -28 percent.

For samples with influent dissolved zinc concentrations ranging from 20 to 300 µg/L, removal rates averaged -24 percent with a 95 percent confidence limit of -34 percent.

A summary table of the treatment efficiency of the four water quality parameters with TAPE screening criteria is presented below.

Table 1.1. Water Quality Treatment Performance Summary

Parameter	Mean Removal Rate (Percent)	Lower Confidence Limit 95 (Percent)[1]	Upper Confidence Limit 95 (Percent)[2]
Total Suspended Solids (influent >100 mg/L)	72.1	62.8	NA
Total Suspended Solids (influent <100 mg/L)	NA	NA	23.6
Total Phosphorus	29.7	19.8	NA
Dissolved Copper	-17.1	-27.5	NA
Dissolved Zinc	-23.9	-34.2	NA

Notes:
NA – not applicable (corresponding statics do not apply to this cell).
[1] Lower confidence limit 95 is the one-sided lower 95% confidence limit on the estimate of the mean percent reduction.
[2] Upper confidence limit 95 is the one-sided upper 95% confidence limit on the estimate of the mean effluent concentration.

1.2 Hydrologic Performance

The CBSF units are configured with an internal bypass weir to bypass stormwater around the filtration chambers when either stormwater runoff rates exceed the design flow rate of the unit, or the media filters become clogged and their treatment capacity diminishes. The hydrologic performance of the CBSF units in this study was evaluated by comparing the quantity of treated to internally bypassed flow. The manufacturer recommended maintenance trigger is based on a visual estimation of sediment accumulation on the filter cartridges that indicates when filters should be replaced (Darcy, 2012). Although this trigger was not exceeded based on sediment accumulation measurements, the filter cartridges were replaced at least annually during this study.

With the default annual maintenance cycles, the two monitored units treated 54 and 64 percent, of the flow volume monitored from October 1, 2009 to September 30, 2011, respectively.

Analysis of flow data indicates that the filters became essentially clogged (i.e., no longer able to treat 50 percent of their design flow rate) approximately 2-½ months after filter replacement in late September at both locations over both of the maintenance cycles monitored.

After the stormwater monitoring began, field crews observed that flow from outside the area originally thought to be the second drainage area was discharging into unit CBSF2. Because of this, both basins were re-delineated to help determine if the units were properly sized for their drainage areas. Using the updated drainage areas and outputs from continuous runoff models, it was determined that the first unit (CBSF1) was properly flow-sized based on the expected runoff volume and the CBSF2 may have been undersized by a factor of 2 for the expected runoff volume. To determine the sizing based on actual flow volumes received by the units (since an unknown quantity of flow externally bypassed both units due to inlet grate clogging), a retrospective flow-based sizing analysis was performed by SPU using two years of monitored flow data which determined that the units received an average of approximately 37 percent more flow than for which they were designed (based on the flow capacity of the number of filter cartridges present). During the study period, rainfall exceeded the historic average by about 37 percent which suggests that the units were sized accurately for runoff volume they would be expected to receive during an average rainfall year.

Based on the retrospective flow analysis, the CBSF units received about 37 percent more flow than what they were designed for; so it can be roughly estimated that they received about 37 percent more solids loading. Accounting for this, the maintenance cycle under average, wet season flow conditions for both units may be closer to 3-½ months. With the reduced loading of an average rainfall year and the resulting 3-½ month maintenance frequency, the maintenance required to sustain the water quality performance of the monitored units is estimated to be approximately three times annually.

Both Washington State and City of Seattle stormwater management manuals require that stormwater treatment facilities such as the CBSFs are designed based on stormwater flow rates estimated from approved continuous runoff models. Although flow-based sizing is the standard sizing practice, a retrospective load-based sizing analysis was performed by SPU using both representative data collected during NPDES stormwater characterization monitoring (Permit Section S8.D) and actual, project specific TSS data. This SPU load-based sizing analysis suggested that CBSF1 was accurately sized while CBSF2 was undersized by a factor of 2 to 3.

The CBSF manufacturer was provided a draft version of this report for review and comment. The manufacturer provided SPU with an alternative loading analysis of the two monitored units which included recommended maintenance intervals for the existing units and an alternative retrospective load-based sizing recommendation. The manufacturer's Statement and alternative analysis is included as an Appendix to this report.

The various sizing analyses performed as part of this study indicate that the monitored CBSFs as designed using standard flow-based sizing methodologies resulted in units that were undersized for an annual maintenance cycle.

2 INTRODUCTION

The City of Seattle (City) has completed monitoring the Stormwater Management StormFilter® (StormFilter) manufactured by Contech Construction Products Inc. (Contech) which is a proprietary stormwater treatment best management practice (BMP). The specific configuration evaluated by the City was the CatchBasin StormFilter™ (CBSF). The monitoring was performed to fulfull a portion of the monitoring requirements of the 2007 National Pollutant Discharge Elimination System (NPDES) Phase I Municipal Stormwater Permit (Permit). The CBSF is frequently installed by the Seattle Department of Transportation (SDOT) to treat roadway stormwater runoff. Currently, there are approximately 90 CBSFs installed in the City. The City was interested in monitoring the effectiveness of this BMP because the media filter cartridge ("StormFilter") has received a basic treatment General Use Level Designation (GULD) by the Washington Department of Ecology (Ecology) based on testing within a large vault application, not a catch basin device.

The CBSF monitoring work was performed in general accordance with the draft Quality Assurance Project Plan (QAPP) submitted to Ecology on February 10, 2008 and approved by Ecology on September 26, 2008. The final QAPP was submitted to Ecology on February 12, 2009 and a revised final QAPP was submitted on March 31, 2011. The monitoring was performed from February 2009 through September 2011.

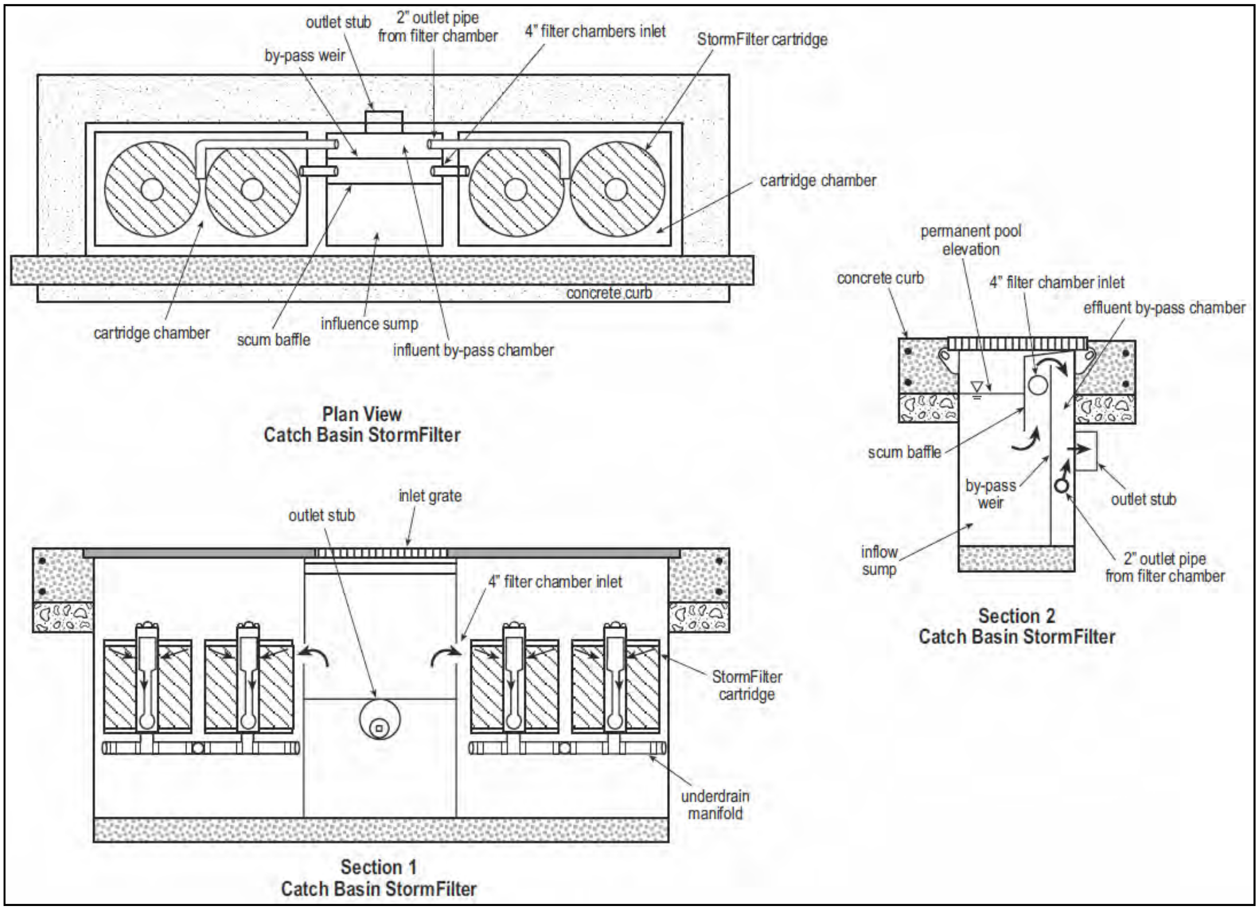
2.1 CatchBasin StormFilter Description

The Contech CatchBasin StormFilter (CBSF) is a passive, flow-through stormwater filtration system. It is engineered to replace a standard catch basin and consists of a steel vault that houses rechargeable cartridges filled with a variety of filtration media

The monitored units, which are model CBSF4, consist of four-cartridges designed to treat up to 0.067 cubic feet per second using a flow rate of 7.5 gallons per minute (gpm) per cartridge and all four cartridges. The CBSF is installed flush with the finished grade, is applicable for small drainage areas from roadways and parking lots, and is used for both retrofit applications and new development.

Each unit is designed with the following primary components: influent sump, scum baffle, two filter cartridge chambers containing two StormFilter cartridges each, an internal bypass weir and an effluent bypass chamber (see Figure 2.1a – Design Details). Stormwater initially enters the influent sump where some treatment may occur via settling of heavier particles. It then passes under the scum baffle, leaving floatable pollutants behind in the influent sump. Next, the stormwater may be routed into one of two cartridge chambers for treatment by the StormFilter cartridges. Alternatively, if the storm flow exceeds the design flow or if the treatment capacity of the StormFilter cartridges has been exceeded; the stormwater can bypass the cartridge chambers entirely by spilling over an internal bypass weir. Filtered effluent from the StormFilter cartridges and bypassed stormwater enter the effluent chamber and are subsequently discharged out of the unit and into the storm drain system via an 8-inch outlet pipe.

Figure 2.1a. CBSF Design Details



The monitored CBSFs were sized using the Western Washington Hydrology Model Version 3 (WWHM3), an Ecology-approved continuous runoff model. The units were sized assuming an online, or flow-through facility, based on the manufacturer's recommendation and the definition provided in the Stormwater Management Manual for Western Washington (Ecology 2005), Section 4.5 Hydraulic Structures, 5.1 Flow Splitter Designs:

"*Many water quality (WQ) facilities can be designed as flow-through or on-line systems with flows above the WQ design flow or volume simply passing through the facility at lower pollutant removal efficiency. However, it is sometimes desirable to restrict flows to WQ treatment* *facilities and bypass the remaining higher flows around them through offline facilities. This can be accomplished by splitting flows in excess of the WQ design flow upstream of the facility and diverting higher flows to a bypass pipe or channel*."

The cartridges tested in this study are zeolite-perlite-granular activated carbon (ZPG) cartridges (see Figure 2.1c for a schematic of the filter cartridge). Each cartridge contains a total of approximately 2.6 cubic feet (CF) of media. The ZPG cartridge consists of an outer layer of perlite that is approximately 1.3 CF in volume and an inner layer, consisting of a mixture of 90 percent zeolite and 10 percent granular activated carbon (GAC), which is approximately 1.3 CF in volume. The cartridge is covered by a plastic hood.

The ZPG cartridges are manufactured to meet the specifications described in Ecology's General Use Level Designation (GULD) for Basic Treatment issued January 2005 and updated December 2007.

Figure 2.1b. Photo of CBSF1 with Covers Removed

The manufacturer refers to the filtration process as "siphon-activated filtration" due to processes occurring within the filter. Stormwater enters each cartridge from the outside and passes through the ZPG media flowing horizontally to the center (Figure 2.1c). As the water rises within the filter chamber, air below the hood is purged via a one-way check valve in the top of the cartridge. A float in the center of each cartridge restricts the stormwater from leaving the cartridge by sealing the exit to the under-drain, causing the stormwater to wet the media evenly and equalizing flow through the media. When stormwater in the filter chamber reaches approximately the top of the float valve, the float lifts and filtered stormwater is allowed to exit the cartridge via the under-drain. This causes the check valve to close which initiates a siphon which draws the stormwater through the filter. When the inflow decreases at the end of the storm, the water level falls below the top of the float and the float falls and reseals the exit to the under-drain.

The influent sump is designed to extend the cartridge life by removal of gross solids. The cartridges are designed to be removed and replaced to maintain water quality performance. According to the manufacturer, units typically need to be maintained (cleaned and cartridges replaced) every one to three years (Atkinson, 2009).

Figure 2.1c. Filter Cartridge Details

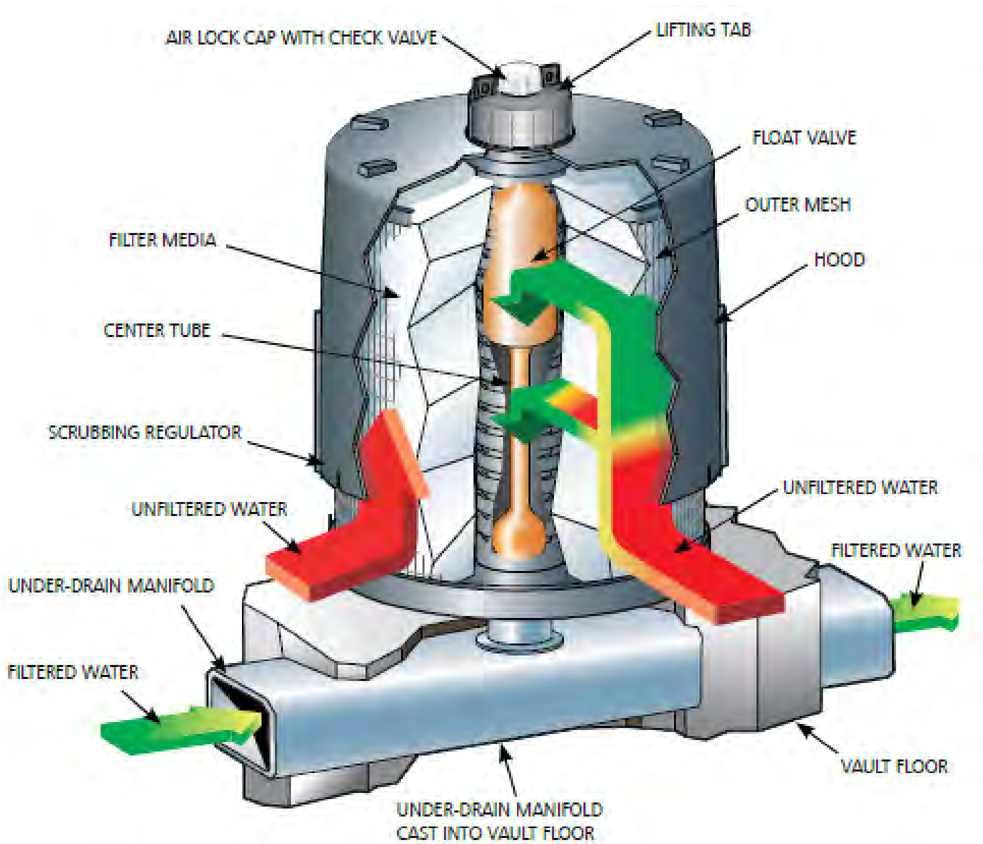


Image from Contech, CPI

2.2 Monitoring Site Descriptions

Fifteen CBSFs were installed along California Avenue SW in West Seattle in 2007 as part of roadway improvements. Two of the units were selected for monitoring. The first unit, referred to as CBSF1, is located on the southeast corner of California Avenue SW and SW Spokane Street. The second unit, referred to as CBSF2, is located on the southeast corner of California Avenue SW and SW Manning Street. Refer to Figure 2.2a – Vicinity Map and Figures 2.2b and c – Site Maps.

The two monitored CBSFs are located in drainage basins classified as commercial land use with roadways being the dominant surface type in both basins. The drainage basins for CBSF1 and CBSF2 measure approximately 0.18 acres and 0.97 acres, respectively. Refer to Figures 2.2b and c for aerial photos of each unit's basin with the basin drainage boundaries delineated.

Most of the basins' areas are impervious with the California Ave. SW northbound road surface representing almost all of the CBSF1 drainage basin and approximately 25 percent of the CBSF2 drainage basin. The remainder of the CBSF2 basin is composed of a portion of SW Charleston St. roadway, rooftops, parking lots and approximately 15 percent pervious areas consisting of landscaping. California Ave SW is lined with mature deciduous trees in both of the monitoring basins and the roadway slopes of California Ave. in the vicinity of the two basins are between 0 and 5 percent. The portion of SW Charleston St. that drains to CBSF2 has slopes between 5 and 15 percent. Development in the project area consists primarily of two story apartment buildings, commercial offices and one medical office.

Table 2.2a. CBSF Site Details

Unit ID	Cross Street	CBSF Install Date	Latitude/Longitude	Basin Size (Acres)	Percent Impervious (approx.)
CBSF1	SW Spokane St	11/7/2007	47° 34' 19.14" N, 122° 23' 12.01" W	0.18	100
CBSF2	SW Manning St	11/6/2007	47° 34' 16.14" N, 122° 23' 12.01" W	0.97	85

Based on traffic counts from the most recent SDOT survey performed over seven days in 2010, the average daily northbound California Ave SW traffic over seven consecutive days is 6,855 vehicles/day and the average daily weekday count is 7,055 vehicles/day. It is notable that the portions of California Ave. SW where the units are located are targeted to be swept by regenerative air street sweepers by the SDOT every two weeks (actual sweeping may have been less frequent due to holidays, weather and other events).

To meet the conditions of the General Use Level Designation (Ecology 2007) and prepare the units for monitoring, the following tasks were performed prior to the initiation of monitoring in February 2009:

- The units were cleaned of sediment and cartridges removed,
- New ZPG cartridges were installed,

Figure 2.2a. Vicinity Map – CBSF Monitoring Locations

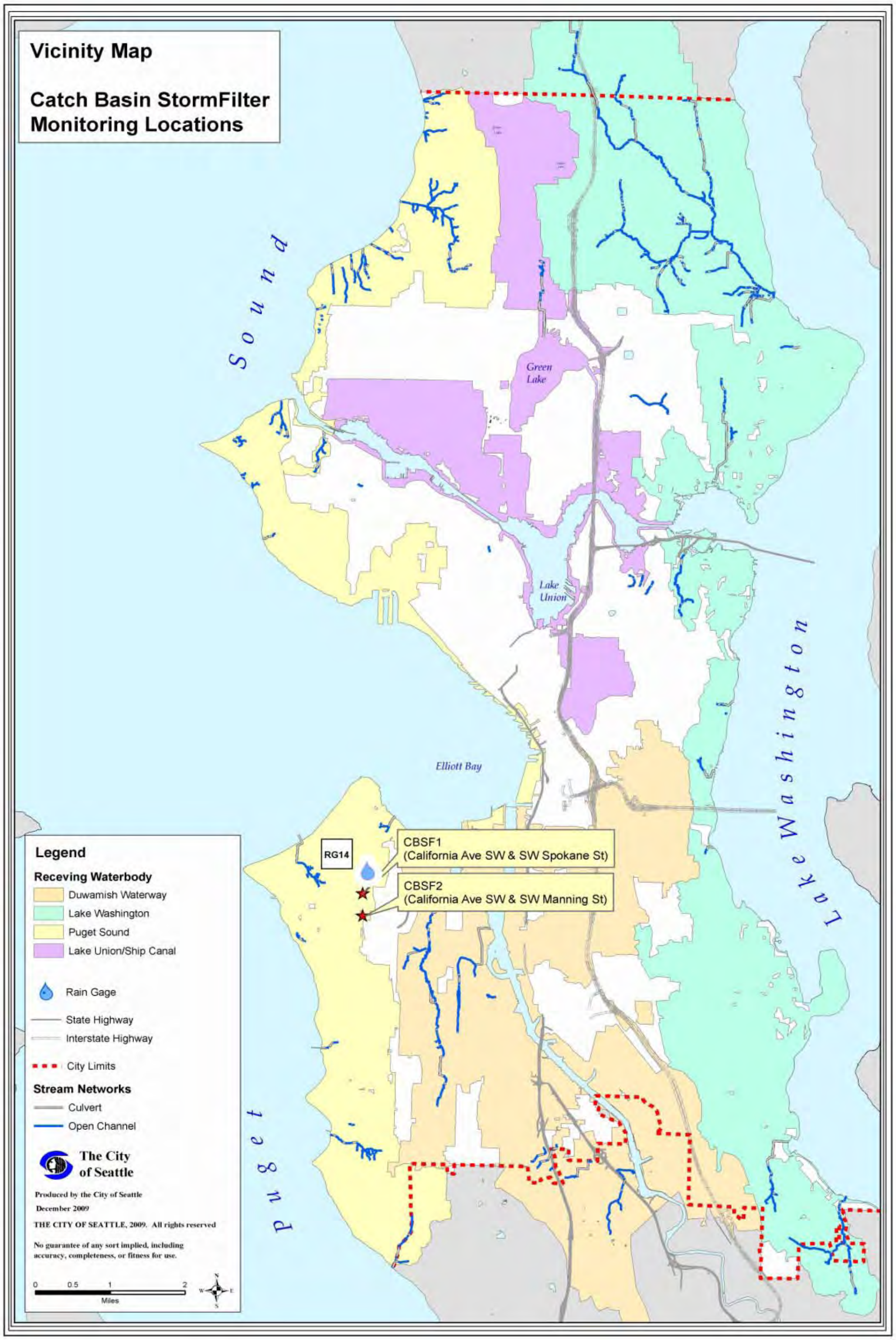
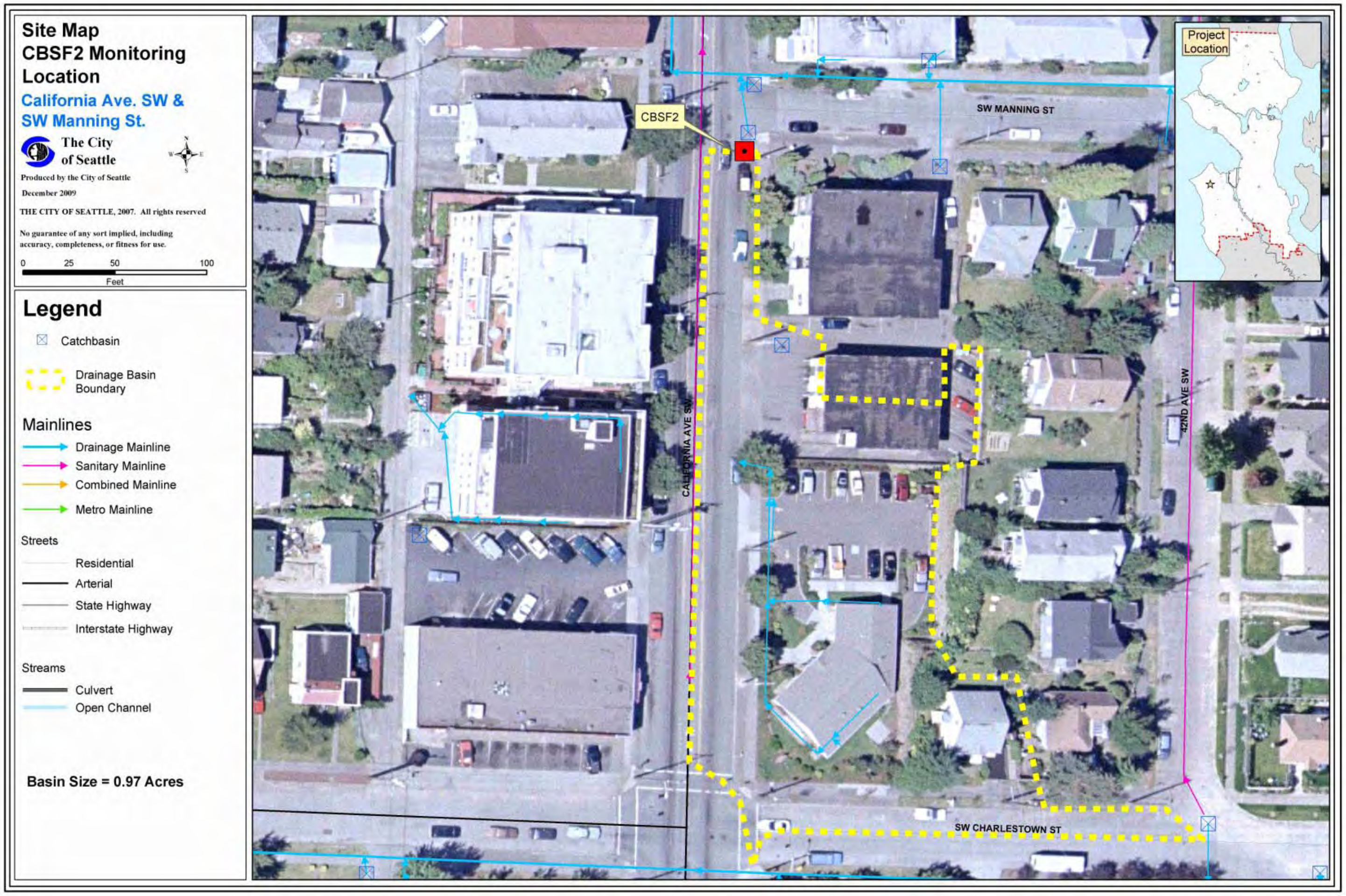


Figure 2.2b. CBSF1 Site Map

Figure 2.2c. CBSF2 Site Map



- The individual cartridge flow rate was reduced from 15 gpm to 7.5 gpm (to replicate the flow rate of the General Use Level Designation) by the addition of an orifice-control disc (orifice weir) placed at the base of the cartridges in the under-drain piping, and
- The CBSF1 unit was adapted to accommodate the lower expected flow rate (discussed below).

Unit sizing of the two monitored units was re-checked prior to beginning the monitoring. Due to the smaller basin and related lower expected flow rate in the CBSF1 basin, only the southern of the two cartridge filtration chambers configured with two filters was in use during the study. This was accomplished by installing plugs in both the 4-inch inlet orifice to the filtration chamber and the 2-inch outlet orifice from the northern filtration chamber. No adaptation was necessary for CBSF2 since the expected flow rate during the project planning phase was close to the water quality design flow rate for the entire unit with both filter chambers online based on the original basin size of 0.23 acres. However, since the final QAPP was submitted and the stormwater monitoring began, field observations indicated the CBSF2 basin captured additional runoff from SW Charlestown Street in the block east of California Ave SW that was not factored into the original basin delineation. Therefore, the CBSF2 basin area was recalculated to be 0.97 acres instead of 0.23 acres that was estimated in the original QAPP. Using this larger basin size, runoff models estimated flow rates into CBSF2 that would require seven to nine filter cartridges to accommodate. Since the maximum number of filters a CBSF unit can hold is four and the study was already underway, CBSF2 was monitored in its original four cartridge configuration.

The following table details basin characteristics and hydrologic modeling results used to size the units.

Table 2.2b. CBSF Design and Sizing Details

	CBSF1 (2 cartridges)	CBSF2 (4 cartridges)
Cross-street	SW Spokane St	SW Manning St
Catchment Area (acres) [1]	0.18	0.97
Modeled water quality design flow (online, cfs) [1]	0.031 to 0.039	0.11 to 0.14
Maximum unit filtered flow rate (cfs) [2]	0.033	0.067

Notes:
1. Expected range estimated using Western Washington Hydrology Model Version 3 (WWHM3) with SeaTac precipitation record from 1948 through 1998 and a scale factor of 1. Road slopes ranging from flat (0 to 5 percent) to steep (greater than 15 percent).
2. Maximum filtered flow rate is based on 7.5 gpm per cartridge.

2.3 Monitoring Plan Overview

To evaluate the water quality performance of the CBSFs, volume-weighted stormwater composite samples were collected from the influent and treated (filtered) effluent of each unit.

The treatment performance of each unit is evaluated based on comparisons of concentrations measured at these stations (i.e., CBSF1-In versus CBSF1-Out, and CBSF2-In versus CBSF2-Out) to calculate percent removals for each unit.

Sediment samples were collected annually, generally at the end of each water year, from the influent sump, filter chamber and effluent bypass chamber (see Figure 2.1a. CBSF Design Details) of each unit.

Flow monitors measured total flow through the units and amount of flow at the internal bypass weir. The purpose of the flow monitors was to quantify the amount of treated and bypassed flow for each unit. The flow monitors were also used to pace the automatic samplers for characterizing influent and effluent water quality.

2.3.1 Flow and Water Quality Sampling Equipment

At each CBSF unit, flow was monitored at two locations: 1) in the 8-inch outlet pipe where it discharges into the downstream catch basin and enters the storm drain system, which measured the combination of treated and bypass flow, and 2) at the bypass weir within the CBSF unit, which measured the flow bypassing the filter chamber(s). Since the units have a low hydraulic residence time and do not infiltrate water, the outlet (also referred to as "effluent") flow volume is considered to represent both the flow entering and leaving the unit and is referred to as the "total" flow.

Accurate flow monitoring in propriety BMPs is a challenging task since the units are compact and not designed for flow monitoring. To facilitate monitoring of total flow, Thel-Mar volumetric weirs were installed in each downstream outlet pipe. To monitor bypass flow, the existing, internal bypass weirs were modified into sharp-crested, rectangular weirs. The weirs are primary measurement devices which constrict and reshape the flow, creating a relationship between hydraulic head and flow. Each weir was associated with a stilling well and an Instrumentation Northwest PS9805 (0-1 psig) submerged pressure sensor for measuring water depth on the upstream face of the weirs. On October 6, 2010, all sensors were replaced with Campbell Scientific Inc (CSI) CS 450L (0-2.9 psi) submerged pressure sensors. The presence of the monitoring weirs does not affect the flow dynamics of the units except that the addition of sharp-crested weir at the bypass weir may act to slightly reduce the occurrence of bypass by slightly raising the elevation of the bypass weir.

Data from the pressure sensors were recorded at 5-minute intervals by CSI CR1000 data loggers (one data logger for each unit). The data loggers were programmed with standard weir equations to convert recorded water level data to discharge in cubic feet per second (cfs). The data loggers were also programmed to control automatic samplers and send alarms based on user-defined conditions. The monitoring equipment layout is discussed below and shown in plan and profile view in Figures 2.3.1c and d, respectively.

Figure 2.3.1a. Photo of Thel-Mar Weir in Downstream Outlet Pipe of CBSF2

Figure 2.3.1b. Photo of Bypass Weir in CBSF2

Isco 6712 automatic samplers (autosamplers) were configured to collect volume-proportional influent and effluent stormwater composite samples from each CBSF unit. Polyethylene tubing (3/8-inch internal diameter) was routed from the point of sample collection back to the autosamplers. Influent sampling stations (designated CBSF1-In and CBSF2-In) were established where the untreated roadway runoff enters each unit. Plastic trays were installed directly below the inlet grate to intercept runoff before it mixed with water in the influent sump. The influent sample line intake was placed in the tray. Effluent sampling stations (designated CBSF1-Out and CBSF2-Out) were established in the under-drain manifold beneath the filter cartridges, by inserting the sample tubing approximately 12-inches up the 2-inch outlet pipe from the filtration chamber. This configuration enabled sampling only treated effluent, as opposed to a mix of treated and untreated effluent in the effluent/bypass chamber. *Note - the location of the effluent sampler tubing (inserted into the under-drain manifold) is not depicted accurately in Figures 2.3.1c and 2.3.1d which are now out of date.* Because both filtration chambers were active in CBSF2, the effluent sampler tubing was randomly alternated between each chamber's outlet pipes from event to event to sample effluent from each active chamber. This was done in order to account for any variability in treatment between the filtration chambers.

The data logger and autosamplers were housed in an enclosure on the sidewalk immediately adjacent to each unit, and the sample tubing and sensor cables were run in conduits to each sampling/monitoring location. Wireless telemetry provided remote communications with the CR1000. A combination of batteries and solar panels powered the loggers and samplers.

SPU rain gage RG14 (06-689) was used to represent rainfall for both CBSF sites. RG14 is located at Lafayette Elementary School which is located at the corner of California Avenue SW and SW Admiral Way; approximately 0.5 miles north of the monitored units (shown on Figure 2.2a).

Figure 2.3.1c. CBSF1 Schematic Monitoring Details for (plan view and side view)
(Note – location of effluent tubing not shown accurately)

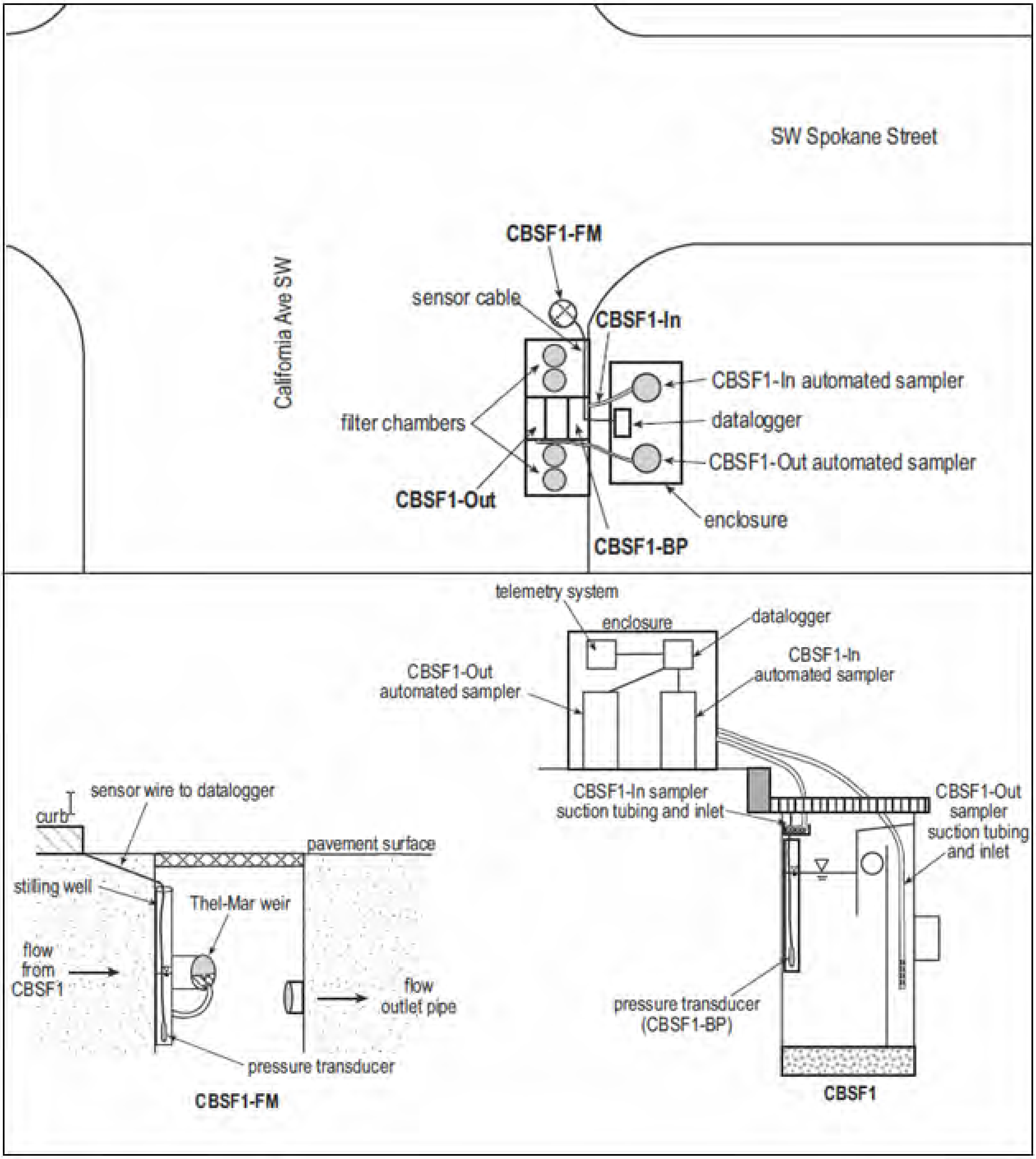


Figure 2.3.1d. CBSF2 Schematic Monitoring Details (plan view and side view)
(Note – location of effluent tubing not shown accurately)

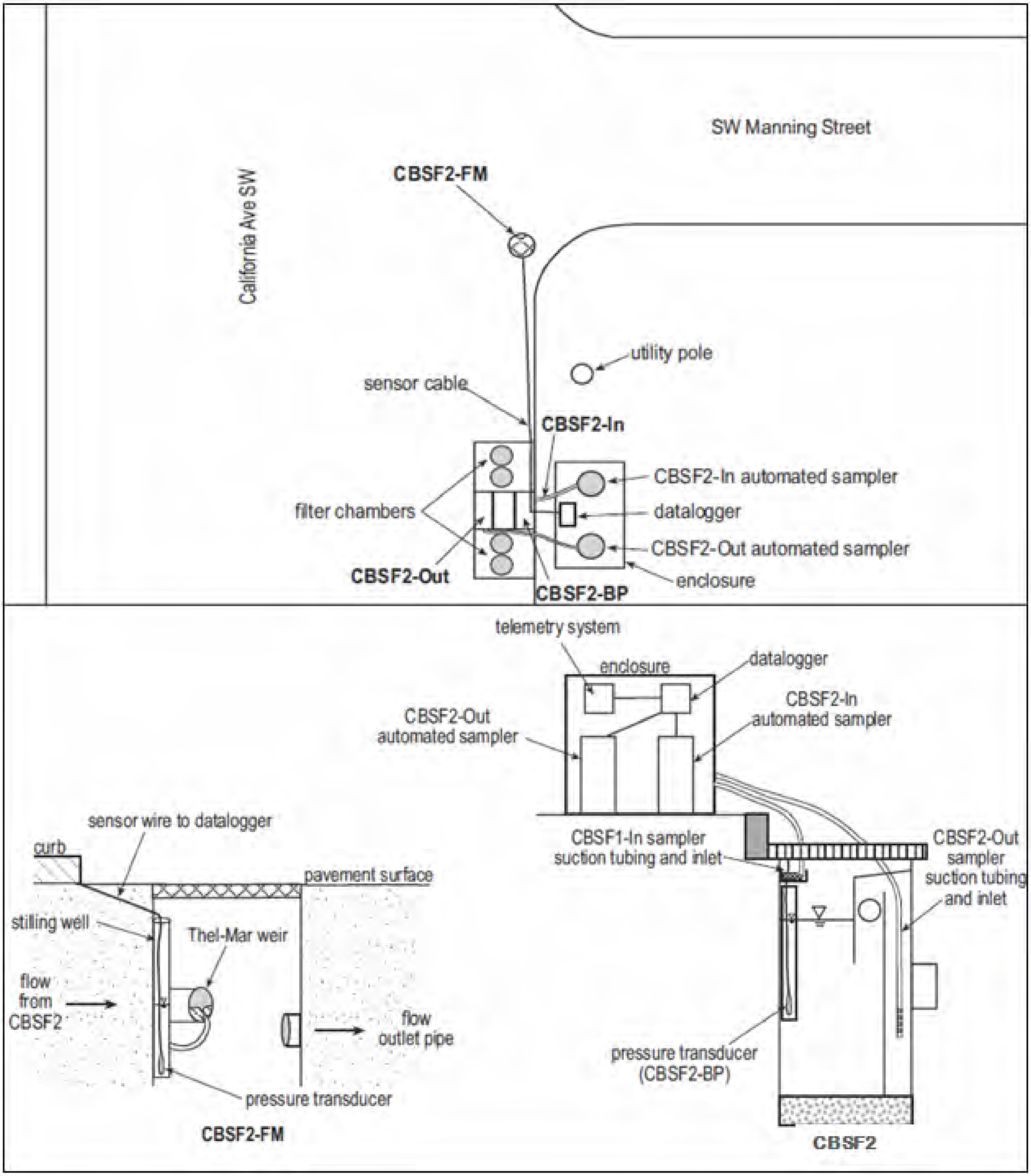
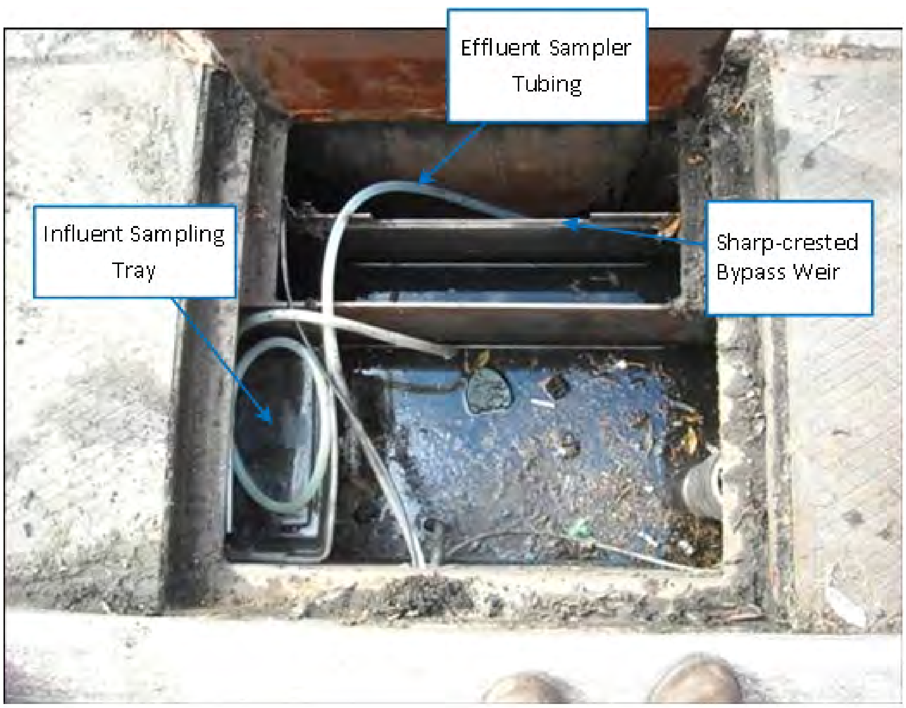


Figure 2.3.1e. Photo of Samplers in Equipment Cabinet

Figure 2.3.1f. Photo of Inlet Chamber showing Sample Tubing



2.3.2 Sediment Monitoring Locations

Sediment accumulation and sediment quality was monitored in each chamber of the two CBSFs to quantify the mass and chemical characteristics of particulates retained by each unit at the following locations:

Influent sump (designated sampling locations CBSF1-Sed1 and CBSF2-Sed1)
Filter chamber (designated sampling locations CBSF1-Sed2 and CBSF2-Sed2)
Effluent by-pass chamber (designated sampling locations CBSF1-Sed3 and CBSF2-Sed3)

3 SAMPLING, MONITORING AND MAINTENANCE PROCEDURES

SPU staff performed all weather tracking, flow monitoring, stormwater sampling and sediment monitoring and sampling activities during Water Years (WY) 2010 and WY2011. Monitoring equipment installation, and limited flow monitoring and stormwater sampling during WY2009 was performed by Herrera Environmental Consultants, Inc (Herrera).

Note on the water year (WY) reference used in this report – The NPDES stormwater permit required monitoring to be based around water years which begin on October 1 and end on September 30, with the second of the two years being the reference for that water year (e.g., WY2011 started on October 1, 2010 and ended on September 30, 2011). Although this report summarizes all data collected during the three water years spanned during this study, the WY designation is referred to in this report when it is helpful to explain monitoring frequency or for presentation of results.

3.1 Weather Tracking and Storm Criteria

Weather and rainfall data were continuously monitored using multiple forecasting, radar and satellite sources to target storms that meet the Permit criteria for a qualifying event, listed in the following table.

Table 3.1. Qualifying Storm Event Criteria

Criteria	Requirements
Target storm depth	A minimum of 0.15 inches of precipitation over a 24-hour period
Rainfall duration	Target storms must have a duration of at least one hour
Antecedent dry period	A period of at least 6 hours preceding the event with less than 0.04 inches of precipitation.
Storm capture coverage	75% (for storms longer than 24 hours, 75% of first 24 hours)
End of storm	A continuous 6-hour period with less than 0.04 inches of precipitation.

3.2 Precipitation Monitoring Procedures

SPU regularly collects precipitation data from a network of 17 tipping bucket rain gages located throughout Seattle. Precipitation data are aggregated over one-minute intervals and transmitted via wireless telemetry to a centralized server. The rain gage network is operated and maintained under contract by ADS Environmental Services, Inc. (ADS).

Rain gage inspection and maintenance is performed on a quarterly basis. Maintenance includes: checking the levelness of the gage and re-leveling, if necessary; and cleaning of filter screens, drain holes and siphons. Gages are verified and calibrated annually by sending a known volume of water through the gage a minimum of two times, averaging the gage's measurement and comparing the average to the known volume. If the measurement is greater than +/- 2 percent of

the actual volume, the gage is adjusted in the field until it reads within 2 percent or replaced with another gage, and the inaccurate gage is sent back to the manufacturer for calibration.
All maintenance and calibration activities and any observed problems are recorded on a data sheet. Calibration information from these data sheets is used to correct the raw rain data.

3.3 Flow Monitoring Procedures

Flow monitoring equipment type and configuration at each site are described in Section 2.3.1. Level and flow data were logged at five-minute intervals and downloaded daily via cellular telemetry. To measure flow, standard dimension weirs (primary devices) were used in conjunction with submerged pressure sensors (secondary devices).

Flow monitoring quality assurance/quality control (QA/QC) procedures are discussed in Section 3.7.2 and the complete flow monitoring QA/QC report is presented in Appendix A.

3.4 Water Quality Sampling and Processing Procedures

Volume-proportioned stormwater composite samples were collected using Isco 6712 autosamplers. The samplers utilize a peristaltic pump to draw stormwater from the strainer installed at the sampling location and distribute it to a 20 L polyethylene (poly) composite bottle in the sampler base.

The data loggers were programmed to trigger the samplers every time a specified volume (referred to as the “trigger volume”) was measured at the outlet flow monitoring location of each CBSF, creating a volume-weighted composite. Each CBSF has one data logger which triggered the influent and effluent samplers simultaneously. Each trigger resulted in the collection of one stormwater aliquot (or subsample) collected by each sampler which was deposited into the 20L composite bottle. Each aliquot was 200 mL so the composite bottle could receive 100 aliquots before becoming full. Bottles were removed and replaced as necessary over the course of each sampled event.

Since stormwater samples, specifically stormwater solids concentrations and related contaminants, are particularly susceptible to bias without proper processing procedures; all composite samples were composited and split (sub-sampled) in SPU’s Water Quality Laboratory (WQL) (or at the contract laboratory during WY2009) using large, custom-made polyethylene churn splitters (see photo in Figure 3.4).

Figure 3.4. Photo of Churn Spittler

3.5 Sediment Monitoring and Sampling Procedures

Sediment was sampled annually at the end of the water year (earlier during WY2011, see Section 4.5). During the annual sediment sampling event, overlying water was removed using a vactor truck and the sediment depth was measured using an engineer's tape measure. Sediment depth was measured at up to five locations (four corners and the center); in each chamber the depths were averaged to determine the average sediment depth per chamber. The depth of sediment accumulated on top of the cartridges was also measured.

One sediment composite sample was collected from each chamber per CBSF. Since both filter chambers were active in CBSF2, one composite was generated from sediments collected from both chambers. Sediment from at least five locations in each chamber was collected using a stainless steel spoon. The sediment from each chamber was placed in a stainless bowl and homogenized by mixing and turning with the spoon. Any foreign debris (e.g., cigarette butts, trash, and inorganic debris greater than 2 centimeters in diameter) was removed. The remaining sediment was transferred into analyte-specific containers.

At the completion of sediment sampling, all accumulated sediment was removed and the units maintained per the manufacturer's instructions.

3.6 Decontamination Procedures

Prior to sampling, all water quality and sediment sampling equipment - which includes sampler tubing, sample bottles, churn splitters, and stainless steel spoons and bowls - were decontaminated with the following procedure:

1. Wash in a solution of laboratory-grade, non-phosphate soap and tap (city) water.
2. Rinse in tap water.
3. Wash in a 10 percent nitric acid/deionized water solution.*
4. Rinse in deionized water.
5. Final rinse in deionized water.

** Nitric wash omitted for stainless steel equipment*

3.7 Sampling and Monitoring QA/QC Procedures

3.7.1 Precipitation Monitoring QA/QC Procedures

All raw rainfall data were reviewed by ADS on a monthly basis. Data were reviewed for errors such as periods of no recorded rainfall when nearby rain gages record rain, excessive or unrealistic measured rainfall, periods of non-rain tips due to calibration or other activity, and other indicators of inaccurate data. Maintenance and calibration data sheets were reviewed to inform the data evaluation. Raw rainfall data were edited to remove erroneous or test tips which are recorded on a monthly edit log. Areas of missing data were either filled using transposed data from the nearest working gage or data were replaced with "*" to indicate missing data. All rain data were flagged with one of the four following qualifiers: 1) "*" - no data, 2) "R" – raw, unedited data, 3) "T" – data transposed from the nearest rain gage with validated data, and 4) "V" – validated data (confirmed accurate or made accurate by deletion of erroneous data). Only validated rain data are presented in this report.

3.7.2 Flow Monitoring QA/QC Procedures

Level and flow data were automatically downloaded on a daily basis. On a monthly basis, the data were inspected for any significant trends in reliability and/or accuracy (i.e., substantial level jump/drop, upward or downward drift, spikes, flat-line data or data gaps). If anomalies were observed, a field crew was deployed to troubleshoot and calibrate the sensors.

Routine flow monitor maintenance visits were performed at a minimum of once per month, prior to every storm event or as needed based on remote real-time monitor checks or data reviews. During these visits, sensors were adjusted to exact level based on manual measurements for the bypass sensors, or by topping off the Thel-Mar weirs by adding water and zeroing the transducers for the outlet sensors. As part of the calibration tracking procedure, level values before and after calibration were recorded. If the before and after values differed by more than 0.02 feet (0.02 feet is less than one percent of the full 2.31 feet sensor range), the data were corrected for the level drift during post processing data editing. The difference between these values was also tracked over time to assess long-term drift. Long term drift was used to indicate when to replace the level sensors. Due to unacceptable sensor drift issues, all sensors were replaced with new sensors once on October 6, 2010.

Raw level data and rain data were transferred into an Isco Flowlink® database for review and editing. Based on before and after values recorded during each maintenance visit and rain data, level data were edited using proportional, fixed offset or constant value correction tools. Finalized level data were converted to flow rates using custom level-to-flow equations generated for each weir based on empirical, controlled flow testing performed in June 2011 (discussed below in Section 5.3.2 and Appendix A). Only edited/finalized data are used for calculations and presented in this report. The complete flow data QA/QC report is present in Appendix A.

Note – flow data and total flow volumes presented in previous Annual Monitoring Reports (submitted March 2010 and March 2011 for Permit compliance) should be considered preliminary estimates since those flow data were produced using untested weir equations provided by the manufacturer or calculated from standard weir equations. All flow data in this report has been recalculated with the empirical rating equations developed in June 2011 (discussed in Section 5.3.2) and are considered final.

3.7.3 Field QC Sample Collection Procedures

During this study, numerous field QC samples were collected to evaluate the sampling operation and to quantify and document bias that can occur in the field and variability that can occur in the laboratory. QC samples provide the ability to assess the quality of the data produced by field sampling and a means for quantifying sampling and analytical bias.

Table 3.7.3 lists the types of QC samples collected, description of how the QC samples were collected, the purpose and information provided by each sample and the number of samples collected during each of the three water years.

The stormwater field split samples were generated in the laboratory by field staff by filling two identical analyte-specific containers simultaneously from the churn splitter. Field stormwater split samples were collected at frequency of 12.1 percent of the stormwater samples collected.

The tubing blanks were made by field staff passing reagent grade deionized water through decontaminated sample intake tubing and peristaltic pump tubing and capturing the blank water in analyte-specific bottles. Each of the four sampler tubing lines was tested once annually. Blanks were taken on the stormwater composite sample bottles and the churn splitter once during the project.

Table 3.7.3. Field QC Sample Summary

QC Sample Type	Code	Description	Purpose/Info Provided	Number Collected WY2009	Number Collected WY2010	Number Collected WY2011	Total Number Collected	Collected on
Field Split Sample	FSS	Primary Environmental Sample (PES) split by field staff	Quantify variability from laboratory procedures	0	5	4	9	Stormwater composite samples
Field Blank Sample	FBS	Blank water passed through decontaminated sampling equipment in the field	Tests cleaning procedures and quantifies contamination from field sampling activities	4	4	6	14	Autosampler tubing, splitters, stormwater sample bottles
Field Duplicate Sample	FDS	Simultaneous sample collected at same location as PES	Quantify variability from field sampling activities Quantify variability from laboratory procedures	1	1	1	3	Sediment samples

The sediment field duplicate samples were collected by field staff by simultaneously filling analyte-specific containers from the homogenized sediment sample. Field duplicate sediment samples were collected at frequency of 21.4 percent of the sediment samples collected.

3.8 Analytical QA/QC Procedures, Methods and Reporting Limits

3.8.1 Analytical QA/QC Procedures

All laboratory data packages received included a hardcopy report and an electronic data deliverable (EDD). The laboratory case narratives were reviewed with each sample delivery group for quality control issues and corrective action taken. The data were evaluated for required method, reporting limit (RL), package completeness, holding time, blank contamination, accuracy and precision.

Each EDD was imported into a validation and review database, where deviations from the Measurement Quality Objectives (MQOs – listed in QAPP) were identified and associated samples were qualified accordingly. Data qualifiers are listed on analytical summary tables found in the body of the report and qualification details are included in the Analytical Data QA/QC report in Appendix B.

3.8.2 Analytical Methods and Reporting Limits

The following tables present the methods and reporting limits (RL) used by the project analytical laboratories. Reporting limits represent the minimum concentration of an analyte in a specific matrix that can be identified and quantified above the method detection limit and within specified limits of precision and bias during routine analytical operating conditions. Reporting limits can vary by individual samples, particularly for sediments where the quantity and dilution analyzed affect the minimum detectable value.

Table 3.8.2a. Stormwater Analytes, Methods and Reporting Limits (RL)

Analyte Group	Analyte	WY2009 RL	WY2010-WY2011 RL	Units	Lab Method
Conventionals	Hardness	0.33	1	mg/L CaCO3	SM2340C
	pH	0.01	0.01	std units	SM4500H
	Solids, Total Suspended	1	0.5	mg/L	SM2540D
	Particle Size Distribution	0.01	0.01	mg/L	ASTMD3977C/TAPE
Metals	Copper - Dissolved	0.5	1	ug/L	EPA200.8
	Copper - Total	0.5	1	ug/L	EPA200.8
	Zinc - Dissolved	4	1	ug/L	EPA200.8
	Zinc - Total	4	1	ug/L	EPA200.8
Nutrients	Orthophosphate	0.01	0.001	mg-P/L	SM4500PF
	Phosphorus, Total	0.02	0.002	mg-P/L	SM4500PF

Table 3.8.2b. Sediment Analytes, Methods and Reporting Limits (RL)

Analyte Group	Analyte	WY2009 RL	WY2010-WY2011 RL	Units	Lab Method
Conventionals	Solids, Total	0.01	0.01	%	SM2540B
	Grain Size	0.1	0.1	%	PSEP-PS
	Solids, Total Volatile	0.01	0.01	%	EPA160.4
Petroleum Hydrocarbons	Diesel Range	25	5	mg/Kg	NWTPH-DX
	Motor Oil	10	10	mg/Kg	NWTPH-DX
Metals	Cadmium	0.3	0.1	mg/kg	EPA200.8
	Copper	0.5	0.5	mg/kg	EPA200.8
	Lead	5	0.1	mg/kg	EPA200.8
	Zinc	2	4	mg/kg	EPA200.8
Nutrients	Phosphorus, Total	3	0.4	mg/kg	SM4500PE

3.9 Maintenance Activities

In accordance with manufacturer recommendations, the CBSF units were maintained a minimum of four times over the course of this study. Maintenance included removing all sediment using a vactor truck, washing the entire unit clean with a pressure washer and replacing all spent cartridges with cartridges recharged by the manufacturer. Maintenance was performed by either City contractors or by SPU Field Operations staff overseen by a Contech representative (September 2009 only).

Both units were maintained on February 10, 2009 to prepare for monitoring activities which officially began February 16, 2009. CBSF1 was accidently cleaned/maintained by the City's contractor on June 15, 2009 against the City's wishes since annual sediment sampling had not yet been performed. Maintenance was performed again on September 23, 2009 at the end of WY 2009, again on September 28, 2010 (end of WY2010), and again on June 9, 2011 (to allow for controlled flow testing of new cartridges – discussed later).

Figure 3.9. Photo of Vactor Cleaning Cartridge Chamber (Cartridges Removed)

Maintenance was performed annually, or sooner, although the one observable sediment loading trigger for maintenance provided by the manufacturer [>0.25 inches sediment accumulation on top of the cartridge (Darcy, 2012)] was not exceeded.

4 SAMPLING AND MONITORING RESULTS

The following section present a summary of storm events sampled during the course of this study and presents the stormwater analytical data. Data analysis and BMP performance are discussed in Section 5.

4.1 Sampled Storm Event Summary

A total of 37 storm events were successfully sampled at the two monitored CBSF locations during the course of this study (19 events at CBSF1 and 18 events at CBSF2). These events qualified for all rainfall and sampling criteria as identified in the NPDES permit.

Events were numbered sequentially at each site so the first event sampled at each site was designated Storm Event (SE)-01. For example, CBSF1 SE-01 and CBSF2 SE-01 are the first events sampled at each site and CBSF1 SE-19 and CBSF2 SE-18 are the last events sampled at each site, respectively.

The precipitation, flow and sample information for each sampled event, are presented in Tables 4.1a and b. This information is also presented graphically on annual and event-specific hydrographs presented in Appendix C.

4.2 Stormwater Analytical Data Summary

The results of the 37 events sampled are presented in several different formats in this report. First, all results are summarized in Tables 4.2a through d, with results for all analytes shown including qualifiers. For presentation purposes, influent data from each site are summarized on the first and second tables and effluent data from each site are summarized on the third and fourth tables. The particle size distribution data are aggregated for all influent and effluent samples collected during the study and presented both in tabular and graphical form below in Section 4.2.1. Summary of pH and hardness data in stormwater are presented in Sections 4.3 and 4.4, respectively.

Later in the report (Section 5.1.3), monitoring results by parameter for the seven main performance parameters are presented with statistical information and performance efficiencies calculated. Statistical summaries of the analytical data in both tabular and graphical formats are presented in Appendix D. Lastly, box plots and summary statistics, including charts plotting influent concentrations against effluent concentrations, are included in Appendix D.

All WY2009 water chemistry analyses were performed by Analytical Resources Inc (ARI) of Tukwila, WA. All subsequent stormwater chemistry analyses were performed by SPU's Water Quality Laboratory in Seattle with the exception of Particle Size Distribution and sediment chemistry, which was analyzed by ARI throughout the duration of this study.

Table 4.1a. CBSF Event Hydrologic Data – Storm Events 01-09

Analyte Name	Goal	SE-01	SE-02	SE-03	SE-04	SE-05	SE-06	SE-07	SE-08	SE-09	SE-10
CBSF1											
Storm Event Start	NA	01-MAR-2009 14:00	02-MAR-2009 18:05	21-OCT-2009 05:00	25-OCT-2009 07:40	05-NOV-2009 10:00	14-DEC-2009 09:00	11-MAR-2010 01:30	25-MAR-2010 04:00	02-APR-2010 05:00	19-MAY-2010 14:00
Storm Event End	NA	02-MAR-2009 09:40	03-MAR-2009 09:20	21-OCT-2009 13:45	26-OCT-2009 13:05	06-NOV-2009 12:00	15-DEC-2009 03:00	11-MAR-2010 13:30	26-MAR-2010 10:00	02-APR-2010 13:30	20-MAY-2010 03:00
Storm Event Duration (hrs)	>1	19.7	15.3	8.8	29.4	26	18	12	30	8.5	13
6-hr Antecedent Rain (in)	<= 0.04	0	0.01	0	0	0	0	0	0	0	0
24-hr Antecedent Rain (in)	NA	0.13	0.25	0	0	0	0	0.05	0	0.01	0
Event Rainfall (in)	>= 0.15	0.39	0.22	0.18	0.95	1.11	0.41	0.3	0.5	0.49	0.4
Event Rainfall Max (in/hr)	NA	0.08	0.07	0.07	0.23	0.17	0.12	0.05	0.1	0.12	0.13
Storm Event Rainfall Mean (in/hr)	NA	0.023	0.015	0.020	0.033	0.043	0.023	0.023	0.022	0.054	0.031
Event Total Flow Max (cfs)	NA	0.039	0.029	0.008	0.145	0.098	0.031	0.017	0.047	0.026	0.111
Event Total Flow Mean (cfs)	NA	0.002	0.002	0.001	0.007	0.004	0.002	0.003	0.002	0.009	0.004
Event Total Flow Volume (cf)	NA	143.3	86.5	40.7	760.9	414.9	116.3	127.3	265.1	267.4	209.7
Event Bypass Flow Max (cfs)	NA	0.000	0.000	0.000	0.162	0.107	0.044	0.017	0.043	0.027	0.207
Event Bypass Flow Mean (cfs)	NA	0.000	0.000	0.000	0.005	0.001	0.003	0.002	0.002	0.009	0.005
Event Bypass Flow Volume (cf)	NA	0.0	0.0	0.0	575.0	109.0	187.4	64.9	170.6	262.1	211.8
No. Composite Sample Aliquots	>= 10	25	14	14	140	25	16	23	147	73	78
Event Flow Volume Sampled (%)	>= 75	95.6	93.3	89.7	99.3	96.8	93.2	97.9	99.8	99.8	99
CBSF2											
Storm Event Start	NA	01-MAR-2009 14:00	02-MAR-2009 18:05	25-OCT-2009 14:00	05-NOV-2009 10:00	14-DEC-2009 09:00	16-DEC-2009 09:00	04-FEB-2010 21:00	10-FEB-2010 11:00	11-MAR-2010 01:30	25-MAR-2010 04:00
Storm Event End	NA	02-MAR-2009 07:20	03-MAR-2009 10:25	26-OCT-2009 14:30	06-NOV-2009 12:00	15-DEC-2009 03:00	17-DEC-2009 02:00	05-FEB-2010 12:00	11-FEB-2010 13:00	11-MAR-2010 13:30	26-MAR-2010 03:00
Storm Event Duration (hrs)	>1	17.3	16.3	24.5	26	18	17	15	26	12	23
6-hr Antecedent Rain (in)	<= 0.04	0	0.01	0	0	0	0.02	0	0	0	0
24-hr Antecedent Rain (in)	NA	0.13	0.25	0	0	0	0.31	0.04	0	0.05	0
Event Rainfall (in)	>= 0.15	0.39	0.22	0.95	1.11	0.41	0.41	0.16	0.23	0.3	0.5
Event Rainfall Max (in/hr)	NA	0.08	0.07	0.23	0.17	0.12	0.06	0.05	0.07	0.05	0.1
Storm Event Rainfall Mean (in/hr)	NA	0.023	0.015	0.038	0.043	0.023	0.024	0.011	0.009	0.023	0.022
Event Total Flow Max (cfs)	NA	0.103	0.125	0.146	0.080	0.164	0.138	0.041	0.046	0.042	0.144
Event Total Flow Mean (cfs)	NA	0.010	0.008	0.014	0.010	0.031	0.023	0.004	0.003	0.010	0.010
Event Total Flow Volume (cf)	NA	631.2	447.8	1222.9	953.7	2002.5	1383.6	227.8	241.8	428.8	837.9
Event Bypass Flow Max (cfs)	NA	0.000	0.000	0.169	0.000	0.087	0.051	0.000	0.009	0.001	0.191
Event Bypass Flow Mean (cfs)	NA	0.000	0.000	0.003	0.000	0.003	0.001	0.000	0.000	0.000	0.005
Event Bypass Flow Volume (cf)	NA	0.0	0.0	298.2	0.0	205.1	41.9	0.0	13.0	0.3	404.4
No. Composite Sample Aliquots	>= 10	42	23	51	25	100	76	27	29	14	141
Event Flow Volume Sampled (%)	>= 75	99.6	94.1	96.9	93	85	99	97.9	97.2	89	99.5

NA – not applicable

Table 4.1b. CBSF Event Hydrologic Data – Storm Events 10-19

Analyte Name	Goal	SE-10	SE-11	SE-12	SE-13	SE-14	SE-15	SE-16	SE-17	SE-18	SE-19
CBSF1											
Storm Event Start	NA	19-MAY-2010 14:00	01-JUN-2010 22:00	08-JUN-2010 21:00	26-OCT-2010 10:00	29-NOV-2010 18:00	04-JAN-2011 19:00	07-MAR-2011 23:30	14-MAR-2011 19:00	13-APR-2011 06:30	27-APR-2011 14:45
Storm Event End	NA	20-MAY-2010 03:00	02-JUN-2010 11:30	09-JUN-2010 12:30	26-OCT-2010 17:40	30-NOV-2010 19:50	05-JAN-2011 08:25	08-MAR-2011 13:20	16-MAR-2011 08:40	14-APR-2011 05:50	28-APR-2011 00:20
Storm Event Duration (hrs)	>1	13	13.5	15.5	7.7	25.8	13.4	13.8	37.7	23.3	9.6
6-hr Antecedent Rain (in)	<= 0.04	0	0.01	0	0	0	0	0	0	0	0.01
24-hr Antecedent Rain (in)	NA	0	0.01	0	0.07	0.03	0	0	0.71	0	0.01
Event Rainfall (in)	>= 0.15	0.4	0.27	0.45	0.2	0.95	0.22	0.15	0.72	0.18	0.22
Event Rainfall Max (in/hr)	NA	0.13	0.04	0.11	0.07	0.09	0.09	0.05	0.14	0.03	0.12
Storm Event Rainfall Mean (in/hr)	NA	0.031	0.019	0.028	0.025	0.037	0.017	0.011	0.019	0.008	0.024
Event Total Flow Max (cfs)	NA	0.111	0.017	0.050	0.023	0.025	0.019	0.013	0.121	0.013	0.034
Event Total Flow Mean (cfs)	NA	0.004	0.002	0.003	0.004	0.008	0.002	0.001	0.003	0.000	0.002
Event Total Flow Volume (cf)	NA	209.7	99.2	169.6	119.7	697.5	111.2	66.7	380.7	28.8	84.2
Event Bypass Flow Max (cfs)	NA	0.207	0.028	0.071	0.000	0.000	0.000	0.001	0.103	0.012	0.029
Event Bypass Flow Mean (cfs)	NA	0.005	0.002	0.004	0.000	0.000	0.000	0.000	0.001	0.000	0.001
Event Bypass Flow Volume (cf)	NA	211.8	102.4	249.7	0.0	0.0	0.0	0.6	99.9	9.2	36.8
No. Composite Sample Aliquots	>= 10	78	16	24	31	95	19	47	64	27	27
Event Flow Volume Sampled (%)	>= 75	99	95.1	95.9	96.9	98.8	95.9	97.8	99.6	95.1	98.3
CBSF2											
Storm Event Start	NA	25-MAR-2010 04:00	19-MAY-2010 14:00	01-JUN-2010 22:00	26-OCT-2010 10:00	29-NOV-2010 18:00	04-JAN-2011 19:00	14-MAR-2011 19:00	13-APR-2011 06:30	27-APR-2011 14:45	
Storm Event End	NA	26-MAR-2010 03:00	20-MAY-2010 05:00	02-JUN-2010 11:30	26-OCT-2010 17:30	30-NOV-2010 19:50	05-JAN-2011 08:05	16-MAR-2011 07:50	14-APR-2011 04:45	27-APR-2011 23:30	
Storm Event Duration (hrs)	>1	23	15	13.5	7.5	25.8	13.1	36.8	22.3	8.8	
6-hr Antecedent Rain (in)	<= 0.04	0	0	0.01	0	0	0	0	0	0.01	
24-hr Antecedent Rain (in)	NA	0	0	0.01	0.07	0.03	0	0.71	0	0.01	
Event Rainfall (in)	>= 0.15	0.5	0.4	0.27	0.2	0.95	0.22	0.72	0.18	0.22	
Event Rainfall Max (in/hr)	NA	0.1	0.13	0.04	0.07	0.09	0.09	0.14	0.03	0.12	
Storm Event Rainfall Mean (in/hr)	NA	0.022	0.031	0.019	0.025	0.037	0.017	0.019	0.008	0.024	
Event Total Flow Max (cfs)	NA	0.144	0.293	0.046	0.046	0.088	0.053	0.315	0.047	0.114	
Event Total Flow Mean (cfs)	NA	0.010	0.012	0.008	0.011	0.020	0.006	0.011	0.002	0.010	
Event Total Flow Volume (cf)	NA	837.9	625.6	392.9	284.9	1892.9	279.1	1411.7	142.5	329.3	
Event Bypass Flow Max (cfs)	NA	0.191	0.482	0.039	0.000	0.033	0.026	0.427	0.021	0.100	
Event Bypass Flow Mean (cfs)	NA	0.005	0.010	0.002	0.000	0.000	0.001	0.005	0.000	0.005	
Event Bypass Flow Volume (cf)	NA	404.4	551.3	101.2	0.0	23.6	60.7	674.0	15.7	146.0	
No. Composite Sample Aliquots	>= 10	141	50	15	28	104	16	74	36	36	
Event Flow Volume Sampled (%)	>= 75	99.5	98.4	97.3	96	98.3	88.1	99	97.2	99.7	

NA – not applicable.

Table 4.2a. Analytical Summary – CBSF1 Influent Stormwater Samples

		SE-01	SE-02	SE-03	SE-04	SE-05	SE-06	SE-07	SE-08	SE-09	SE-10	SE-11	SE-12	SE-13	SE-14	SE-15	SE-16	SE-17	SE-18	SE-19
		CBSF1-IN	CBSF1-IN	CBSF1-IN	CBSF1-IN	CBSF1-IN	CBSF1-IN	CBSF1-IN	CBSF1-IN	CBSF1-IN	CBSF1-IN	CBSF1-IN	CBSF1-IN	CBSF1-IN	CBSF1-IN	CBSF1-IN	CBSF1-IN	CBSF1-IN	CBSF1-IN	CBSF1-IN
Analyte	Units	3/01/09	3/02/09	10/21/09	10/25/09	11/05/09	12/14/09	3/11/10	3/25/10	04/02/10	5/19/10	6/01/10	6/08/10	10/26/10	11/29/10	1/04/11	3/07/11	3/14/11	4/13/11	4/27/11
Nutrients																				
Phosphorus, Total	mg-P/L	0.412	0.52	0.232	0.105	0.193	0.211	0.129 J	0.17	0.0665	0.268 J	0.0795 J	0.0265 J	0.267	0.459	0.061	0.0609	0.129	0.0198	0.0491
Orthophosphate	mg-P/L	0.008	0.014	0.0968 J	0.0396 J	0.0765 J	0.0334 J	0.0188	0.0259	0.0138	0.0997 J	0.00576 J	0.0072 J	0.0645	0.0164	0.025	0.0206	0.014	0.00376	0.044
Metals																				
Copper, Total	ug/L	30.4	30.2	19.7	10.7	14.2	29.1	22.6	30.3	13.5	37.9	11	20.5	27.1	37.6	14	11.8	21.5	14.2	24.8
Copper, Dissolved	ug/L	4.6 J	3.7 J	10.4	3.53	6.19	4.59	7.46	8.78	5.16	14.7	7.47	6.92	9.44	3.59	5.16	6.02	2.67	6.05	9.44
Zinc, Total	ug/L	146	158	81.2	53.6	74.2	135	68.2	136	61	180	53.3	99.9	120	202	67.7	42.4	90.4	149	123
Zinc, Dissolved	ug/L	16	15	34.1	18.8	32.3	18.5 J	26.7	29.6	22.2	51.5	38.7	38.2	37.2	15.8 J	27.6	16.8 J	14.3	118	36.2
Conventionals																				
pH	std units	7.76	6.49	7.32	6.98	7.07	6.75 J	7.2	7.03	6.95	6.72	7.32 J	6.8	7.13	NM	7.12	7.33	7.49	6.95	6.99
Total Suspended Solids	mg/L	144	168	92.5 J	93.5	54.5 J	105 J	29.5	130 J	38.6	221	30.4	96.3	77.7	141	57.5	25.6	90.4	20.9	56.3
Hardness	mg/L CaCO3	28	26	21.8	10.3	19.1	8.46	15.4	17.9	8.37	37.1	16.6	18.7	26.5	18.2	13.6	10.6	8.5	45.7	14.6
Sediment Conc.																				
> 500 um	mg/L	16.43	50.73	69.61 J	43.27 J	7.92 J	105 J	3.51 J	91.85 J	3.29 J	186.5 J	6.95 J	46.18 J	16.6 J	158.5 J	25.9 J	4.1 J	32.9 J	4.9 J	42.4 J
500 to 250 um	mg/L	10.55	15.15	4.66 J	6.36 J	5.1 J	12.77 J	0.36 J	13.41 J	1.88 J	9.77 J	0.7 J	18.67 J	4.2 J	6.4 J	2.5 J	1 J	4.9 J	5.8 J	4.7 J
250 to 125 um	mg/L	0.01 U	8.6	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.09 J	0.01 UJ	8.33 J	3.97 J	0.62 J	6.2 J	16.9 J	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ
125 to 62.5 um	mg/L	0.1	21.76	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	14.38 J	0.01 UJ	15.01 J	8.05 J	3.35 J	12.4 J	17.8 J	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ
62.5 to 3.9 um	mg/L	157.2	175.6	12.31 J	28.08 J	30.06 J	19.52 J	14.43 J	52.05 J	0.01 UJ	50.05 J	21.63 J	14.76 J	41 J	84.8 J	3.4 J	0.01 UJ	5.4 J	0.01 UJ	42.5 J
3.9 to 1 um	mg/L	26.69	38.4	24.49 J	4.32 J	4.72 J	6.19 J	10.36 J	7.64 J	11.56 J	6.46 J	3.67 J	2.34 J	8.4 J	16.9 J	25 J	16.9 J	41.8 J	30.3 J	10.3 J
< 1 um	mg/L	8.12	11.75	10.2 J	1.61 J	1.22 J	2.29 J	5.37 J	4.85 J	15.14 J	2.66 J	0.79 J	0.01 UJ	3.6 J	9.5 J	13.1 J	28.7 J	30.8 J	63.2 J	4.6 J

Notes:
U - Analyte was not detected at or above the reported result.
J- Analyte was positively identified. The reported result is an estimate.
UJ- Analyte was not detected at or above the reported estimate.
NM – Not measured.

Table 4.2b. Analytical Summary – CBSF2 Influent Stormwater Samples

		SE-01	SE-02	SE-03	SE-04	SE-05	SE-06	SE-07	SE-08	SE-09	SE-10	SE-11	SE-12	SE-13	SE-14	SE-15	SE-16	SE-17	SE-18
		CBSF2-IN	CBSF2-IN	CBSF2-IN	CBSF2-IN	CBSF2-IN	CBSF2-IN	CBSF2-IN	CBSF2-IN	CBSF2-IN	CBSF2-IN	CBSF2-IN	CBSF2-IN	CBSF2-IN	CBSF2-IN	CBSF2-IN	CBSF2-IN	CBSF2-IN	CBSF2-IN
Analyte	Units	3/01/09	3/02/09	10/25/09	11/05/09	12/14/09	12/16/09	2/04/10	2/10/10	3/11/10	3/25/10	5/19/10	6/01/10	10/26/10	11/29/10	1/04/2011	3/14/11	4/13/11	4/27/11
Nutrients																			
Phosphorus, Total	mg-P/L	1.34	0.28	0.103 J	0.125	0.117 J	0.0731 J	0.0159 J	0.0866 J	0.0789 J	0.0977	0.111 J	0.0442 J	0.0941	0.17	0.072	0.0757 J	0.038	0.0194
Orthophosphate	mg-P/L	0.014	0.016	0.038 J	0.0322 J	0.043 J	0.0123 J	0.00855	0.0138	0.0143	0.0221	0.0372 J	0.00601 J	0.0274	0.0093	0.016	0.00824	0.016	0.0207
Metals																			
Copper, Total	ug/L	26.8	17.8	7.24	9.1	19.1	11.6	6.33	14.9	10.3	20.5	33.7	13.1	10.5	20	11.2	17.6	27.5	27.6
Copper, Dissolved	ug/L	2.9	2.7	2.75	3.66	7.04	3.12	2.88	4.57	4.48	4.88	7.41	4.84	4.24	2.18	3.55	1.59	7.63	7.31
Zinc, Total	ug/L	190	107	36.9	47.1	91.9	48.7	36.5	80.8	52	121	184	70	54.6	113	78.7	91.3	112	147
Zinc, Dissolved	ug/L	11	13	15.7 J	18.5 J	27.1 J	17.2 J	13.8 J	20.7 J	19.5 J	22.2 J	29.4	23.3 J	21.8 J	13.1 J	17.3 J	10.4	31.2	27.5 J
Conventionals																			
pH	std units	6.57	6.67	6.99	7.09	7 J	7.23	7.4	7.37	7.12	7.06	6.88	7.16 J	6.9	NM	7.16	7.32	7.16	7.06
Total Suspended Solids	mg/L	179	116	34.8	29.3 J	61 J	39.5	5.95 J	52.2 J	25.6	119	360	44	37	185	46.4	215 J	57.4	136 J
Hardness	mg/L $CaCO_3$	51	20	9.66	16.1	14.6	11.4	14.1	17.7	13.1	13.5	21.7	14.7	15.3	12.8	13.3	9.3	18.7	14.4
Sediment Conc.																			
> 500 um	mg/L	4390	25.62	13.99 J	0.34 J	20.45 J	9.19 J	6.73 J	23.19 J	25.89 J	123.3 J	107.4 J	53.64 J	9.8 J	98.9 J	29.2 J	89.1 J	6.8 J	12.7 J
500 to 250 um	mg/L	655	12.92	9.22 J	0.45 J	4.61 J	1.84 J	1.35 J	4.3 J	4.49 J	24.48 J	30.99 J	10.92 J	3.6 J	17.7 J	13.8 J	44.2 J	4.1 J	16.2 J
250 to 125 um	mg/L	3.76	19.11	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	18.9 J	2.4 J	0.5 J	5.9 J	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ
125 to 62.5 um	mg/L	27.86 U	35.11	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	25.9 J	3.53 J	8.8 J	11.5 J	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ
62.5 to 3.9 um	mg/L	158.1 U	185.5	25.18 J	21.53 J	0.03 J	0.01 UJ	0.01 UJ	24.93 J	0.01 UJ	23.67 J	53.81 J	8.15 J	21.1 J	40.3 J	0.01 UJ	0.01 UJ	0.01 UJ	86.4 J
3.9 to 1 um	mg/L	19.94	21.39	5.25 J	4.54 J	27.81 J	44.1 J	6.42 J	6.89 J	8.53 J	29.43 J	5.05 J	1.01 J	4.1 J	6.8 J	20.8 J	47.4 J	31.6 J	14.5 J
< 1 um	mg/L	6.35	6.94	1.58 J	1.95 J	16.19 J	55.9 J	9.51 J	3.89 J	12.53 J	14.71 J	2.54 J	0.46 J	1.8 J	3.9 J	26.7 J	77.6 J	55.4 J	7.1 J

Notes:
U - Analyte was not detected at or above the reported result.
J- Analyte was positively identified. The reported result is an estimate.
UJ- Analyte was not detected at or above the reported estimate.
NM – Not measured.

Table 4.2c. Analytical Summary – CBSF1 Effluent Stormwater Samples

		SE-01	SE-02	SE-03	SE-04	SE-05	SE-06	SE-07	SE-08	SE-09	SE-10	SE-11	SE-12	SE-13	SE-14	SE-15	SE-16	SE-17	SE-18	SE-19
		CBSF1-OUT	CBSF1-OUT	CBSF1-OUT	CBSF1-OUT	CBSF1-OUT	CBSF1-OUT	CBSF1-OUT	CBSF1-OUT	CBSF1-OUT	CBSF1-OUT	CBSF1-OUT	CBSF1-OUT	CBSF1-OUT	CBSF1-OUT	CBSF1-OUT	CBSF1-OUT	CBSF1-OUT	CBSF1-OUT	CBSF1-OUT
Analyte	Units	3/01/09	3/02/09	10/21/09	10/25/09	11/05/09	12/14/09	3/11/10	3/25/10	4/02/10	5/19/10	6/01/10	6/08/10	10/26/10	11/29/10	1/04/11	3/07/11	3/14/11	4/13/11	4/27/11
Nutrients																				
Phosphorus, Total	mg-P/L	0.222	0.274	0.218	0.109	0.212	0.109	0.0866 J	0.0782	0.0656	0.134 J	0.0415 J	0.0577	0.282	0.23	0.057	0.0411 J	0.051	0.0356	0.0445
Orthophosphate	mg-P/L	0.008	0.013	0.0535 J	0.0327 J	0.0854 J	0.0317 J	0.0151	0.0336	0.0185	0.0286 J	0.0161 J	0.0269 J	0.0671	0.0137 J	0.01	0.0088	0.007	0.0075	0.0226
Metals																				
Copper, Total	ug/L	17.9	19.8	15.1	6.88	11.3	17.3	11.3	15.9	8.53	19.4	8.41	11.3	28	23.3	11.7	18.9	10.6	27.1	22.1
Copper, Dissolved	ug/L	5.2	4.4	10.2	2.21	6.01	6.54	7.34	10.4	5.79	11.8	5.48	7.79	15.5	5.06	5.54	8.77	4.15	10.1	12.2
Zinc, Total	ug/L	125	100	55.8	30.2	49.4	63.1	43.1	56.3	37.8	96.2	42.6	62.1	89.8	114	70	85.3	52.8	145	88.6
Zinc, Dissolved	ug/L	29	20	31.9	15.2 J	22.9 J	21.5 J	28.7	40.2	28.8	76.2	35.2	54.7	42.1	18.7 J	45.1	53.1	25.8	72.4	48
Conventionals																				
pH	std units	6.65	6.53	7.34	7.02	7.07	7.07 J	7.05	6.72	6.71	6.44	6.86 J	6.54	7.04	NM	7.14	6.91	7.19	7.14	6.85
Total Suspended Solids	mg/L	64.5	91.5	26.5 J	20.9	24.4 J	31.8 J	9.55	6.11	6.61	17.5	15.5	8.43 J	39.3	63.5	21.4	33.2	20.9	46.4	29.6
Hardness	mg/L $CaCO_3$	24	15	29.5	12.4	22.8	11.4	19.2	23.5	15	40.9	20.9	23.9	27.3	10.1	28.3	42	12.3	30	16.5
Sediment Conc.																				
> 500 um	mg/L	4.28 J	0.01 UJ	0.01 UJ	0.11 J	0.34 J	0.01 UJ	0.01 UJ	0.01 UJ	0.11 J	0.85 J	0.21 J	0.34 J	6.7 J	3.4 J	0.4 J	5 J	1.9 J	6.7 J	0.5 J
500 to 250 um	mg/L	4.89 J	5.41 J	0.01 UJ	0.01 UJ	1.49 J	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.73 J	0.11 J	0.34 J	4.6 J	3.9 J	0.6 J	3.1 J	1.4 J	3.5 J	0.2 J
250 to 125 um	mg/L	0.03 J	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	1.76 J	1.28 J	0.15 J	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ
125 to 62.5 um	mg/L	43.15 J	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	6.5 J	4.07 J	6.72 J	0.01 UJ	0.9 J	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ
62.5 to 3.9 um	mg/L	148.5 J	135.5 J	4.6 J	17.2 J	49.14 J	1.62 J	0.01 UJ	0.01 UJ	0.01 UJ	16.78 J	8.75 J	23.14 J	38.4 J	48.6 J	18.7 J	0.01 UJ	0.01 UJ	0.01 UJ	14.7 J
3.9 to 1 um	mg/L	28.3 J	30.98 J	33.65 J	3.5 J	7.8 J	1.69 J	3.83 J	4.49 J	2.97 J	2.09 J	1.77 J	4.52 J	11.8 J	12.7 J	6.7 J	15.7 J	10.9 J	27.1 J	7.5 J
< 1 um	mg/L	12.06 J	9.33 J	15.04 J	1.3 J	3.07 J	0.7 J	6.63 J	8.19 J	5.1 J	0.86 J	0.54 J	1.01 J	5.1 J	6.7 J	4.3 J	29.6 J	21 J	57.3 J	3.2 J

Notes:
U - Analyte was not detected at or above the reported result.
J- Analyte was positively identified. The reported result is an estimate.
UJ- Analyte was not detected at or above the reported estimate.
NM – Not measured.

Table 4.2d. Analytical Summary – CBSF2 Effluent Stormwater Samples

		SE-01	SE-02	SE-03	SE-04	SE-05	SE-06	SE-07	SE-08	SE-09	SE-10	SE-11	SE-12	SE-13	SE-14	SE-15	SE-16	SE-17	SE-18
		CBSF2-OUT	CBSF2-OUT	CBSF2-OUT	CBSF2-OUT	CBSF2-OUT	CBSF2-OUT	CBSF2-OUT	CBSF2-OUT	CBSF2-OUT	CBSF2-OUT	CBSF2-OUT	CBSF2-OUT	CBSF2-OUT	CBSF2-OUT	CBSF2-OUT	CBSF2-OUT	CBSF2-OUT	CBSF2-OUT
Analyte	Result Units	3/01/09	3/02/09	10/25/09	11/05/09	12/14/09	12/16/09	2/04/10	2/10/10	3/11/10	3/25/10	5/19/10	6/01/10	10/26/2010	11/29/10	1/04/11	3/14/11	4/13/11	4/27/11
Nutrients																			
Phosphorus, Total	mg-P/L	0.236	0.236	0.0447 J	0.114	0.112 J	0.0685 J	0.0178 J	0.0642 J	0.0493 J	0.075	0.077 J	0.0398 J	0.101	0.0681	0.048	0.0321	0.018	0.0172
Orthophosphate	mg-P/L	0.011	0.014	0.0238 J	0.0388 J	0.0223 J	0.0106 J	0.009	0.0107	0.0115	0.0178	0.0207 J	0.00229 J	0.0256	0.0067	0.011	0.00467	0.012	0.00269
Metals																			
Copper, Total	ug/L	16	14.8	3.95	7.72	13.5	8.29	5.23	10.9	8.68	12	25.9	8.98	10.2	10.2	9.82	8.59	19.4	16.1
Copper, Dissolved	ug/L	3.8	3.2	2.26	5.13	6.65	3.72	3.34	5.46	5.71	6.88	11.3	4.97	5.92	2.59	6.86	3.19	9.48	8.45
Zinc, Total	ug/L	79	80	17.5	38.2	54.5	38.2	28.6	52.9	35.6	53.4	91.2	43	50.9	49.5	45.1	43.1	95.6	75
Zinc, Dissolved	ug/L	15	15	12 J	29.6 J	29.6 J	19.6 J	21.3 J	28.5 J	22.4 J	29.1 J	53.8	26.7 J	29.6	13.3 J	33	16.9	44	37
Conventionals																			
pH	std units	6.57	6.66	6.97	7.09	6.85 J	7.11	7.3	7.36	7.12	7.01	6.7	7.2 J	6.99	NM	7.2	7.23	7.13	6.96
Total Suspended Solids	mg/L	72	79.6	11.6	14.3 J	22.2 J	9.76	19.6 J	20 J	11.5	16.3	30.6	17.2	16	22.3	13.8	21.5	28.9	30.2
Hardness	mg/L $CaCO_3$	21	18	7.6	17.1	19.2	11.4	16.7	21.6	13.8	13.2	19.7	13.4	16.2	9.7	17	11.3	21.2	15.7
Sediment Conc.																			
> 500 um	mg/L	2.37 J	0.01 UJ	0.01 UJ	0.34 J	0.11 J	0.01 UJ	0.12 J	0.01 UJ	0.01 UJ	2.33 J	2.6 J	0.34 J	3.3 J	2.2 J	0.6 J	3.5 J	0.3 J	0.01 UJ
500 to 250 um	mg/L	7.3 J	2.02	0.01 UJ	0.45 J	0.01 UJ	0.01 UJ	1.17 J	0.34 J	0.5 J	0.01 UJ	0.34 J	1.01 J	0.1 J	4.6 J	0.5 J	3.2 J	0.2 J	3.9 J
250 to 125 um	mg/L	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	2.55 J	0.43 J	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ
125 to 62.5 um	mg/L	0.01 UJ	3.26 J	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	7.01 J	1.34 J	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ	0.01 UJ
62.5 to 3.9 um	mg/L	0.01 UJ	112.2 J	15.06 J	21.53 J	0.01 UJ	0.01 UJ	0.01 UJ	15.52 J	0.01 UJ	0.01 UJ	15.05 J	3.08 J	22.4 J	22.9 J	0.01 UJ	0.01 UJ	0.01 UJ	24.1 J
3.9 to 1 um	mg/L	68 J	14.14 J	3.88 J	4.54 J	1.75 J	5.18 J	3.92 J	4.68 J	1.01 J	7.23 J	1.32 J	0.35 J	7.7 J	6.4 J	9.8 J	12.7 J	33.1 J	8.3 J
< 1 um	mg/L	68 J	6.31 J	1.07 J	1.95 J	2.25 J	6.82 J	7.37 J	2.78 J	1.65 J	10.58 J	0.95 J	0.18 J	3.4 J	3.3 J	14 J	22.2 J	64.2 J	3.5 J

Notes:
U - Analyte was not detected at or above the reported result.
J- Analyte was positively identified. The reported result is an estimate.
UJ- Analyte was not detected at or above the reported estimate.
NM – Not measured.

4.2.1 Particle Size Distribution Summary

The following table summarizes stormwater particle size distribution data (PSD) measured on the 37 paired samples collected during this project. All influent data were aggregated and all effluent data were aggregated to produce this summary.

Table 4.2.1a. Particle Size Distribution Summary Data

Particle Size (microns)	Wentworth Scale Name	Influent Distribution (% mass of total)	Effluent Distribution (% mass of total)	Mass Percent Reduction
> 500	Coarse sand and greater	61.0%	2.7%	99.2%
500 to 250	Medium sand	10.1%	3.1%	94.3%
250 to 125	Fine Sand	1.0%	0.4%	93.2%
125 to 62.5	Very fine sand	2.1%	4.1%	64.4%
62.5 to 3.9	Silt	14.3%	43.5%	44.5%
3.9 to 1	Clay	6.2%	23.1%	31.6%
< 1	Colloids	5.3%	23.0%	21.2%

For influent samples, the largest percentages of particles measured are classified as coarser than medium sand with the silt-sized particles representing the second largest fraction by percent.

The CBSFs consistently reduced all ranges of particle sizes ranging from mass reductions (based on average mass in each range) of 99 percent for the coarsest fraction to 21.2 percent for the finest fraction. Treatment efficiency was directly related to particle size which is typical of most stormwater BMPs.

The PSD data are charted on the following three figures: Figure 4.2.1b presents all the influent PSD data with one line representing each event, Figure 4.2.1c presents all the effluent PSD data with one line representing each event and Figure 4.2.1d presents the average of all influent PSD data charted against the average of all effluent PSD.

Figure 4.2.1b. Influent Particle Size Distribution Data – All Events

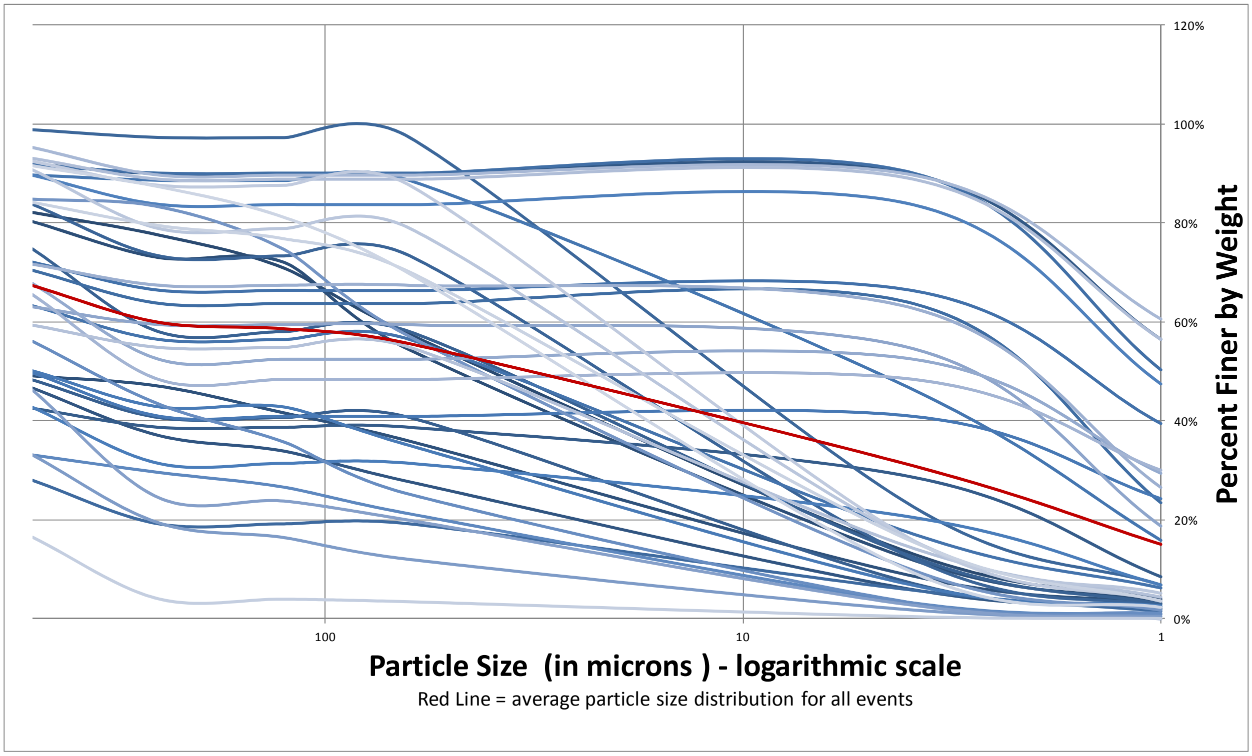


Figure 4.2.1c. Effluent Particle Size Distribution Data – All Events

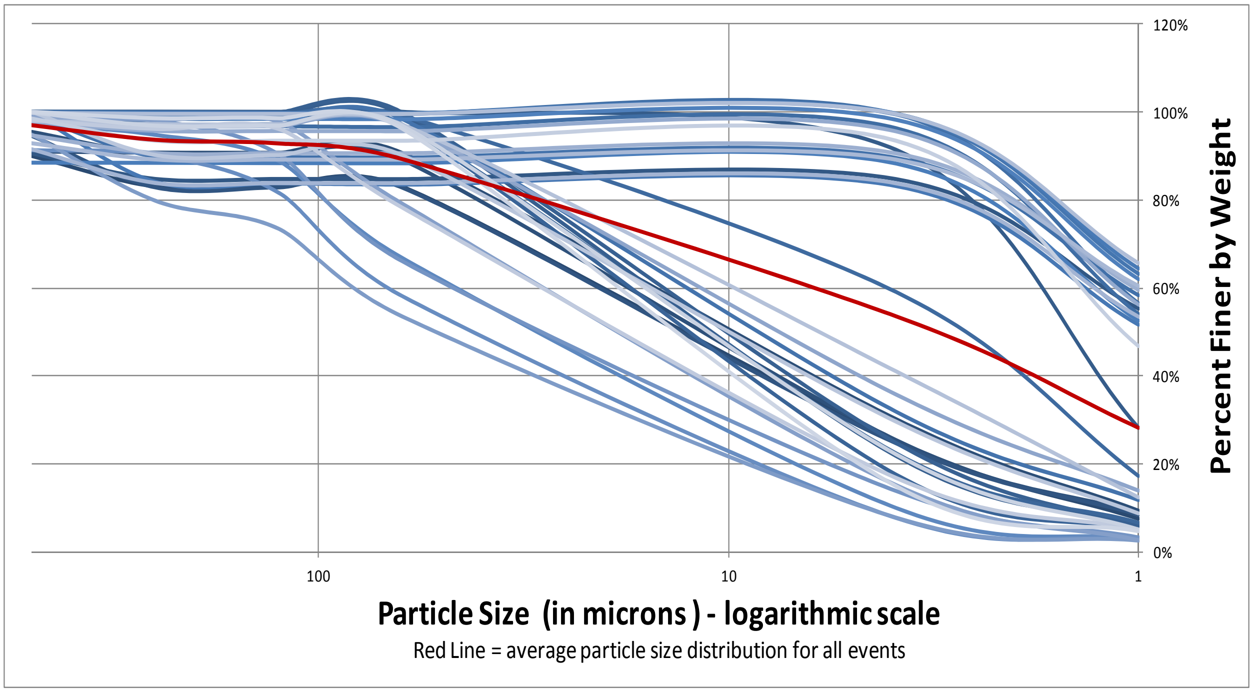
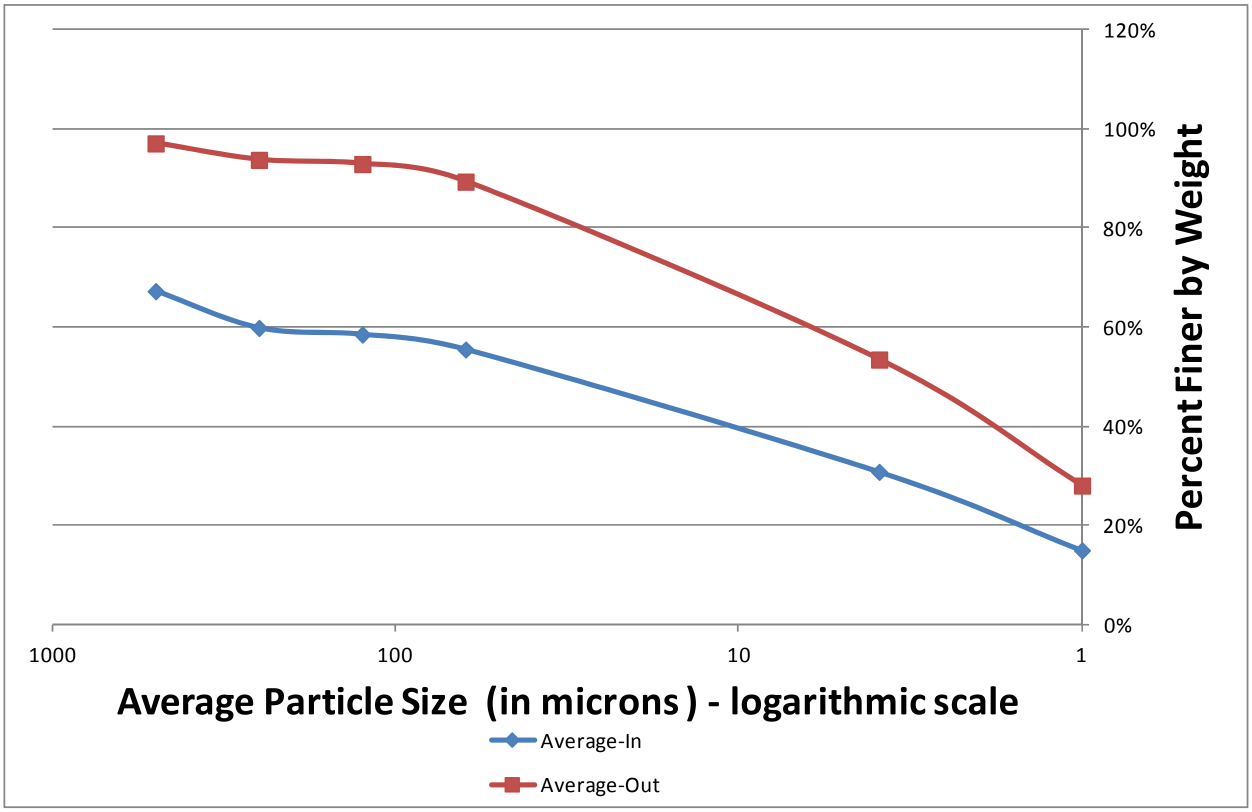


Figure 4.2.1d. Average Influent Versus Effluent Particle Size Distribution Data



4.3 pH

Influent pH values ranged from 6.49 to 7.76, with a median value of 7.08. Effluent pH values ranged from 6.44 to 7.36, with a median value of 7.01.

4.4 Hardness

Influent hardness values ranged from 8.37 to 51.00 mg/L calcium carbonate ($CaC0_{3)}$, with a median value of 15.35 mg/L $CaC0_3$. Effluent hardness values ranged from 7.60 to 42.00 mg/L $CaC0_3$, with a median value of 18.00 mg/L $CaC0_3$.

4.5 Sediment Monitoring and Sampling Results

Three rounds of sediment samples were collected during this study on the following dates: September 23, 2009, September 28, 2010 and June 9, 2011.

The first two rounds of sediment sampling corresponded with the end of the water year. Since the Permit required monitoring to begin in February 2009, the monitoring and sediment accumulation period of WY2009 was limited to February to October 2009. The accumulation period during WY2009 at CBSF1 was further limited when the City's maintenance contractor mistakenly cleaned the unit on June 19, 2009. WY2010 represented a complete year of sediment accumulation. WY2011 sediment accumulation monitoring and sampling was performed ahead of the original annual schedule to correspond with flow testing activities performed in June 2011 (discussed in Section 5.3.2). The controlled flow testing procedure required that the CBSF units be cleaned.

Sediment depth was monitored to determine average depth in each chamber of the CBSF units. The average depth was converted to volume and mass using the unit dimensions and bulk density data calculated by ARI. During the September 2009 sediment sampling event there was insufficient quantities of sediment present to collect samples from all chambers. Sediment chemical and geotechnical analysis was performed by ARI.

4.5.1 Sediment Accumulation Monitoring Results

The results of the sediment accumulation monitoring for each water year is presented in Tables 4.5.1a-c. The accumulation period for each water year is presented in the same tables. It is important to note that the roadway in the CBSF area was targeted to be swept by street sweepers approximately every two weeks (actual sweeping frequency is affected by holidays, weather events, etc.) so the accumulation quantities measured are assumed to be less than a roadway that is not swept.

Table 4.5.1a. WY2009 Sediment Accumulation Data

Location (chamber)	ID	Average Sediment Depth (ft)	Sediment Volume (CF)	Wet Density (lbs/CF)	Dry Density (lbs/CF)	Wet Sediment Mass (kg)[1]	Dry Sediment Mass (kg)[2]	Total Wet Sed Mass per Unit (kg)	Total Dry Sed Mass per Unit (kg)	Accum-ulation Period (Days)
CBSF1-Influent	CBSF1-Sed1	0.27	1.08	NM	NM	40.5	15.2	54.6	23.9	100
CBSF1-Filter	CBSF1-Sed2	0.04	0.31	NM	NM	14.0	8.7			
CBSF1-Effluent	CBSF1-Sed3	0	0	NM	NM	0	0			
CBSF2-Influent	CBSF2-Sed1	1.22	4.92	82.6	31.0	184.7	69.3	259.3	115.6	225
CBSF2-Filter	CBSF2-Sed2	0.11	1.65	99.4	61.7	74.6	46.3			
CBSF2-Effluent	CBSF2-Sed3	0	0	NM	NM	0	0			

Notes:

NM – Not measured due to insufficient quantity for analysis.
[1] Calculated from wet density of 82.6 and 99.4 lbs/CF from CBSF2 influent and chamber samples, respectively.
[2] Calculated from dry density of 31.0 and 61.7 lbs/CF from CBSF2 influent and chamber samples, respectively.

Table 4.5.1b. WY2010 Sediment Accumulation Data

Location (chamber)	ID	Average Sediment Depth (ft)	Sediment Volume (CF)	Wet Density (lbs/CF)	Dry Density (lbs/CF)	Wet Sediment Mass (kg)	Dry Sediment Mass (kg)	Total Wet Sed Mass per Unit (kg)	Total Dry Sed Mass per Unit (kg)	Accum-ulation Period (Days
CBSF1-Influent	CBSF1-Sed1	0.75	3.03	68.1	12.8	93.8	17.6	102.1	19.1	370
CBSF1-Filter	CBSF1-Sed2	0.03	0.24	68.8	11.7	7.5	1.3			
CBSF1-Effluent	CBSF1-Sed3	0.03	0.03	69.8	15.7	0.8	0.2			
CBSF2-Influent	CBSF2-Sed1	1.25	5.05	73.5	22.6	168.7	51.9	225.9	65.8	370
CBSF2-Filter	CBSF2-Sed2	0.11	1.65	68.8	14.9	51.6	11.2			
CBSF2-Effluent	CBSF2-Sed3	0.14	0.14	87	41.8	5.5	2.7			

During the controlled flow testing of CBSF1 on June 7, 2011, the high volume discharged from the hydrant dislodged a portion of the sediment stored in the CBSF influent sump. Because this occurred prior to the sediment accumulation measurements for WY2011, the associated results for CBSF1-Sed1 have been qualified with a greater than sign to account for this lost fraction of sediment. Flow testing procedures were modified before testing CBSF2 to avoid dislodging sediment in that unit.

Table 4.5.1c. WY2011 Sediment Accumulation Data

	ID	Average Sediment Depth (ft)	Sediment Volume (CF)	Wet Density (lbs/CF)	Dry Density (lbs/CF)	Wet Sediment Mass (kg)	Dry Sediment Mass (kg)	Total Wet Sed Mass per Unit (kg)	Total Dry Sed Mass per Unit (kg)	Accum-lation Period (Days)
CBSF1-Influent	CBSF1-Sed1	>0.33	>1.35	55.6	23.7	>34.1	>32.0			
CBSF1-Filter	CBSF1-Sed2	0.21	1.53	76.7	25.6	53.3	39.1	>96.3	>35.0	254
CBSF1-Effluent	CBSF1-Sed3	0.25	0.27	73.3	21.8	8.8	5.8			
CBSF2-Influent	CBSF2-Sed1	1.25	5.05	80.1	31.5	183.9	159.1			
CBSF2-Filter	CBSF2-Sed2	0.14	2.08	77.6	28.3	73.4	58.9	268.9	103.7	254
CBSF2-Effluent	CBSF2-Sed3	0.21	0.22	116.6	46	11.7	10.2			

The annual sediment accumulation amounts suggest that the default annual maintenance cycle is sufficient since the accumulated sediment depth measured on top of the cartridges ranged from 0-0.25 inches for the accumulation periods monitored, which just reached the 0.25-inch maintenance trigger level for some of the cartridges during the last quarter of the accumulation period. The manufacturer does not provide a maintenance trigger for sediment depth accumulated on the floor of the cartridge chambers.

The sediment accumulation monitoring measured most, but not all, of the sediment captured by the units over the accumulation period. The unmeasured portion was captured by the filter cartridges. Due to difficulties quantifying the mass or volume retained in the cartridges, the sediment retained in the cartridges was not quantified. Based on laboratory testing, the manufacturer has determined that each cartridge can retain 18 pounds (8.2 kilograms) of sediment (Contech 2012).

4.5.1 Sediment Analytical Data Summary

The analytical results of sediment sampling over the duration of this study are summarized in Table 4.5.1. The fines portion (clay to coarse silt) of the grain size analysis was not performed on several samples (noted with “NM” in the table) because the sample did not contain the required 5 grams of fines in the pipette portion of the analysis.

Table 4.5.1. Analytical Summary - Sediment Data

		WY2009		WY2010						WY2011					
		CBSF2-SED1	CBSF2-SED2	CBSF1-SED1	CBSF1-SED2	CBSF1-SED3	CBSF2-SED1	CBSF2-SED2	CBSF2-SED3	CBSF1-SED1	CBSF1-SED2	CBSF1-SED3	CBSF2-SED1	CBSF2-SED2	CBSF2-SED3
		Influent	Filter	Influent	Filter	Effluent	Influent	Filter	Effluent	Influent	Filter	Effluent	Influent	Filter	Effluent
Analyte	Units	09/23/2009	09/23/2009	09/28/2010	09/28/2010	09/28/2010	09/28/2010	09/28/2010	09/28/2010	06/09/2011	06/09/2011	06/09/2011	06/09/2011	06/09/2011	06/09/2011
Petroleum Hydrocarbons															
Diesel Range Hydrocarbons	mg/kg	1200	680	300	650	240	360	510	240	630	3500	1800	1800	1600	1600
Motor Oil	mg/kg	2900	3600	2400	4500	2000	2100	3300	1700	1800	9300	6800	4600	4800	4100
Nutrients															
Phosphorus, Total	mg/kg	394	162	931	1940	452	249	717	332	256	566	717	220 J	400	231
Metals															
Cadmium, Total	mg/kg	0.6	0.4	1 U	1	1.5	0.7	1.5	0.8	0.2 U	0.6	0.6	0.5	0.6	0.5
Copper, Total	mg/kg	45.6	35.9	78	135	128	51	163	57	44	97	142	76	68	71
Lead, Total	mg/kg	86	42	67	120	133	58	127	64	28.9	69.5	77.5	84 J	82.9	105
Zinc, Total	mg/kg	287	177	340	570	570	230	560	205	120	340	400	320	340	310
Conventionals															
Solids, Total	%	39.8	53.6	16.3 J	22.1 J	26.7 J	45.3 J	32.2 J	55.6 J	53.8	28.9	27	40.7	40.7	46.2
Solids, Total Volatile	%	19.7	8.44	57.42 J	48.29 J	40.83 J	19.82 J	30.01 J	11.13 J	11.61 J	22.07 J	33.98 J	19.08 J	18.11 J	16.66 J
Grain Size															
Gravel	%	18.8	6.7	41.9	29	19.3	25.9	17.6	7.6	32.5	3.8	11.4	13.1	5.3	4.2
Very Coarse Sand	%	17.5	15.8	17.8	17.2	14.5	14.2	16	11.9	22.2	7.2	19.6	14.9	11.8	8.7
Coarse Sand	%	19.4	25.8	10.6	12.4	12.4	17.9	17.7	21.5	20.4	17.1	20.3	22.2	22.2	13.7
Fine Sand	%	12.8	11.1	4.6	6.2	8.7	11.6	9.1	11.8	4	11.8	8.8	12.8	11.9	21.4
Medium Sand	%	20.3	24.3	7.4	9.8	12	20.3	16.5	26.7	12.8	30.3	18.7	22.4	25.4	24.3
Very Fine Sand	%	4.9	4.9	2.2	3.4	4.4	3.8	4.8	9.9	1.3	4.3	3.8	4.5	4.6	10.9
Coarse Silt	%	NM	0.4	NM	NM	4.3	NM	3	1.5	6.8 J	8.8 J	6.3 J	1.9 J	4 J	4.8 J
Medium Silt	%	NM	5.8	NM	NM	15.3	NM	5.3	3	6.8 U	5.5	3.2	2.6	5.3	5.1
Fine Silt	%	NM	1.9	NM	NM	4.8	NM	4.1	1.7	6.8 U	4	2.2	1.6	3.3	2.9
Very Fine Silt	%	NM	1.4	NM	NM	2.1	NM	2.6	1.5	6.8 U	3.3	1.7	1.2	2.4	2
9-10 Phi Clay	%	NM	0.3	NM	NM	0.3	NM	0.9	0.9	6.8 U	1.1	0.2	0.4	0.9	0.2
8-9 Phi Clay	%	NM	0.9	NM	NM	0.5	NM	1.2	0.8	6.8 U	1.5	1.1	0.4	1.7	0.9
>10 Phi Clay	%	NM		NM	NM	1.3	NM	1.3	1.1	6.8 U	1.3	2.8	2	1.3	1
Total Fines	%	6.3 J	11.3 J	15.6	21.9	28.7	6.3	18.3	10.5	6.8	25.5	17.5	10.1	18.7	16.9

Notes:
U - Analyte was not detected at or above the reported result.
J- Analyte was positively identified. The reported result is an estimate.
NM - Not measured. Insufficient fines to perform analysis.

This page intentionally left blank.

5 Data Analysis

The following sections discuss the evaluation of the water quality and hydrologic performance of the CBSF units.

5.1 Water Quality Performance Evaluation

5.1.1 Data Used to Evaluate Performance

The minimum required sample number goal for NPDES BMP monitoring is summarized in section S8.F.4 of the Permit which also states that Permittees must use appropriate sections of the TAPE guidance manual for "preparing, implementing, and reporting on the results of the BMP evaluation program." The Permit requires that sufficient samples be collected to determine mean effluent concentration and mean percent removals for each BMP type with 90 to 95% confidence and 75-80% power. Independent of these statistical requirements, Permittees are required to collect a minimum of 12 and a maximum of 35 samples. A total of 37 paired samples were collected over the course of this study; consequently, the sample size requirement in the Permit was met and monitoring is considered complete. These samples qualified for all weather and sampling criteria listed in Table 3.1. Since both CBSFs are of a similar design and only treated effluent that passed through the filters was analyzed, data from the CBSFs were pooled to evaluate the performance of both CBSFs' performance collectively.

TAPE has specified treatment performance goals that vendors of BMPs are to meet to achieve certification for their product. However, following verbal instruction from Ecology representatives, the City and other Phase I Permittees are not required to evaluate whether BMPs meet the same performance goals. Rather, the intent of the S8.F.4 monitoring was to objectively monitor BMPs to add to the collective knowledge of BMP performance. Thus, no comparisons to the TAPE treatment goals are made in this report.

TAPE provides treatment goals and influent concentration requirements for each parameter applicable to the treatment category of the BMP. For Permit compliance, the City proposed evaluating treatment performance using the basic treatment (total suspended solids), enhanced treatment (dissolved copper and zinc) and phosphorus treatment (total phosphorus) categories. The Permit required analyzing for three additional parameters: total copper, total zinc and orthophosphate which do not have treatment goals nor influent concentration requirements listed in TAPE. In this report, these three additional parameters will be summarized using all collected data regardless of influent concentration since no guidance is available for evaluating low influent concentration data for these parameters.

5.1.2 Treatment Efficiency Calculation Procedures

Statistical analyses were performed to determine significance of differences in pollutant concentrations between the influent and effluent data across individual storm events. It is important to note that this evaluation considers the efficiency of treated stormwater only and does not consider the overall BMP efficiency by factoring in bypassed or untreated flows. This is consistent with the manufacturer's 2004 Technical Evaluation Engineering Report (TEER) submittal for GULD approval (Minton 2004) and conversations with Ecology representatives who indicated treatment efficiencies should be evaluated for treated flows, and bypass quantities should be evaluated separately as a unit sizing issue.

The specific null hypothesis (H_o) and alternative hypothesis (H_a) for this one-tailed analysis are as follows:

H_o: Effluent pollutant concentrations are equal to or greater than influent concentrations.
H_a: Effluent concentrations are less than influent concentrations.

Pollutant removal efficiencies for parameters of concern were calculated for all storm samples using TAPE *Method #1: Individual storm reduction in pollutant concentration*. The change (in percent) in pollutant concentration during each individual storm (%C) was calculated as:

$$\%C = 100 \times \frac{(C_{in} - C_{eff})}{C_{in}}$$

Where:

C_{in} = volume-weighted influent concentration (also known as the Event Mean Concentration or EMC), and

C_{eff} = volume-weighted effluent concentration (EMC).

Pollutant removal efficiencies for total suspended solids (TSS) are presented in Table 5.1.3a. CBSF treatment performance for TSS was quantified differently using the two-tiered influent concentration criteria listed in TAPE: 1) for TSS >100 mg/L the average percent removal was quantified; and 2) for TSS <100 mg/L the average effluent concentration was quantified. One event with an influent TSS concentration below 20 mg/L was not included in either category because this concentration is considered too low to accurately evaluate treatment efficiency.

Pollutant removal efficiencies for total phosphorus, dissolved copper and dissolved zinc are presented in Table 5.1.3b. These parameters were screened using the following influent concentration criteria listed in TAPE:

- Total phosphorus: 100 to 500 µg/L
- Dissolved copper: 5 to 20 µg/L
- Dissolved zinc: 20 to 300 µg/L

Sample pairs with influent concentrations outside the above ranges were excluded from pollutant removal calculations.

Pollutant removal efficiencies for total copper, total zinc and orthophosphate are presented in Table 5.1.3c. These water quality parameters are required by the Permit but are not specifically addressed in the TAPE guidance and consequently influent concentrations were not screened prior to pollutant reduction calculations.

To provide some measure of the uncertainty in the removal efficiency estimates, a bootstrap estimate of the 95 percent confidence limit around mean removal efficiency was calculated for each parameter (Helsel and Hirsch 2002). Bootstrapping offers a distribution-free method for estimates of confidence intervals of a measure of central tendency (in this case the average percent removal).

To perform the bootstrapping approach, the TSS, total phosphorus, dissolved copper and dissolved zinc data were first screened based on influent data criteria identified in the 2011 TAPE. The total zinc, total copper and orthophosphate data were not screened. The percent reduction values for each valid event were then sampled randomly with replacement until a new synthetic percent reduction dataset of equivalent size was generated. The mean percent reduction was then calculated on the synthetic dataset and the process was repeated until 5,000 estimates of the average percent reduction were generated. After sorting the resultant 5,000 average percent reduction values, the 250th element constitutes the one-tailed bootstrapped lower 95 percent confidence limit of the mean. The one-tailed lower 95 percent confidence limit establishes a threshold over which there is 95 percent assurance that the true mean population lies. The bootstrapped confidence intervals are presented in Tables 5.1.3a-c. The bootstrap procedure was performed using Ecology's publically available TAPE bootstrap calculator (http://www.wastormwatercenter.org/files/library/tape-bootstrap-ci-calculator-2011-08.xls).

Bootstrapping was also used to calculate the one-tailed upper 95 percent confidence limit about the mean effluent TSS concentrations for sample pairs with influent concentrations between 20 and 100 mg/L (per TAPE 2011 protocol). The results of this analysis are presented in Table 5.1.3a.

Subsequent to the calculation of bootstrapped confidence intervals, screened influent and effluent data were tested for significant difference using a one-tailed Wilcoxon signed-rank test (a nonparametric analog to Student's T-test) (Helsel and Hirsch 2002). For each parameter, statistical significance in these tests was evaluated based on an α-level of 0.05. The results of this hypothesis testing are presented at the bottom Tables 5.1.3a through c. Lastly, a power test was conducted to determine if the hypothesis tests exhibited sufficient power (at least 80 percent) to be deemed valid by the criteria in the Permit. The power of a statistical test is the probability that the test will falsely accept the null hypothesis. An online calculator recommended by Ecology (http://www.dssresearch.com/toolkit/spcalc/power_a2.asp) was used for this analysis. The Permit indicates that the power must be at least 80 percent for each data set being tested before sampling can cease (increased sample size tends to increase power). However, collecting more than 35 samples is not required regardless of power.

5.1.3 Treatment Efficiency Results

The following first three tables present treatment efficiency and descriptive statistics for all water quality samples collected during this study. The fourth table presents a summary of treatment efficiency for all seven parameters analyzed. Data with applicable TAPE screening criteria were screened as discussed in Section 5.1.2.

Table 5.1.3a. TSS Water Quality Performance Statistics

		TSS (influent <100 mg/L)		TSS (influent >100 mg/L)		
Site	Date	IN	OUT	IN	OUT	% diff
CBSF1	3/2/09	---	---	144	64.5	55.2
CBSF1	3/3/09	---	---	168	91.5	45.5
CBSF1	10/21/09	92.5	26.5	---	---	---
CBSF1	10/26/09	93.5	20.9	---	---	---
CBSF1	11/6/09	54.5	24.4	---	---	---
CBSF1	12/14/09	---	---	105	31.8	69.7
CBSF1	3/11/10	29.5	9.6	---	---	---
CBSF1	3/26/10	---	---	130	6.11	96.0
CBSF1	4/2/10	38.6	6.61	---	---	---
CBSF1	5/20/10	---	---	221	17.5	91.4
CBSF1	6/2/10	30.4	15.5	---	---	---
CBSF1	6/9/10	96.3	8.43	---	---	NA
CBSF1	10/26/10	77.7	39.3	---	---	---
CBSF1	11/30/10	---	---	141	63.5	55.4
CBSF1	1/5/11	57.5	21.4	---	---	---
CBSF1	3/8/11	25.6	33.2	---	---	---
CBSF1	3/16/11	90.4	20.9	---	---	---
CBSF1	4/14/11	20.9	46.4	---	---	---
CBSF1	4/27/11	56.3	29.6	---	---	---
CBSF2	3/2/09	---	---	179	72	59.8
CBSF2	3/3/09	---	---	116	79.6	31.4
CBSF2	10/26/09	34.8	11.6	---	---	---
CBSF2	11/6/09	29.3	14.3	---	---	---
CBSF2	12/14/09	61.0	22.2	---	---	---
CBSF2	12/17/09	39.5	9.8	---	---	---
CBSF2	2/5/10	*5.95*	*19.6*	---	---	---
CBSF2	2/11/10	52.2	20.0	---	---	---

Site	Date	TSS (influent <100 mg/L)		TSS (influent >100 mg/L)		
		IN	OUT	IN	OUT	% diff
CBSF2	3/11/10	25.6	11.5	---	---	---
CBSF2	3/26/10	---	---	119	16.3	86.3
CBSF2	5/20/10	---	---	360	30.6	91.5
CBSF2	6/2/10	44.0	17.2	---	---	---
CBSF2	10/26/10	37.0	16.0	---	---	---
CBSF2	11/30/10	---	---	185	22.3	87.9
CBSF2	1/5/11	46.4	13.8	---	---	---
CBSF2	3/16/11	---	---	215	21.5	83.1
CBSF2	4/14/11	57.4	28.9	---	---	---
CBSF2	4/27/11	---	---	136	30.2	70.4
Total n		24	24	13	13	NA
Qualifying n [1]		23	23	13	13	NA
LCL95 [2]		NA	NA	NA	NA	62.8
mean		NA	20.3	NA	NA	72.1
UCL95 [3]		NA	23.6	NA	NA	NA
Sig difference? [4]		**yes (Wilcoxon)**		**yes (Wilcoxon)**		
Power (%)		100		100		

Notes-
--- no data listed since applicable screening criteria not met. Data listed under applicable screening tier.
NA – not applicable (statics do not apply to this cell)
Italics indicates values not used in performance calculations due to influent concentrations being below lowest screening threshold.

[1] Calculated sample number based on influent concentration screening per TAPE 2011.

[2] LCL95 is the one-sided lower 95% confidence limit on the estimate of the mean percent reduction.

[3] UCL95 is the one-sided upper 95% confidence limit on the estimate of the mean effluent concentration.

[4] Significance of differences (α = 0.05) between influent and effluent concentrations were determined with a non-parametric Wilcoxon Signed Rank Test run on the sample pairs after TAPE 2011 screening of influent concentrations.

Significant differences (differences in influent and effluent mean values that can be established with at least 95 percent confidence) were observed for TSS and the power analysis indicated that the hypothesis tests for TSS had sufficient power to be deemed valid (exceeding the Permit goal of 75-80% power).

For samples with influent TSS concentrations exceeding 100 mg/L, removal rates ranged from 31 to 95 percent, with a mean value of 72.1 percent. The lower 95 percent confidence limit of the mean percent TSS reduction was 62.8 percent. For samples with influent TSS concentrations below 100 mg/L, effluent removal concentrations averaged 20.3 percent with an upper 95 confidence limit of 23.6 percent.

Table 5.1.3b. Total Phosphorus and Dissolved Metals Water Quality Performance Statistics

Site	Date	Total Phosphorus (µg/L)			Dissolved Cu (µg/L)			Dissolved Zn (µg/L)		
		IN	OUT	% diff	IN	OUT	% diff	IN	OUT	% diff
CBSF1	3/2/09	**412**	**222**	46.1	4.6	5.2	---	16	29	---

Site	Date	Total Phosphorus (µg/L)			Dissolved Cu (µg/L)			Dissolved Zn (µg/L)		
		IN	OUT	% diff	IN	OUT	% diff	IN	OUT	% diff
CBSF1	3/3/09	520	274	---	3.7	4.4	---	15	20	---
CBSF1	10/21/09	**232**	**218**	6.0	**10.4**	**10.2**	1.9	**34.1**	**31.9**	6.5
CBSF1	10/26/09	**105**	**109**	-3.8	3.53	2.21	---	18.8	15.2	---
CBSF1	11/6/09	**193**	**212**	-9.8	**6.19**	**6.01**	2.9	**32.3**	**22.9**	29.1
CBSF1	12/14/09	**211**	**109**	48.3	4.59	6.54	---	18.5	21.5	---
CBSF1	3/11/10	**129**	**86.6**	32.9	**7.46**	**7.34**	1.6	**26.7**	**28.7**	-7.5
CBSF1	3/26/10	**170**	**78.2**	54.0	**8.78**	**10.4**	-18.5	**29.6**	**40.2**	-35.8
CBSF1	4/2/10	66.5	65.6	---	**5.16**	**5.79**	-12.2	**22.2**	**28.8**	-29.7
CBSF1	5/20/10	**268**	**134**	50.0	**14.7**	**11.8**	19.7	**51.5**	**76.2**	-48.0
CBSF1	6/2/10	79.5	41.5	---	**7.47**	**5.48**	26.6	**38.7**	**35.2**	9.0
CBSF1	6/9/10	26.5	57.7	---	**6.92**	**7.79**	-12.6	**38.2**	**54.7**	-43.2
CBSF1	10/26/10	**267**	**282**	-5.6	**9.44**	**15.5**	-64.2	**37.2**	**42.1**	-13.2
CBSF1	11/30/10	**459**	**230**	49.9	3.59	5.06	---	15.8	18.7	---
CBSF1	1/5/11	61.1	57	---	**5.16**	**5.54**	-7.4	**27.6**	**45.1**	-63.4
CBSF1	3/8/11	60.9	41.1		**6.02**	**8.77**	-45.7	16.8	53.1	---
CBSF1	3/16/11	**129**	**50.9**	60.5	2.67	4.15		14.3	25.8	---
CBSF1	4/14/11	19.8	35.6	---	**6.05**	**10.1**	-66.9	**118**	**72.4**	38.6
CBSF1	4/27/11	49.1	44.5	---	**9.44**	**12.2**	-29.2	**36.2**	**48**	-32.6
CBSF2	3/2/09	1340	236	---	2.9	3.8	---	11	15	---
CBSF2	3/3/09	**280**	**236**	15.7	2.7	3.2	---	13	15	---
CBSF2	10/26/09	**103**	**44.7**	56.6	2.75	2.26	---	15.7	12	---
CBSF2	11/6/09	**125**	**114**	8.8	3.66	5.13	---	18.5	29.6	---
CBSF2	12/14/09	**117**	**112**	4.3	**7.04**	**6.65**	5.5	**27.1**	**29.6**	-9.2
CBSF2	12/17/09	73.1	68.5	---	3.12	3.72	---	17.2	19.6	---
CBSF2	2/5/10	15.9	17.8	---	2.88	3.34	---	13.8	21.3	---
CBSF2	2/11/10	86.6	64.2	---	4.57	5.46	---	**20.7**	**28.5**	-37.7
CBSF2	3/11/10	78.9	49.3	---	4.48	5.71	---	19.5	22.4	---
CBSF2	3/26/10	97.7	75	---	4.88	6.88	---	**22.2**	**29.1**	-31.1
CBSF2	5/20/10	**111**	**77**	30.6	**7.41**	**11.3**	-52.5	**29.4**	**53.8**	-83.0
CBSF2	6/2/10	44.2	39.8	---	4.84	4.97	---	**23.3**	**26.7**	-14.6
CBSF2	10/26/10	94.1	101	---	4.24	5.92	---	**21.8**	**29.6**	-35.8
CBSF2	11/30/10	**170**	**68.1**	59.9	2.18	2.59	---	13.1	13.3	---
CBSF2	1/5/11	71.8	47.8	---	3.55	6.86	---	17.3	33	---
CBSF2	3/16/11	75.7	32.1	---	1.59	3.19	---	10.4	16.9	---
CBSF2	4/14/11	37.9	17.9	---	**7.63**	**9.48**	-24.2	**31.2**	**44**	-41.0
CBSF2	4/27/11	19.4	17.2	---	**7.31**	**8.45**	-15.6	**27.5**	**37**	-34.5
Total n		37	37	17	37	37	17	37	37	20
Qualifying n [1]		17	17	17	17	17	17	20	20	20
LCL95 [2]		NA	NA	**19.8**	NA	NA	**-27.5**	NA	NA	**-34.2**
mean		204.8	140.2	29.7	7.8	9.0	-17.1	34.8	40.2	-23.9
Sig difference? [3]		**yes (Wilcoxon)**			**yes (Wilcoxon)**			**yes (Wilcoxon)**		
Power (%)		65.6			39			24		

Notes-
--- No % difference listed since applicable screening criteria not met.

Bold indicates values used in percent reduction calculations.

[1] Calculated sample number based on influent concentration screening per TAPE 2011.

[2] LCL95 is the one-sided lower 95% confidence limit on the estimate of the mean percent reduction .

[3] Significance of differences ($\alpha = 0.05$) between influent and effluent concentrations were determined with a non-parametric Wilcoxon Signed Rank Test run on the sample pairs after TAPE 2011 screening of influent concentrations.

Significant differences (differences in influent and effluent mean values that can be established with at least 95 percent confidence) were observed for total phosphorus, dissolved copper and dissolved zinc. Although the minimum power goal of 75-80 percent was not achieved for these three parameters, greater than 35 samples were collected and consequently the permit requirement was met.

For samples with influent total phosphorus concentrations ranging from 100 to 500 µg/L, removal rates ranged from -9.8 to 60.5 percent with a mean value of 29.7 percent. The lower 95 percent confidence limit of the mean percent total phosphorus reduction was 19.8 percent.

For samples with influent dissolved copper concentrations ranging from 5 to 20 µg/L, removal rates ranges from -66.9 to 26.6 percent with a mean value of -17.1 percent. The lower 95 percent confidence limit of the mean percent dissolved copper reduction was -27.5 percent. For samples with influent total dissolved zinc concentrations ranging from 20 to 300 µg/L, removal rates ranges from -82.9 to 38.6 percent with a mean value of -23.9 percent. The lower 95 percent confidence limit of the mean percent dissolved zinc reduction was -34.2 percent.

The average negative percent removal calculated for both metals suggests that there is an "export" of dissolved copper and zinc for the events monitored. The phenomenon of negative percent removals is often exhibited in BMP performance studies. These negative percent removals for the dissolved metals is likely due to a combination of the relatively low influent concentrations and internal processes causing the desorption or dissolution of total metal particulates within the BMP's filter chamber or filter itself.

Dissolved, or more correctly termed "filtered," metals are metals measured after a sample has been passed through a 0.45 micron filter and acidified to a pH of 2. Metals in stormwater undergo continuous changes between precipitated, dissolved and colloidal forms. Although it is outside the scope of this performance evaluation to determine what is causing the metals species changes in this BMP, it noteworthy that compiled performance data from the International Stormwater Best Management Practice Database (Geosyntec and WWE 2008) found that dissolved zinc "effluent concentrations appear to be greater than influent concentrations for detention basins, hydrodynamic devices and wetland basins." In the same paper, no significant difference was observed for dissolved copper between influent and effluent EMCs for media filter BMP studies in the database. This summary of worldwide BMP data indicates that the dissolved metal treatment performance of the CBSF observed during this study is not unusual when compared to other stormwater BMPs. In addition, a different filter media would be used if dissolved metals treatment was the primary treatment goal of this BMP.

Table 5.1.3c. Orthophosphate and Total Metals Water Quality Performance Statistics

Site	Date	Orthophosphate (µg/L)			Total Cu (µg/L)			Total Zn (µg/L)		
		IN	OUT	% diff	IN	OUT	% diff	IN	OUT	% diff
CBSF1	3/2/09	8	8	0.0	30.4	17.9	41.1	146	125	14.4
CBSF1	3/3/09	14	13	7.1	30.2	19.8	34.4	158	100	36.7
CBSF1	10/21/09	96.8	53.5	44.7	19.7	15.1	23.4	81.2	55.8	31.3
CBSF1	10/26/09	39.6	32.7	17.4	10.7	6.88	35.7	53.6	30.2	43.7
CBSF1	11/6/09	76.5	85.4	-11.6	14.2	11.3	20.4	74.2	49.4	33.4
CBSF1	12/14/09	33.4	31.7	5.1	29.1	17.3	40.5	135	63.1	53.3
CBSF1	3/11/10	18.8	15.1	19.7	22.6	11.3	50.0	68.2	43.1	36.8
CBSF1	3/26/10	25.9	33.6	-29.7	30.3	15.9	47.5	136	56.3	58.6
CBSF1	4/2/10	13.8	18.5	-34.1	13.5	8.53	36.8	61	37.8	38.0
CBSF1	5/20/10	99.7	28.6	71.3	37.9	19.4	48.8	180	96.2	46.6
CBSF1	6/2/10	5.76	16.1	-179.5	11	8.41	23.5	53.3	42.6	20.1
CBSF1	6/9/10	7.2	26.9	-273.6	20.5	11.3	44.9	99.9	62.1	37.8
CBSF1	10/26/10	64.5	67.1	-4.0	27.1	28	-3.3	120	89.8	25.2
CBSF1	11/30/10	16.4	13.7	16.5	37.6	23.3	38.0	202	114	43.6
CBSF1	1/5/11	25.4	10.2	59.8	14	11.7	16.4	67.7	70	-3.4
CBSF1	3/8/11	20.6	8.8	57.3	11.8	18.9	-60.2	42.4	85.3	-101.2
CBSF1	3/16/11	13.7	7.22	47.3	21.5	10.6	50.7	90.4	52.8	41.6
CBSF1	4/14/11	3.76	7.47	-98.7	14.2	27.1	-90.8	149	145	2.7
CBSF1	4/27/11	44	22.6	48.6	24.8	22.1	10.9	123	88.6	28.0
CBSF2	3/2/09	14	11	21.4	26.8	16	40.3	190	79	58.4
CBSF2	3/3/09	16	14	12.5	17.8	14.8	16.9	107	80	25.2
CBSF2	10/26/09	38	23.8	37.4	7.24	3.95	45.4	36.9	17.5	52.6
CBSF2	11/6/09	32.2	38.8	-20.5	9.1	7.72	15.2	47.1	38.2	18.9
CBSF2	12/14/09	43	22.3	48.1	19.1	13.5	29.3	91.9	54.5	40.7
CBSF2	12/17/09	12.3	10.6	13.8	11.6	8.29	28.5	48.7	38.2	21.6
CBSF2	2/5/10	8.55	9	-5.3	6.33	5.23	17.4	36.5	28.6	21.6
CBSF2	2/11/10	13.8	10.7	22.5	14.9	10.9	26.8	80.8	52.9	34.5
CBSF2	3/11/10	14.3	11.5	19.6	10.3	8.68	15.7	52	35.6	31.5
CBSF2	3/26/10	22.1	17.8	19.5	20.5	12	41.5	121	53.4	55.9
CBSF2	5/20/10	37.2	20.7	44.4	33.7	25.9	23.1	184	91.2	50.4
CBSF2	6/2/10	6.01	2.29	61.9	13.1	8.98	31.5	70	43	38.6
CBSF2	10/26/10	27.4	25.6	6.6	10.5	10.2	2.9	54.6	50.9	6.8
CBSF2	11/30/10	9.29	6.66	28.3	20	10.2	49.0	113	49.5	56.2
CBSF2	1/5/11	15.8	10.9	31.0	11.2	9.82	12.3	78.7	45.1	42.7
CBSF2	3/16/11	8.24	4.67	43.3	17.6	8.59	51.2	91.3	43.1	52.8
CBSF2	4/14/11	15.7	11.6	26.1	27.5	19.4	29.5	112	95.6	14.6
CBSF2	4/27/11	20.7	2.69	87.0	27.6	16.1	41.7	147	75	49.0
Total n		37	37	37	37	37	37	37	37	37
LCL95[1]		NA	NA	-11.7	NA	NA	16.9	NA	NA	23.4

Site	Date	Orthophosphate (µg/L)			Total Cu (µg/L)			Total Zn (µg/L)		
		IN	OUT	% diff	IN	OUT	% diff	IN	OUT	% diff
mean		26.6	20.4	7.1	19.6	13.9	25.1	100.1	64.3	31.3
Sig difference? [2]		**yes (Wilcoxon)**			**yes (Wilcoxon)**			**yes (Wilcoxon)**		
power %)		35.8			94.7			99		

[1] LCL95 is the one-sided lower 95% confidence limit on the estimate of the mean percent reduction.

[2] Significance of differences (α = 0.05) between in and out concentrations were determined with a non-parametric Wilcoxon Signed Rank Test.

Significant differences (differences in influent and effluent mean values that can be established with at least 95 percent confidence) were observed for orthophosphate, total copper and total zinc. The power analysis indicated that the hypothesis tests for total copper and zinc had sufficient power to be deemed valid (exceeding the Permit goal of 75-80% power). Although the minimum power goal of 75-80 percent was not achieved for orthophosphate, greater than 35 samples were collected and consequently the permit requirement was met.

Using all data, the mean orthophosphate removal rate was 7.1 percent and the lower 95 percent confidence limit of the mean percent removal was -11.7 percent.

Using all data, the mean total copper and zinc removal rates was 25.1 and 31.3 percent, respectively and the lower 95 percent confidence limit of the mean removal was 16.9 and 23.4 percent, respectively.

The following table presents a summary of water quality treatment performance for the main seven water quality parameters analyzed during this study.

Table 5.1.3d. Water Quality Treatment Performance Summary – All Parameters

Parameter	Mean Removal Rate (Percent)	Lower Confidence Limit 95 (Percent)[1]	Upper Confidence Limit 95 (Percent)[2]
Total Suspended Solids (influent >100 mg/L)	72.1	62.8	NA
Total Suspended Solids (influent <100 mg/L)	NA	NA	23.6
Total Phosphorus	29.7	19.8	NA
Orthophosphate	7.1	-11.7	NA
Total Copper	25.1	16.9	NA
Dissolved Copper	-17.1	-27.5	NA
Total Zinc	31.3	23.4	NA
Dissolved Zinc	-23.9	-34.2	NA

Notes:
NA – not applicable (corresponding statics do not apply to this cell).
[1] Lower confidence limit 95 is the one-sided lower 95% confidence limit on the estimate of the mean percent reduction.
[2] Upper confidence limit 95 is the one-sided upper 95% confidence limit on the estimate of the mean effluent concentration.

5.2 Pollutant Removal as a Function of Flow Rate

To assess if pollutant removal was influenced by flow rates, an analysis of pollutant removal efficiency relative to flow rate was conducted. This regression analysis is not required by the Permit but is a new requirement in the revised 2011 TAPE. In order to isolate the effect of influent concentration on percent removal, the data were screened based on influent concentration ranges identified in the 2011 TAPE, as discussed in the previous section. The resultant screened data were regressed against influent concentrations to verify that the relationship was not driving percent removal calculations. The linear regression analysis indicated that there was no significant relationship between influent concentration and percent removal. The screened data were then plotted against the average total flow for the associated sampled event and presented in Figures 5.2a and b. This procedure was only conducted for the parameters with influent criteria identified in the 2011 TAPE; consequently, total copper, total zinc and orthophosphate are not presented in the figures.

Figure 5.2a indicates that at CBSF1 there is a weak (insignificant) negative relationship between average influent flow and percent removal of total phosphorus (R^2=0.001, p-value=0.970), dissolved copper (R^2=0.119, p-value=0.249) and dissolved zinc (R^2=0.033, p-value=0.568). In

Figure 5.2a. CBSF1 Pollutant Removal as Function of Flow Rate

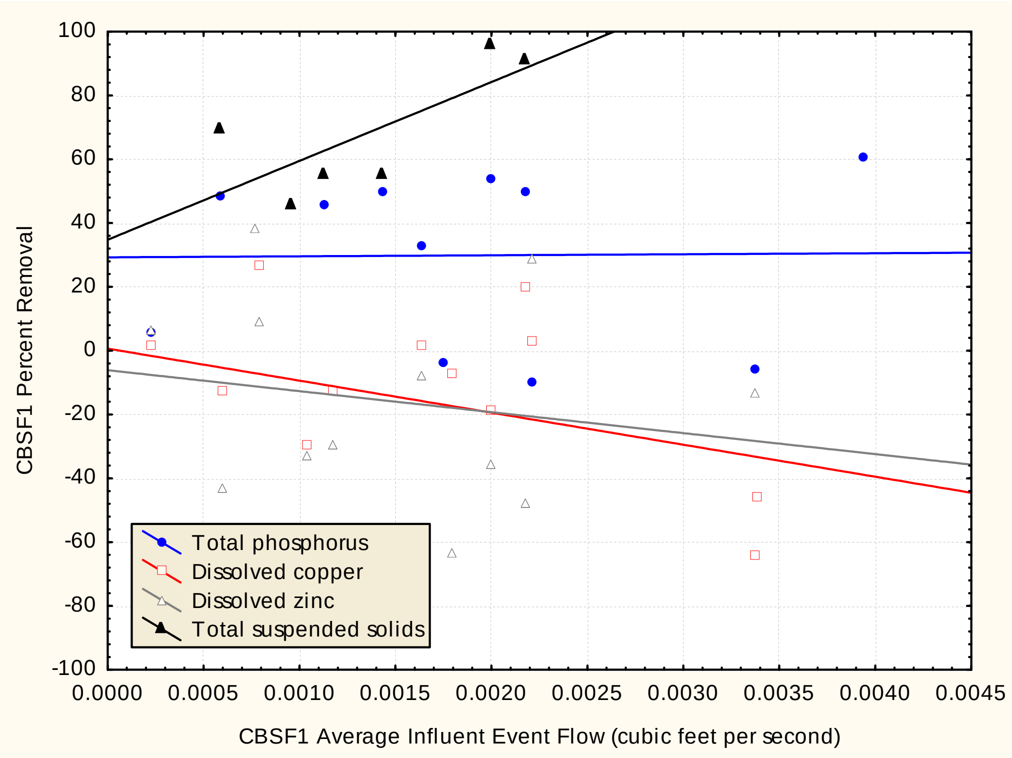
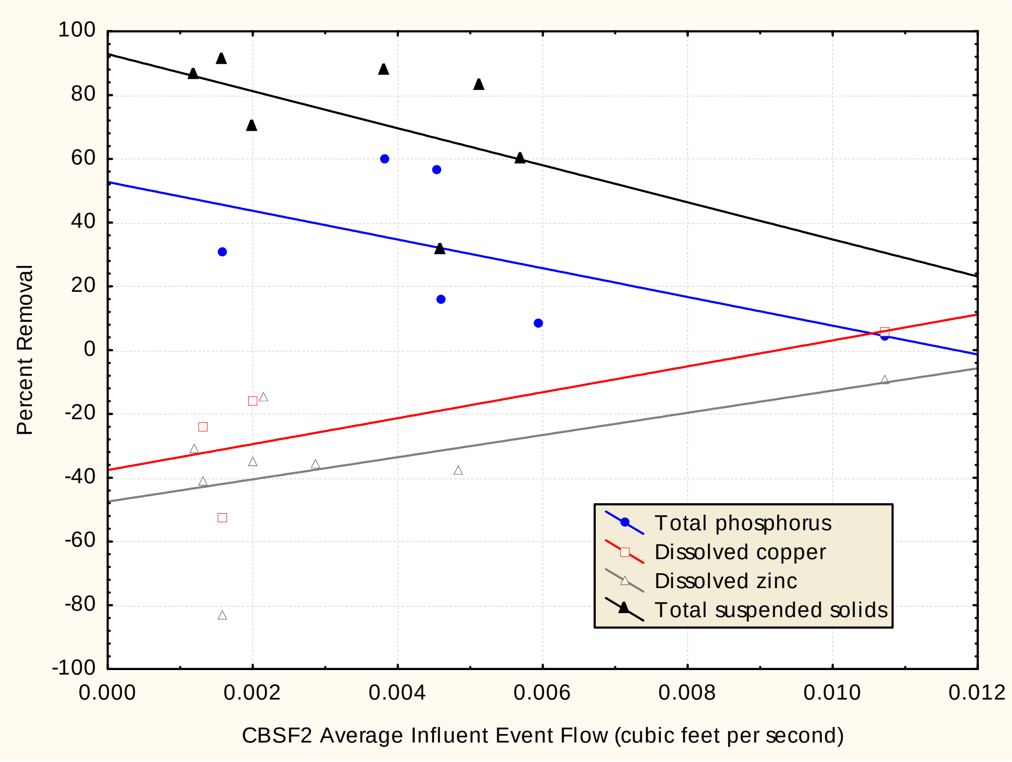


Figure 5.2b. CBSF2 Pollutant Removal as Function of Flow Rate



theory, as flow rates increase percent removal should decrease because decreased residence time within the system limits the efficacy of the settling and filtration processes. Conversely, TSS removal appears to increase with increasing flow although this pattern is also not significant (R^2=0.534, p-value=0.099). This is likely the result of the larger events mobilizing more solids than smaller events, resulting in elevated influent concentrations which typically results in higher percent removal rates.

At CBSF2, the relationship between flow and total suspended solids (R^2=0.066, p-value=0.579), dissolved copper (R^2=0.152, p-value=0.610) and dissolved zinc (R^2=0.001, p-value=0.967) removal was also weak (Figure 5.2b). However, total phosphorus exhibited a stronger (though not statistically significant) negative relationship to flow (R^2=0.444, p-value=0.148). At lower flow rates the total phosphorus percent removal was close to 50 percent while at higher flow rates the percent removal approached 0 percent. This may suggest that over-sizing a CBSF system may increase the ability to remove phosphorus, but because this pattern was not seen at CBSF1, the result is inconclusive.

In general, the results from this analysis indicate there is no relationship between flow and pollutant removal performance over storms and flow rates monitored since all p-values are greater than 0.05.

5.3 Hydrologic Performance Evaluation

The following section discusses the hydrologic performance of the two CBSF units. For this analysis, only the two complete years of flow and rainfall data, from October 1, 2009 to September 30, 2011 (entire water years 2010 and 2011), are used. The first three sections provide background and context for the hydrologic performance evaluation while the discussion of the hydrologic performance of the units can be found beginning in Section 5.3.4.

5.3.1 Historical Data Rainfall Comparison

Rainfall data from the project rain gage (RG14) for water years 2010 and 2011 were compared against the 32-year historic record for this gage (1978-2009) to provide context for interpreting the hydrologic performance of the CBSFs. The table below summarizes rainfall data for RG14.

Table 5.3.1. RG14 Historical Rainfall Comparison

Mean Annual Rainfall 1978-2009 (inches)	WY2010 Rainfall (inches)	WY2011 Rainfall (inches)	WY2010 Difference From Mean (inches)	WY2011 Difference From Mean (inches)	WY2010 Difference From Mean (percent)	WY2011 Difference From Mean (percent)
34.23	47.21	46.31	+12.98	+12.08	+37.9%	+35.3%

Since both of the water years monitored had mean annual rainfall amounts that exceeded the historical average by over 25 percent, the years monitored are considered to have above average rainfall that is not representative of a typical year.

5.3.2 Controlled Flow Testing for Flow Quality Assurance

While analyzing flow data from WY2010, the preliminary data indicated that flow was bypassing the cartridge chambers at a greater frequency and volume than was anticipated. As a result of extensive field checks, calibration and editing; the level data are considered accurate over the course of this study. However, since the flow values were derived by converting level data to flow using untested equations (for the Thel-Mar weir, the equations were provided by the weir manufacturer and for the sharp-crested custom weir at the bypass, the equation came from a weir equation found in a standard flow measurement handbook – Isco 2008), the accuracy of the conversions and thus calculated flow was unknown.

In June 2011, staff from SPU's Meter Shop assisted SPU Monitoring staff in the controlled application of water from a hydrant into each CBSF with a closed channel flow meter to generate new rating curves for each of the four monitoring points. Based on the results of this complex and comprehensive QA step; new, custom rating curves were derived for each flow monitoring point.

The controlled testing indicated that the original rating curves and preliminary calculated flow at the outlet/total flow location were generally accurate to within +/- 10 percent at typical flow ranges. The original bypass weir rating curve resulted in flow calculations, especially at higher flows, that were as much as 50 percent lower than actual. Thus, this testing resulted in a re-calculation of flow data that resulted in more bypass flow than originally was reported. Refer to Appendix A for the complete results of this testing and a comparison of the pre- and post-test rating curves.

5.3.3 Inlet Grate Clogging

The QAPP for the project assumed all runoff in each CBSF drainage basin would enter the inlet grate of the unit and either be filtered by flowing through the filter chamber or bypass the filters via the internal bypass weir within the unit. In reality, field observations indicated that a considerable amount of runoff bypassed the units entirely due to blockage of the inlet grate by leaves and debris. In general, the units monitored for this study received nearly weekly attention and debris removal by sampling staff during the wet season and the roadways were targeted to be swept every two weeks by SDOT street sweepers. Despite these efforts, clogging was an ongoing a problem during this study. Clogging was worse and more frequent as leaves accumulated in the right-of-way from September to November, but was observed to occur as late as February.

The following pictures show inlet grate clogging both during dry periods and storm events. Photographs taken during storm events illustrate the runoff flowing around, not into, the units (hereafter referred to as “external bypass”).

Figure 5.3.3a. Inlet grate clogging at CBSF1 during dry, fall conditions

Figure 5.3.3b. Inlet grate clogging at CBSF1 during mid-winter conditions

Figure 5.3.3c. Complete inlet grate clogging at CBSF2 showing flow bypassing inlet

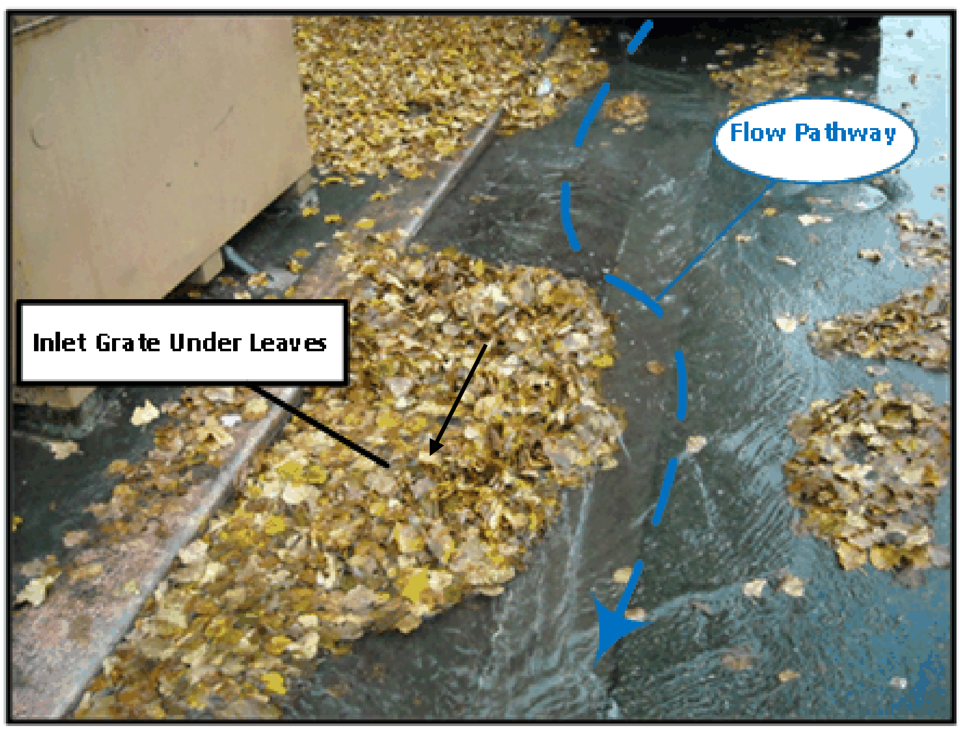


Figure 5.3.3d. Partial inlet grate blockage at CBSF2 showing flow bypassing inlet

Excessive inlet grate blockage is attributed to three factors of the inlet grate design of the monitored units:

1. A gap between the outside edge of the grate and inside edge of the metal casting on top of the unit allows debris to get caught in the gap. The gap can be best observed in Photos 5.3.3a (gap filled with sand/gravel) and 5.3.3d (upstream gap filled with leaves, downstream gap relatively clear). Even a small amount of leaves/debris caught in this gap served as an effective dam which prevented runoff from entering the units (5.3.3d).

2. The grate style of the monitored units (referred to as "traditional" in this report) has slots with the long-dimensions orientated parallel to curb and thicker metal between the openings, resulting in less open area (shown in Photos 5.3.3a-d). This grate style is more prone to clogging than grates with thinner metal surrounding larger openings, and which has metal slants orientated diagonally relative to the roadway surface (termed a "vaned" grate – show in photo 5.3.3f).

3. A metal cover flap over the effluent/bypass chamber (which prevents unfiltered stormwater from flowing directly to the effluent pipe) is located within ½ to 1-½ inches below the grate's bottom extending under approximately 40 percent of the grate opening (see Photo 5.3.3e and sketch on Figure 2.1a, figure section 2 – cover flap is unlabeled but illustrated below inlet grate in the side view). This cover essentially serves as a barrier which traps debris directly below the grate. This debris eventually accumulates and entirely clogs the grate openings over the cover flap. When the grate above the cover is completely clogged, the surface area of the inlet grate is effectively reduced by approximately 40 percent. In addition, when this cover is oriented against the curb, as it was at CBSF2, the clogged portion of the grate is directly in the flow line along the curb. This orientation exacerbated the grate clogging issue. The following photo, taken of a CBSF unit located on Lake City Way in Northeast Seattle, shows debris remaining on the cover after the maintenance contractor had removed the grate for cleaning.

Figure 5.3.3e. Sediment accumulated on metal cover flap (grate removed)

Some inlet grate clogging can be expected for any inlet to the storm drain system but the clogging observed with the CBSF units is considered excessive. To determine if the observed clogging was unique to the two monitored unit and was possibly: 1) related to the leaves in the CBSF1 and 2 basins, or 2) due to the older, traditional grate style (which has been replaced with vaned grates on newer units); visual inspections were performed on the City's most recently installed (summer 2010) CBSFs on South Columbian Way. The Columbian Way CBSFs have the newer, vaned grates and are located on a roadway with minimal and smaller trees (planted in conjunction with 2010 roadway improvements and CBSF installations). Of the 10 Columbian

Way CBSFs inspected on October 27, 2011, all grates were partially clogged and 8 of 10 of the units have complete clogging over the metal cover flap meaning the grate was approximately 40 percent clogged or greater. Half of these units were oriented with the flap on the curb side so the clogging was directly in the flow pathway.

Figure 5.3.3f. Columbian Way vaned grate style CBSF showing clogging

The external runoff bypass due to these issues was not directly quantified and is therefore missing from the overall water budget in assessments of each unit's hydrologic performance (see next section). However, visual observations during monitored storm events indicated that as much as 50 percent of the roadway runoff during some events may have flowed past, not into, each CBSF due to inlet grate clogging. Based on this estimate, the external flow bypassing problem caused by the clogging substantially compromises the treatment effectiveness of the monitored units.

5.3.4 Hydraulic Performance Analysis Overview

Each CBSF unit is rated for a specific design flow rate, which is 0.033 cfs for CBSF1 and 0.067 cfs for CBSF2 (based on two 7.5 gpm cartridges in CBSF1 and four 7.5 gpm cartridges in CBSF2). Influent storm flows at or below the design flow rate are expected to be treated by the filter cartridges. As influent flows exceed the design rate, water level within the units rise and some of the influent flows are expected to bypass the cartridge chamber via the internal bypass (hereafter, referred to as "internal bypass"). As the cartridges become clogged, their treatment capacity is reduced and the treated flow rate is expected to decrease.

The occurrence and volume of internal bypass is discussed in the following sections. Internal bypass occurred during 26 of the 37 stormwater events sampled. The table below presents aggregated flow data over the study duration to give a general sense of how much flow each unit treated.

Table 5.3.4. Treated versus Internal Bypass Flow Summary October 1, 2009 through September 30, 2011

Site	Total Flow (cubic feet)	Internal Bypass Flow (cubic feet)	Treated Flow (cubic feet)	Volume Treated
CBSF1	55,055	25,414	29,642	54%
CBSF2	161,926	59,130	102,795	64%

Based on the aggregate flow data, the occurrence of internal bypass is considered more than is acceptable since neither unit treated close to 91 percent of the annual volume (91 percent annual volume treatment is the criteria listed in the state's stormwater management manual). Since the hydraulic performance of the units is dependent on sizing, refer to Sections 5.3.6 and 5.3.7 for a discussion of a retrospective unit sizing and rainfall analysis for additional perspective of the internal bypass issue relative to actual unit sizing.

5.3.5 Average Treated Flow Rate during Bypass versus Time

The current TAPE document (TAPE 2011) indicates that to quantify the maintenance requirements of a system, the proponent should assess system hydraulic performance through time. This assessment is based on analyzing treated flow rates during periods of bypass as a function of time. In theory, the treated flow rate during bypass should be approximately equal to the design flow rate of the system. As the system clogs, bypass will occur at a lower flow rate and consequently, the treated flow rate during bypass will decrease. The manufacturer of the CBSF has indicated that when the system has reached 50 percent of the design flow rate capacity, the cartridge filters should be replaced (Darcy, personal communication 2011).

To calculate treated flow rate during internal bypass, storm events were delineated based on the precipitation criteria in the TAPE. Subsequently, the internal bypass flow rate was subtracted from the total flow rate for each individual event during which bypass occurred. Next, the treated flow rate values during periods of no bypass (equivalent to total flow rate) were discarded. The resultant treated flow rate during bypass values were averaged for each event to derive an "average treated flow rate during bypass" value for each event during which internal bypass occurred.

The CBSF1 and CBSF2 units have design flow rates of 0.033 and 0.067 cfs, respectively, based on the number of cartridges in each unit. If the average treated flow rate during internal bypass begins trending below the design flow rate, it would be an indication that the filters are clogging and causing the system to bypass prematurely. This analysis controls for precipitation depth because once the system enters internal bypass the treated flow rate is relatively constant. This is because the treated flow rate is controlled by the water depth above the cartridges. Once the systems go into internal bypass this vertical head only varies slightly through the course of the bypass period because water rapidly pours over the wide bypass weir before the water level within the filter chambers can raise substantially.

The average treated flow rate during bypass values are plotted versus time in Figures 5.3.5a and b. Each blue circle represents a storm event that met qualifying criteria and during which bypass occurred. The red trend line is a LOWESS (locally weighted scatterplot smoothing) curve; which is a method of smoothing data using a local regression model fit to each point and the points close to it. When reviewing these graphs, it is important to remember that smaller storms with no bypass are not plotted, but these smaller storms would still be loading the cartridge filters and thus diminishing filters' capacity. Filter replacement, performed three times during the study period, is displayed by vertical gray bars. As is apparent, immediately after new filters were installed the average treated flow rate during bypass was at or above the design flow rate. However, the filters quickly begin to clog and within an average of two and a half months the filters for both units over both annual maintenance cycles were at 50 percent of their design capacity.

As a check of the cartridge flow rates calculated by subtracting bypass from total flow (charted in Figures 5.3.5a and b), during controlled flow testing on June 7-8, 2011 a closed channel flow monitor was used to determine the actual combined cartridge flow of each unit. The combined cartridge flow rate of CBSF1 was 0.5 gpm (0.001 cfs) while the rate of CBSF2 was 6.5 gpm (0.01 cfs) which matches the rates during the same period calculated from the logged flow data. After testing, the cartridges were removed and inspected. The media in one of the two cartridges in CBSF1 was dry which implied complete surface occlusion (clogging) of this cartridge.

This rapid clogging could be influenced by the introduction of tree leaves to the system. The first two filter replacements were performed in late September and leaf fall occurs within the following two months. However, the third filter replacement occurred in June 2011 and the limited monitoring data from the time of that replacement until the end of the study in October 2011 suggest that the filters at CBSF1 may have already reached 50 percent of design capacity by mid-September as a result of loading from occasional summer storms (not displayed since bypass did not occur during these smaller storms).

These data indicate that CBSF1 and CBSF2 clogged within approximately 2-½ months after each maintenance event. The rapid filter clogging resulted in less flow being treated by the units and will require filter replacement to occur more frequently than annually.

Figure 5.3.5a. CBSF1 Temporal Plot of Treated Flow Rate and Precipitation Depth

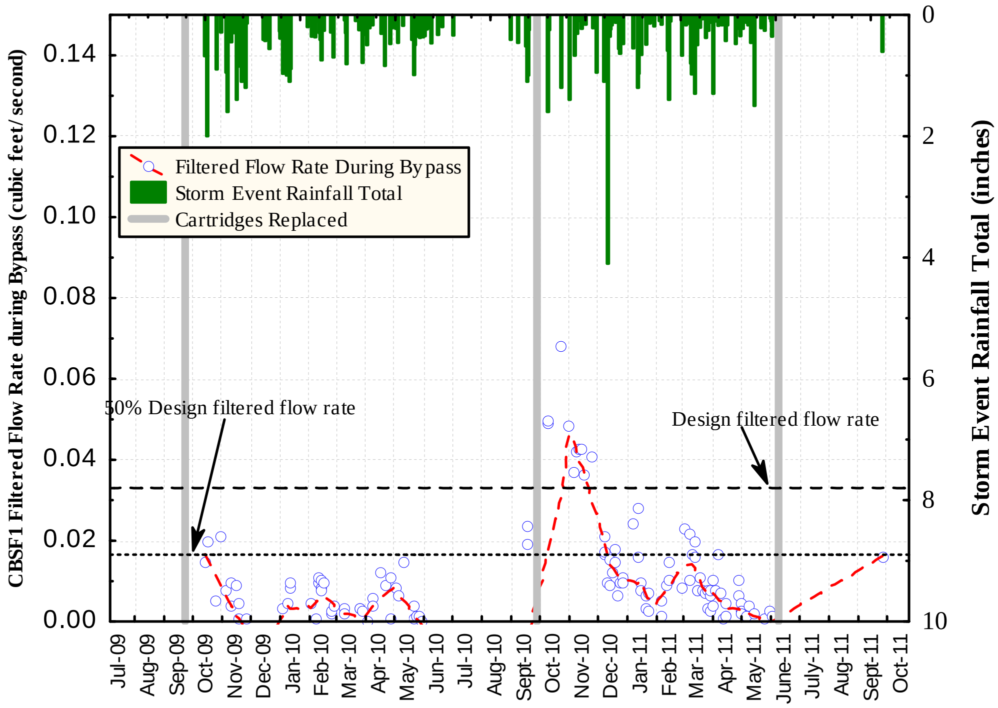
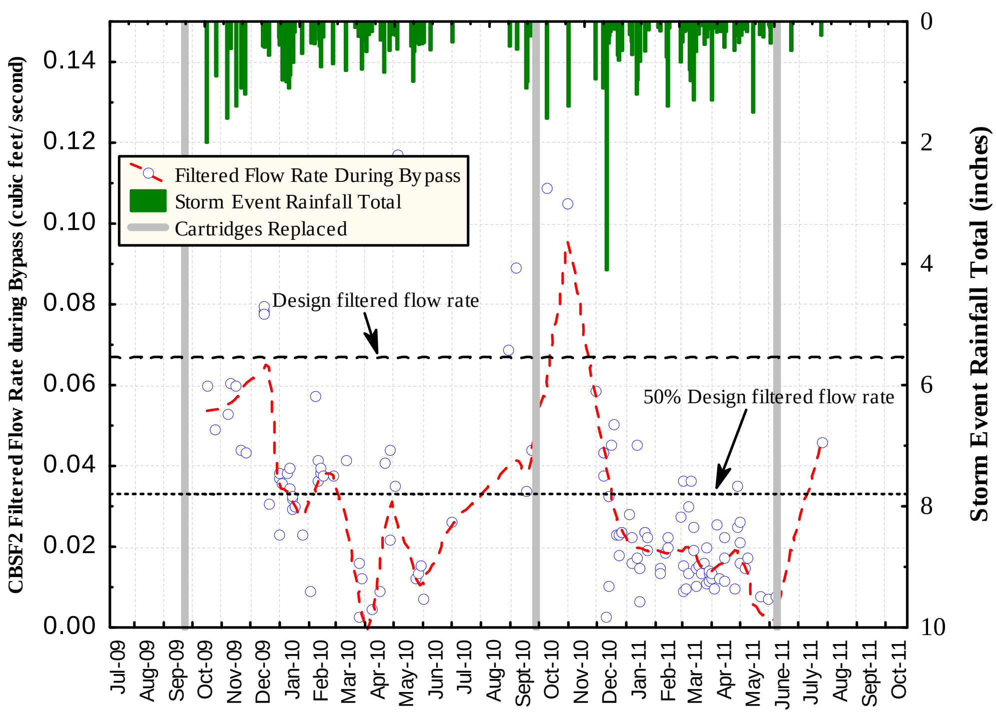


Figure 5.3.5b. CBSF2 Temporal Plot of Treated Flow Rate and Precipitation Depth



5.3.6 Retrospective Flow-Based Sizing Analysis

Accurate flow-based sizing of BMPs is complicated by the difficulty in accurately defining the boundaries of urban drainages and the reliance on imperfect models to predict flow rates. In addition, BMP sizing is based on rainfall averages, which results in BMPs being undersized in wet years and oversized in dry years. As is displayed on Table 5.3.1, precipitation amounts measured at rain gage RG14 for Water Years 2010 and 2011 were above the historical average by approximately 37 percent. Since the rainfall was above average during the monitoring period, it is to be expected that the monitored CBSF units would appear "undersized" during the course of this study due to the above average rainfall. Table 5.3.6 presents system sizing information including the modeled design flow rate, the theoretical design flow rate and the retrospective design flow rate (calculated from monitored flows).

The modeled design flow rate was derived using two separate continuous hydrologic models. The Western Washington Hydrology Model (Version 3) was used for the initial project sizing prior to construction. However, the City has since moved to using MGSFlood (Version 4). Consequently, both models were run during the data analysis phase of the project to reassess the sizing of both units. As is shown in the table, MGSFlood produced design flow rate results that are slightly lower than WWHM3. The design flow rate is defined as the flow rate which must be able to pass through the filters without bypass in order for 91 percent of the annual runoff volume from the basin to be treated.

The theoretical design flow rate is the flow capacity of the cartridges. This is the flow rate that the cartridges can filter without going into bypass conditions. This number is provided by the manufacturer based on previous studies of cartridge filtered flow rates under various pressure heads. As is presented in Table 5.3.6, CBSF1 had a theoretical design flow rate that exceeded the modeled flow rate, while CBSF2 did not. This is because the CBSF2 basin size was reassessed after monitoring began and it was determined that the basin was over four times larger than originally determined (originally estimated at 0.23 acres and now estimated at 0.97 acres). However, proper sizing during the duration of the study cannot be determined with modeled design flows and theoretical design flow rates alone; actual flow data are required for this type of retrospective analysis.

In order to determine if the CBSF units were properly sized based on actual flow conditions during the duration of the study; a retrospective design flow rate analysis was conducted. The hydrograph generated from monitored flows during the 2-year duration of the study was analyzed using a custom script written in the programming language Python™ (version 2.6) that progressively "sliced" the hydrograph at different flow rates until the volume calculated beneath the flow rate curve was equivalent to 91 percent of the total 2-year volume actually measured during this study. The corresponding flow rate at this point is the actual design flow rate for the study period, or what is termed the "retrospective design flow rate" in Table 5.3.6. This retrospective design flow rate exceeded the theoretical design flow rate at both CBSF1 and CBSF2 by approximately 36 and 39 percent, respectively. As discussed previously, 2010 and 2011 were both characterized by approximately 37 percent above normal precipitation, so the discrepancy can be explained by the higher than average rainfall and resulting flow conditions during the course of the study.

Although the modeled design flow rate for CBSF2 indicates it may have undersized by a factor of 2, it is assumed that it actually received much less actual flow than the modeled flow predicted due to the inlet grate clogging and external bypass issue discussed earlier. The retrospective flow sizing analysis suggests that the monitored units were both properly sized for an average water year based on the flow that the units actually received.

Table 5.3.6. Retrospective Flow-Based Sizing Analysis

Site	No. of active cartridges	Updated Basin Size (acres)	Percent impervious	Basin slope (%)	On-line Facility Modeled Design Flow Rate (cfs) [1]		Theoretical Design Flow Rate (cfs) [2]	Retrospective Design Flow Rate WY2010-2011 (cfs) [3]
					WWHM3	MGS		
CBSF1	2	0.18	100	0-5	0.031	0.025	0.033	0.045
CBSF2	4	0.97	85	5-15	0.136 [4]	0.116 [4]	0.067	0.093

Notes:
WWHM3 = Western Washington Hydrology Model (Version 3)
MGS = MGSFlood (Version 4)
cfs = cubic feet per second
[1] Modeled maximum flow rate which must be treated in order to treat 91% of the annual modeled runoff volume.
[2] Maximum treatable flow rate based on media cartridge hydraulics and number of cartridges (each cartridge can treat 0.017 cfs).
[3] Measured maximum flow rate which, if treated, would result in treatment of 91% of the measured annual runoff volume
[4] Assumes remaining 15 percent of land cover is lawn on till.

The above normal precipitation and resulting higher flows during the monitoring period have implications for the maintenance interval. As indicated above in Section 5.3.5, during the study the filters in both units clogged within approximately 2-½ months following both replacement events in late September. But because the CBSF units received 36-39 percent more flow than what they were designed for using flow-based sizing, it is assumed that they were introduced to 36-39 percent more solids loading. Based on this assumption, the maintenance cycle under average rainfall year flow conditions may be closer to 3-½ months (a 37 percent increase over 2-½ months) during the same wet period.

5.3.7 Retrospective Load-Based Sizing Analysis

Smaller proprietary BMPs such as CBSFs are typically sized using continuous runoff models such as WWHM3 or MGSFlood based on expected flow rates only, as required by both state and city stormwater management manuals. According to the manufacturer, for units downstream of detention, they typically provide recommendation for sizing that accounts for annual mass load (Contech 2004 and 2012). Units not located downstream of detention are to be sized using a flow-based sizing methodology as required by the applicable regulatory authority (Contech 2012) such as was performed for the project units. Although the monitored CBSFs are not located downstream of detention, SPU conducted a retrospective load-based sizing analysis using the Simple Method and a range of TSS concentrations to estimate the number of cartridges that would be needed based on the load each cartridge can treat. For this analysis, it was assumed that the cartridges would be replaced once annually and that each cartridge can retain 36 pounds of sediment [specifically, 18 pounds retained in each cartridge and 18 pounds on the cartridge chamber floor per the manufacturer's laboratory testing (Contech 2012)] before maintenance is required.

Estimated sediment loading for the each basin was calculated based on the product of the annual runoff volume and TSS concentration. Average annual runoff was calculated using the Simple Method (Schueler 1987):

$$R = P\ x\ Pj\ x\ RV$$

Where:

R = annual runoff (inches rainfall as runoff)

P = annual rainfall (inches) = 34.23 (historic average at project rain gage)

Pj = fraction of annual rainfall events that produce runoff = 0.9

$$RV = 0.05 + 0.9\ x\ Ia$$

Ia = percent impervious area (100 percent for CBSF1 and 85 percent for CBSF2)

Under state and city stormwater manuals, stormwater treatment devices are sized using continuous runoff models to treat 91 percent of the runoff generated over the modeling time period which allows for high flows to bypass the units. For this analysis, the estimated average annual runoff was multiplied by 91 percent (0.91) to calculate the annual runoff the units are designed to treat.

Two different TSS concentrations were considered for this analysis. The first was the mean TSS concentration based on 32 flow-weighted composite stormwater samples collected over water years 2009-2011 at the City's commercial land use NPDES stormwater characterization monitoring site. The mean TSS concentration from this commercial land use monitoring station is 50 mg/L. The second TSS concentration used is the mean TSS concentration measured at each CBSF unit during this study. These TSS means were 88 and 97 mg/L at CBSF1 and CBSF2, respectively.

In addition, the CBSF influent sump (inlet chamber) was assigned varying levels of pretreatment performance to estimate theoretical loading that the filter cartridges experience. The following three pretreatment scenarios were evaluated:

- 0 percent TSS removal
- 20 percent TSS removal
- 75 percent removal of coarse sand and heavier particle fractions.

The results of the mass loading analysis are presented in Table 5.3.7 below. If these units had been sized for annual maintenance under average annual loading conditions based on TSS data from the City's NPDES commercial monitoring station, CBSF1 would require one cartridge and CBSF2 would require four to seven cartridges. If the units were designed using actual TSS data measured during this project, CBSF1 would require one to three cartridges and CBSF2 would require 7-13 cartridges depending on the pretreatment credit assigned.

Table 5.3.7. Retrospective Load-Based Sizing Analysis

	CBSF1		CBSF2	
	Land use TSS based design[a]	Actual TSS design[b]	Land use TSS based design[a]	Actual TSS design[b]
No credit for pretreatment in influent sump				
Estimate annual runoff treated (cubic feet)	16,603	16,603	79,710	79,710
Mean TSS (mg/L)	50	88	50	97
Average annual TSS load (pounds)	52	91	249	483
Number of cartridges (load-based sizing)	1.4	2.5	6.9	13.4
Assume 20% TSS removal in influent sump[c]				
Average annual TSS load (pounds)	41	73	199	386
Number of cartridges (load-based sizing)	1.2	2.0	5.5	10.7
Assume remove 75% of coarse sand and heavier particles in influent sump[d]				
Average annual TSS load (pounds)	28	49	135	262
Number of cartridges (load-based sizing)	0.8	1.4	3.7	7.3

Notes-
a. TSS from Seattle's commercial land use stormwater characterization monitoring site (C1) used.
b. Average actual TSS from site-specific stormwater data.
c. Simple percent removal calculation. No adjustment for PSD.
d. Coarse sand and heavier particles removed in inlet chamber since are assumed to not affect cartridge longevity.

For comparative purposes, Contech conducted an alternative retrospective load-based sizing analyses using measured PSD data (refer to Appendix E).

6 MAINTENANCE AND DESIGN CONSIDERATIONS

Although not explicitly required by the NPDES Permit, maintenance costs, maintenance frequency, and design and installation considerations are important when selecting or evaluating a stormwater BMP.

6.1 Maintenance Frequency

Using the visible sediment triggers provided by the manufacturer, annual maintenance appeared adequate at the units monitored. However, by analyzing the cartridge flow performance (discussed in Section 5.3), the maintenance frequency for the units studied should have been about 3-½ months during the wet season.

6.2 Maintenance Costs

As part of the City's routine maintenance activities, the City's maintenance contractor was asked to provide a cost estimate to perform maintenance on the 15 CBSFs located on California Ave SW, with specific estimates for each unit.

The following table lists the contractor's costs per maintenance visit specific to each of the two monitored units. The costs include all labor, equipment (both truck and recharged cartridges), traffic control and sediment and used media disposal. The cost difference between the two sites is primarily related to the number of active cartridges that need to replaced, with the contractor's estimate for each cartridge cost and related shipping to be $105 per cartridge.

Table 6.2. CBSF Maintenance Visit Cost Estimate

Site	Number of Cartridges	Maintenance Cost Estimate per Event
CBSF1	2	$1,203
CBSF2	4	$1,398

Using these costs, each maintenance event of the two units monitored costs $2,601.

6.3 Other Design Considerations

This section lists some of the maintenance or design-related elements of the CBSF that have been observed by field monitoring staff, maintenance crews or the general public that may benefit from design modifications. The CBSF manufacturer has demonstrated a willingness to continuously improve many design elements of the CBSF and StormFilter products. The following is a list of recommendations that would improve the function or acceptance of CBSFs:

1. Modify inlet grate design. The traditional grate style of the tested units is problematic both from a functional and safety point of view. The city's standard grate, a vaned grate, is less hazardous to cyclists than a traditional grate since the openings on a traditional grate is large enough for a bike wheel to partially enter. In the City's August 15, 1997 letter to the manufacturer listing six issues of concern, changing the grate style to the City's standard vaned grate was an included item. The manufacturer has accommodated this request and uses a vaned grate on newer units; therefore, ongoing problems related to this issue will be limited to the monitored units and other CBSFs in Seattle from that era. SPU has a Bike Safety program focused on replacing traditional grates such as those on the monitored CBSFs (which are hazardous to bikes) to the vaned grates so the grates on the monitored units will eventually be replaced by SPU.

2. Modify design of metal cover flap preventing untreated flow from short circuiting treatment. Also discussed in Section 5.3.3, the lack of adequate clearance between the bottom of the inlet grate and the top of the metal flap over the effluent chamber is problematic in trapping solids which clog the inlet grate. This is considered a critical design flaw because once grate clogging occurs, runoff may flow around and not into the unit which eliminates the water quality benefit of installing this BMP and may result in safety problems related to street flooding.

3. Create secure attachment for orifice weir in under-drain manifold. The orifice weirs (used to reduce flow from 15 to 7.5 gpm) are thin (~0.01 feet thick), lightweight disks that are held in the under-drain manifold by gravity only. They are very easy to dislodge while pressure washing or vactoring solids during unit maintenance. These orifice weirs should be securely attached to the under-drain manifold piping so they cannot be dislodged accidently.

4. Add additional holes in the cartridge chamber covers to facilitate removal. Each cartridge chamber is covered by a large metal cover estimated to weigh over 100 pounds. The monitored units have holes in the lids for a puller near the center of each long edge (orientated parallel to the curb) of the lid. Removal of the lid from this edge is awkward for one laborer and can result in the worker lurching into the traffic lane when lifting the lid, or a second worker needing to lean over the lid to assist in leveraging off the cover. Additional holes in the two short edges of the lid would provide additional and potentially easier/safer lid removal options.

5. Reduce cartridge chamber lid movement/noise. At several other CBSF locations in Seattle, the City has received complaints from neighbors of the noise caused by heavier vehicles rattling the metal cartridge chamber lid against the metal vault body. One proposed solution to this problem could be to change the vault material to precast concrete since a metal lid on a concrete structure typically generates less noise.

7 Conclusions

Water quality and hydrologic monitoring were performed on two CatchBasin StormFilter (CBSF) units beginning in February 2009 and continuing through September 2011. During this period, a total of 37 qualifying storm events were sampled across both units, meeting the requirements of the NPDES stormwater permit. Since all of the Permit's statistical goals could only be met for a limited number of analytes, sampling continued until the permit maximum number of samples (35) was obtained. Because the maximum number of samples were obtained and additional monitoring would not add to the City's knowledge of the performance of this BMP, this performance study is considered completed.

The water quality treatment performance of the units was evaluated by comparing influent to effluent concentrations of stormwater treated (as opposed to bypassed) by the units. For samples with influent total suspended solids (TSS) concentrations exceeding 100 mg/L, the mean percent reduction was 72 percent and the lower 95 percent confidence limit was 63 percent. For samples with influent TSS concentrations below 100 mg/L, effluent removal concentrations averaged 20 percent with an upper 95 confidence limit of 24 percent.

For samples with influent total phosphorus concentrations ranging from 0.1 to 0.5 mg/L, the mean percent reduction was 30 percent and the lower 95 percent confidence limit was 20 percent. Dissolved copper and zinc removal was not observed since the effluent dissolved metals concentrations where higher than the influent concentrations for the storms sampled.

The results from this study indicate there is no significant relationship between influent flow rates and pollutant removal performance of treated stormwater over storms and flow rates monitored.

The inlet grate design and underlying metal cover over the effluent chamber of the tested units was prone to frequent and substantial clogging which resulted in an unknown amount of stormwater runoff flowing around and not into each unit. This is considered a critical design issue with this BMP that is recommended to be modified.

The design cartridge flow rates were achieved for a short period immediately following unit maintenance but quickly decreased in subsequent months. During the two full water years that this study spanned, the cartridges for both units became effectively clogged (at or below 50 percent of the design flow rate) approximately 2-½ months after each late-September maintenance visit. Due to the rapid clogging, the units bypassed frequently resulting in a more than is acceptable amount of stormwater not receiving treatment.

Accounting for the flow that unit's actually received and wetter than average rainfall during the years monitored, it is assumed that the units would need to be maintained approximately every 3-½ months to maintain water quality performance during the wet season.

Due to the rapid filter clogging, the units' sizing was revisited during the data analysis phase of the project. Several different flow- and load-based retrospective sizing analyses were conducted, including one analysis performed by the CBSF manufacturer. The units were originally designed using a flow-based sizing methodology which is consistent with state and city regulations and sizing guidance on the manufacturer's website. The results of the City's retrospective flow-based sizing analysis indicate that the units were undersized by the same percentage that the measured rainfall exceeded the long-term annual average. Thus, the units appear to be properly flow-sized for an average rainfall year based on actual, monitored flows.

A retrospective load-based sizing analysis conducted by SPU indicates that CBSF1 was accurately sized while CBSF2 was undersized by a factor of 2 to 3. The manufacturer provided an alternative load-based retrospective sizing analysis.

The conclusion from this study and the multiple sizing analyses performed is that using the standard flow-based sizing methodology can result in undersized CBSF units that may clog and bypass more frequently than is acceptable or require multiple maintenance visits per year to maintain water quality performance.

8 References

Atkinson, William. November/December 2009. *"Stormwater BMP Maintenance Practices."* Stormwater Journal, pp 10-14.

Contech. 2004. *Engineering Guidelines – Sizing Methodologies for the Stormwater Management StormFilter.* September 30, 2004.

Contech. 2012. *Statement from Contech Construction Products Inc. on the Draft Seattle Public Utilities CatchBasin StormFilter Report (12/13/2011).* January 31, 2012.

Darcy, Sean. 2012. Personal Communication (meeting at SPU discussing draft report). Contech Construction Products Inc.

Darcy, Sean. 2011. Personal Communication (phone communication to schedule June 2011 flow testing to research internal bypass and general discussion about filter clogging). Contech Construction Products Inc.

Ecology. 2007. *General Use Level Designation for Basic (TSS) Treatment for CONTECH Stormwater Solutions Inc. Stormwater Management StormFilter.* Washington State Department of Ecology, Olympia, Washington. January 2005. (Updated December 2007).

Ecology. 2008. *Guidance for Evaluating Emerging Stormwater Treatment Technologies: Technology Assessment Protocol - Ecology (TAPE).* Publication No. 02-10-037, Washington State Department of Ecology, Olympia, Washington.

Ecology. 2011. *Technical Guidance Manual for Evaluating Emerging Stormwater Treatment Technologies: Technology Assessment Protocol - Ecology (TAPE*). Publication No. 11-10-061 (revision of 2008 guidance), Washington State Department of Ecology, Olympia, Washington.

Geosyntec and WWE. 2008. Analysis of Treatment System Performance. International Stormwater Best Management Practices (BMP) Database Overview of Performance by BMP Category and Common Pollutant Type [1999-2008]. June 2008.

Helsel, D.R., and R.M. Hirsch. 2002. *Statistical Methods in Water Resources*. Elsevier, Amsterdam.

Isco (Teledyne Isco). 2008. *Isco Open Channel Flow Measurement Handbook, Sixth Edition.* Teledyne Isco, Inc., Lincoln, Nebraska.

Minton, Gary. Resource Planning Associates. October 29, 2004, *Evaluation of the Stormwater Management StormFilter Treatment System: Data Validation Report and Summary of the Technical Evaluation Engineering Report (TEER) by Stormwater Management*.

Schueler, T. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs.* Metropolitan Washington Council of Governments. Washington, DC

Seattle Public Utilities. March 31, 2011. *CatchBasin StormFilter BMPs, Quality Assurance Project Plan, Revision R2D0 (Final),*

Seattle Public Utilities. August 15, 2007. Letter to Jim Lenhart of Contech listing six issues of concern regarding CBSF installation and maintenance.

9 ACKNOWLEDGEMENTS

The following personnel were responsible for the success of this study:

Seattle Public Utilities – QAPP development, project management, field staff, and reporting
Doug Hutchinson - principal investigator, field lead, report author
Rex Davis, Adam Bailey, Tim McDonald – sampling staff
Amy Minichillo, Lea Beard - chemistry data validators
Beth Schmoyer – SPU load-based analysis
Shelly Basketfield – QAPP author

Water Quality Laboratory (SPU) – primary environmental laboratory
Jim Dunn (project manager) and staff

Analytical Resources, Inc – secondary analytical laboratory (particle size distribution and sediment analysis, and stormwater in WY2009)
Mark Harris (project manager) and staff

Herrera Environmental Consultants – monitoring design and equipment installation, statistical analysis, flow data validation and report peer review
Dylan Ahearn and John Lenth

This Page Intentionally Left Blank.

Appendix A FLOW MONITORING QUALITY ASSURANCE/QUALITY CONTROL REPORT

This Page Intentionally Left Blank.

This Flow Monitoring Quality Assurance/Quality Control (QA/QC) report documents results of the QA/QC review of time series level and flow data generated for the Catch Basin StormFilter™ (CBSF) performance evaluation project. The following discussion will include QA/QC practices, a discussion of methods used to derive site-specific level to flow conversion equations, and an assessment of flow data quality. This QA/QC report discusses flow data collected from October 1, 2009 through September 30, 2011.

A1. Flow Monitoring Locations

Detailed descriptions and figures of the flow monitoring equipment and monitored locations for this project are included in the body of the report. The four flow monitoring locations for this project are listed in the following table.

Table A1. Flow Monitoring Locations

Site	Location	Outlet/Total Location	Bypass Location
CBSF1	California Ave SW and SW Spokane St	CBSF1-FM	CBSF1-BP
CBSF2	California Ave SW and SW Manning St	CBSF2-FM	CBSF2-BP

At CBSF1-FM and CBSF2-FM, 8-inch diameter Thel-Mar weirs were installed in the effluent pipe in the catch basin immediately downstream of the two monitored CBSFs. A submersible pressure transducer level sensor in a stilling well connected to the weirs was used to measure water levels upstream of each weir. At CBSF1-BP and CBSF2-BP, a custom-made, sharp-crested, 1-foot rectangular weir with end constrictions was mounted on the internal bypass weir of each unit. Water level behind the weir was measured in a stilling well using a submersible pressure transducer level sensor.

The following sections present a quality assurance review of the data collected from these monitoring locations. The data were assessed for the following data quality indicators: bias, completeness, representativeness and comparability. Where applicable, the data are compared to specific Measurement Quality Objectives (MQOs) for each data quality indicator that were in identified in the Quality Assurance Project Plan (QAPP) for the project.

A2. Bias

Bias can be introduced into level and flow data by:

- Sensor drift and displacement
- Sensor non-linearity
- Inaccurate rating equations
- Debris clogging the primary device
- Flows exceeding the measurement range of the primary device

These sources of bias are assessed separately below.

A2.1 Sensor Drift and Displacement

Over 90 level checks and calibrations were performed on the four level sensors for each monitoring location (Table A1) over the duration of this project. During each calibration, pre- and post-calibration level measurements were recorded. Figures A2.1a-d present the control charts used to track the difference between actual versus recorded level during the calibration visits.

Each control chart contains a warning limit (one standard deviation from the mean) and a control limit (two standard deviations from the mean). The amount the actual level varies from the level recorded by the level sensor is called the drift. Sensor level drift was generally within the warning limit, with before and after calibration values averaging around +/- 0.02 feet (which is less than one percent of the full span sensor range of 2.31 feet). Minor drift was observed from October 2009 through May 2010 (with the exception of one or two points). Beginning in May 2010, increased drift began occurring at all four level sensors; the pattern persisted through the summer of 2010. It is unknown whether the drift was a result of drier summer conditions and stagnant water (sensors remain submerged even during dry weather) or the age of the sensors (submerged pressure transducers contain a flexible internal diaphragm which can deform or harden over time resulting in increased level drift and the need for replacement). Due to this unacceptable drift, all level sensors were removed and replaced on October 6, 2010 with sensors manufactured by a different vendor. After this point the calibrations were all within the control limits. The drift during this period, and all other periods when actual level measurements differed from the recorded level readings by more than 0.02 feet were edited using proportional, fixed offset and constant value correction tools to create finalized level data. Only finalized level data were used for flow calculations.

Figure A2.1a. CBSF1-FM Level Control Chart

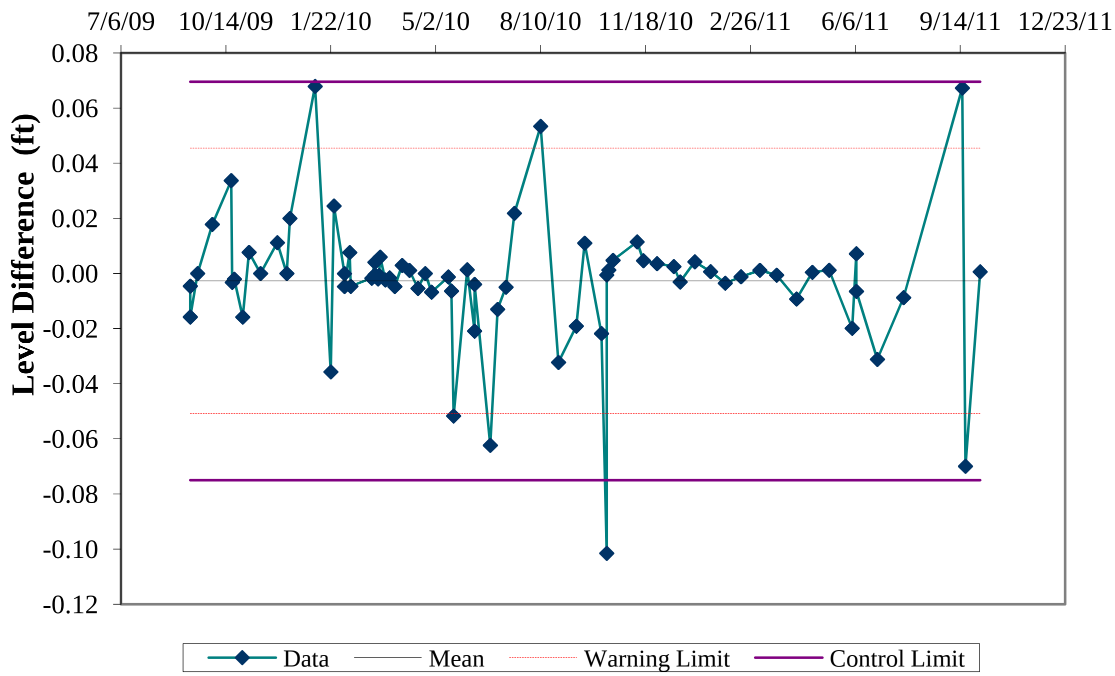


Figure A2.1b. CBSF1-BP Level Control Chart

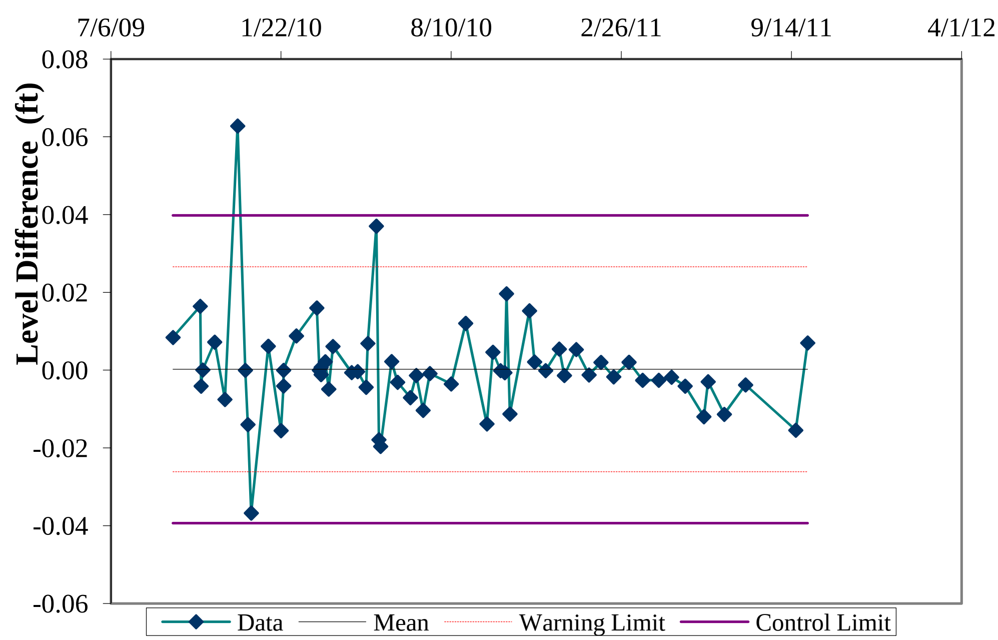


Figure A2.1c. CBSF2-FM Level Control Chart

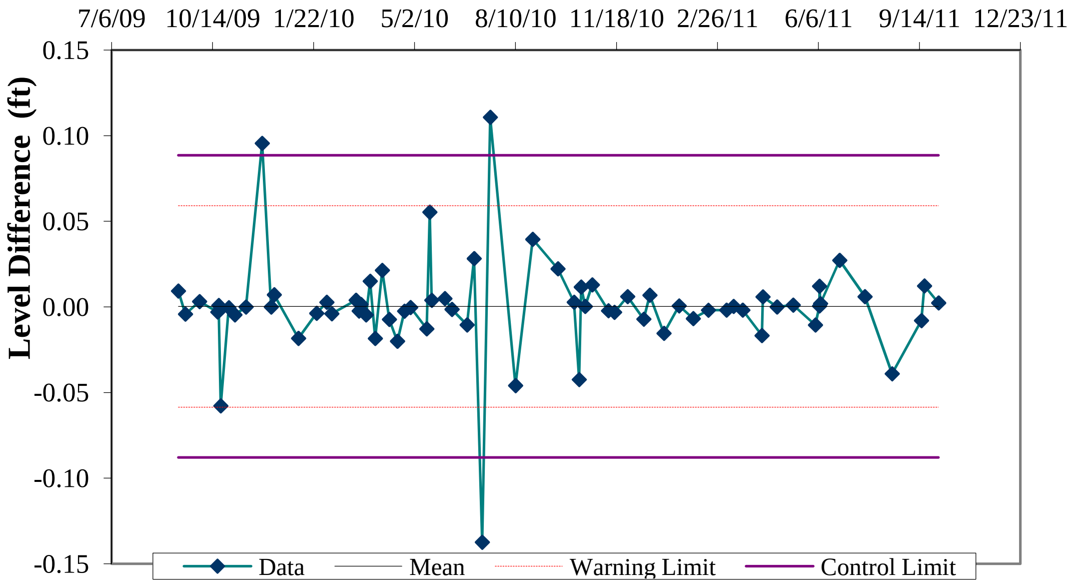
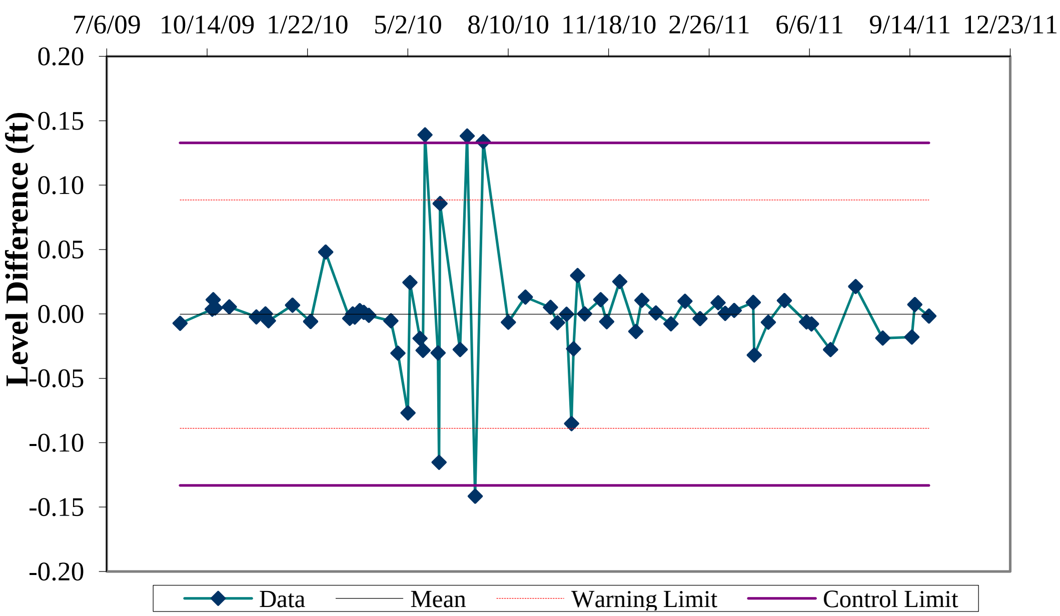


Figure A2.1d. CBSF2-BP Level Control Chart



A2.2 Level Sensor Non-linearity

Linearity in a level sensor is defined by the relationship between increased water level and the corresponding increase in the measured reading. This relationship should be consistent and linear such that when the water level is raised by 0.1 feet the sensor reading increases by 0.1 feet. Ideally, this relationship is consistent through the measurement range (i.e., lowest to highest recorded depths) observed during the study period.

Near the end of the project on June 7-8, 2011, a field test was conducted to assess the bias introduced from non-linearity in the sensors. The water level was progressively raised at each flow monitoring location using water from a nearby hydrant (hydrant testing discussed below). Once flows stabilized, a manual measurement was recorded along with the measurement from the sensor. This was repeated at multiple depths and the average percent difference calculated. The project QAPP indicates that an acceptable level bias error is 10 percent. The tables below indicate that this method quality objective was met at all the stations except CBSF1-BP. The next sections explain remedial measures taken to reduce this bias.

Table A2.2a. CBSF1-FM Level Linearity Bias

Date/Time	**Manual Level (ft)**	**Sensor Level (ft)**
6/7/11 12:11	0.06	0.064
6/7/11 12:17	0.08	0.075
6/7/11 12:28	0.09	0.081
6/7/11 12:35	0.093	0.101
6/7/11 12:41	0.115	0.109
6/7/11 12:50	0.175	0.182
6/7/11 13:07	0.25	0.226
6/7/11 13:28	0.32	0.356
Total	1.183	1.194
Average Percent Difference		**-0.93%**

Table A2.2b. CBSF1-BP Level Linearity Bias

Date/Time	**Manual Level (ft)**	**Sensor Level (ft)**
6/7/11 12:11	0.015	0.011
6/7/11 12:28	0.025	0.013
6/7/11 12:35	0.035	0.020
6/7/11 12:41	0.037	0.024
6/7/11 12:50	0.067	0.054
6/7/11 13:07	0.11	0.089
6/7/11 13:28	0.125	0.116

Date/Time	Manual Level (ft)	Sensor Level (ft)
6/7/11 13:40	0.15	0.138
6/7/11 13:47	0.165	0.152
6/7/11 13:53	0.175	0.158
6/7/11 14:00	0.18	0.170
6/7/11 14:02	0.21	0.187
Total	1.294	1.132
Average Percent Difference		**12.52%**

Table A2.2c. CBSF2-FM Level Linearity Bias

Date/Time	Manual Level (ft)	Sensor Level (ft)
6/8/11 9:42	0.07	0.067
6/8/11 9:54	0.085	0.077
6/8/11 10:03	0.09	0.086
6/8/11 10:15	0.11	0.106
6/8/11 10:25	0.12	0.116
6/8/11 10:32	0.175	0.174
6/8/11 10:42	0.245	0.248
6/8/11 10:53	0.3	0.306
Total	1.195	1.180
Average Percent Difference		**1.26%**

Table A2.2d. CBSF2-BP Level Linearity Bias

Date/Time	Manual Level (ft)	Sensor Level (ft)
6/8/11 9:42	0.014	0.004
6/8/11 9:54	0.017	0.006
6/8/11 10:03	0.02	0.008
6/8/11 10:15	0.025	0.017
6/8/11 10:25	0.029	0.020
6/8/11 10:32	0.06	0.049
6/8/11 10:42	0.085	0.078
6/8/11 10:53	0.1	0.095
6/8/11 11:01	0.12	0.112
6/8/11 11:07	0.13	0.128
6/8/11 11:11	0.15	0.142
6/8/11 11:20	0.17	0.157
6/8/11 11:25	0.2	0.214

Date/Time	Manual Level (ft)	Sensor Level (ft)
Total	1.12	1.030
Average Percent Difference		**8.04%**

A2.3 Controlled Flow Testing and New Rating Equations

During review of water year 2010 flow data, comparisons of total flow (measured at the outlet monitoring locations) to bypass flow (measured at the internal weir located upstream from the total flow/outlet monitoring locations) indicated that there were certain intense storms where the calculated bypass flow rate exceeded the total flow rate for at least one reading during the event. Actual bypass flow cannot, in reality, exceed total flow since total flow is the combination of treated and bypass flow. The source of this error might have been non-linearity (as mentioned in the previous section), errors in discharge estimation due to non-uniform hydraulics, inaccurate equations used to convert depth to flow, debris stuck in a weir that caused elevated level readings and/or flows exceeding the measurement range or the weirs. To correct for most of these sources of bias (except for debris obstruction), actual site-specific level to flow conversions (i.e., rating curves) for the weirs at all four monitoring locations (Table A1) were generated by controlled flow testing on June 7-8, 2011 with water applied from a hydrant.

Staff from SPU's Water Operations Meter Shop assisted during the controlled flow testing. A Neptune closed channel flow monitor (Figure A2.3a) was connected to a nearby water hydrant. This closed channel flow monitor is the City's test meter used to check the accuracy of permanent water meters. Its accuracy is checked monthly in a SPU test facility and it is sent back to the manufacturer annually for calibration. At the start of the controlled flow testing, a bucket and stopwatch test using a graduated 30 gallon container was performed to check the accuracy of the closed channel flow monitor (Figure A2.3b). This test confirmed that the meter was accurate within 5 percent.

Figure A2.3a. Closed Channel Test Flow Monitor

Next, water was released from the hydrant into each CBSF unit at specified flow rates monitored by the Neptune closed channel flow monitor (Figure A2.3c). Once steady-state flow was achieved, the actual level and the level measured by the level sensors (the "sensor level") were recorded along with the Neptune closed channel flow monitor flow rate. This process was repeated for 13 different flow rates ranging from 2 gallons per minute (gpm) to 200 gpm for CBSF1 and from 2 gpm to 250 gpm for CBSF2. This represented nearly the full range of flows monitored during the study period.

Figure A2.3b. Bucket Testing the Closed Channel Flow Monitor

One of the primary issues with measuring flow at the total flow stations (CBSF1-FM, CBSF2-FM) was that during storm peaks, flow depths exceeded the maximum graduated depth of the 8-inch Thel-mar weirs since the rating equation provided by the Thel-mar manufacturer went to a maximum depth of 0.325 feet (3.9 inches). This "over-topping" of the weirs led to inaccurate estimates of flow at high flow rates. During controlled flow testing, a new rating curve was developed for CBSF1-FM and CBSF2-FM which extended beyond the maximum graduated depth of the weirs. These new curves were used to re-calculate flows based on the measured sensor level so they also account for the non-linearity discussed in the previous section.

The results of this controlled flow testing are presented in Figures A2.3d and e. The figures display a graphical representation of the original hydraulic equation as well as the field data from the controlled flow testing (empirical data). For the Thel-Mar weirs, the original equation was provided by the weir manufacturer. For the 1-foot compound rectangular weir, the original equation was generated from equations in the *Isco Open Channel Flow Measurement Handbook* (Isco 2008).

Figure A2.3c. Performing Controlled Flow Test at CBSF2

Figure A2.3d. 8-inch Thel-Mar Weir Equation Versus Actual Flow/Level Relationship Determined From Controlled Flow Testing

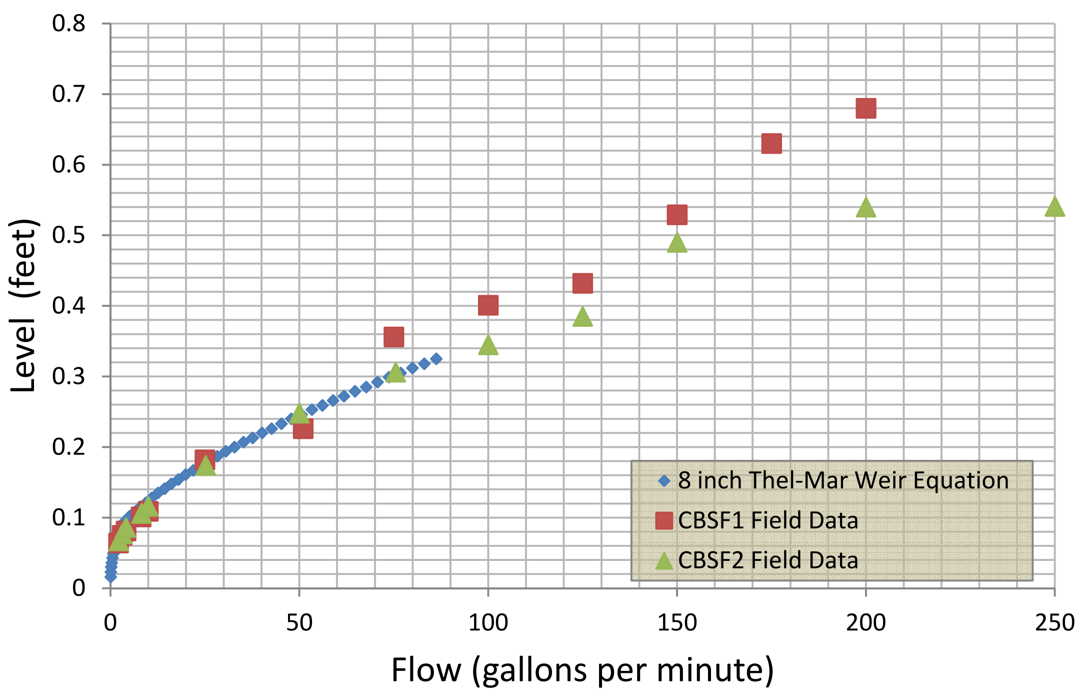
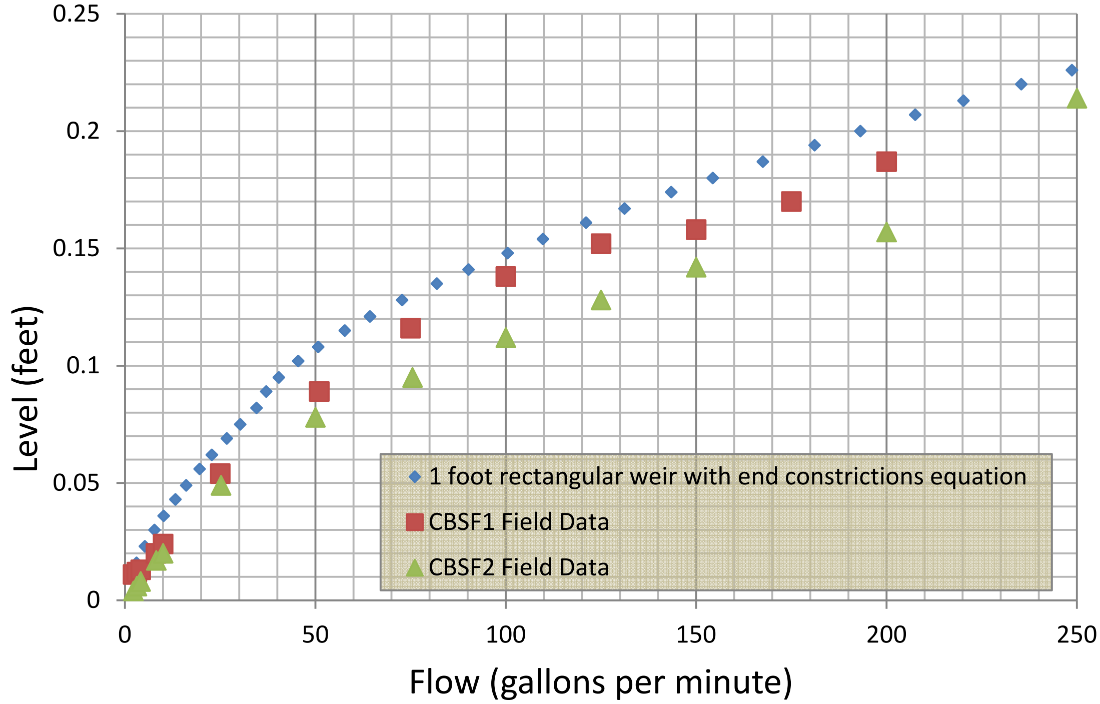


Figure A2.3e. 1-foot Rectangular Weir Equation Versus Actual Flow/Level Relationships Determined From Controlled Flow Testing



As is shown on Figure A2.3d, the Thel-Mar weir equation and the empirical (field) data align closely for the majority of the operating range of the weir equation. Near the top end of the weir equation range the relationship diverges. The new rating curves developed from the field data from the controlled flow testing (labeled "field data" in the above charts) were applied to the corrected level data from CBSF1-FM and CBSF2-FM to generate a final flow dataset which was used in subsequent analyses. This final data set is more accurate than what would have been estimated using the standard 8-inch Thel-Mar weir equation.

At CBSF1-BP and CBSF2-BP, the results from the flow testing indicated that the original 1-foot rectangular weir with end-constrictions equation was not accurate enough for valid flow measurement throughout the entire range of level readings. At CBSF1-BP, flows were underestimated by an average of 24.5 percent based on the equation, while at CBSF2-BP flows were underestimated by an average of 46.9 percent. The new rating curves for each bypass weir were applied to the corrected level data from CBSF1-BP and CBSF2-BP to generate final corrected flow data.

Since the rating equations used the logged sensor level data, biases resulted from sensor level non-linearity were reduced when logged level data was converted to flow values because the custom rating curve uses the sensor level, not the actual level.

A2.4 Anomalous Data, Data Spikes, or Small Data Gaps

Anomalous data spikes, drops, and small data gaps in the level data at each of the four monitoring stations were corrected using Isco Flowlink (ver. 5.1) and Aquarius (ver. 2.5) software. All raw data were saved alongside corrected data in the project files. Small data gaps (less than 60 minutes) were filed using linear interpolation. Data gaps that were too large to fill through linear interpolation were quantified relative to the total flow record to assess the MQO for Completeness (see next section).

A3. Completeness

Completeness was assessed based on the occurrence of gaps in the data record for all continuous level and flow data. The MQO for completeness requires that no less than 10 percent of the total data record is missing due to equipment malfunction or other operational problems. At CBSF1-FM and CBSF1-BP, 1.4 percent of the data were missing. At CBSF2-FM and CBSF2-BP, 1.2 percent of the data were missing. Consequently, the completeness MQO of 90 percent data present was met at all four stations.

A4. Representativeness

Representativeness is the degree to which data accurately and precisely represent the environmental condition of a site. It is difficult to establish quantitative representative criteria for hydrologic data and there was no MQO listed in the QAPP for this data quality indicator. To assess the representativeness of the hydrologic data collected during this study, rainfall data from the project rain gage (RG14) for water years 2010 and 2011 were compared against the 32-year historic record for this gage (1978-2009). The table below summarizes rainfall data for RG14.

Table A4. RG14 Historical Rainfall Comparison

Mean Annual Rainfall 1978-2009 (inches)	WY2010 Rainfall (inches)	WY2011 Rainfall (inches)	WY2010 Difference From Mean (inches)	WY2011 Difference From Mean (inches)	WY2010 Difference From Mean (percent)	WY2011 Difference From Mean (percent)
34.23	47.21	46.31	+12.98	+12.08	+37.9%	+35.3%

Since both of the water years monitored had mean annual rainfall amounts that exceeded the historical average by over 25 percent, the years monitored are considered to have above average rainfall that is not representative of a typical year. This above average rainfall did not affect the quality of the data but can be assumed to affect the CBSFs' performance as discussed in the body of the report.

A5. Comparability

Comparability is the confidence with which one data set can be compared to another. Comparability can be related to accuracy and precision, as these quantities are measures of data reliability. Although there is no numeric MQO for this data quality indicator, standard monitoring procedures, units of measurement, and reporting conventions were used in this study to meet the quality indicator of data comparability.

Determining the comparability of recorded or logged flow to "actual" flow rates is difficult and rarely done, especially since flow is a calculated value (for this project, flow is calculated from level data) and typically the accuracy of the primary measurements (level only, for this project) are compared to actual measured values. Industry standards for acceptable flow data accuracy range from +/- 75 to 90 percent.

As was mentioned earlier, comparisons of total flow (measured at the outlet location) to bypass flow (measured at the internal weir located upstream from the total flow/outlet location) indicated that there were certain intense storms where the calculated bypass flow rate exceeded the total flow rate for at least one five-minute reading during the storm event. Since actual bypass flow cannot in reality exceed total flow since total flow is the combination of treated and bypass flow, extensive controlled flow testing was performed to generate new, location-specific rating curves to convert level data to flow. After generating new curves and recalculating flow data, the volume and occurrence of bypass actually increased over the original measurements.

Analysis of the final, edited flow data indicated that bypass flow rate exceeded total flow rate for at least one logged interval in 12 of the 37 sampled storms. The 12 events in question all contained periods of intense rainfall (maximum rainfall rates typically exceeding 0.1 inches/hour) and occurred during periods when the CBSF media filters were either partially or substantially clogged. When the filters become clogged it is expected that bypass flow rates would essentially equal total flow rate since most of the flow would bypass the cartridges. In addition, flow readings are averaged over five minute periods so it is not expected that bypass and total readings would line up precisely especially during intense flow periods.

The occurrence of bypass flow exceeding total flow was occasional and did not follow a pattern other than occurring during periods of intense rainfall. Based on calibrations, confirmations, and editing; the final level data are considered accurate. Based on the controlled flow testing and new rating curves, the level to flow conversions are also considered accurate. What cannot be determined retrospectively was if there were periods within some events when hydraulics at the monitoring locations were different than the hydraulics observed during calibration procedures. The most obvious cause of such variability is debris obstructing the weirs. Weirs typically provide more accurate estimations of flow than stations without primary devices, but they can be susceptible to obstruction from debris. For example, leaves, plastic bags, or other trash from the roadway can get caught in the weir and temporarily alter the level to flow relationship by restricting the weir opening. Even a small obstruction can result in a flow calculation discrepancy, especially for the broad bypass weir since the difference of 0.01 foot equates to approximately 25 gpm of calculated flow at the bypass weir.

To quantify the discrepancy that occurred during the 12 storms, the peak instantaneous bypass flow rate during the storm was compared to the peak instantaneous total flow rate. This analysis considers the worst case scenario by looking at the peak rate instead of average during the events. During the 12 events, the peak bypass rate recorded exceeded the peak total rate by an average of 20 percent. Given that flow estimation in pipes is frequently cited as only accurate to within +/- 20 percent, this worst-case discrepancy was considered acceptable for the purposes of this study. Since these occurrences were occasional and resulted in a worst case scenario of 20 percent difference for the highest single bypass flow reading recorded during less than one third of sampled events, flow data collected during this study are considered acceptable.

A6. Summary

All hydrologic MQOs identified in the project QAPP (SPU 2008) were met for the water level data collected at CBSF1-FM, CBSF2-FM, and CBSF2-BP. Level bias due to non-linearity exceeded the bias MQO at CBSF1-BP, but this was addressed by developing a custom rating curve for that location (based on controlled flow testing). Specifically, inaccuracies in the water level data were corrected when converted to flow values because the new, custom rating curve corrects for the inaccuracy in level by using the sensor level, not the actual level. The analysis of sensor drift indicated that on a few occasions drift exceeded the control limit at each of the stations. This was addressed by applying prorated drift corrections and replacing the level sensors on October 6, 2010 when the drift became unacceptable.

Twelve of the 37 events sampled contained at least one measured reading when the bypass flow rate exceeded the total flow rate. The source of this discrepancy is unknown but assumed to be due to debris obstructing the weirs for short periods during the events. Although these occurrences result in periods when the amount of bypass may be overestimated, the occurrences were very limited and the difference between calculated bypass and total flow are considered acceptable.

After assessing the quality of the hydrologic data at CBSF1-FM, CBSF1-BP, CBSF2-FM, and CBSF2-BP; it was found that the final flow data are acceptable to evaluate the performance of this BMP.

A7. References

Isco (Teledyne Isco). 2008. *Isco Open Channel Flow Measurement Handbook, Sixth Edition.* Teledyne Isco, Inc., Lincoln, Nebraska.

SPU. 2008. Quality Assurance Project Plan: NPDES Phase I Municipal Stormwater Permit, CatchBasin StormFilter BMPs. Seattle Public Utilities. Seattle, Washington.

Appendix B ANALYTICAL DATA QUALITY ASSURANCE/QUALITY CONTROL REPORT

This Page Intentionally Left Blank.

This analytical data Quality Assurance/Quality Control (QA/QC) report addresses all analytical laboratory and field sample data generated for the Catch Basin StormFilter™ (CBSF) performance evaluation project. The following discussion will include QA/QC practices and results for analytical laboratory and field sample data for all samples collected over the course this performance evaluation. Samples were collected from March 2, 2009 to June 9, 2011. QA/QC evaluation documented in previously submitted Annual Reports (dated March 2010 and March 2011) is considered preliminary. Since the study is now complete, all data were re-evaluated within the complete context of data generated and QA/QC results and flagging contained in this report are considered final.

B1. Analytical Data QA/QC Procedures

All laboratory data packages were received with a hardcopy report and an electronic data deliverable (EDD). For each sample delivery group, laboratory case narratives were reviewed for quality control issues and the corrective action(s) taken. Data were evaluated for required methods, holding times, reporting limits, accuracy, precision and blank contamination.

Each EDD was imported into a review template where deviations from the measurement quality objectives (MQOs) were identified and associated samples were qualified accordingly.

Data qualifiers were applied to sample chemistry data based on the results of validation. Four data qualifier codes were used; U, J, UJ and R.

Table B1. Data Qualifier Definitions

Qualifier	Definition
U	Analyte was analyzed for, but not detected above reported result.
J	Reported result is an estimated quantity.
UJ	Analyte was analyzed for, but not detected above reported estimate.
R	Result value was rejected. Result should not be used in analyses.

One result value per sample per analyte is reported. Where the laboratory performed dilutions or re-analyses that resulted in multiple valid values, the result with the lowest detection limit is reported.

B2. Analytical Methods and Reporting Limits

Over the duration of this study which spanned three water years, two laboratories were used to perform the primary stormwater sample analyses: Analytical Resources Inc. (ARI) analyzed stormwater samples collected from Water Year (WY) 2009 and Seattle Public Utilities' (SPUs')

Water Quality Laboratory analyzed stormwater samples collected from WY2010 and WY2011. Particle size distribution analysis of stormwater and sediment chemistry analysis was performed by ARI over the entire study. The two laboratories used slightly different reporting limits for stormwater sampling. As a result, the analytical results from WY2009 are assessed using a slightly different set of reporting limits then the results from WY2010 and WY2011.

The following tables present the methods and reporting limits (RL) used by the laboratories. Reporting limits represents the minimum concentration of an analyte in a specific matrix that can be identified and quantified above the method detection limit and within specified limits of precision and bias during routine analytical operating conditions. Reporting limits can vary by individual samples, particularly for sediments where the quantity and dilution analyzed affect the minimum detectable value.

Table B2a. Stormwater Analytes, Methods and Reporting Limits

Analyte Group	Analyte	WY2009 RL	WY2010-WY2011 RL	Units	Lab Method
Conventionals	Hardness	0.33	1	mg/L CaCO3	SM2340C
	pH	0.01	0.01	std units	SM4500H
	Solids, Total Suspended	1	0.5	mg/L	SM2540D
	Particle Size	0.01	0.01	mg/L	ASTMD3977C
Metals	Copper - Dissolved	0.5	1	ug/L	EPA200.8
	Copper - Total	0.5	1	ug/L	EPA200.8
	Zinc - Dissolved	4	1	ug/L	EPA200.8
	Zinc - Total	4	1	ug/L	EPA200.8
Nutrients	Orthophosphate	0.01	0.001	mg-P/L	SM4500PF
	Phosphorus, Total	0.02	0.002	mg-P/L	SM4500PF

Table B2b. Sediment Analytes, Methods and Reporting Limits

Analyte Group	Analyte	WY2009 RL	WY2010-WY2011 RL	Units	Lab Method
Conventionals	Solids, Total	0.01	0.01	%	SM2540B
	Grain Size	0.1	0.1	%	PSEP-PS
	Solids, Total Volatile	0.01	0.01	%	EPA160.4
Petroleum Hydrocarbons	Diesel Range	25	5	mg/Kg	NWTPH-DX
	Motor Oil	10	10	mg/Kg	NWTPH-DX
Metals	Cadmium	0.3	0.1	mg/kg	EPA200.8
	Copper	0.5	0.5	mg/kg	EPA200.8
	Lead	5	0.1	mg/kg	EPA200.8

Analyte Group	Analyte	WY2009 RL	WY2010-WY2011 RL	Units	Lab Method
	Zinc	2	4	mg/kg	EPA200.8
Nutrients	Phosphorus, Total	3	0.4	mg/kg	SM4500PE

B3. Laboratory Data QA/QC Evaluation Results

B3.1 Holding Time

All sample results were assessed for holding time compliance in accordance with 40 CFR (Code of Federal Regulations) Part 136. For composite samples, the sample time used was the last aliquot in each composite.

Analytical results obtained outside of holding time, but within 2x the holding time have been qualified as estimated (J). Qualification based on holding time is only applied to the specific results described herein.

Holding time exceedances for total suspended solids were determined to be the result of internal sampling processing errors at SPU's laboratory during the first storm samples they analyzed for this project. Corrective actions have been taken and no TSS holding time errors were experienced later during this study.

One batch of samples for pH was analyzed fifteen days past the holding time due to a receiving error at the laboratory. The results of this analysis have been rejected (R) and are listed in Table B3.1b. Corrective action was taken to insure subsequent samples were analyzed within holding time. No further action was taken.

Holding times were met for all results except as listed the tables below.

Table B3.1a. Holding Time Exceedances for Water Samples - Qualified J

Analyte	Sample ID	Sample Date	Reason
pH	CBSF1-IN	12/14/2009 23:00	Analyzed past holding by 2 days
pH	CBSF1-OUT	12/14/2009 23:00	Analyzed past holding by 2 days
pH	CBSF2-IN	12/14/2009 23:45	Analyzed past holding by 2 days
pH	CBSF2-OUT	12/14/2009 23:45	Analyzed past holding by 2 days
pH	CBSF2-IN	6/2/2010 9:44	Analyzed past holding by 1 day
pH	CBSF2-OUT	6/2/2010 9:44	Analyzed past holding by 1 day
pH	CBSF1-IN	6/2/2010 11:21	Analyzed past holding by 1 day
pH	CBSF1-OUT	6/2/2010 11:25	Analyzed past holding by 1 day
pH	CBSF1-OUT	6/2/2010 11:26	Analyzed past holding by 1 day

Analyte	Sample ID	Sample Date	Reason
pH	CBSF1-IN	6/8/2010 0:00	Analyzed past holding by 1 day
pH	CBSF1-OUT	6/8/2010 0:00	Analyzed past holding by 1 day
pH	CBSF1-OUT	6/8/2010 0:00	Analyzed past holding by 1 day
Solids, Total Suspended	CBSF1-IN	10/21/2009 11:50	Analyzed past holding by 2 days
Solids, Total Suspended	CBSF1-OUT	10/21/2009 11:50	Analyzed past holding by 2 days
Solids, Total Suspended	CBSF2-IN	11/6/2009 7:19	Analyzed past holding by 6 days
Solids, Total Suspended	CBSF2-OUT	11/6/2009 7:19	Analyzed past holding by 6 days
Solids, Total Suspended	CBSF1-IN	11/6/2009 9:35	Analyzed past holding by 6 days
Solids, Total Suspended	CBSF1-OUT	11/6/2009 9:35	Analyzed past holding by 6 days
Solids, Total Suspended	CBSF1-IN	12/14/2009 23:00	Analyzed past holding by 2 days
Solids, Total Suspended	CBSF1-OUT	12/14/2009 23:00	Analyzed past holding by 2 days
Solids, Total Suspended	CBSF2-IN	12/14/2009 23:45	Analyzed past holding by 2 days
Solids, Total Suspended	CBSF2-OUT	12/14/2009 23:45	Analyzed past holding by 2 days
Solids, Total Suspended	CBSF2-IN	2/5/2010 6:40	Analyzed past holding by 7 days
Solids, Total Suspended	CBSF2-OUT	2/5/2010 6:40	Analyzed past holding by 7 days
Solids, Total Suspended	CBSF1-IN	2/11/2010 9:52	Analyzed past holding by 1 day
Solids, Total Suspended	CBSF1-OUT	2/11/2010 9:52	Analyzed past holding by 1 day
Solids, Total Suspended	CBSF2-OUT	2/11/2010 10:26	Analyzed past holding by 1 day
Solids, Total Suspended	CBSF2-IN	2/11/2010 10:27	Analyzed past holding by 1 day

Table B3.1b. Holding Time Exceedances for Water Samples - Qualified R

Analyte	Sample ID	Sample Date	Reason
pH	CBSF1-OUT	11/30/10 19:00	Analyzed past holding by 15 days
pH	CBSF2-IN	11/30/10 18:02	Analyzed past holding by 15 days
pH	CBSF2-OUT	11/30/10 18:02	Analyzed past holding by 15 days

Table 3.1c. Holding Time Exceedances for Sediment Samples - Qualified J

Analyte	Sample ID	Sample Date	Reason
Solids, Total	CBSF1-SED1	9/28/2010 12:12	Analyzed past holding by 2 days
Solids, Total	CBSF1-SED2	9/28/2010 12:25	Analyzed past holding by 2 days
Solids, Total	CBSF1-SED3	9/28/2010 12:40	Analyzed past holding by 2 days
Solids, Total	CBSF2-SED1	9/28/2010 10:40	Analyzed past holding by 2 days
Solids, Total	CBSF2-SED2	9/28/2010 10:32	Analyzed past holding by 2 days
Solids, Total	CBSF2-SED3	9/28/2010 11:35	Analyzed past holding by 2 days

Analyte	Sample ID	Sample Date	Reason
Solids, Total Volatile	CBSF1-SED1	9/28/2010 12:12	Analyzed past holding by 2 days
Solids, Total Volatile	CBSF1-SED2	9/28/2010 12:25	Analyzed past holding by 2 days
Solids, Total Volatile	CBSF1-SED3	9/28/2010 12:40	Analyzed past holding by 2 days
Solids, Total Volatile	CBSF2-SED1	9/28/2010 10:40	Analyzed past holding by 2 days
Solids, Total Volatile	CBSF2-SED2	9/28/2010 10:32	Analyzed past holding by 2 days
Solids, Total Volatile	CBSF2-SED3	9/28/2010 11:35	Analyzed past holding by 2 days

B3.2 Blanks

Laboratory method blanks were generated and analyzed by the laboratories in association with primary environmental samples. The following table lists the qualification actions resulting from the blank results.

Table B3.2a Blank Validation Criteria

Blank	Sample	Action
Blank > RL	Sample < RL	Qualify sample result as non-detect (U) at the Reporting Limit.
	RL < Sample < Blank	Qualify sample result as non-detect (U) at the reported concentration.
	Blank < Sample < 10x Blank	Qualify sample result as estimated (J).
	10x Blank < Sample	No qualification needed.
Blank < (-RL)	Sample < RL	Qualify sample result as estimated non-detect (UJ) at Reporting Limit.
	RL < Sample < 10x Blank	Qualify sample result as estimated (J).
	10x Blank < Sample	No qualification needed.
(-RL) < Blank < RL	Sample < RL	Qualify sample result as non-detect (U) at Reporting Limit.
	RL < Sample	No qualification needed.

RL – reporting limit

The following table illustrates the application of qualifiers to sample results based on the blank QC sample types.

Table B3.2b. Association of Blank QC Qualifiers to Results

Blank Sample Type	Associated Results
Method Blank	All results in prep batch
Filter Blank	All results from same sample delivery group
Trip Blank	All results from same sample delivery group
Tubing Blank	All composite results from project water year and same site
Bottle Blank/Splitter Blank/Bailer Blank	All composite results from project water year
Grab Sampler Equipment Blank	All grab results from project water year

All laboratory method blank results were within control limits with the exception of those listed below. For the method blanks exceedances below, corrective action has been taken and associated sample results were qualified accordingly.

Table B3.2c. Method Blank Exceedances for Water Samples

Analyte	Analysis Date	Result	RL	Units
Orthophosphate	4/7/2010	0.00109	0.001	mg/L
Phosphorus, Total	7/7/2010	0.00317	0.002	mg/L
Phosphorus, Total	7/13/2010	0.00416	0.002	mg/L

Field and equipment blanks were collected and analyzed in addition to laboratory method blanks. The results of these additional blanks can be found in the *Field Sample QC/QC Results* section later in this report.

No method blank exceedances were observed for blank samples associated with sediment samples.

B3.3 Accuracy

Accuracy is the degree of agreement between an observed value and an accepted reference value. Accuracy was demonstrated by analysis of matrix spikes (MS), laboratory control samples (LCS), reference materials (RM) and surrogate compounds (SUR). Laboratory control limits were used when provided. The following table lists the qualification actions resulting from the accuracy analysis.

Table B3.3a. Accuracy Validation Criteria

%Recovery*	Sample	Action
%R < LowLimit	Sample ≤ RL	Qualify sample result as estimated non-detect (UJ).
	RL < Sample	Qualify sample result as estimated (J).
	Parent† > 4x spike added	No qualification needed.
UppLimit < %R	Sample ≤ RL	No qualification needed.
	RL < Sample	Qualify sample result as estimated (J).
	Parent > 4x spike added	No qualification needed.

RL – reporting limit

† Parent - The sample from which an aliquot is used to make the spiked QC sample.

* The percent recovery of the spiked compound and is calculated as:

$$\%R = \frac{(Spiked\ QC\ Sample\ Result - Parent\ Sample\ Result)}{Spike\ amount}$$

The following table illustrates the application of qualifiers to sample results based on the accuracy QC sample types.

Table B3.3b. Association of Accuracy QC to Sample Results

QC Sample Type	Associated Results
LCS/LCSD/RM	All results in prep batch
MS/MSD	All results in prep batch
Surrogate	Results for associated analyte in current sample only

All accuracy QC results were within control limits except as noted below. Sample results associated with QC exceedances have been qualified accordingly.

Table B3.3c. Accuracy Exceedances for Water Samples

Analyte	Type	Analysis Date	Out	Action
Orthophosphate	MS	12/30/2009	Low	Associated results qualified (J/UJ).
Orthophosphate	MS	6/15/2010	Low	Associated results qualified (J/UJ).
Orthophosphate	RM	6/15/2010	Low	Associated results qualified (J/UJ).
Phosphorus, Total	MS	1/14/2010	High	Associated results qualified (J)
Phosphorus, Total	RM	3/18/2010	High	Associated results qualified (J)

In the previously submitted Annual Reports for WY2009 and WY2010, the laboratory control samples for dissolved zinc were assessed using incorrect control limits. This error, due to a reporting error in the laboratory EDDs, resulted in false “out-of-control” alerts having been previously reported. The analysis runs have been reassessed using the correct control limits per EPA Method 200.8 and all sample results have been re-qualified accordingly.

Table B3.3d. Accuracy Exceedances for Sediment Samples

Analyte	Type	Analysis Date	Out	Action
Bromobenzene	SUR	9/28/2010	Low	Surrogate recoveries low. Samples reanalyzed with same results. Matrix interference assumed. Associated Gasoline Range Hydrocarbon results qualified (J/UJ).
Trifluorotoluene	SUR	9/28/2010	Low	
Bromobenzene	SUR	6/16/2011	Low	Surrogate recoveries low. Samples reanalyzed with same results. Matrix interference assumed. Associated Gasoline Range Hydrocarbon results qualified (J/UJ).
Trifluorotoluene	SUR	6/16/2011	Low	

B3.4 Precision

Precision is the degree of observed reproducibility of measurement results. Precision was demonstrated by analysis of laboratory sample duplicates (LD), field sample duplicates (FD), laboratory control sample duplicates (LCSD) and matrix spike duplicates (MSD). The following table lists the qualification actions resulting from the precision analysis.

Table B3.4a. Precision Validation Criteria

Matrix	Original & Duplicate		Associated Sample	Action
	Criteria 1	Criteria 2		
Water	Both Original and Dup Results < 5x RL	$\lvert$original - duplicate$\rvert$ > RL	Result < RL	Qualify sample results as estimated non-detect (UJ).
			Result > RL	Qualify sample results as estimated (J).
		$\lvert$original - duplicate$\rvert$ ≤ RL	All	No qualification needed.
Sed		$\lvert$original - duplicate$\rvert$ > 2x RL	Result < RL	Qualify sample results as estimated non-detect (UJ).
			Result > RL	Qualify sample results as estimated non-detect (UJ).
		$\lvert$original - duplicate$\rvert$ ≤ 2x RL	All	No qualification needed.
Water	Either Original or Dup Results > 5x RL	RPD† > 20*%	Result < RL	Qualify sample results as estimated non-detect (UJ).
			Result > RL	Qualify sample results as estimated (J).
		RPD ≤ 20*%	All	No qualification needed.
Sed		RPD > 35%	Result < RL	Qualify sample results as estimated non-detect (UJ). Note in report.
			Result > RL	Qualify sample results as estimated (J).
		RPD ≤ 35%	All	No qualification needed.

RL – Reporting Limit

† RPD – Relative Percent Difference between the original and the duplicate, calculated as follows:

$$RPD = 100 \times \left| \frac{(original - duplicate)}{Mean\ (original, duplicate)} \right|$$

* An RPD control limit of 25% was used when assessing field duplicate water samples.

The following table illustrates the application of qualifiers to sample results based on the precision QC sample types.

Table B3.4b. Association of Precision QC to Sample Results

QC Sample Type	Associated Results
Lab Dup	All results in prep batch
LCSD	All results in prep batch
MSD	All results in prep batch
Field Dup/ Field Split	Parent sample results only

All precision laboratory QC results were within control parameters except as noted below. Associated sample results were qualified and no further action was needed.

The following table presents precision exceedances for all analytes expect for particle size distribution which are discussed below the table.

Table B3.4c. Precision Exceedances for Water Samples

Analyte	Date	Result	Units	RPD (|Δ|)	Action
Phosphorus, Total	3/2/2010	0.0219	mg/L	20.6	Associated results qualified (J/UJ)
Phosphorus, Total	7/7/2010	0.349	mg/L	26.4	Associated results qualified (J/UJ)

RPD – Relative percent difference

|Δ| - Absolute difference

Professional judgment was used to assess the usability of particle size distribution (PSD) data generated by method ASTMD3977C. The majority of precision QC samples for PSD (lab duplicates and field splits) were outside control limits. This combined with an ambiguity regarding method application and instrumentation, and a lack of control data has resulted in reduced confidence in PSD data. Specifically, there is a notable absence of particles reported in the 250 to 125 micron and 125 to 62.5 micron ranges, which are the two ranges below the 250 micron sieve (the smallest of the nest sieves used before measuring the sediment not retained on the sieves by laser diffraction). The laboratory analyst reported that she did not rinse the sieves with reagent-grade water because of concerns with sample dilution. The lack of rinsing likely resulted in smaller particles being retained in the sieves. Due to these reasons, all PSD results (518 results) have been qualified J/UJ.

Notably, due to inherit problems with PSD analysis by laser diffraction; the 2011 revised TAPE protocol has moved away from using this method for further performance evaluation studies.

No exceedances were observed for precision QC samples associated with sediment samples.

B4. Field Sample QA/QC Results

The following section discusses the results of QA/QC samples generated in the field or laboratory by field staff.

B4.1 Filter Blank QC Samples

One dissolved metals filter blank sample was prepared for each storm event. The filter blank samples were prepared in the laboratory by filtering deionized water through a purchased pre-cleaned 0.45 micron filter.

The filter blank samples from water years 2010 and 2011 had dissolved zinc concentrations ranging from 1.07 to 2.91 µg/L. Based on these filter blank results, the filter itself is considered a source of the very low levels of dissolved zinc contamination. In WY 2009, when the contract laboratory's dissolved zinc reporting limit was 4 µg/L; no dissolved zinc was detected in the filter blank or filtered tubing blank samples. This lack of detectable dissolved zinc is attributed to the higher reporting limit censoring the trace amounts of zinc added by the filtering process. For WY2010 and WY2011, the dissolved zinc RL was lowered to 0.5 µg/L and the low level filter blank detections began being reported.

The permit-specified reporting limits for total and dissolved zinc are 5 and 1 µg/L, respectively. If the reporting limits for dissolved zinc were equivalent to the required total zinc reporting limit, there would be no detectable concentrations of zinc in the filter blank samples to report. In addition, the dissolved zinc contamination attributed to the filter was very consistent in all filtered blank samples (from approximately 1 to 3 µg/L). Given that trace contributions were evenly added to all dissolved zinc samples through the filtration process, the bias to the samples is equivalent so the influent to effluent comparison in this performance study is not significantly affected by the filter blank contamination.

The proposed corrective action is to have all filters (which are purchased pre-cleaned) receive an additional nitric acid rinse prior to use in the laboratory. This proposed corrective action was not implemented in time to affect the results of this study.

No orthophosphate results were flagged as a result of filter blank results since all blanks were below detection limits, except for one which had a result just slightly above the reporting limit and not high enough to result in flagging based on criteria presented previously.

Table B4.1. Filter Blank Data

Analyte	Copper, Dissolved	Zinc, Dissolved	Orthophosphate
Report Limit	1	1	0.001
Units	ug/L	ug/L	mg/L
12/14/2009	0.5 U	**2.47**	NM

Analyte	Copper, Dissolved	Zinc, Dissolved	Orthophosphate
Report Limit	1	1	0.001
Units	ug/L	ug/L	mg/L
12/17/2009	0.5 U	**2.91**	NM
2/5/2010	0.5 U	**2.32**	0.001 U
2/11/2010	0.5 U	**2.47**	0.001 U
3/11/2010	0.5 U	**1.91**	0.001 U
3/26/2010	0.5 U	**2.05**	**0.00132 J**
4/2/2010	0.5 U	**2.32**	0.001 U
5/20/2010	0.5 U	**2.11**	0.001 UJ
6/3/2010	0.5 U	**1.07**	0.001 UJ
6/10/2010	0.5 U	**2.49**	0.001 UJ
10/26/2010	0.5 U	**2.10**	0.001 U
11/30/2010	0.5 U	**2.37**	0.001 U
1/5/2011	0.5 U	**2.34**	0.001 U
3/8/2011	0.5 U	**2.12**	0.001 U
3/16/2011	0.5 U	0.5 U	0.001 U
4/14/2011	0.5 U	**2.85**	0.001 U
4/27/2011	0.5 U	**1.20**	0.001 U

NM- not measured. No blanks generated on these sample dates.

B4.2 Field Equipment Blanks

Equipment blank QC samples were collected in the field in the form of tubing blank samples (four per year collected on the autosampler tubing), one churn splitter blank and one composite bottle blank. One sample was collected from the sampler tubing at each monitoring station each year after decontaminating the tubing during setup for a storm event. These field equipment blank samples were analyzed for all of the composite analytes except for particle size distribution, pH and hardness.

Results of the 12 tubing blank samples are summarized in the table below. Blank values with an asterisk (*) next to them indicate that all associated primary samples had results greater than 10 times the blank contamination and no qualification was necessary.

Field equipment blank results were acceptable and resulted in no QC action, except as listed below:

- Two primary sample dissolved copper results from site CBSF1-IN were qualified (J) due to corresponding copper hits in the tubing blanks.
- During WY 2010, some primary sample dissolved zinc results were qualified due to dissolved zinc contamination in tubing blank samples. For these equipment blanks, the dissolved fraction was prepared by filtration through purchased pre-cleaned filters. In all

but one case, the total zinc fraction was below detection and in all cases it was less than the dissolved fraction. For this reason, it is believed that this contamination was the result of zinc contamination in the filters, not due to contamination in the sampling tubing. See the *Filter Blank QC Sample Result* section above for more details.

- Three total phosphorus primary sample results were qualified (J) due to elevated levels in the tubing blanks.

Table B4.2a. Tubing Blank Results – WY2009

Analyte	Units	2009 Tubing Blank Samples			
		CBSF1-IN	CBSF1-OUT	CBSF2-IN	CBSF2-OUT
		2/18/2009 3:09 PM	2/18/2009 3:26 PM	2/18/2009 2:11 PM	2/18/2009 2:32 PM
Copper, Dissolved	ug/L	**1**	0.5 U	0.5 U	0.5 U
Copper, Total	ug/L	**1.6***	0.5 U	0.5 U	0.5 U
Zinc, Dissolved	ug/L	4 U	4 U	4 U	4 U
Zinc, Total	ug/L	4 U	4 U	4 U	4 U
Orthophosphate	mg/L	0.004 U	0.004 U	0.004 U	0.004 U
Phosphorus, Total	mg/L	0.008 U	0.008 U	0.008 U	**0.010***

Table 4.2b. Tubing Blank Results – WY2010

Analyte	Units	2010 Tubing Blank Samples			
		CBSF1- IN	CBSF1-OUT	CBSF2-IN	CBSF2-OUT
		2/4/2010 13:40	2/4/2010 14:00	2/4/2010 10:46	2/4/2010 10:50
Copper, Dissolved	ug/L	1 U	1 U	1 U	1 U
Copper, Total	ug/L	1 U	1 U	1 U	1 U
Zinc, Dissolved	ug/L	**1.76***	**2.78**	**2.55**	**3.46**
Zinc, Total	ug/L	1 U	1 U	1 U	**1.56***
Orthophosphate	mg/L	0.001 U	0.001 U	0.001 U	0.001 U
Phosphorus, Total	mg/L	**0.002***	**0.002***	**0.003**	**0.0024**

Table 4.2c. Tubing Blank Results – WY2011

Analyte	Units	2011 Tubing Blank Samples			
		CBSF1-IN	CBSF1-OUT	CBSF2-IN	CBSF2-OUT
		3/14/11 14:35	**3/14/11 14:45**	**3/14/2011 13:30**	**3/14/2011 13:40**
Copper, Dissolved	ug/L	0.5 U	0.5 U	0.5 U	0.5 U

Analyte	Units	2011 Tubing Blank Samples			
		CBSF1-IN	CBSF1-OUT	CBSF2-IN	CBSF2-OUT
		3/14/11 14:35	3/14/11 14:45	3/14/2011 13:30	3/14/2011 13:40
Copper, Total	ug/L	1 U	1 U	1 U	1 U
Zinc, Dissolved	ug/L	1 U	1 U	1 U	1 U
Zinc, Total	ug/L	1 U	1 U	1 U	1 U
Orthophosphate	mg/L	0.001 U	0.001 U	0.001 U	0.001 U
Phosphorus, Total	mg/L	0.002 U	0.002 U	0.002 U	0.002 U

Table 4.2d. Other Equipment Blank Results

Analyte	Units	Other Equipment Blanks	
		Splitter Blank	Bottle Blank
		3/15/2011 9:15	3/15/2011 8:45
Copper, Dissolved	ug/L	0.5 U	0.5 U
Copper, Total	ug/L	1 U	1 U
Zinc, Dissolved	ug/L	1 U	1 U
Zinc, Total	ug/L	1 U	1 U
Orthophosphate	mg/L	0.001 U	0.001 U
Phosphorus, Total	mg/L	0.002 U	0.002 U

U – Analyte was not detected above the reported result.
* - Associated sample results were all greater than 10 times the blank results and no qualification was needed.

B4.3 Stormwater Split Samples

Nine stormwater samples were spilt for analysis in the laboratory as field precision QC samples. These field split samples were generated in the laboratory by filling two identical analyte-specific containers simultaneously from the churn splitter.

Field split precision results were within control limits, except as listed below:

- Three out of the nine composite split results for orthophosphate exceeded the control limits. Associated sample results were qualified (J) and no further action was needed.
- Three of nine total phosphate composite split results exceeded the control limits. Associated sample results were qualified (J) and no further action was needed.
- Four of nine total suspended solids (TSS) composite split results exceeded the control limits. TSS is considered by many stormwater and surface water monitoring experts to be a fundamentality unreliable measurement for natural waters (i.e., for non-wastewater samples) because of the large variance in paired TSS samples. The United States Geologic Survey (USGS) has completed many studies on TSS analysis and have determined that TSS is not appropriate for analysis of natural waters. However, the TAPE protocol requires the use of TSS as the method to evaluate solids treatment effectiveness. To compensate for the inherent variability of TSS in stormwater, the TSS primary environmental sample results reported in the body of the report and used for this

performance evaluation were obtained by averaging the original primary and field split results for the nine TSS samples that had corresponding split samples. This recalculation to generate nine new primary TSS results had a minor effect on the overall evaluation and resulted in increasing the mean TSS reduction of the CBSFs monitored by less than one percent. The original and split TSS sample results are displayed in Tables B4.31-c at the end of this QA/QC report.

Multiple split samples for multiple particle size fractions were outside control limits for particle size distribution. As is discussed above in the analytical QA/QC section, there is lower confidence in the quality of the particle size distribution data especially in the 250-125 and 125-62.5 micron size ranges due to the lack of rinsing of the sieves. Due to these reasons, all particle size distribution data are considered estimates (J).

Stormwater split sample results are shown on tables on the following pages. The tables list the laboratory qualifier (if applicable) adjacent to the corresponding sample result and the qualifier to be assigned to associated samples after the RPD or absolute difference column.

B4.4 Sediment Duplicate Samples

Three field duplicate QC samples were generated from the sediment samples, collected at a rate of one per annual sediment sampling event. The table following the stormwater split results shows a comparison of results between the sediment samples and corresponding duplicate results. The table lists the laboratory data qualifier adjacent to the corresponding sample result. The field split qualifier, which is based on qualification rules, is listed after the RPD or absolute difference column.

Sediment field duplicate precision results were within control limit except as noted below:

- One of three results for total fines exceeded the control limits. The associated sample result was qualified as estimated (J) and no further action was needed.
- One of three sediment sample duplicates had precision results exceeding control limits for wet density, dry density, lead, total phosphorus and course silt. Associated results in the parent sample were qualified as estimated (J). No further action was needed.

Table B4.4a. Composite Water Sample Split Data

Analyte	Reporting Limit	Units	CBSF1-IN				CBSF1-OUT				CBSF1-OUT			
			3/26/2010 Parent	3/26/2010 Split	RPD or (|Δ|)	Qualifier	4/2/2010 Parent	4/2/2010 Split	RPD or (|Δ|)	Qualifier	5/20/2010 Parent	5/20/2010 Split	RPD or (|Δ|)	Qualifier
pH	1	PH	7.03	7.03	0		6.71	6.71	0		6.44			
Dissolved Copper	1	ug/L	8.75	8.78	0.34		5.79	5.73	1.04		11.8	12.2	3.33	
Total Copper	1	ug/L	32.5	30.3	7.01		8.53	8.54	0.117		19.4	19.5	0.514	
Dissolved Zinc	1	ug/L	29.8	29.6	0.67		28.8	28.5	1.05		76.2	82	7.33	
Total Zinc	1	ug/L	146	136	7.09		37.8	36.5	3.45		96.2	98.1	1.96	
Hardness	2	mg/L CaCO3	16.9	17.9	5.75		15	14.7	2.02		40.9	36.3	11.9	
Solids, Total Suspended	0.5	mg/L	106	154	**36.9**	**J**	7.22	6	18.4		19.1	15.9	18.3	
Orthophosphate	1	mg/L	0.0291	0.0259	11.6		0.0185	0.0187	1.08		0.0286	0.0383	**29**	**J**
Phosphorus, Total	2	mg/L	0.182	0.170	6.82		0.0656	0.0618	5.96		0.134	0.0954	**33.6**	**J**
Sediment Conc.														
< 1 um	0.01	mg/L	4.85	3.96	**20.2**	**J**	5.1	3.73	**31**	**J**	0.86	0.82	4.76	
3.9 to 1 um	0.01	mg/L	7.64	6.99	8.88		2.97	2.24	**28**	**J**	2.09	2.08	0.48	
62.5 to 3.9 um	0.01	mg/L	52.05	49.04	5.96		0.01 U	0.01 U	0		16.78	15.4	8.51	
125 to 62.5 um	0.01	mg/L	14.38	14	2.68		0.01 U	0.01 U	0		6.5	6.16	5.37	
250 to 125 um	0.01	mg/L	0.09	0.06	**40**	**J**	0.01 U	0.01 U	0		1.76	2.1	19.3	
500 to 250 um	0.01	mg/L	13.41	10.87	**20.9**	**J**	0.01 U	0.01 U	0		0.73	0.01 U	**(0.73)**	**J/UJ**
> 500 um	0.01	mg/L	91.85	148.9	**47.4**	**J**	0.11	0.79	**151**	**J**	0.85	0.01 U	**(0.85)**	**J/UJ**

Notes:

U - Analyte was not detected above the reported result.

J- Analyte was positively identified. The reported result is an estimate.

UJ- Analyte was not detected above the reported estimate.

RPD – Relative percent difference

|Δ| - Absolute difference

Table B4.4b. Composite Water Sample Split Data (continued)

Analyte	Reporting Limit	Units	CBSF1-OUT				CBSF1-OUT				CBSF1-OUT			
			6/2/2010 Parent	6/2/2010 Split	RPD or (|Δ|)	Qualifier	6/9/2010 Parent	6/9/2010 Split	RPD or (|Δ|)	Qualifier	11/30/2010 Parent	11/30/2010 Split	RPD or (|Δ|)	Qualifier
pH	1		6.86	6.82	(0.04)		6.54	6.54	0		6.94 R	7.09 R	NA	
Dissolved Copper	1	ug/L	5.48	5.89	7.21		7.79	7.93	1.78		5.06	4.36	(0.7)	
Total Copper	1	ug/L	8.41	9.77	15		11.3	11	2.69		23.3	23.5	0.855	
Dissolved Zinc	1	ug/L	35.2	37.9	7.39		54.7	56.1	2.53		18.7 J	17.3 J	7.78	
Total Zinc	1	ug/L	42.6	43.1	1.17		62.1	64.1	3.17		114	114	0	
Hardness	2	mg/L $CaCO_3$	20.9	20.6	1.44		23.9	25.9	8.03		10.1	11.5	13.0	
Solids, Total Suspended	0.5	mg/L	15.7	15.3	2.58		11	5.85	**60.1**	**J**	62.9	64.1	1.89	
Ortho-phosphate	1	mg/L	0.0161	0.0099	**47.7**	**J**	0.0269	0.0269	0		0.0137	0.0319	**79.8**	**J**
Phosphorus, Total	2	mg/L	0.0415	0.0404	2.69		0.0577	0.0591	2.4		0.230	0.240	4.26	
Sediment Conc.														
< 1 um	0.01	mg/L	0.54	0.1	**138**	**J**	1.01	0.79	**24.4**	**J**	6.7	8.7	**26.0**	**J**
3.9 to 1 um	0.01	mg/L	1.77	0.33	**137**	**J**	4.52	3.39	**28.6**	**J**	12.7	16.7	**27.2**	**J**
62.5 to 3.9 um	0.01	mg/L	8.75	1.63	**137**	**J**	23.14	18.08	**24.6**	**J**	48.6	59	19.3	
125 to 62.5 um	0.01	mg/L	4.07	0.83	**132**	**J**	6.72	5.65	17.8		0.9	8	**160**	**J**
250 to 125 um	0.01	mg/L	1.28	0.27	**130**	**J**	0.15	1.07	**151**	**J**	0.01 U	0.01 U	NA	
500 to 250 um	0.01	mg/L	0.11	0.44	**120**	**J**	0.34	0.33	2.98		3.9	3.2	19.7	
> 500 um	0.01	mg/L	0.21	0.33	**44.4**	**J**	0.34	0.01 U	**(0.34)**	**J/UJ**	3.4	2.4	**34.5**	**J**

Notes:

U - Analyte was not detected above the reported result.

J- Analyte was positively identified. The reported result is an estimate.

UJ- Analyte was not detected above the reported estimate.

RPD – Relative percent difference

|Δ| - Absolute difference

Table B4.4c. Composite Water Sample Split Data (continued)

Analyte	Reporting Limit	Units	CBSF1-OUT				CBSF2-IN				CBSF2-IN			
			3/8/2011	3/8/2011	RPD	Qualifier	3/16/2011	3/16/2011	RPD	Qualifier	4/27/2011	4/27/2011	RPD	Qualifier
			Parent	Split	or (|Δ|)		Parent	Split	or (|Δ|)		Parent	Split	or (|Δ|)	
pH	1	PH	6.91	6.89	NA		7.32	7.29	NA		7.06	6.98	NA	
Dissolved Copper	1	ug/L	8.77	8.98	2.37		1.59	1.47	(0.12)		7.31	7.13	2.49	
Total Copper	1	ug/L	18.9	18.9	0		17.6	16.2	8.28		27.6	25.4	8.30	
Dissolved Zinc	1	ug/L	53.1	54.6	2.79		10.4 J	9.95 J	4.42		27.5 J	22.9 J	18.3	
Total Zinc	1	ug/L	85.3	85.6	0.351		91.3	91.5	0.219		147	125	16.18	
Hardness	2	mg/L CaCO3	42	42.5	1.18		9.3	9.35	(0.05)		14.4	14.3	0.697	
Solids, Total Suspended	0.5	mg/L	34	32.3	5.13		127	302	**83.6**	J	102	170	**50.0**	J
Ortho-phosphate	1	mg/L	0.0088	0.008	9.52		0.00824	0.00837	1.57		0.0207	0.0168	20.8	
Phosphorus, Total	2	mg/L	0.0411	0.0746	**57.9**	J	0.0757	0.0977	**25.4**	J	0.0194	0.0191	1.56	
Sediment Conc.														
< 1 um	0.01	mg/L	29.6	22.6	26.8	J	77.6	85.3	9.45		7.1	6.9	2.86	
3.9 to 1 um	0.01	mg/L	15.7	12	26.7	J	47.4	52	9.26		14.5	13.8	4.95	
62.5 to 3.9 um	0.01	mg/L	0.01 U	0.01 U	NA		0.01 U	0.01 U	NA		86.4	83	4.01	
125 to 62.5 um	0.01	mg/L	0.01 U	0.01 U	NA		0.01 U	0.01 U	NA		0.01 U	0.01 U	NA	
250 to 125 um	0.01	mg/L	0.01 U	0.01 U	NA		0.01 U	0.01 U	NA		0.01 U	0.01 U	NA	
500 to 250 um	0.01	mg/L	3.1	3.2	3.17		44.2	50.9	14.1		16.2	16.8	3.64	
> 500 um	0.01	mg/L	5	4.1	19.8		89.1	132.5	**39.2**	J	12.7	31.1	**84.0**	J

Notes:

U - Analyte was not detected above the reported result.

J- Analyte was positively identified. The reported result is an estimate.

UJ- Analyte was not detected above the reported estimate.

RPD – Relative percent difference

|Δ| - Absolute difference

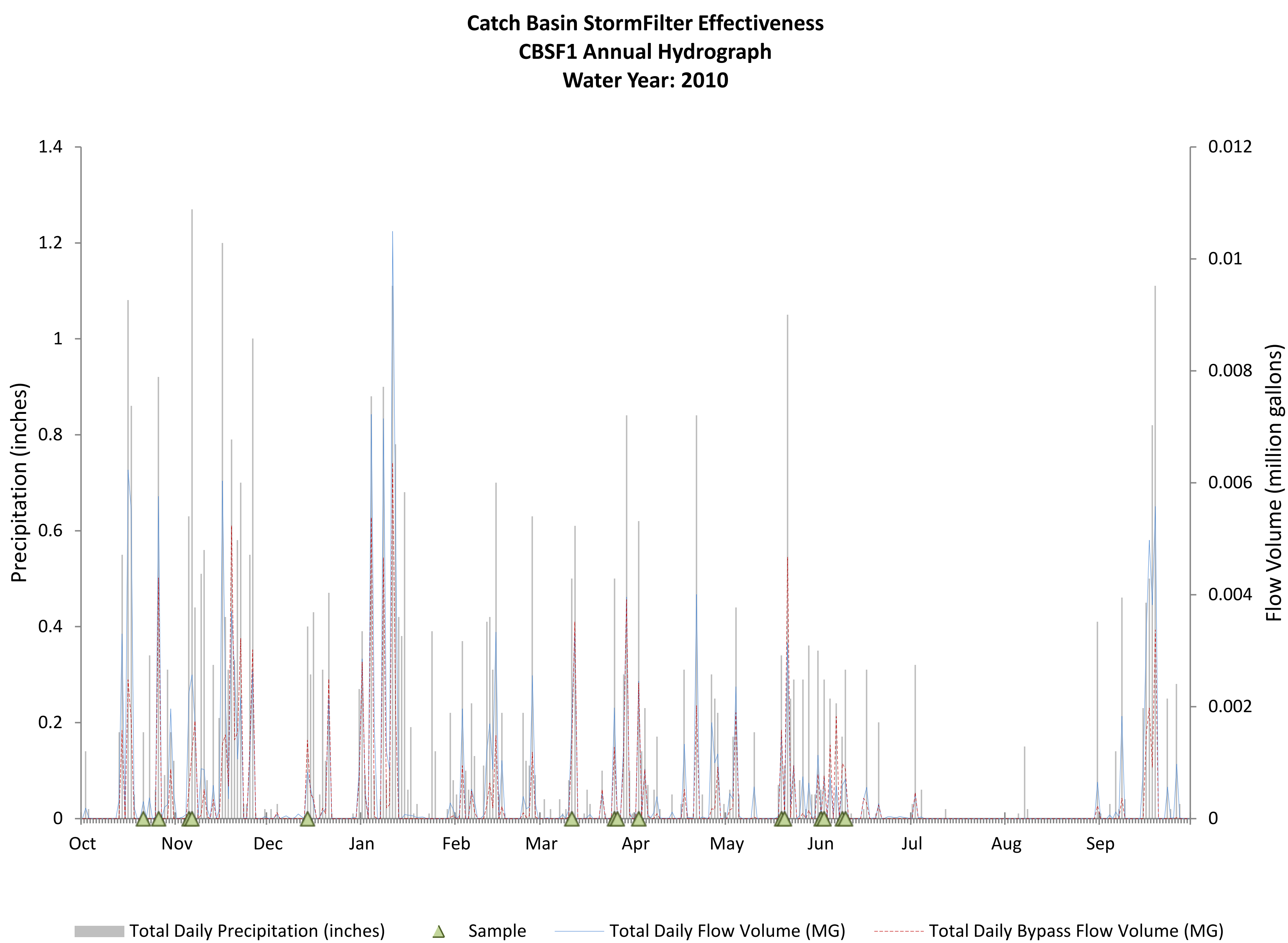
Table B4.4d. Sediment Duplicate Sample Data

Analyte	Reporting Limit	Units	CBSF2-SED1				CBSF2-Sed1				CBSF2-SED1			
			9/23/2009	9/23/2009	RPD		9/28/2010	9/28/2010	RPD		6/9/2011	6/9/2011	RPD	
			Parent	Split	or (|Δ|)	Qual.	Parent	Split	or (|Δ|)	Qual.	Parent	Split	or (|Δ|)	Qual.
Dry Density	0.1	LB/CUFT	82.6	77.8	5.99		22.6	23.7	4.75		46 J	27.3 J	**51.0**	**J**
Wet Density	0.1	LB/CUFT	31	28.7	7.71		73.5	76.1	3.48		116.6	77.4	**40.4**	**J**
Solids, Total	0.01	%	39.8	38	4.63		45.3	52.1	14		40.7	32.8	21.5	
Solids, Total Volatile	0.01	%	19.7	19.45	1.28		19.82	15.43	24.9		19.08	24.67	25.6	
Cadmium	0.2	mg/kg	0.6	0.6	0		0.7	0.8	(0.1)		0.5	0.5	0	
Copper	0.5	mg/kg	45.6	54	16.9		51	54	5.71		76	56	30.3	
Lead	1	mg/kg	86	78	9.76		58	71	20.2		84 J	186 J	**75.6**	**J**
Zinc	4	mg/kg	287	264	8.35		230	240	4.26		320	290	9.84	
Phosphorus, Total	0.4	mg/kg	394	409	3.74		249	180	32.2		220 J	751 J	**109.4**	**J**
Diesel Range Hydrocarbons	5	mg/kg	1200	1100	8.70		360	480	28.6		1800	1700	5.71	
Motor Oil	10	mg/kg	2900	2800	3.51		2100	2700	25		4600	4200	9.09	
Gravel	0.1	%	18.8	15.3	20.5		25.9	23.3	10.6		13.1	9.8	28.8	
Very Coarse Sand	0.1	%	17.5	18.1	3.37		14.2	14.5	2.09		14.9	16.4	9.58	
Coarse Sand	0.1	%	19.4	18.4	5.29		17.9	18.3	2.21		22.2	20.3	8.94	
Medium Sand	0.1	%	20.3	20.1	0.990		20.3	20.5	0.98		22.4	22.5	0.445	
Fine Sand	0.1	%	12.8	13	1.55		11.6	11.6	0		12.8	13.1	2.317	
Very Fine Sand	0.1	%	4.9	5.2	5.94		3.8	3.9	2.6		4.5	4.8	6.45	
Coarse Silt	0.1	%	NM	NM	NA		NM	0.6	NA		1.9 J	5.2 J	**93.0**	**J**
Medium Silt	0.1	%	NM	NM	NA		NM	2.4	NA		2.6	2.7	3.77	
Fine Silt	0.1	%	NM	NM	NA		NM	1.7	NA		1.6	1.6	0	
Very Fine Silt	0.1	%	NM	NM	NA		NM	1.4	NA		1.2	1.1	8.70	
8-9 Phi Clay	0.1	%	NM	NM	NA		NM	0.7	NA		0.4	0.5	(0.1)	
9-10 Phi Clay	0.1	%	NM	NM	NA		NM	0.6	NA		0.4	0.3	(0.1)	
>10 Phi Clay	0.1	%	NM	NM	NA		NM	0.5	NA		2	1.9	5.13	
Total Fines	0.1	%	6.3	9.9	**44.4**	**J**	6.3	7.8	21.3		10.1	13.3	27.4	

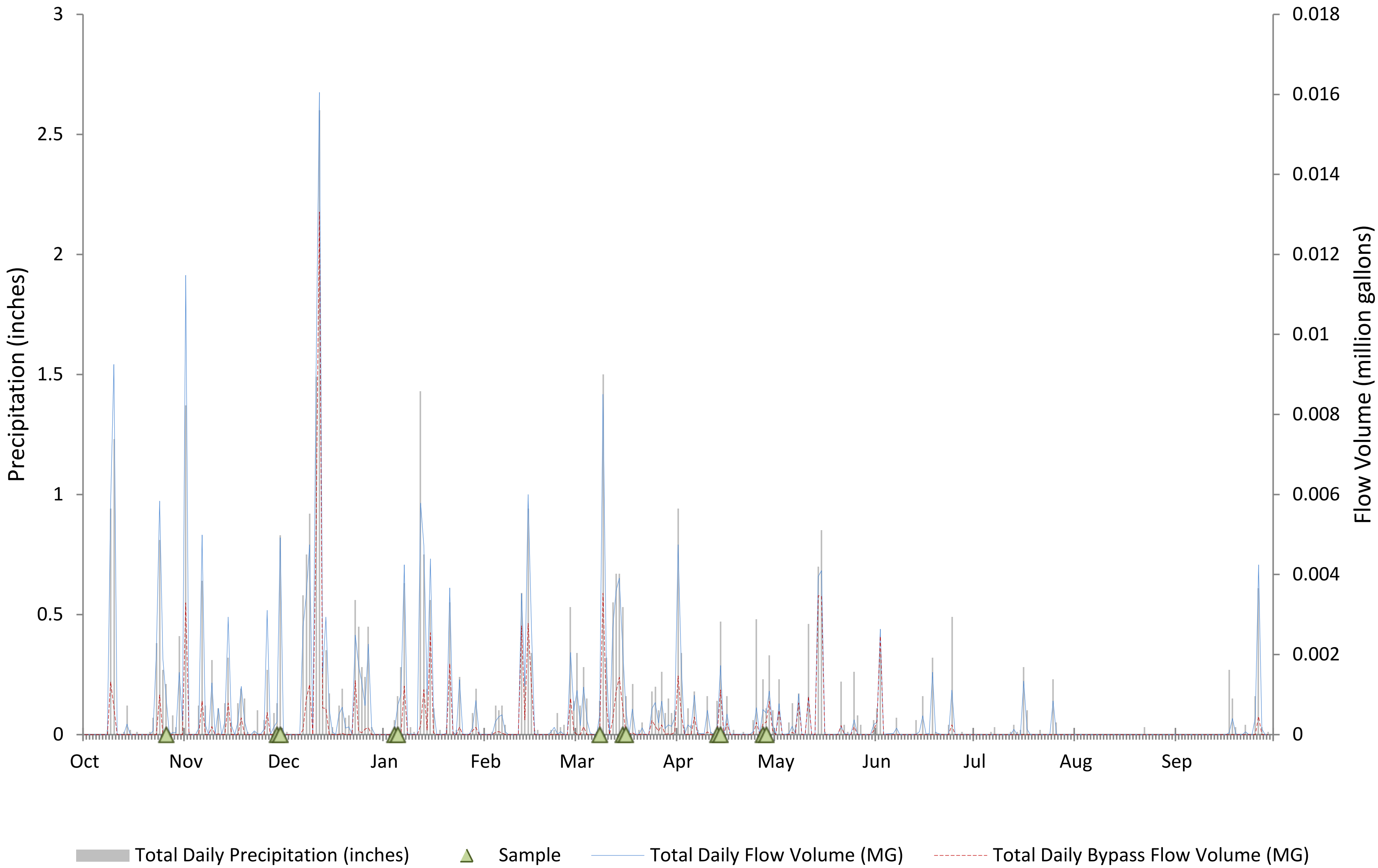
City of Seattle

Appendix C ANNUAL AND EVENT HYDROGRAPHS

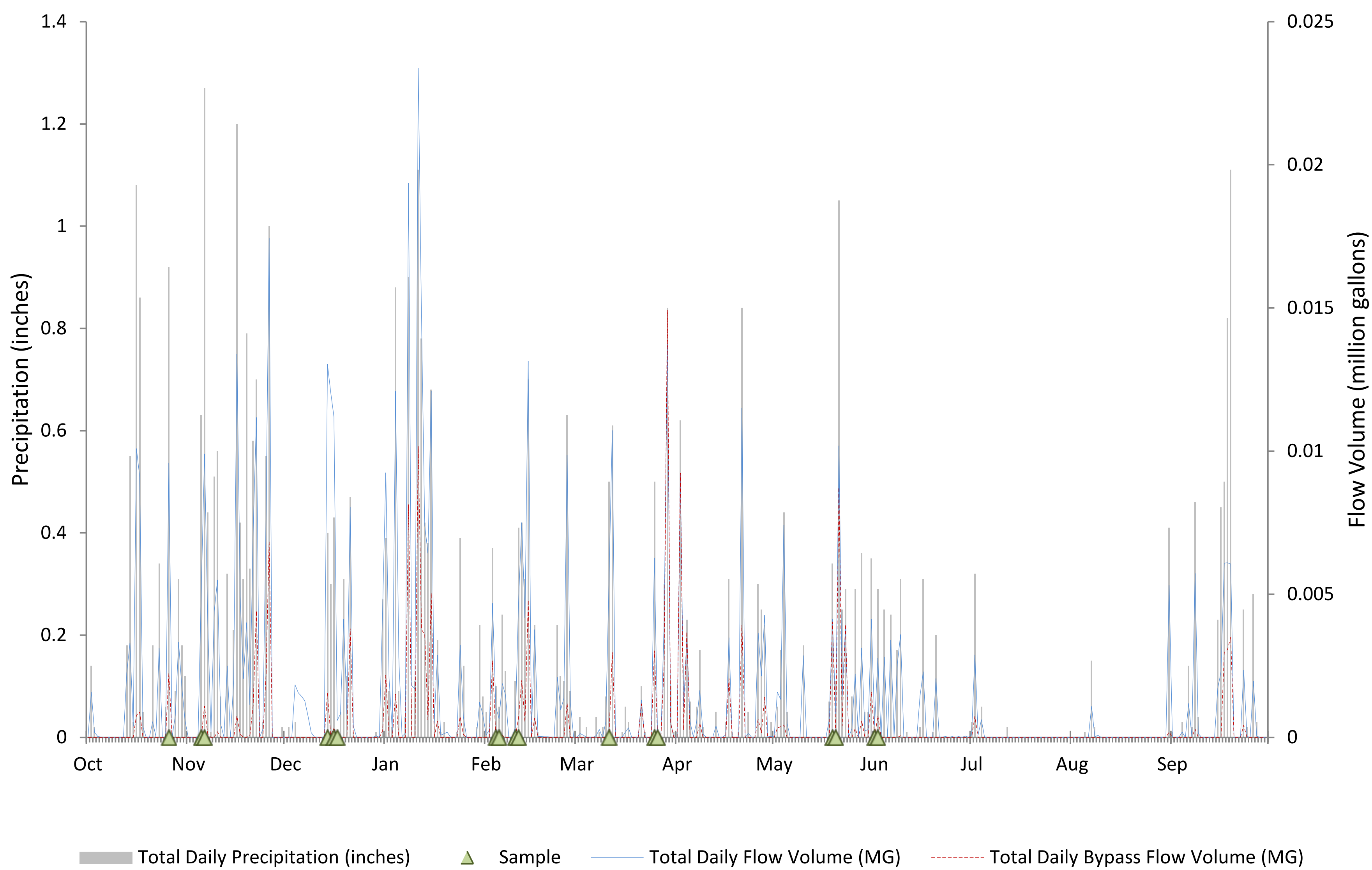
This Page Intentionally Left Blank.


Catch Basin StormFilter Effectiveness
CBSF1 Annual Hydrograph
Water Year: 2010
Precipitation (inches)
Flow Volume (million gallons)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.012
0.01
0.008
0.006
0.004
0.002
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Total Daily Precipitation (inches)
Sample
Total Daily Flow Volume (MG)
Total Daily Bypass Flow Volume (MG)

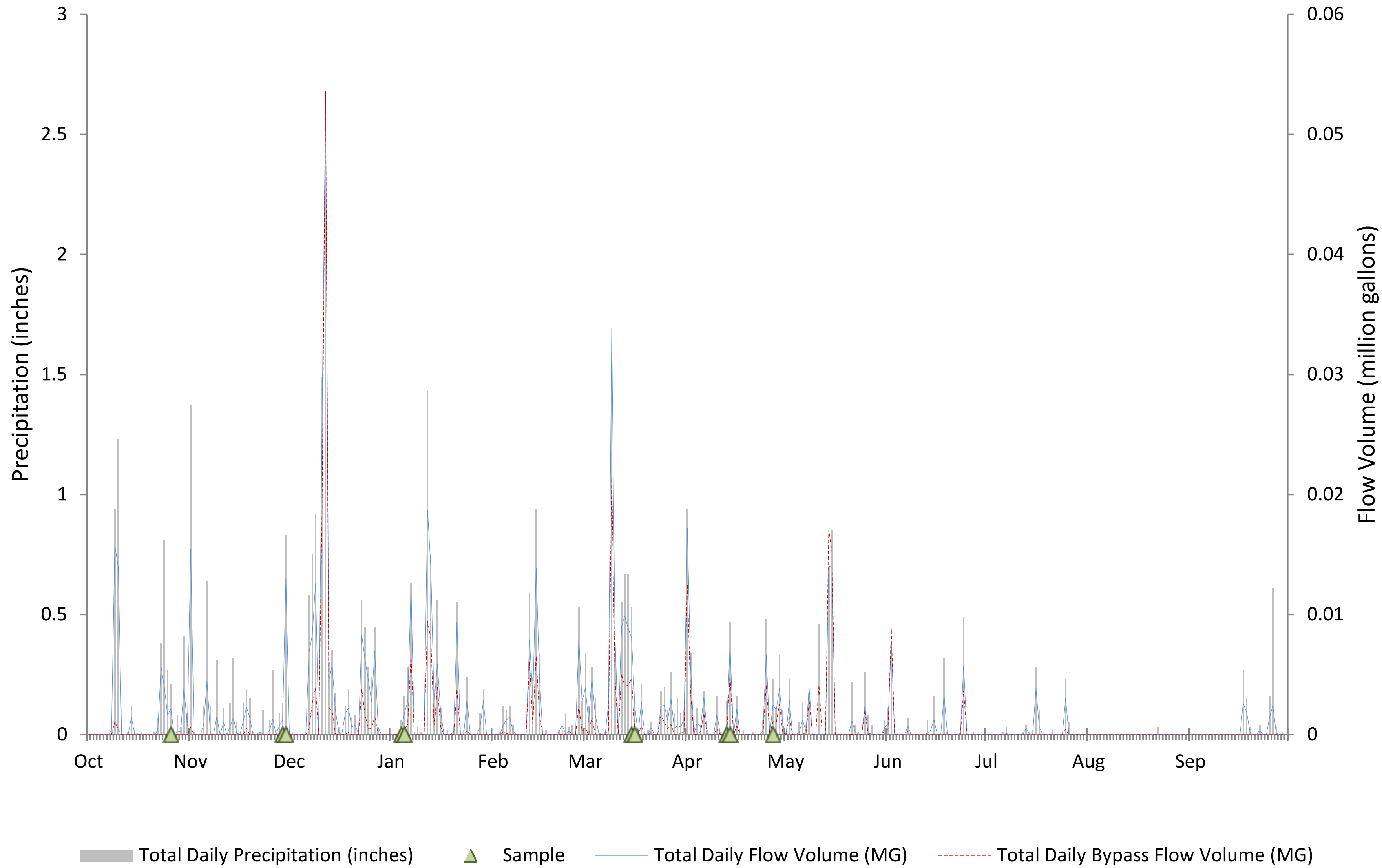
Catch Basin StormFilter Effectiveness
CBSF1 Annual Hydrograph
Water Year: 2011

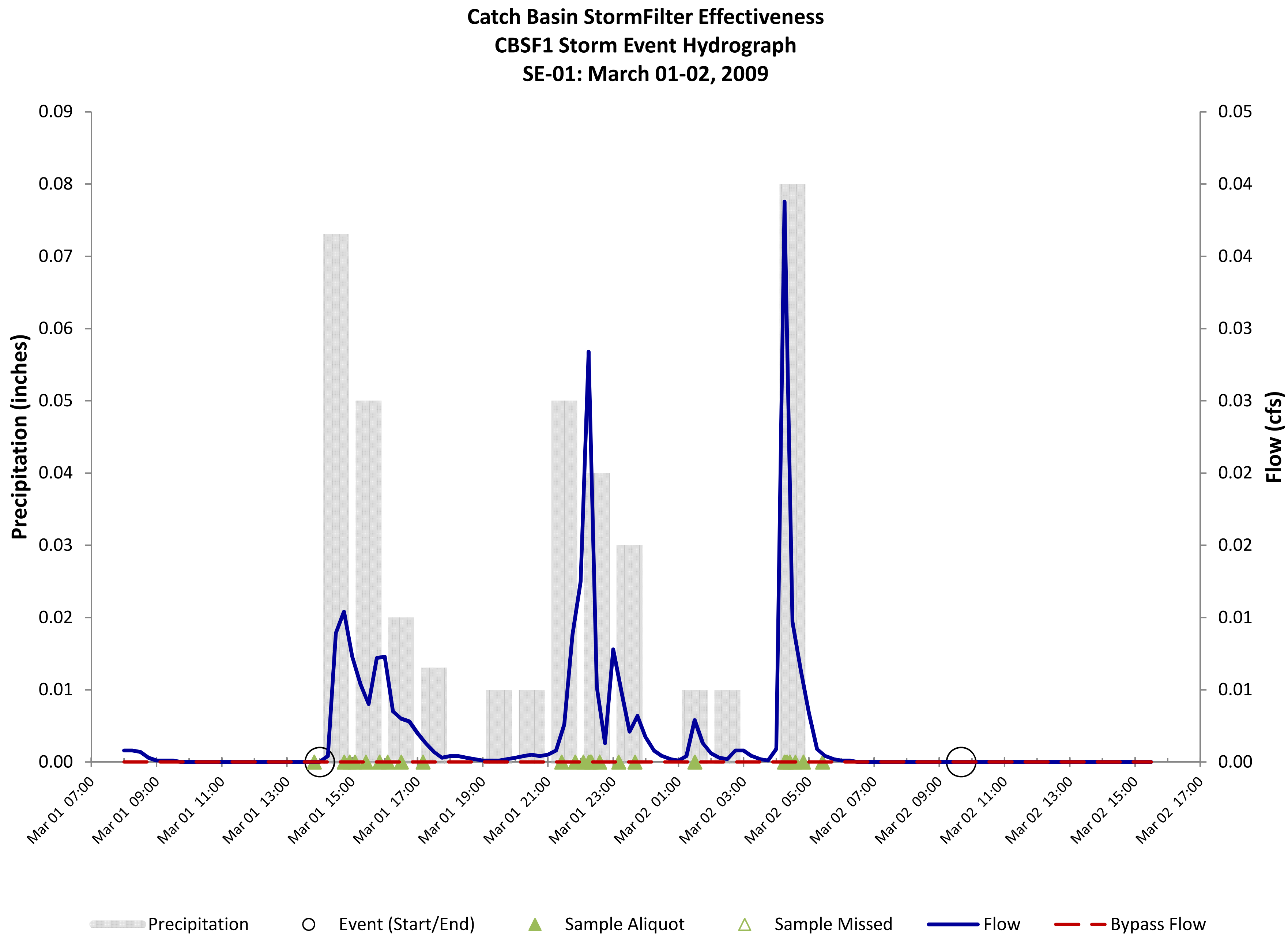


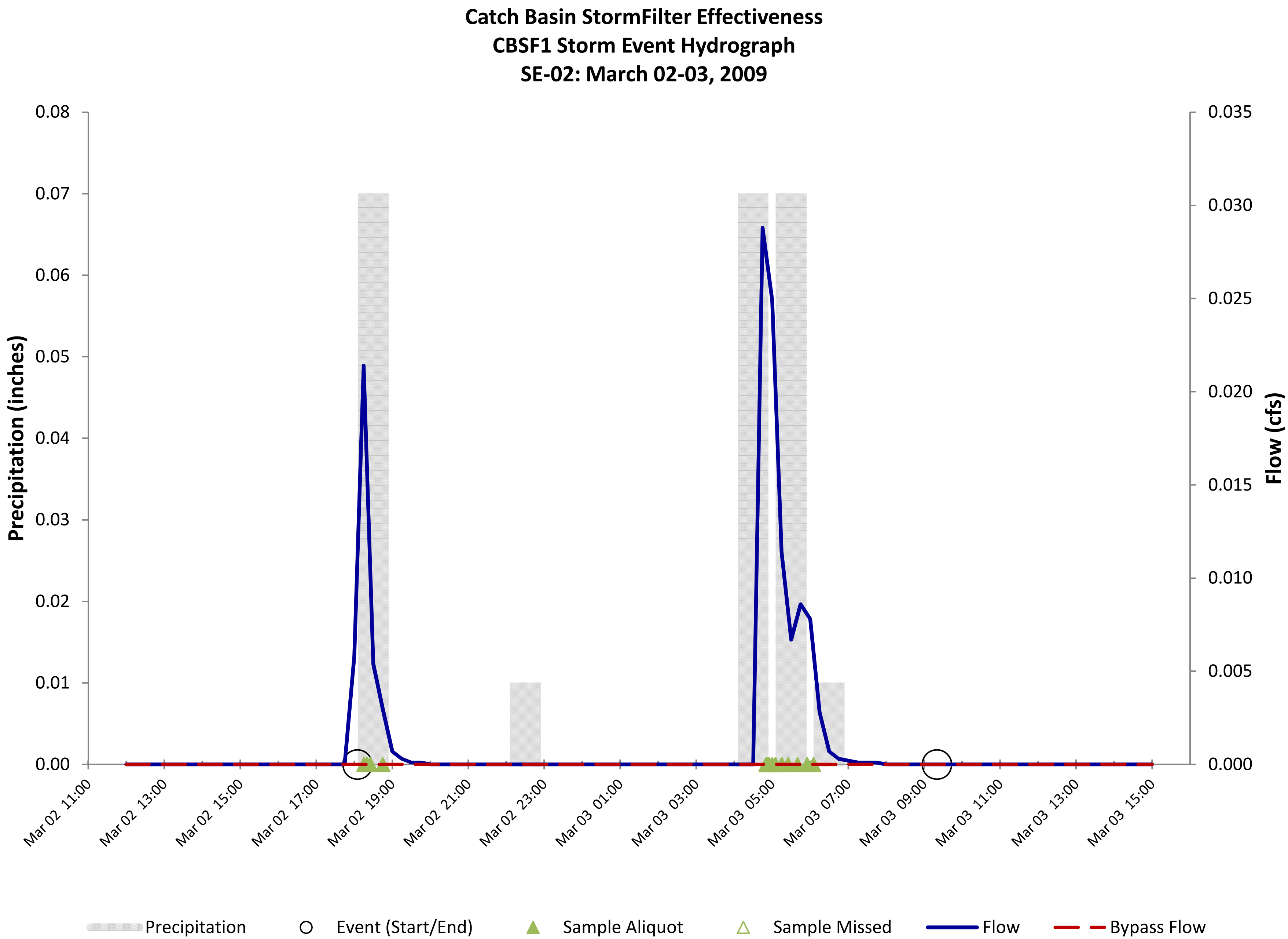
Catch Basin StormFilter Effectiveness
CBSF2 Annual Hydrograph
Water Year: 2010



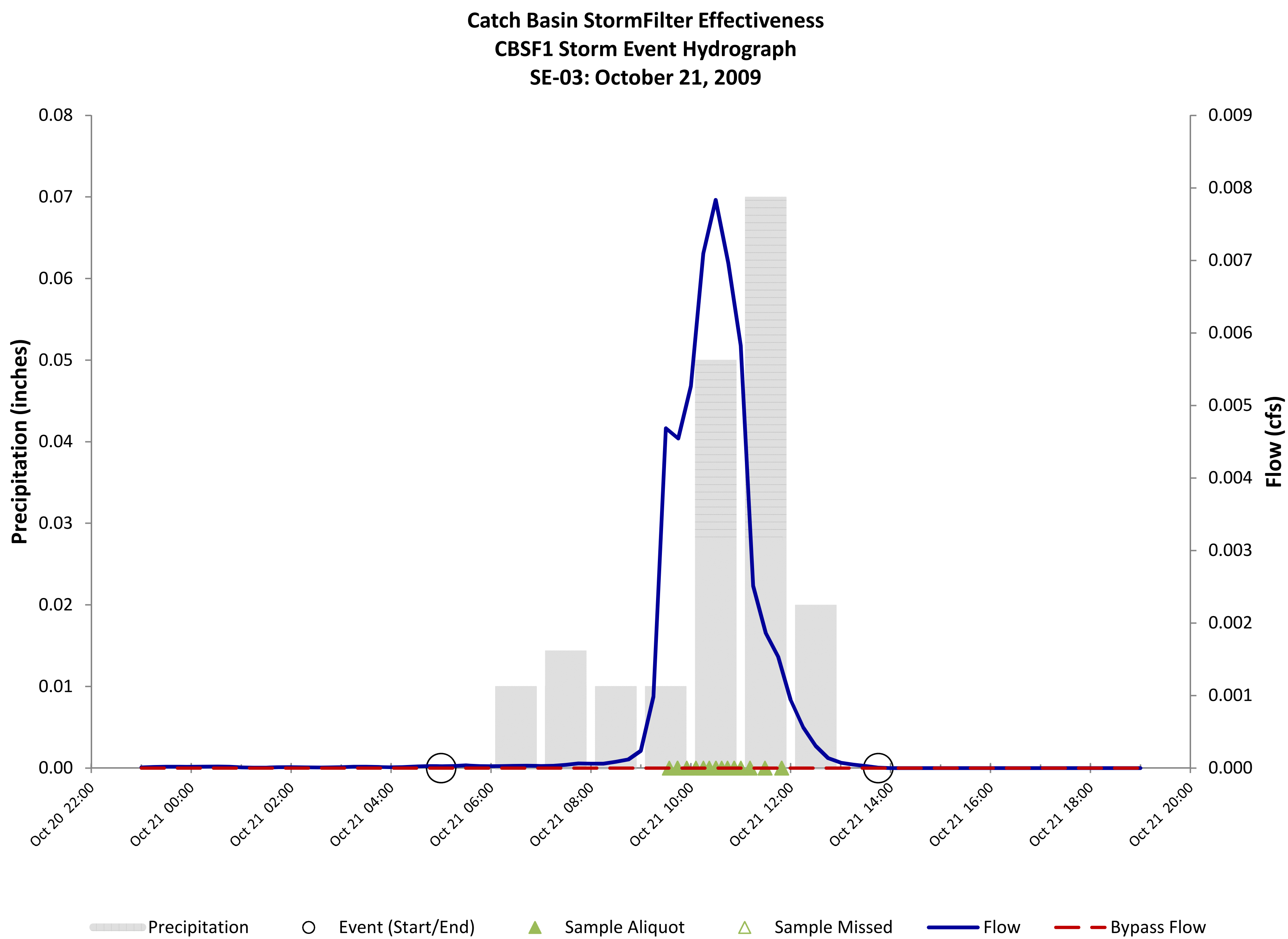
Catch Basin StormFilter Effectiveness
CBSF2 Annual Hydrograph
Water Year: 2011

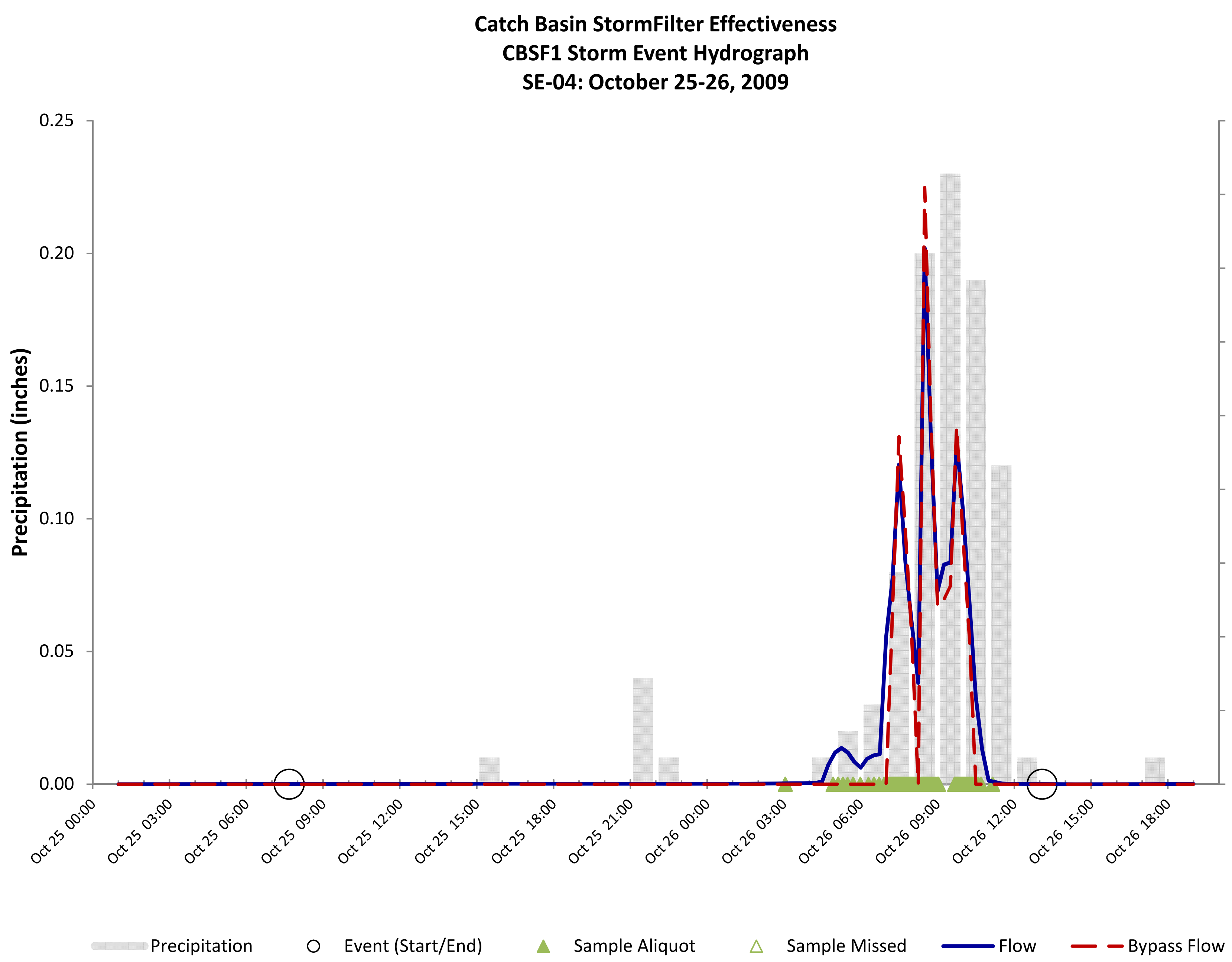



Catch Basin StormFilter Effectiveness
CBSF1 Storm Event Hydrograph
SE-01: March 01-02, 2009
Precipitation (inches)
Flow (cfs)
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.05
0.04
0.04
0.03
0.03
0.02
0.02
0.01
0.01
0.00
Mar 01 07:00
Mar 01 09:00
Mar 01 11:00
Mar 01 13:00
Mar 01 15:00
Mar 01 17:00
Mar 01 19:00
Mar 01 21:00
Mar 01 23:00
Mar 02 01:00
Mar 02 03:00
Mar 02 05:00
Mar 02 07:00
Mar 02 09:00
Mar 02 11:00
Mar 02 13:00
Mar 02 15:00
Mar 02 17:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow

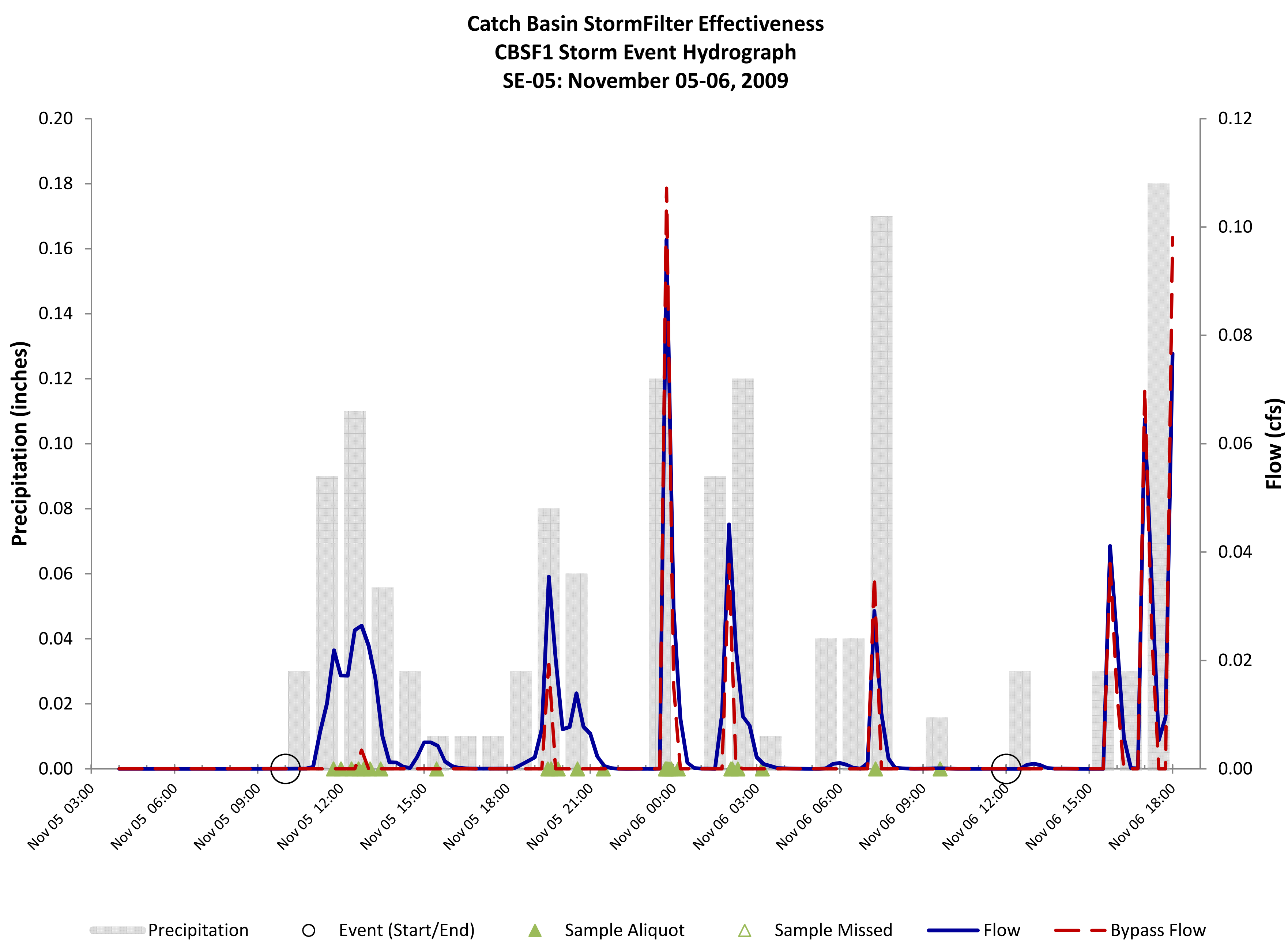


Catch Basin StormFilter Effectiveness
CBSF1 Storm Event Hydrograph
SE-02: March 02-03, 2009
Precipitation (inches)
Flow (cfs)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
Mar 02 11:00
Mar 02 13:00
Mar 02 15:00
Mar 02 17:00
Mar 02 19:00
Mar 02 21:00
Mar 02 23:00
Mar 03 01:00
Mar 03 03:00
Mar 03 05:00
Mar 03 07:00
Mar 03 09:00
Mar 03 11:00
Mar 03 13:00
Mar 03 15:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow

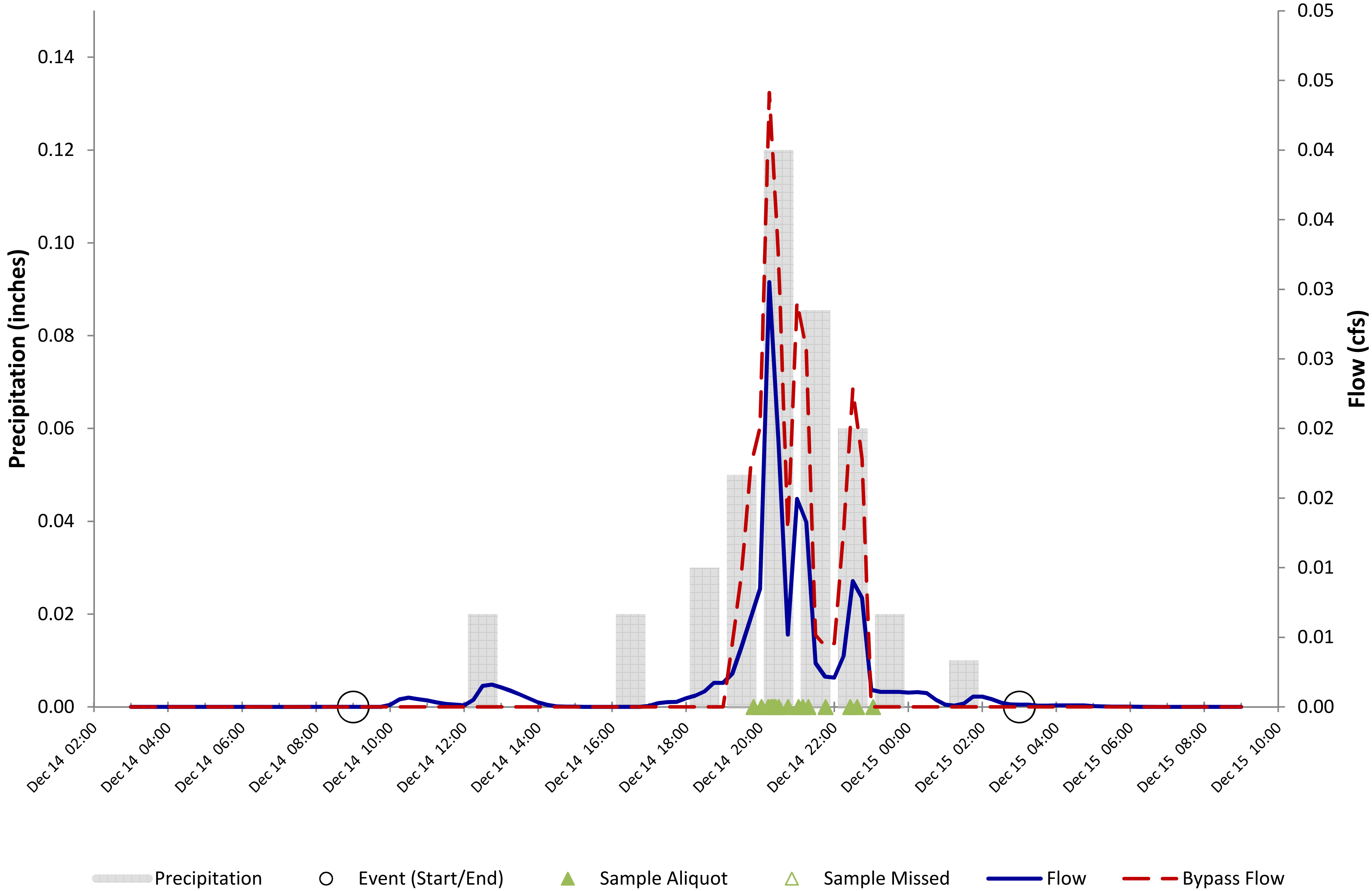

Catch Basin StormFilter Effectiveness
CBSF1 Storm Event Hydrograph
SE-03: October 21, 2009
Precipitation (inches)
Flow (cfs)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
Oct 20 22:00
Oct 21 00:00
Oct 21 02:00
Oct 21 04:00
Oct 21 06:00
Oct 21 08:00
Oct 21 10:00
Oct 21 12:00
Oct 21 14:00
Oct 21 16:00
Oct 21 18:00
Oct 21 20:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow



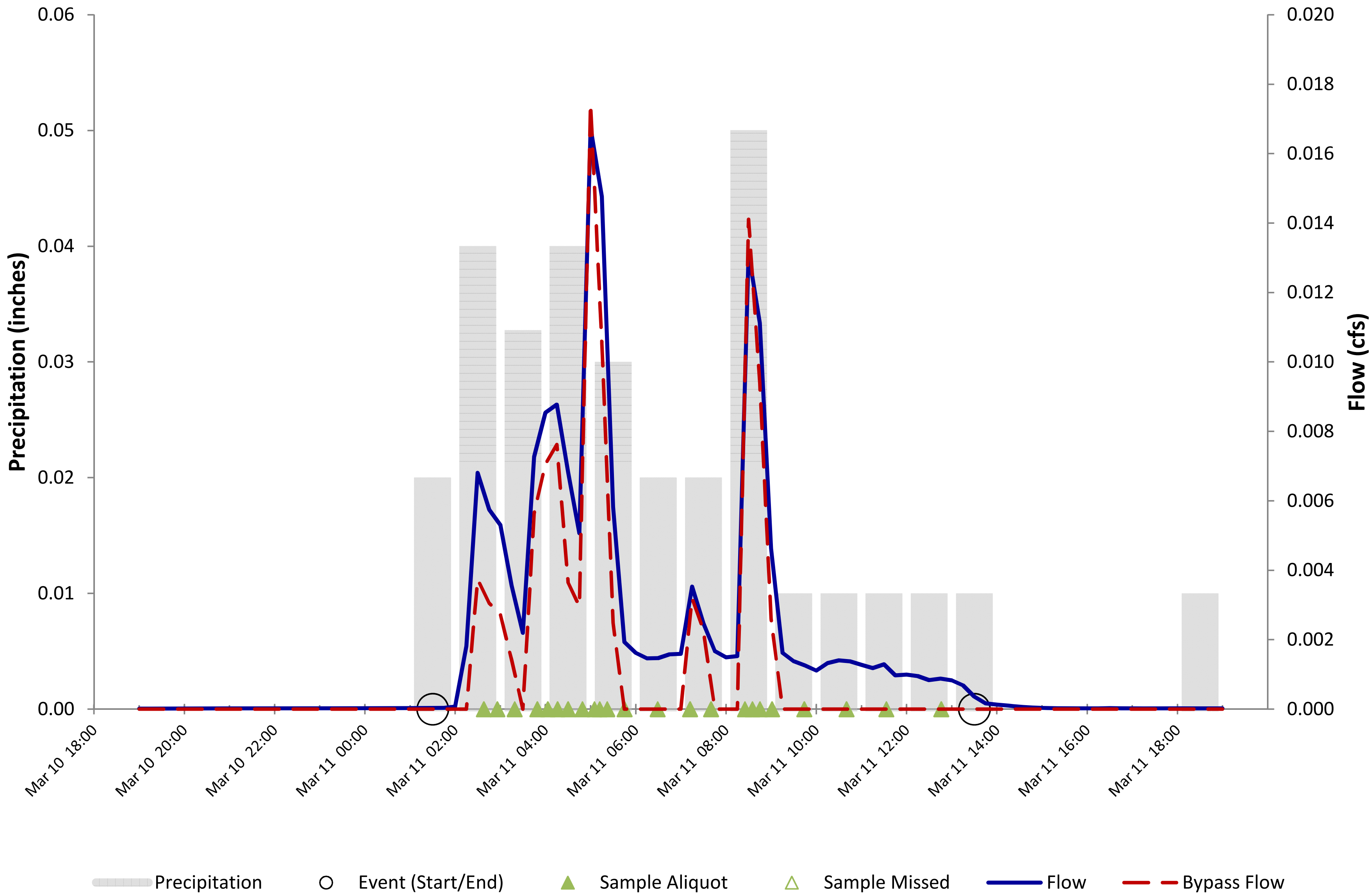
Catch Basin StormFilter Effectiveness
CBSF1 Storm Event Hydrograph
SE-04: October 25-26, 2009
Precipitation (inches)
Flow (cfs)
0.25
0.20
0.15
0.10
0.05
0.00
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Oct 25 00:00
Oct 25 03:00
Oct 25 06:00
Oct 25 09:00
Oct 25 12:00
Oct 25 15:00
Oct 25 18:00
Oct 25 21:00
Oct 26 00:00
Oct 26 03:00
Oct 26 06:00
Oct 26 09:00
Oct 26 12:00
Oct 26 15:00
Oct 26 18:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow


Catch Basin StormFilter Effectiveness
CBSF1 Storm Event Hydrograph
SE-05: November 05-06, 2009
Precipitation (inches)
Flow (cfs)
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Nov 05 03:00
Nov 05 06:00
Nov 05 09:00
Nov 05 12:00
Nov 05 15:00
Nov 05 18:00
Nov 05 21:00
Nov 06 00:00
Nov 06 03:00
Nov 06 06:00
Nov 06 09:00
Nov 06 12:00
Nov 06 15:00
Nov 06 18:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow

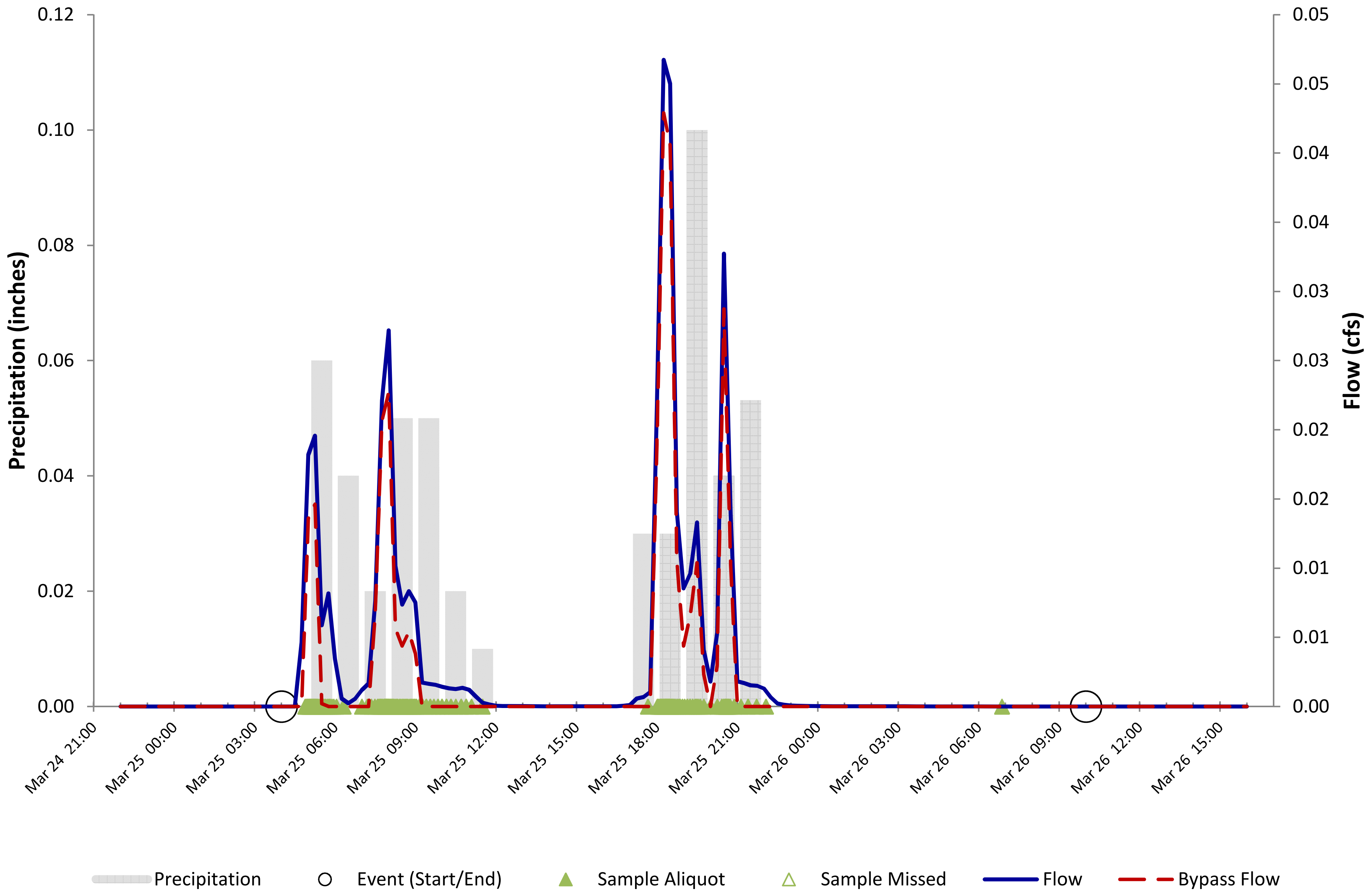
Catch Basin StormFilter Effectiveness
CBSF1 Storm Event Hydrograph
SE-06: December 14-15, 2009

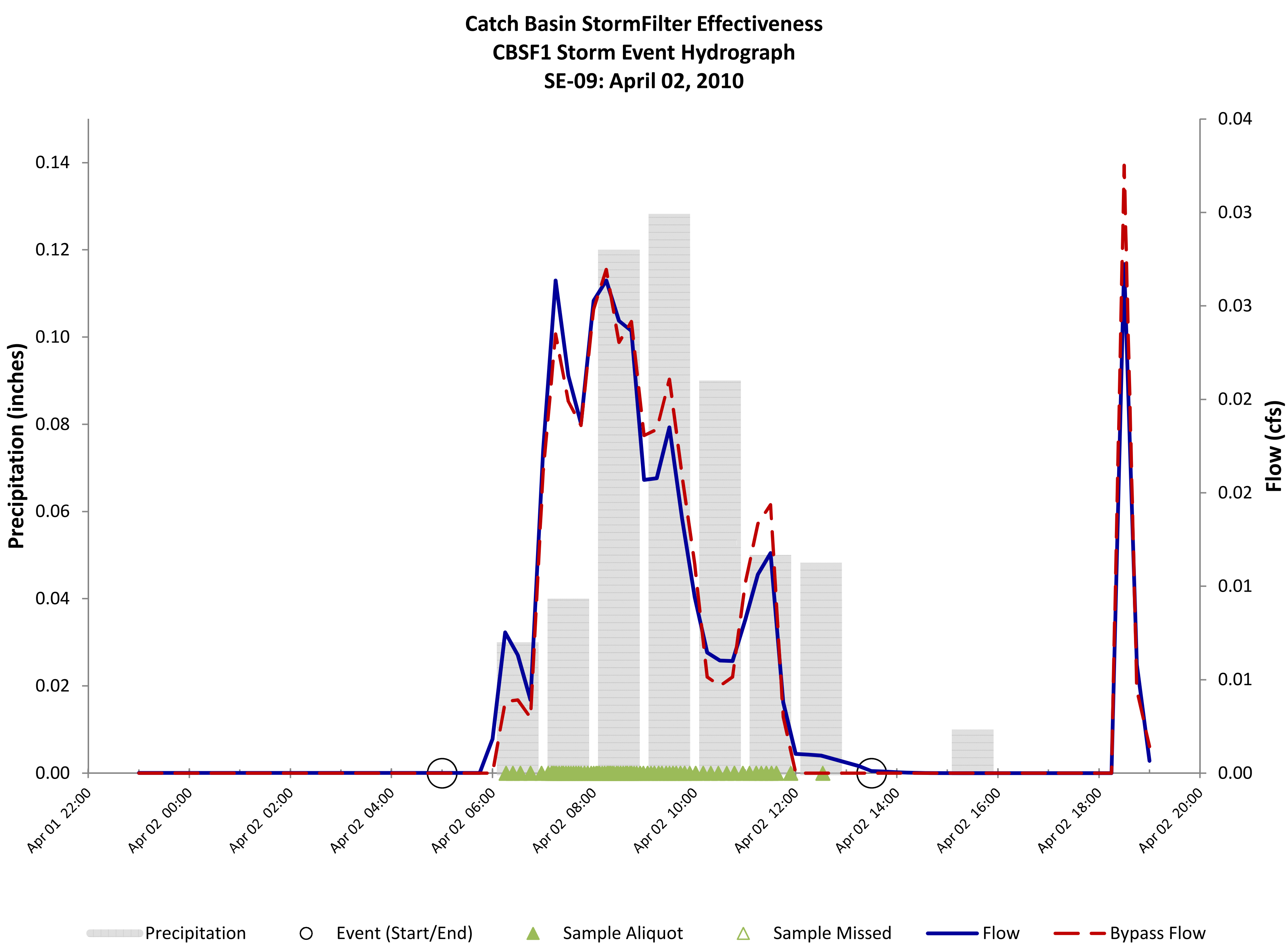


Catch Basin StormFilter Effectiveness
CBSF1 Storm Event Hydrograph
SE-07: March 11, 2010

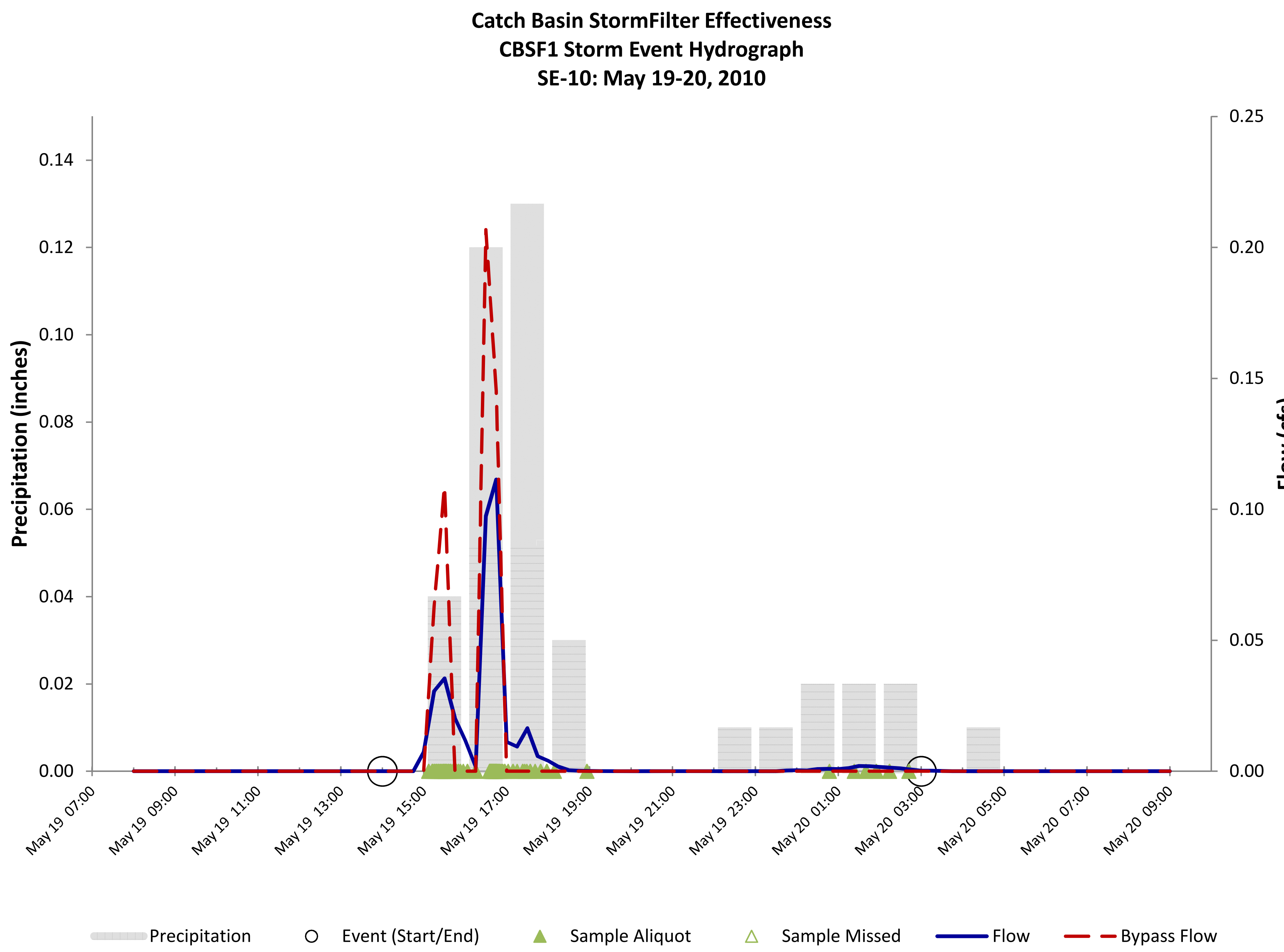


Catch Basin StormFilter Effectiveness
CBSF1 Storm Event Hydrograph
SE-08: March 25-26, 2010

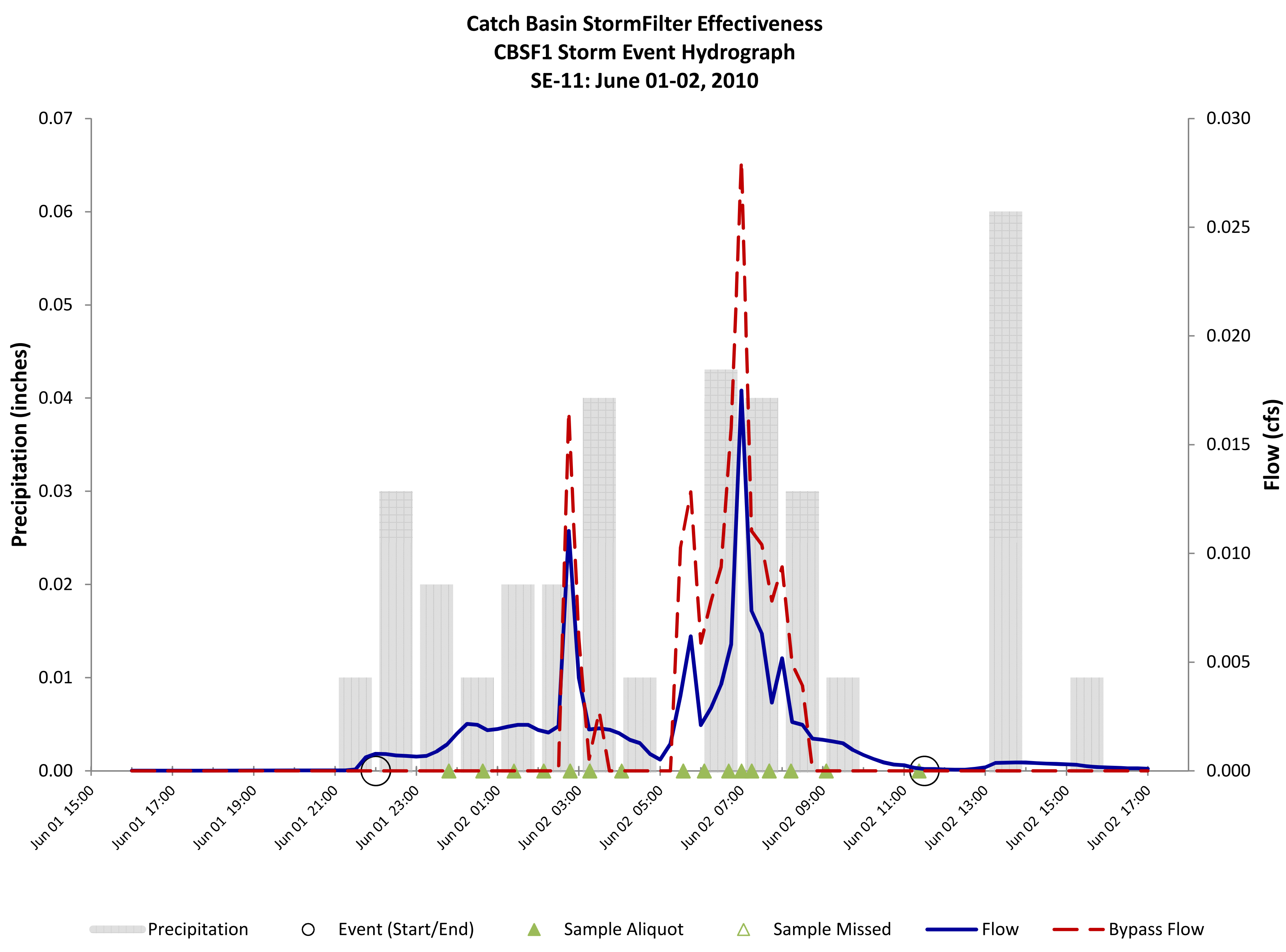




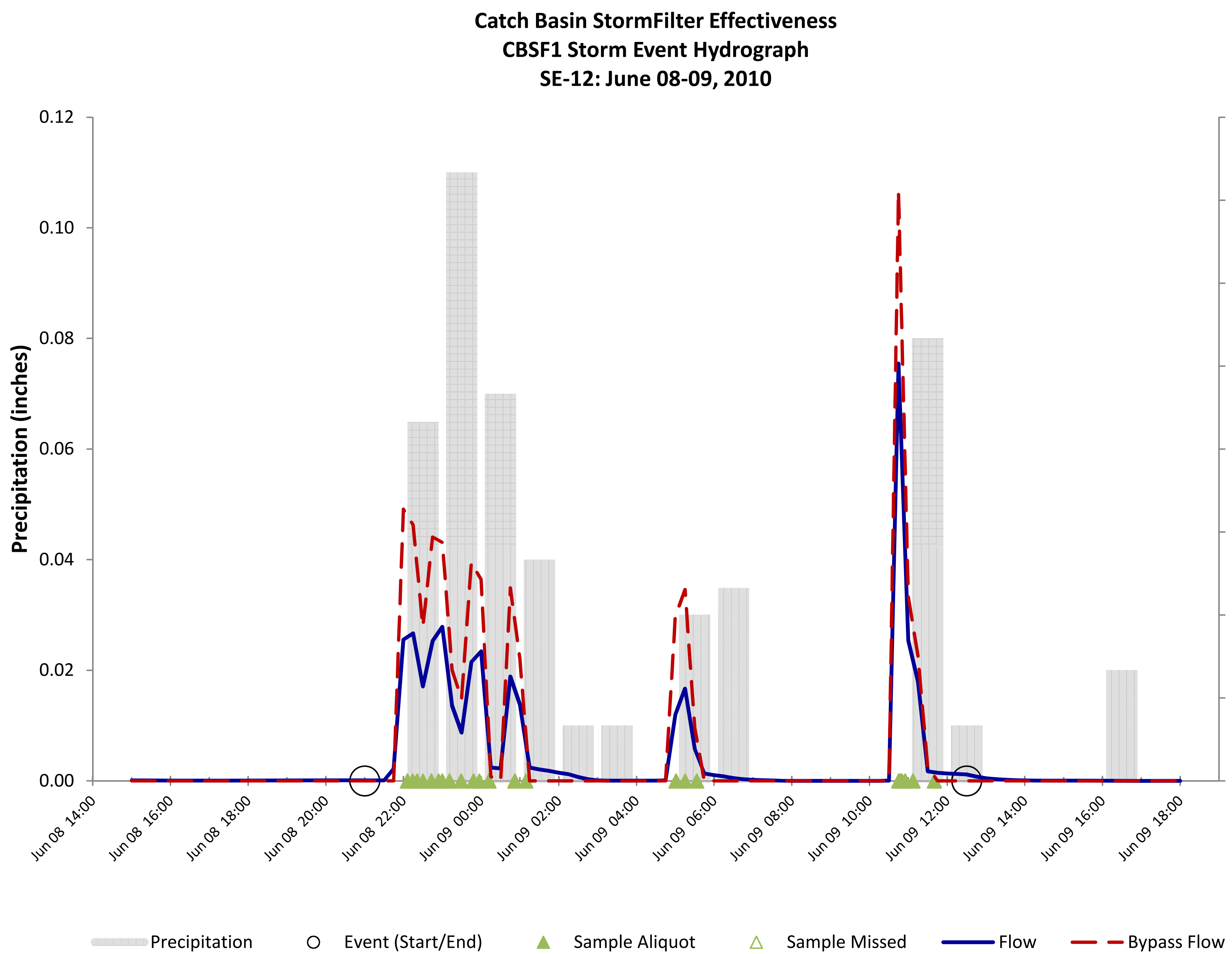
Catch Basin StormFilter Effectiveness
CBSF1 Storm Event Hydrograph
SE-09: April 02, 2010
Precipitation (inches)
Flow (cfs)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.04
0.03
0.03
0.02
0.02
0.01
0.01
0.00
Apr 01 22:00
Apr 02 00:00
Apr 02 02:00
Apr 02 04:00
Apr 02 06:00
Apr 02 08:00
Apr 02 10:00
Apr 02 12:00
Apr 02 14:00
Apr 02 16:00
Apr 02 18:00
Apr 02 20:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow



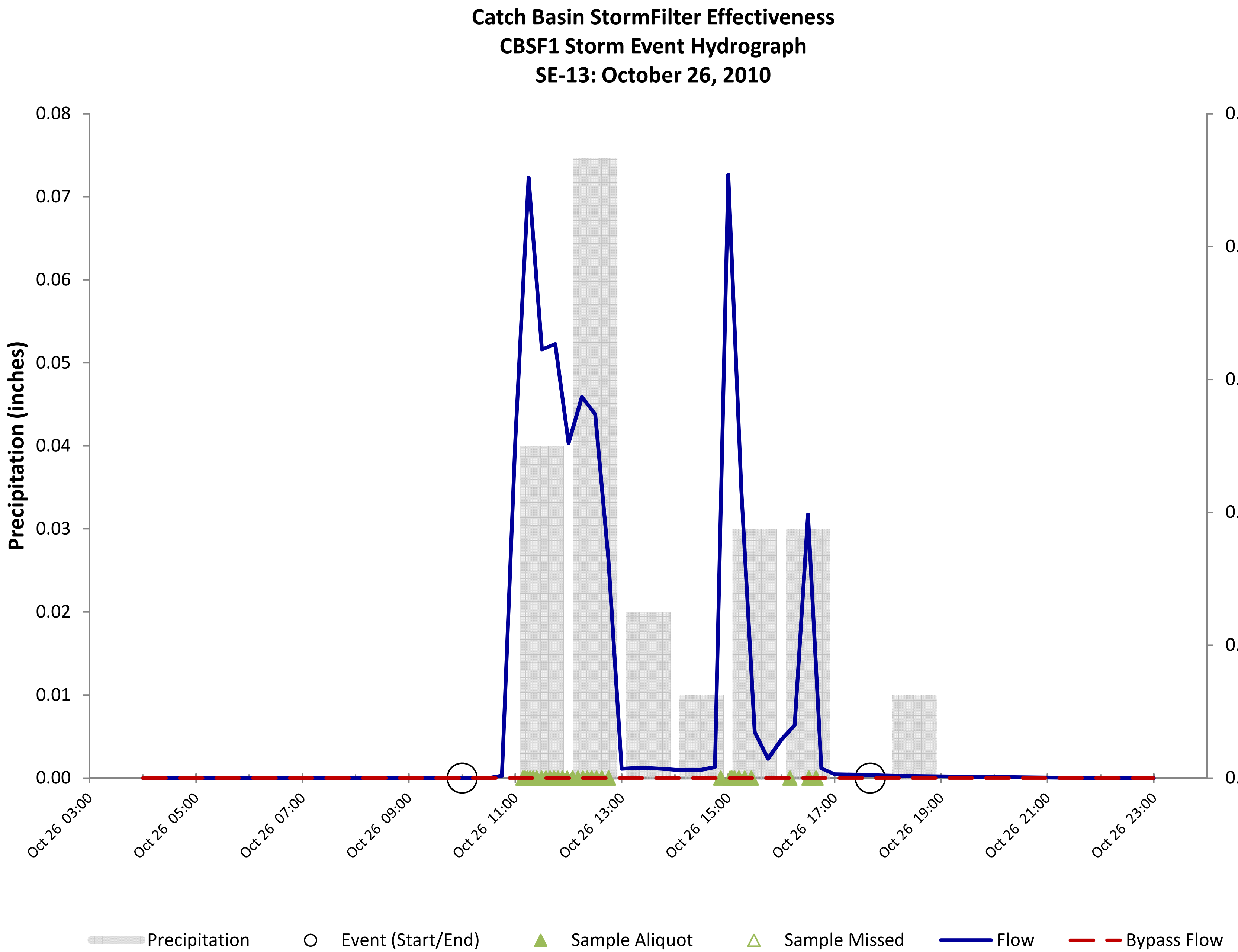
Catch Basin StormFilter Effectiveness
CBSF1 Storm Event Hydrograph
SE-10: May 19-20, 2010
Precipitation (inches)
Flow (cfs)
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.00
0.05
0.10
0.15
0.20
0.25
May 19 07:00
May 19 09:00
May 19 11:00
May 19 13:00
May 19 15:00
May 19 17:00
May 19 19:00
May 19 21:00
May 19 23:00
May 20 01:00
May 20 03:00
May 20 05:00
May 20 07:00
May 20 09:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow



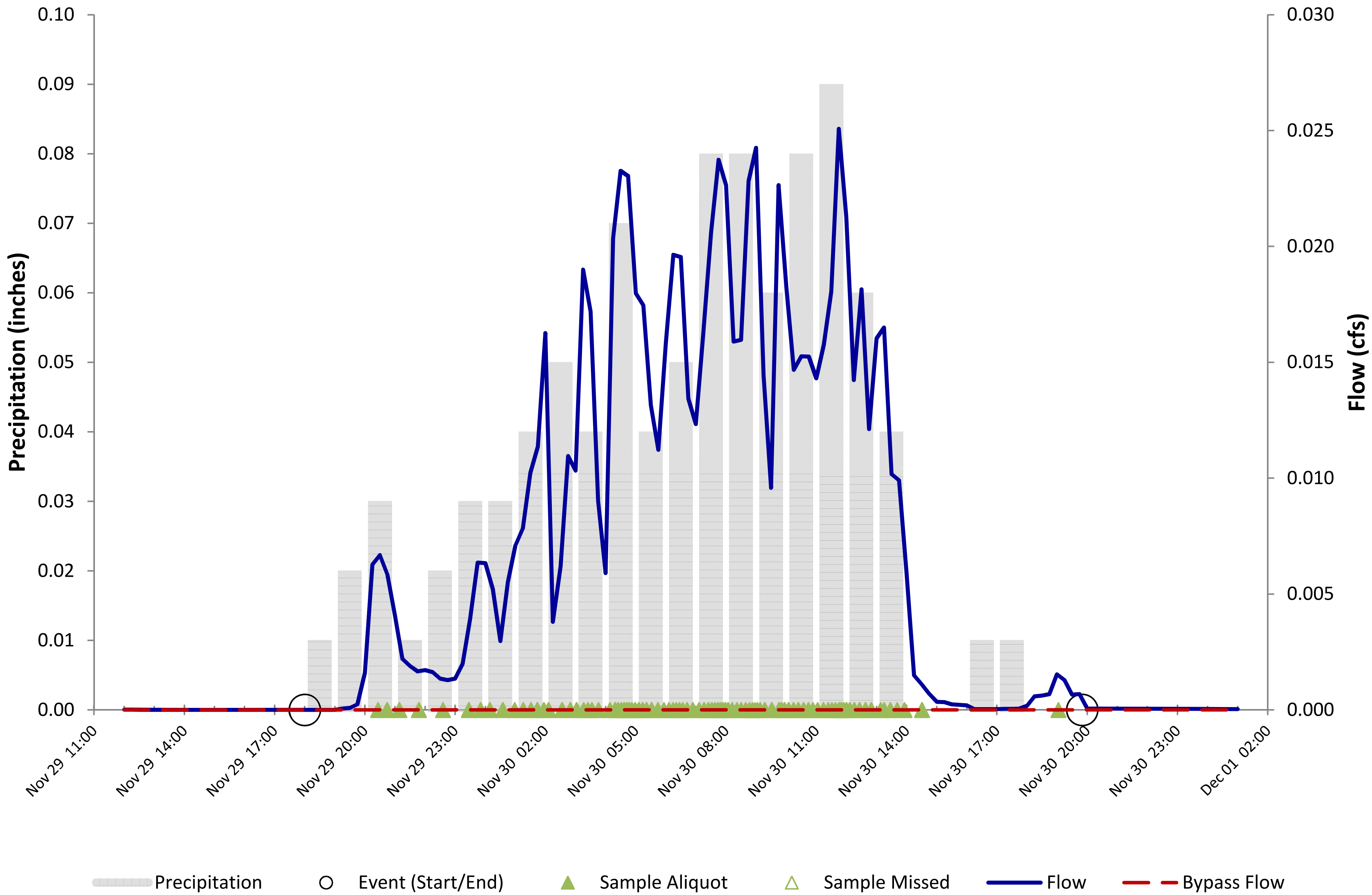
Catch Basin StormFilter Effectiveness
CBSF1 Storm Event Hydrograph
SE-11: June 01-02, 2010
Precipitation (inches)
Flow (cfs)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.030
0.025
0.020
0.015
0.010
0.005
0.000
Jun 01 15:00
Jun 01 17:00
Jun 01 19:00
Jun 01 21:00
Jun 01 23:00
Jun 02 01:00
Jun 02 03:00
Jun 02 05:00
Jun 02 07:00
Jun 02 09:00
Jun 02 11:00
Jun 02 13:00
Jun 02 15:00
Jun 02 17:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow

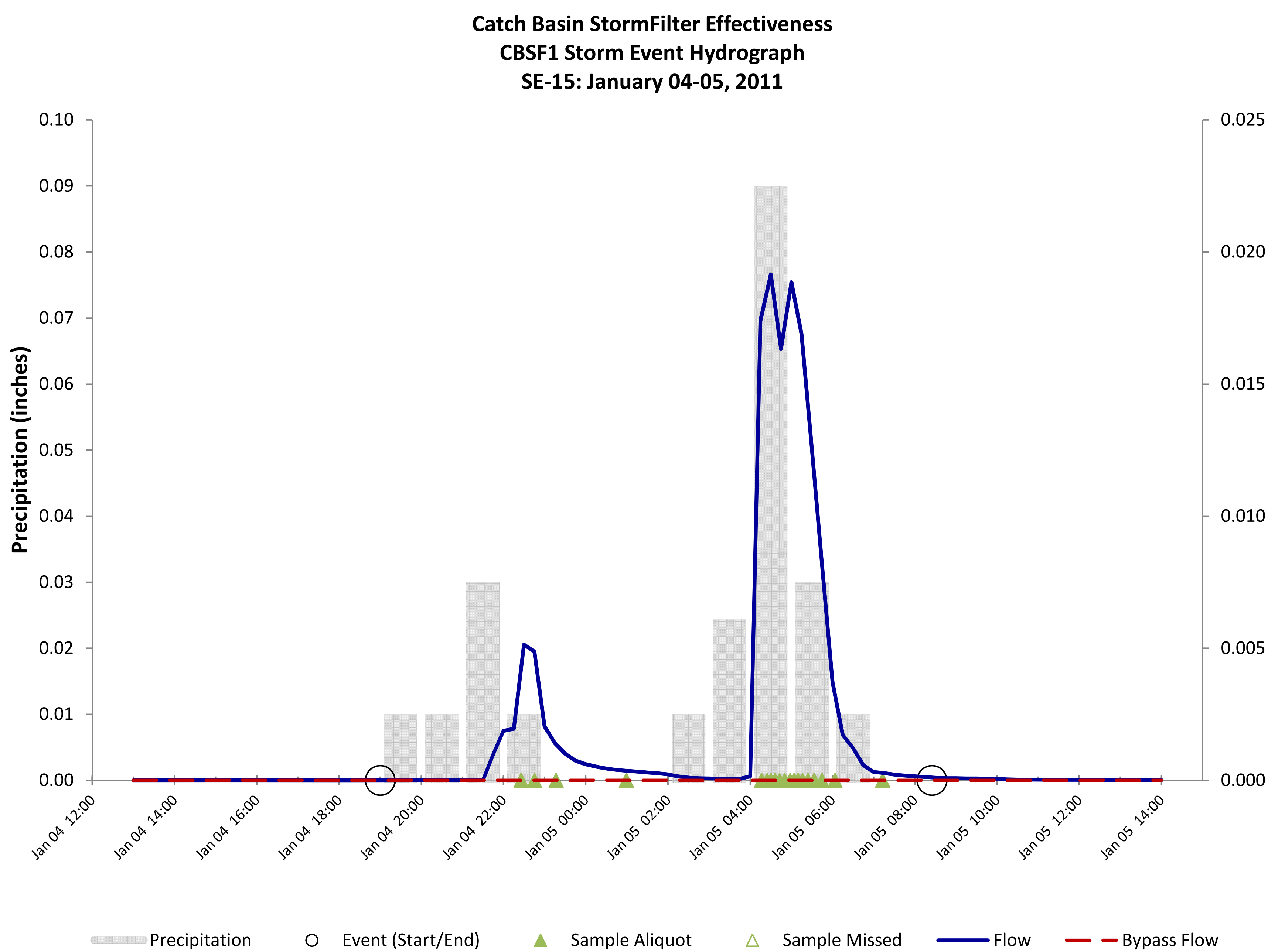


Catch Basin StormFilter Effectiveness
CBSF1 Storm Event Hydrograph
SE-12: June 08-09, 2010
Precipitation (inches)
Flow (cfs)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Jun 08 14:00
Jun 08 16:00
Jun 08 18:00
Jun 08 20:00
Jun 08 22:00
Jun 09 00:00
Jun 09 02:00
Jun 09 04:00
Jun 09 06:00
Jun 09 08:00
Jun 09 10:00
Jun 09 12:00
Jun 09 14:00
Jun 09 16:00
Jun 09 18:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow

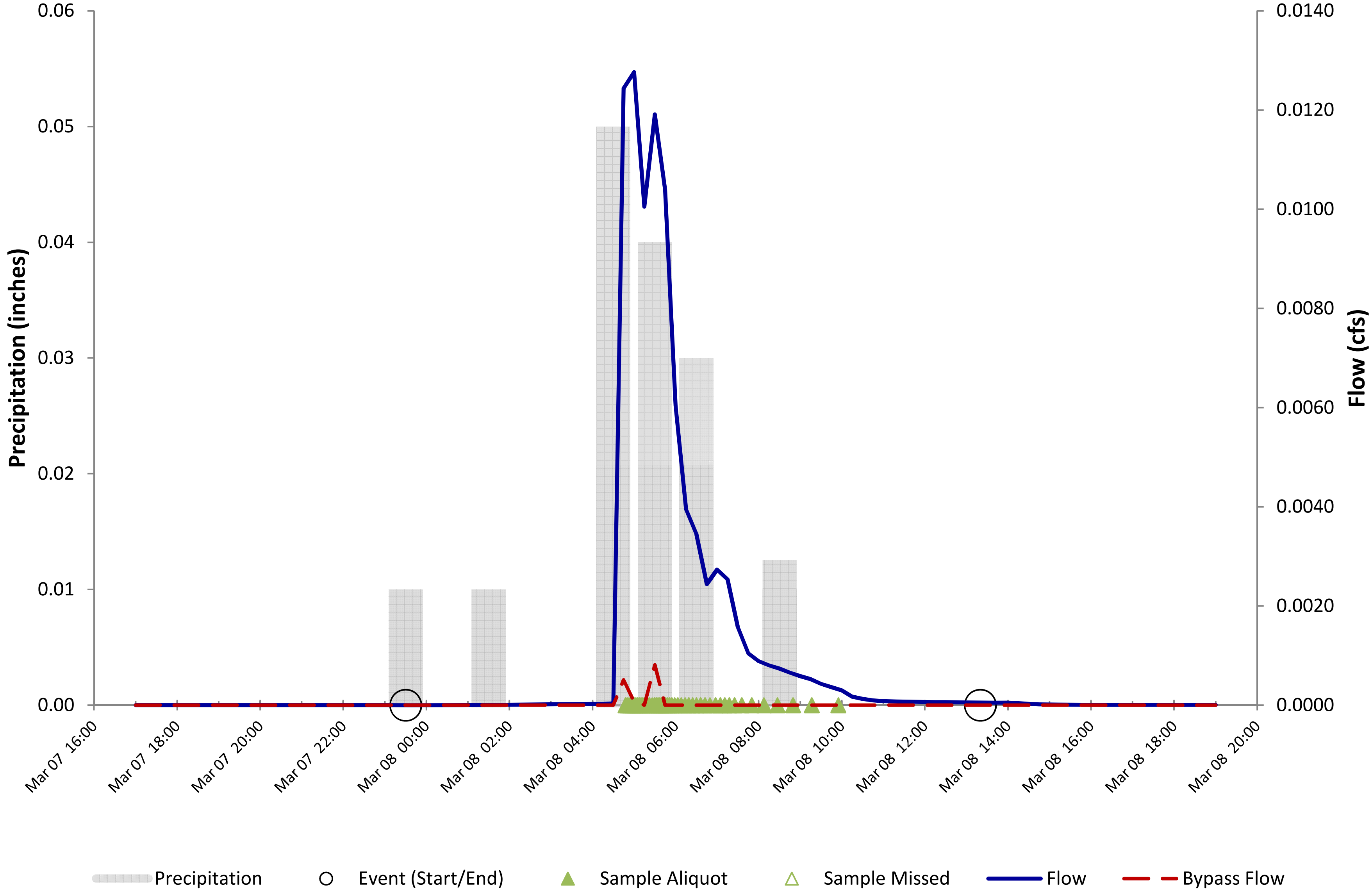

Catch Basin StormFilter Effectiveness
CBSF1 Storm Event Hydrograph
SE-13: October 26, 2010
Precipitation (inches)
Flow (cfs)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.025
0.020
0.015
0.010
0.005
0.000
Oct 26 03:00
Oct 26 05:00
Oct 26 07:00
Oct 26 09:00
Oct 26 11:00
Oct 26 13:00
Oct 26 15:00
Oct 26 17:00
Oct 26 19:00
Oct 26 21:00
Oct 26 23:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow

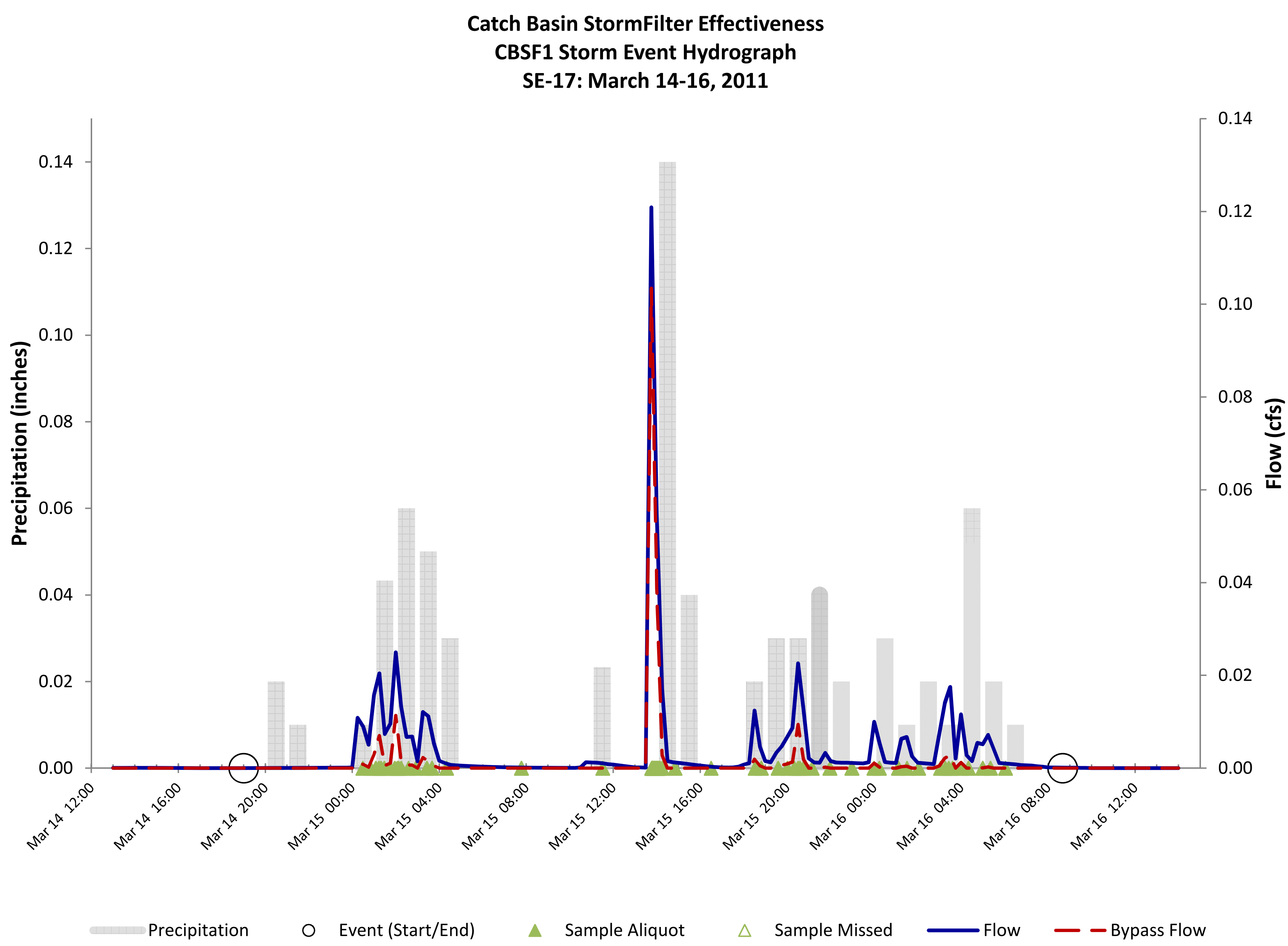
Catch Basin StormFilter Effectiveness
CBSF1 Storm Event Hydrograph
SE-14: November 29-30, 2010

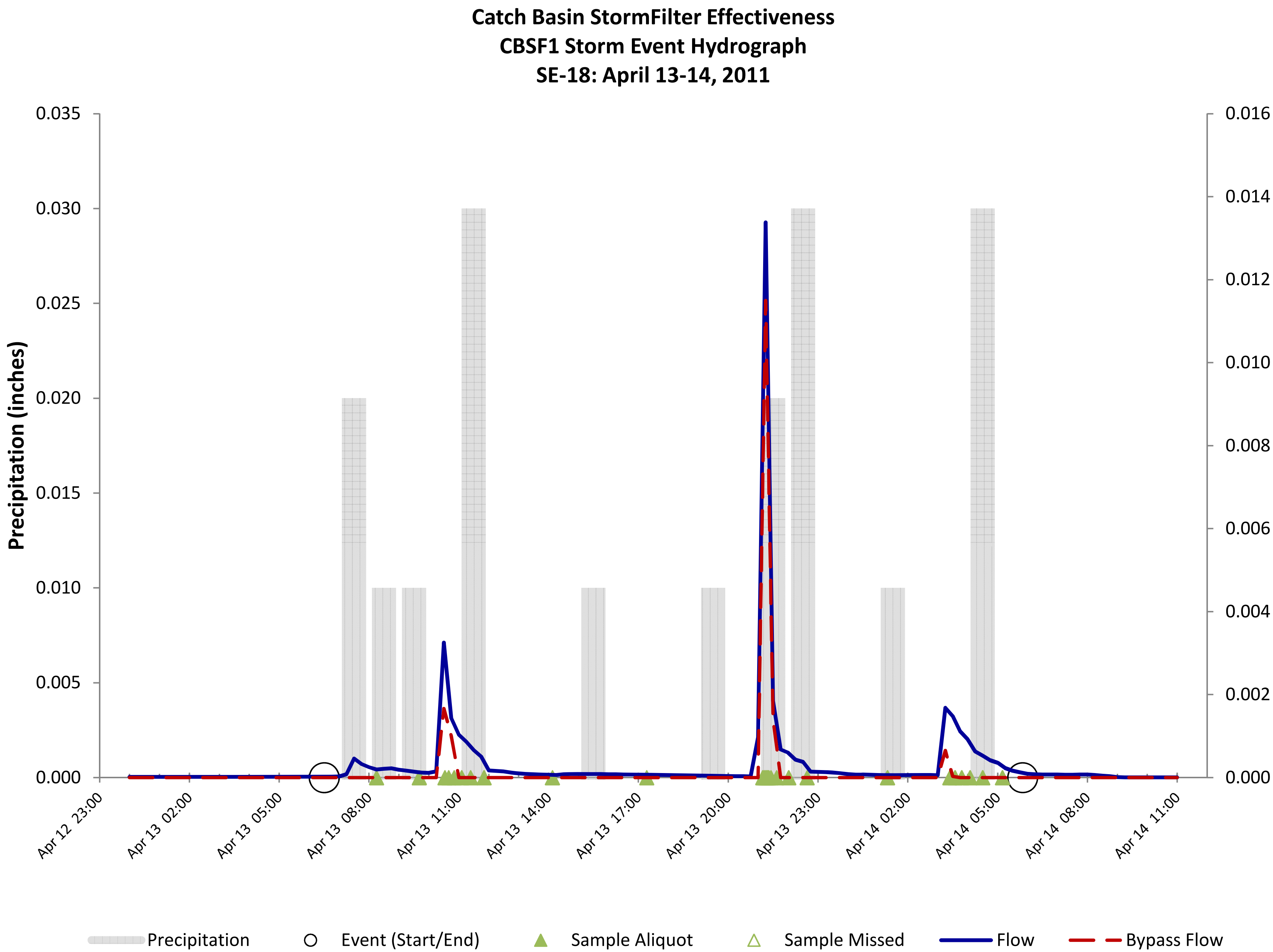


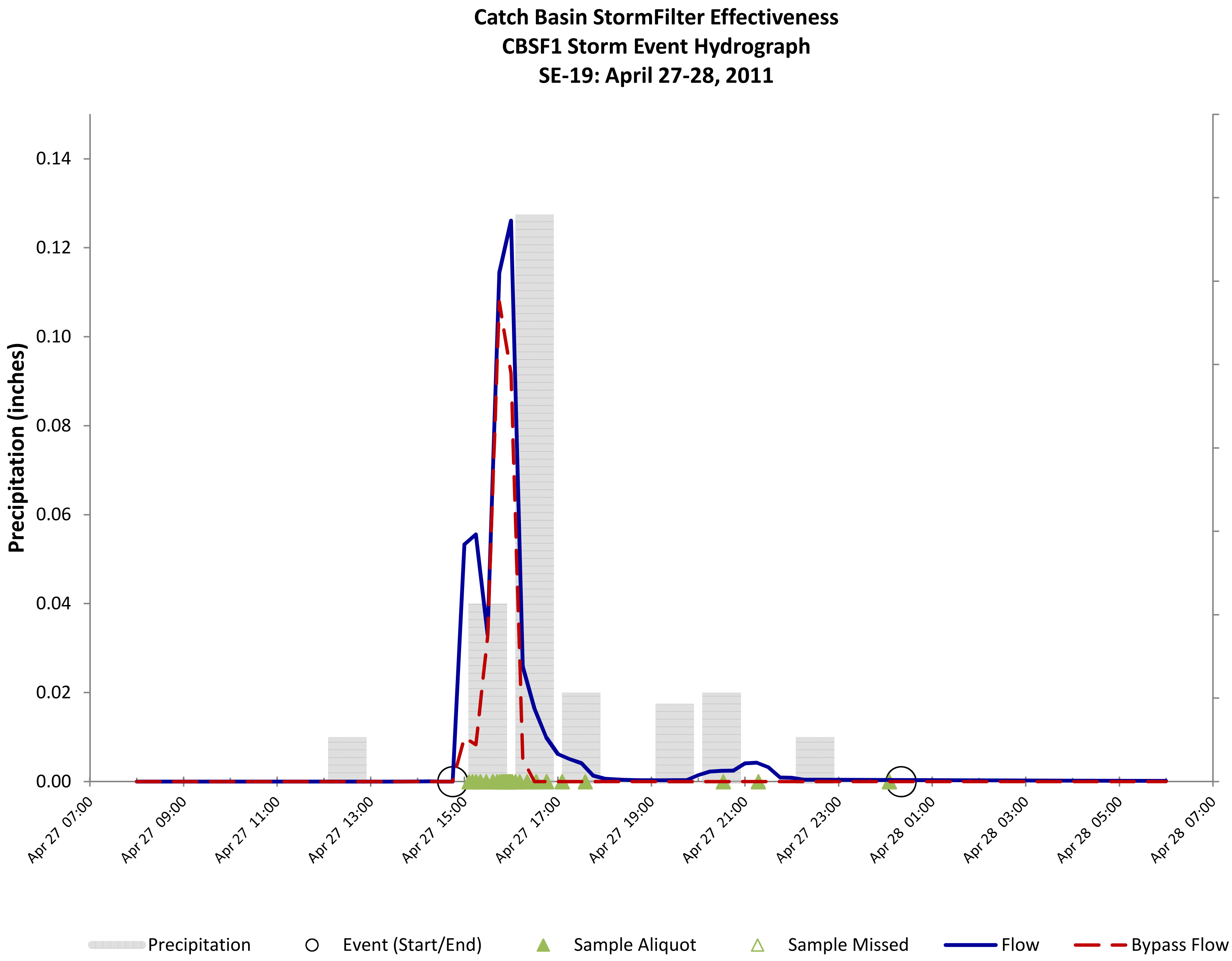

Catch Basin StormFilter Effectiveness
CBSF1 Storm Event Hydrograph
SE-15: January 04-05, 2011
Precipitation (inches)
Flow (cfs)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.025
0.020
0.015
0.010
0.005
0.000
Jan 04 12:00
Jan 04 14:00
Jan 04 16:00
Jan 04 18:00
Jan 04 20:00
Jan 04 22:00
Jan 05 00:00
Jan 05 02:00
Jan 05 04:00
Jan 05 06:00
Jan 05 08:00
Jan 05 10:00
Jan 05 12:00
Jan 05 14:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow

Catch Basin StormFilter Effectiveness
CBSF1 Storm Event Hydrograph
SE-16: March 07-08, 2011

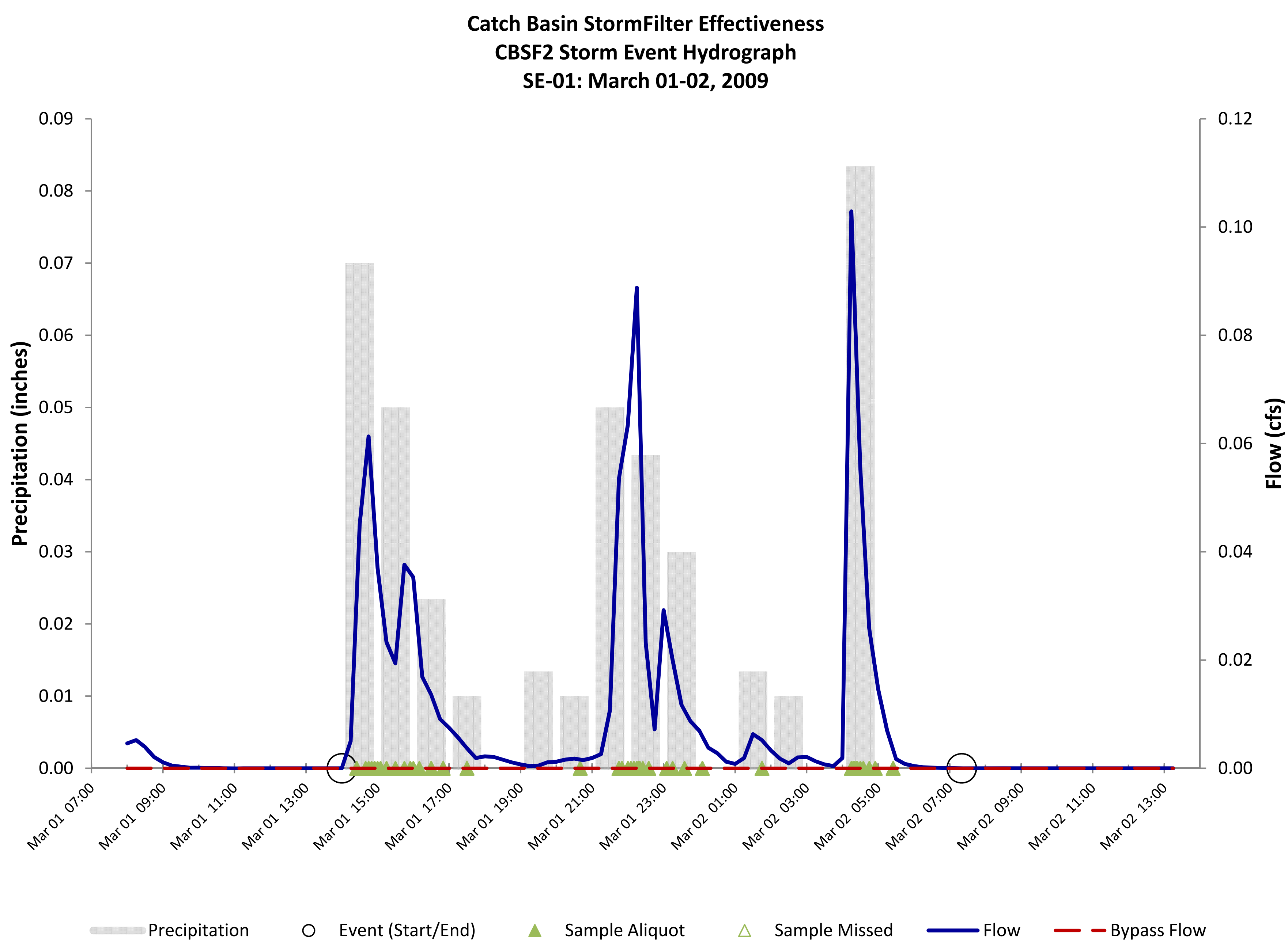



Catch Basin StormFilter Effectiveness
CBSF1 Storm Event Hydrograph
SE-17: March 14-16, 2011
Precipitation (inches)
Flow (cfs)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Mar 14 12:00
Mar 14 16:00
Mar 14 20:00
Mar 15 00:00
Mar 15 04:00
Mar 15 08:00
Mar 15 12:00
Mar 15 16:00
Mar 15 20:00
Mar 16 00:00
Mar 16 04:00
Mar 16 08:00
Mar 16 12:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow

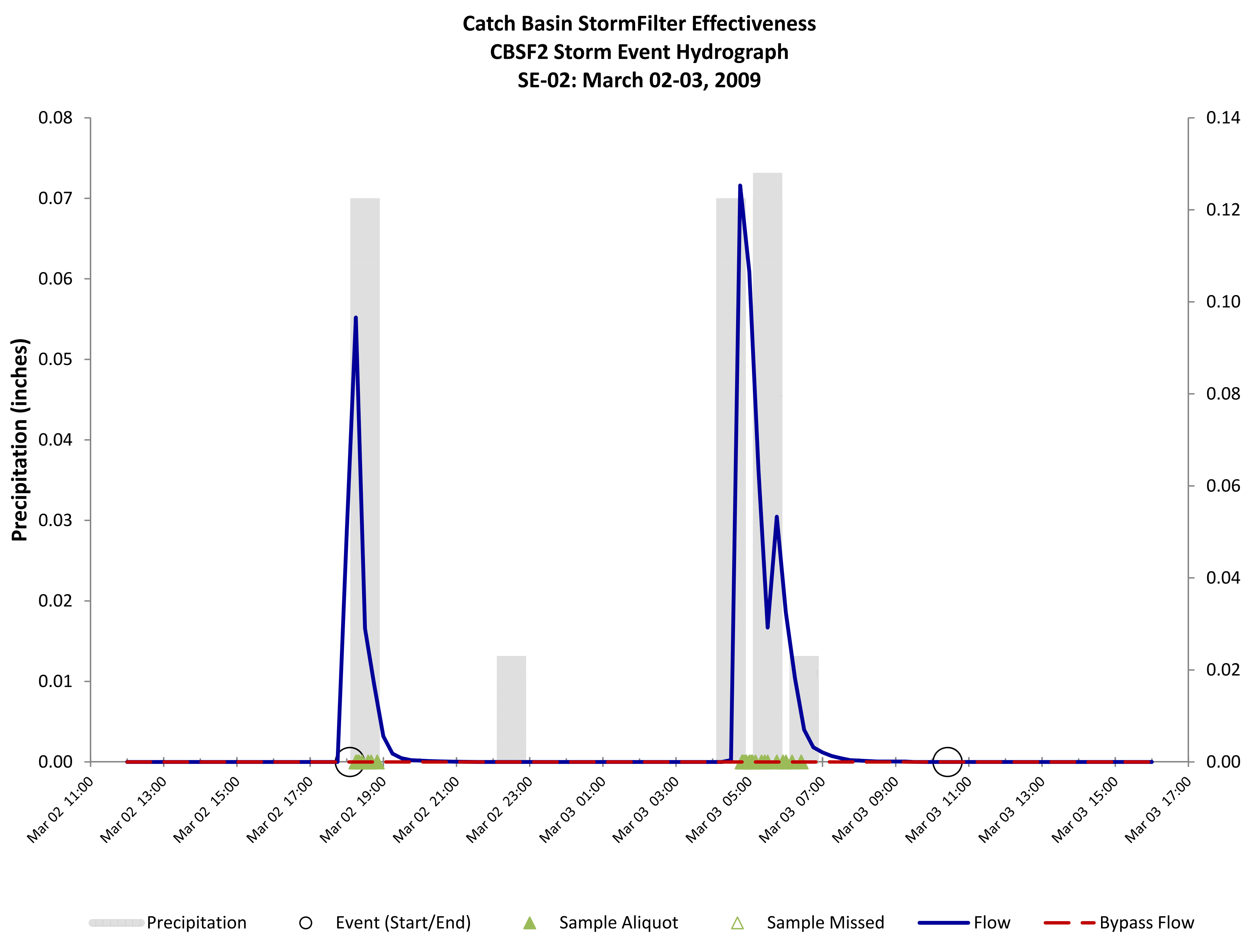

Catch Basin StormFilter Effectiveness
CBSF1 Storm Event Hydrograph
SE-18: April 13-14, 2011
Precipitation (inches)
Flow (cfs)
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Apr 12 23:00
Apr 13 02:00
Apr 13 05:00
Apr 13 08:00
Apr 13 11:00
Apr 13 14:00
Apr 13 17:00
Apr 13 20:00
Apr 13 23:00
Apr 14 02:00
Apr 14 05:00
Apr 14 08:00
Apr 14 11:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow



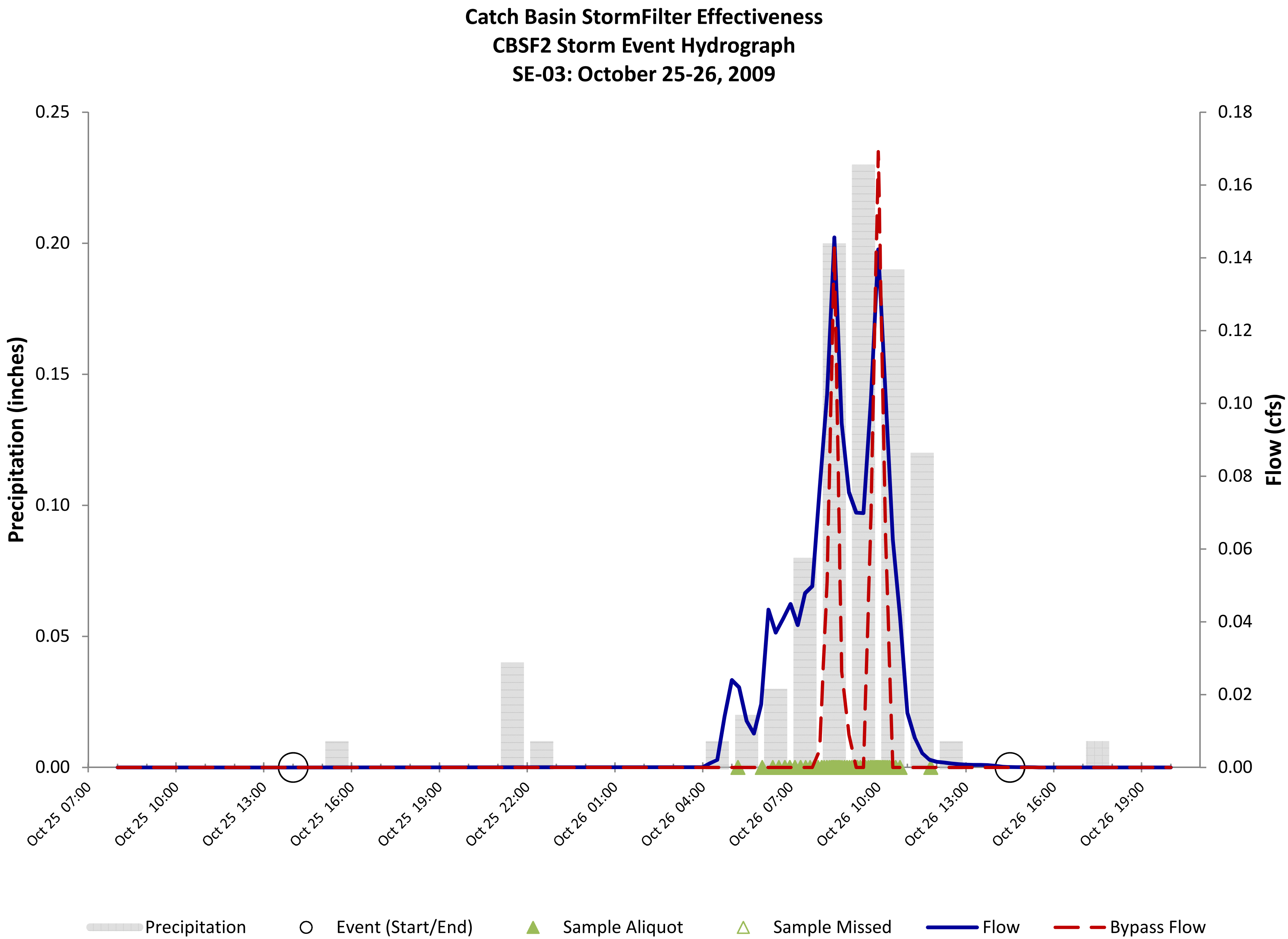
Catch Basin StormFilter Effectiveness
CBSF1 Storm Event Hydrograph
SE-19: April 27-28, 2011
Precipitation (inches)
Flow (cfs)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
Apr 27 07:00
Apr 27 09:00
Apr 27 11:00
Apr 27 13:00
Apr 27 15:00
Apr 27 17:00
Apr 27 19:00
Apr 27 21:00
Apr 27 23:00
Apr 28 01:00
Apr 28 03:00
Apr 28 05:00
Apr 28 07:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow



Catch Basin StormFilter Effectiveness
CBSF2 Storm Event Hydrograph
SE-01: March 01-02, 2009
Precipitation (inches)
Flow (cfs)
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Mar 01 07:00
Mar 01 09:00
Mar 01 11:00
Mar 01 13:00
Mar 01 15:00
Mar 01 17:00
Mar 01 19:00
Mar 01 21:00
Mar 01 23:00
Mar 02 01:00
Mar 02 03:00
Mar 02 05:00
Mar 02 07:00
Mar 02 09:00
Mar 02 11:00
Mar 02 13:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow

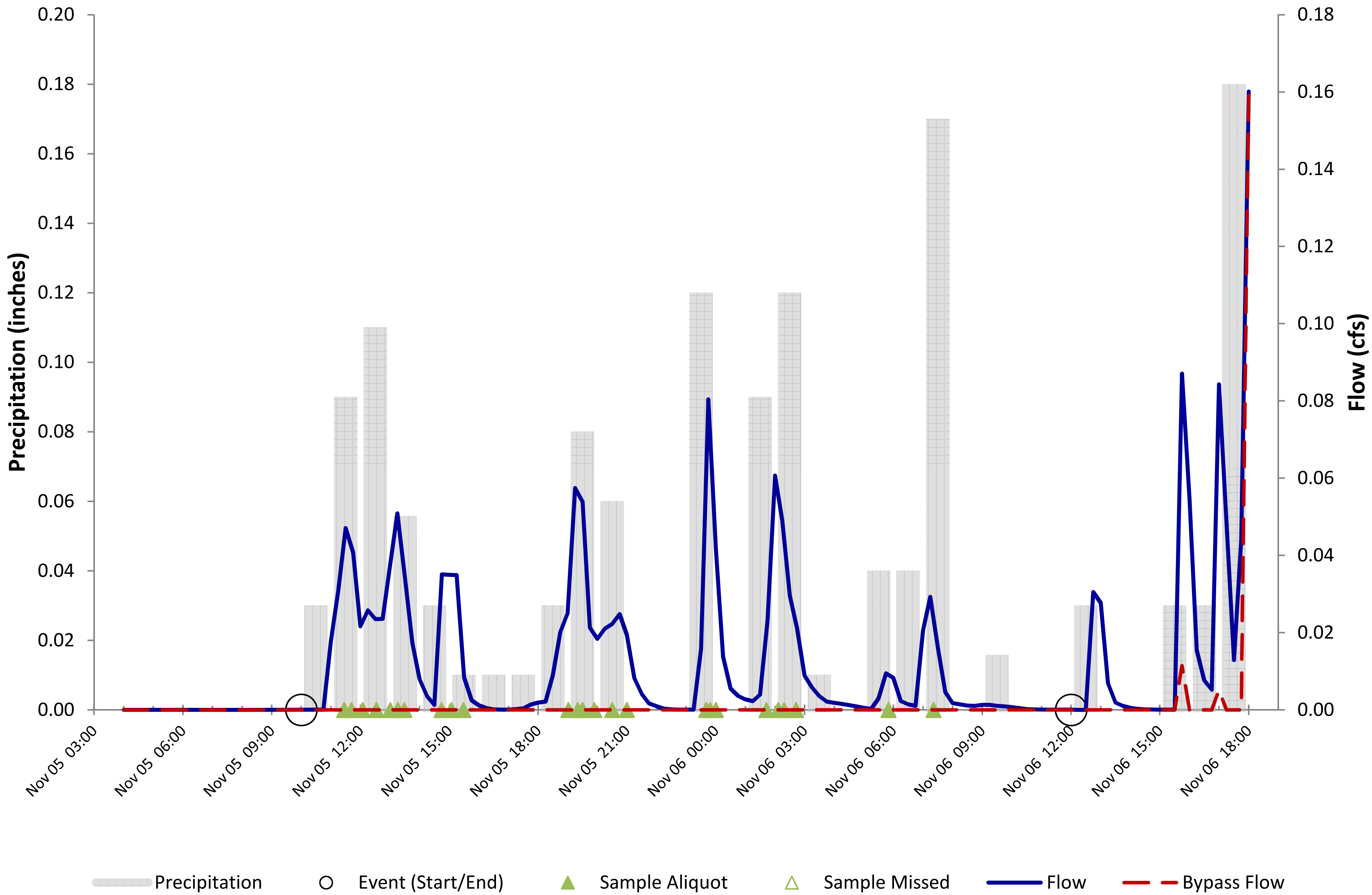


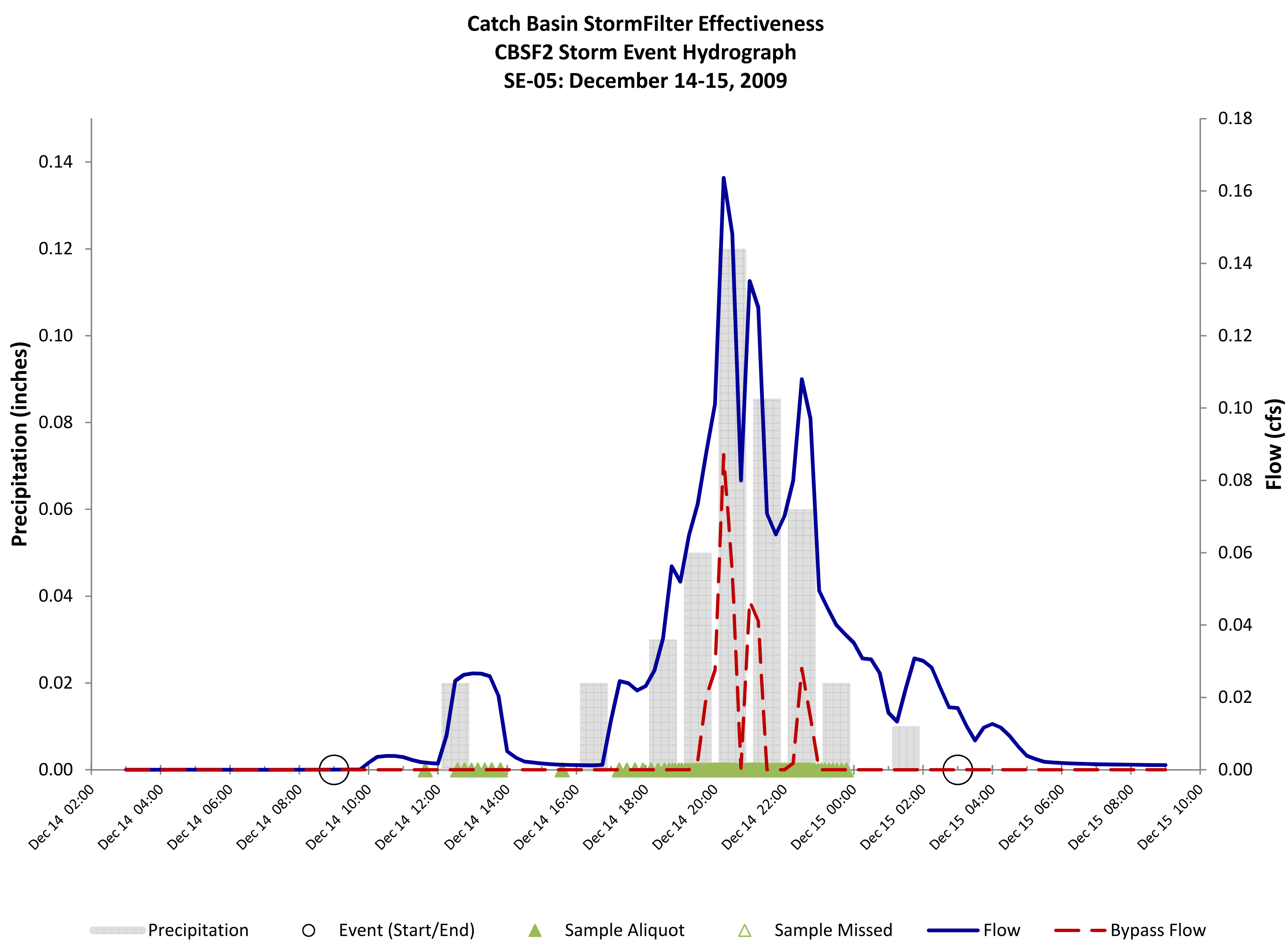
Catch Basin StormFilter Effectiveness
CBSF2 Storm Event Hydrograph
SE-02: March 02-03, 2009
Precipitation (inches)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Flow (cfs)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Mar 02 11:00
Mar 02 13:00
Mar 02 15:00
Mar 02 17:00
Mar 02 19:00
Mar 02 21:00
Mar 02 23:00
Mar 03 01:00
Mar 03 03:00
Mar 03 05:00
Mar 03 07:00
Mar 03 09:00
Mar 03 11:00
Mar 03 13:00
Mar 03 15:00
Mar 03 17:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow



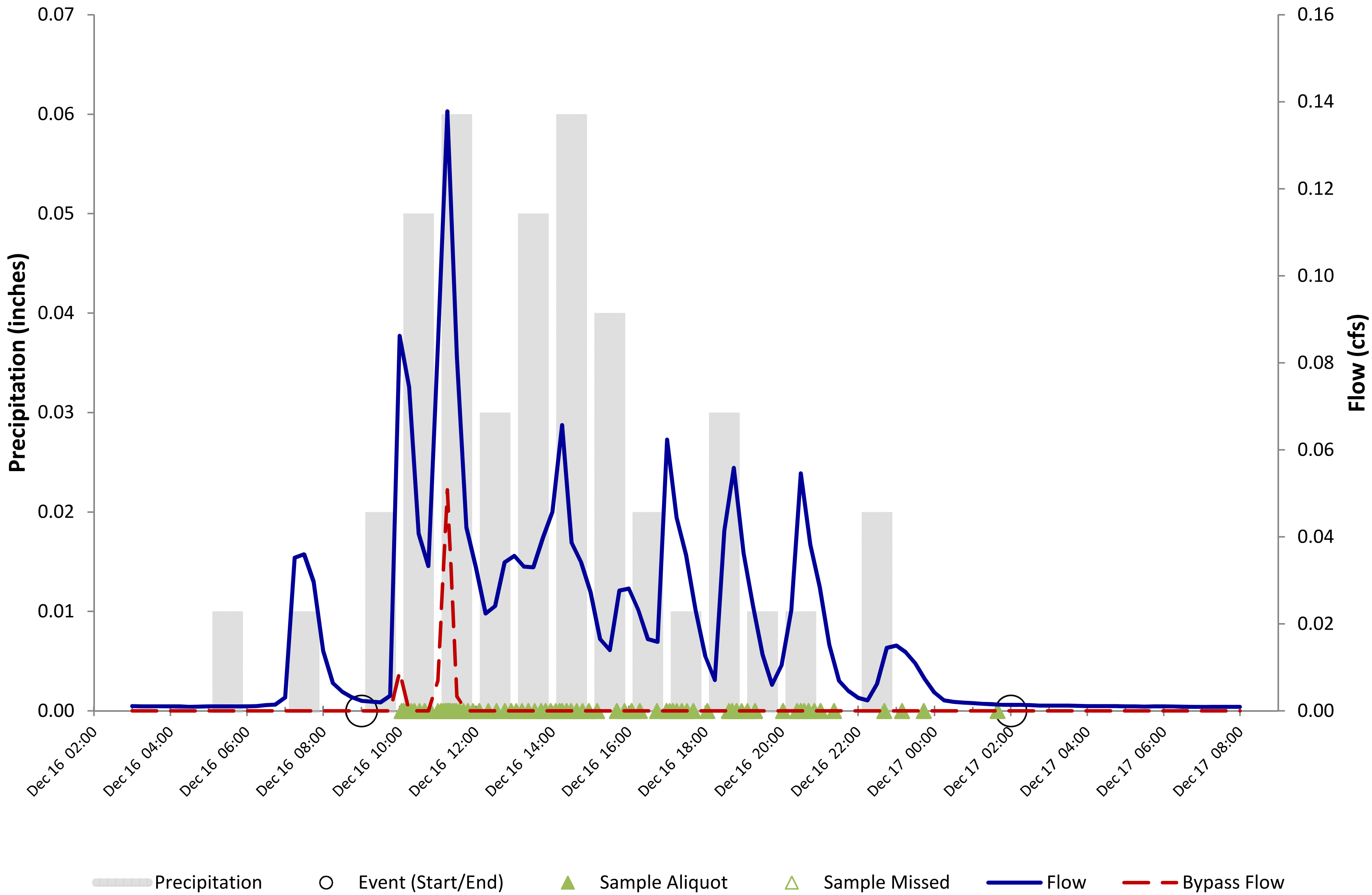
Catch Basin StormFilter Effectiveness
CBSF2 Storm Event Hydrograph
SE-03: October 25-26, 2009
Precipitation (inches)
Flow (cfs)
0.25
0.20
0.15
0.10
0.05
0.00
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Oct 25 07:00
Oct 25 10:00
Oct 25 13:00
Oct 25 16:00
Oct 25 19:00
Oct 25 22:00
Oct 26 01:00
Oct 26 04:00
Oct 26 07:00
Oct 26 10:00
Oct 26 13:00
Oct 26 16:00
Oct 26 19:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow

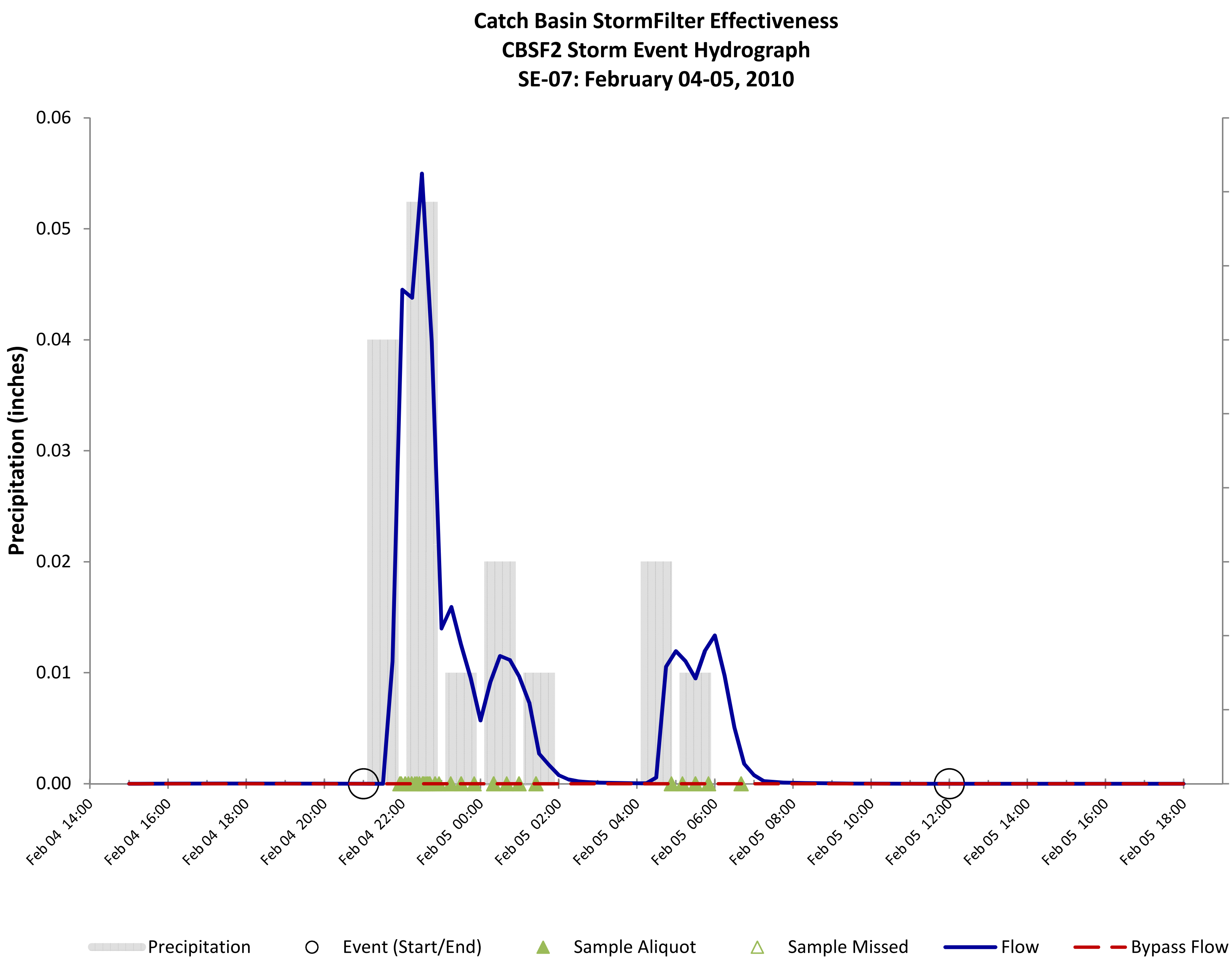
Catch Basin StormFilter Effectiveness
CBSF2 Storm Event Hydrograph
SE-04: November 05-06, 2009



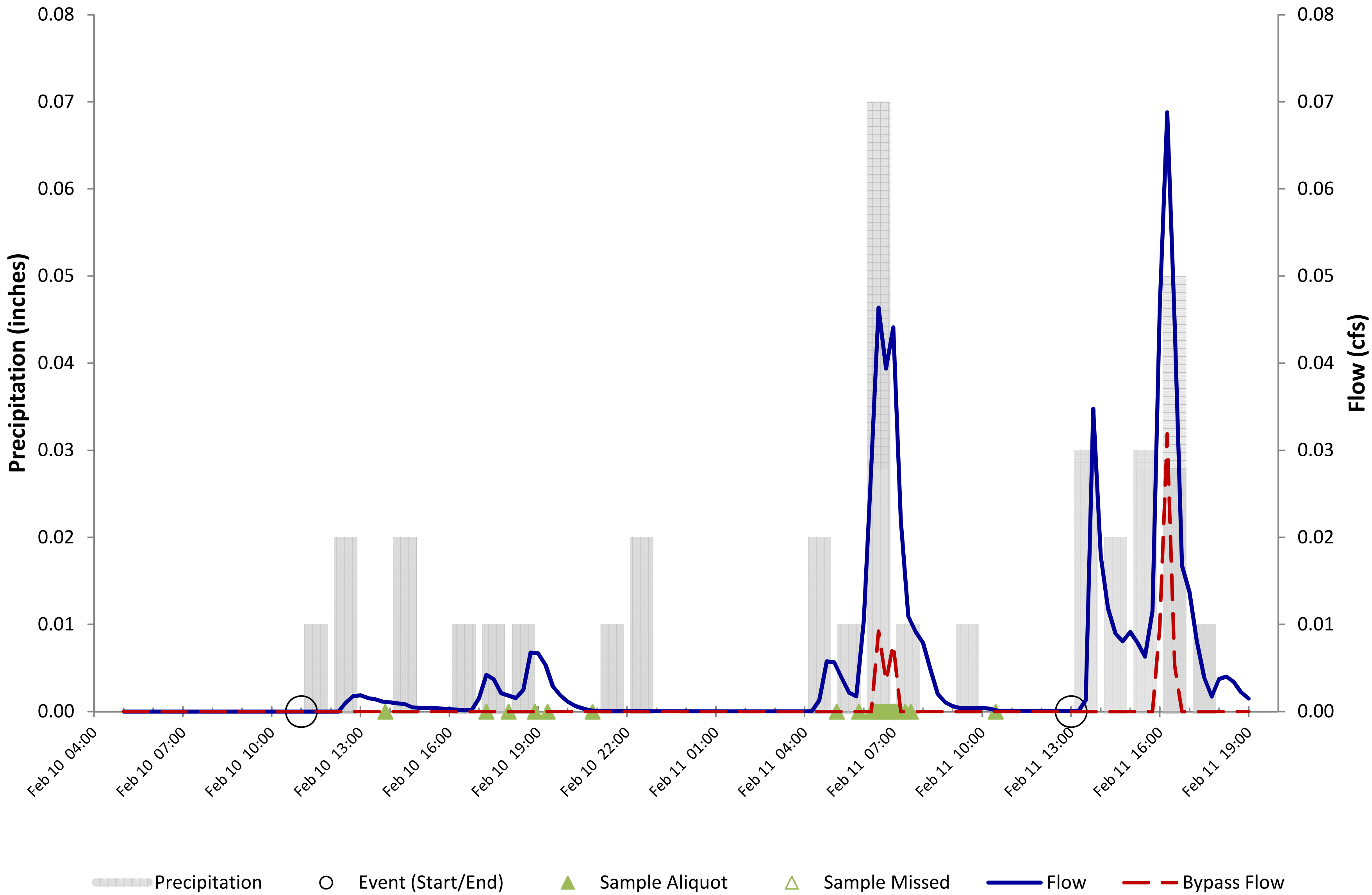

Catch Basin StormFilter Effectiveness
CBSF2 Storm Event Hydrograph
SE-05: December 14-15, 2009
Precipitation (inches)
Flow (cfs)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Dec 14 02:00
Dec 14 04:00
Dec 14 06:00
Dec 14 08:00
Dec 14 10:00
Dec 14 12:00
Dec 14 14:00
Dec 14 16:00
Dec 14 18:00
Dec 14 20:00
Dec 14 22:00
Dec 15 00:00
Dec 15 02:00
Dec 15 04:00
Dec 15 06:00
Dec 15 08:00
Dec 15 10:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow

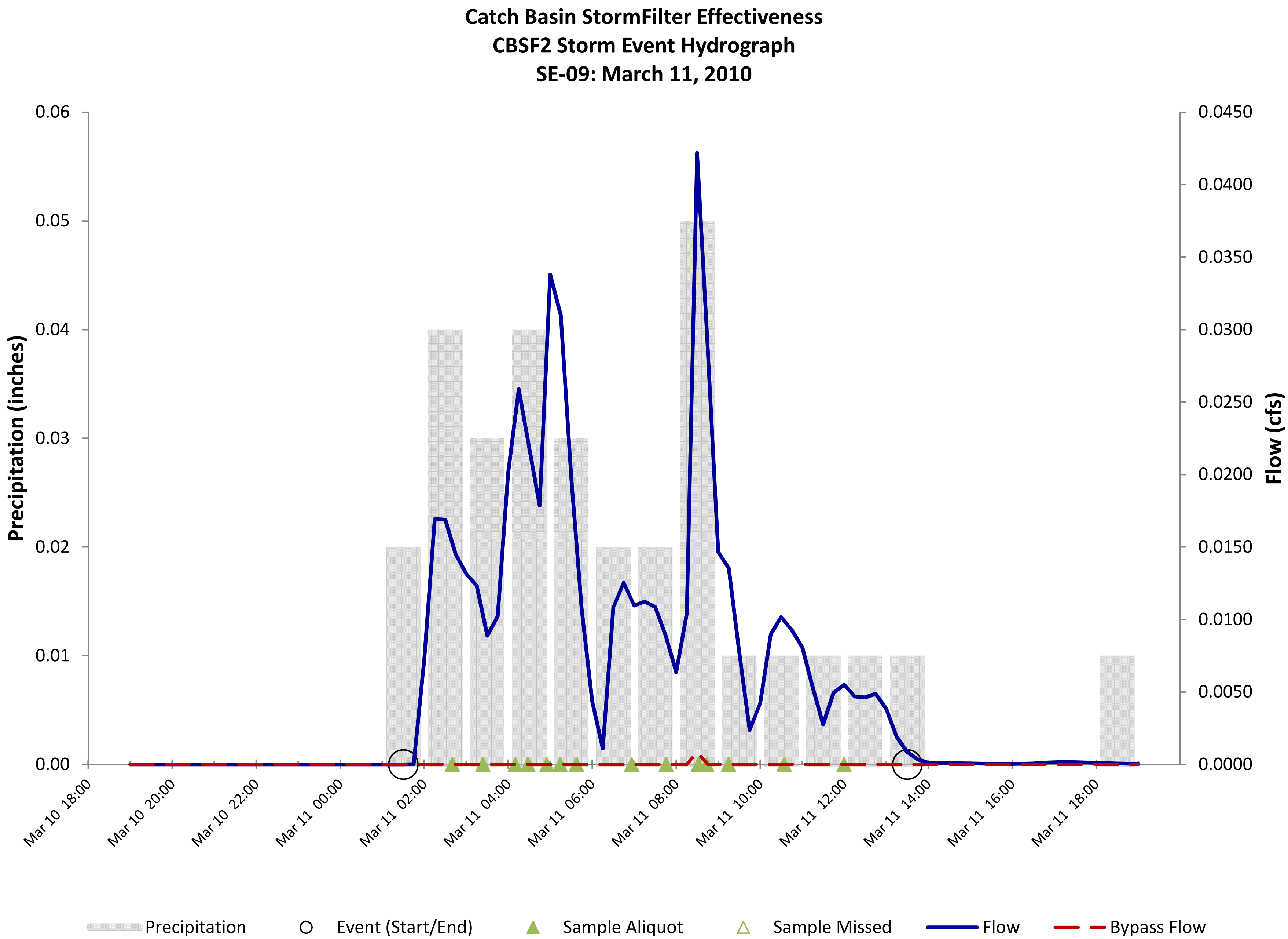
Catch Basin StormFilter Effectiveness
CBSF2 Storm Event Hydrograph
SE-06: December 16-17, 2009



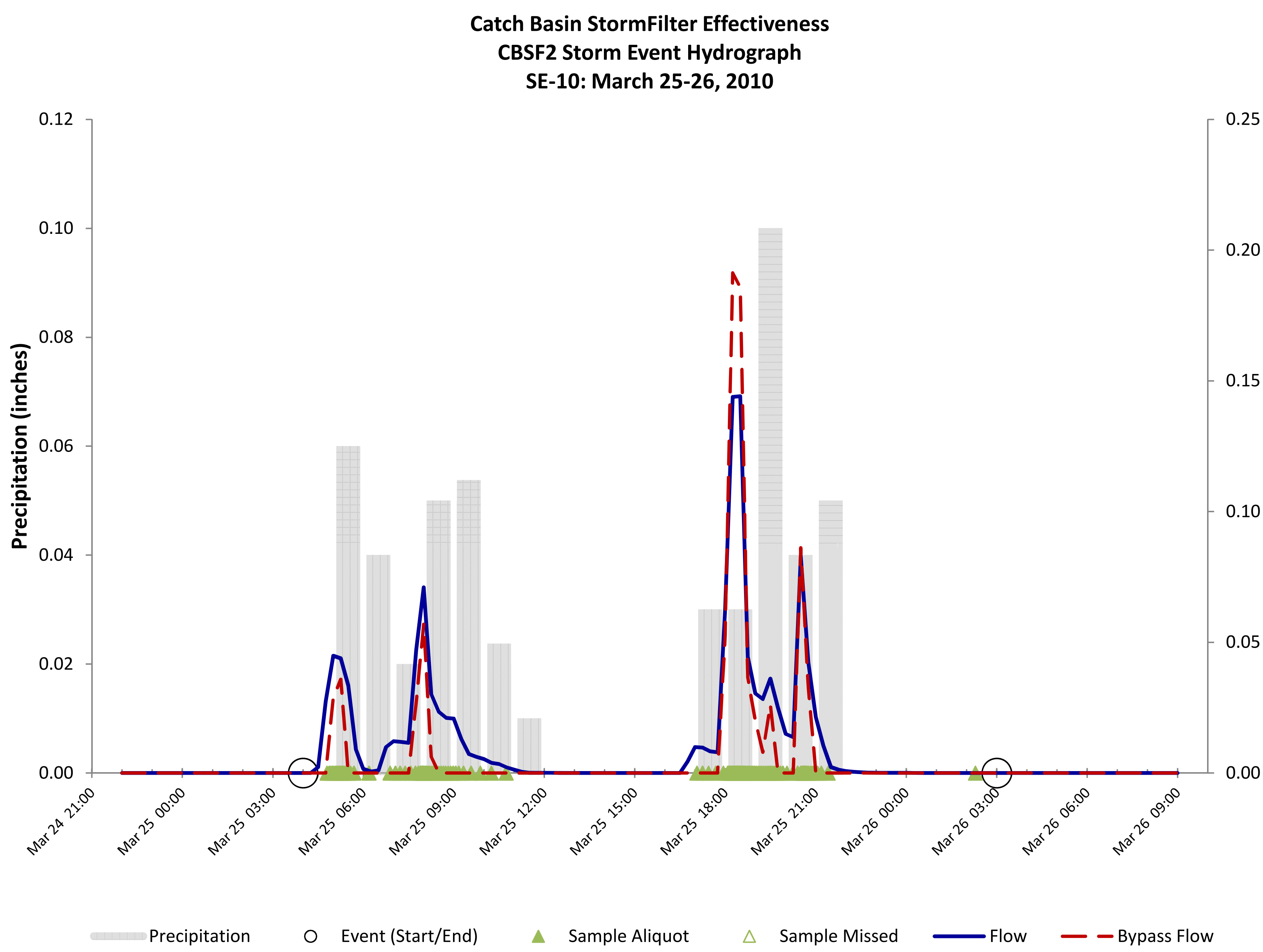

Catch Basin StormFilter Effectiveness
CBSF2 Storm Event Hydrograph
SE-07: February 04-05, 2010
Precipitation (inches)
Flow (cfs)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.05
0.04
0.04
0.03
0.03
0.02
0.02
0.01
0.01
0.00
Feb 04 14:00
Feb 04 16:00
Feb 04 18:00
Feb 04 20:00
Feb 04 22:00
Feb 05 00:00
Feb 05 02:00
Feb 05 04:00
Feb 05 06:00
Feb 05 08:00
Feb 05 10:00
Feb 05 12:00
Feb 05 14:00
Feb 05 16:00
Feb 05 18:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow

Catch Basin StormFilter Effectiveness
CBSF2 Storm Event Hydrograph
SE-08: February 10-11, 2010

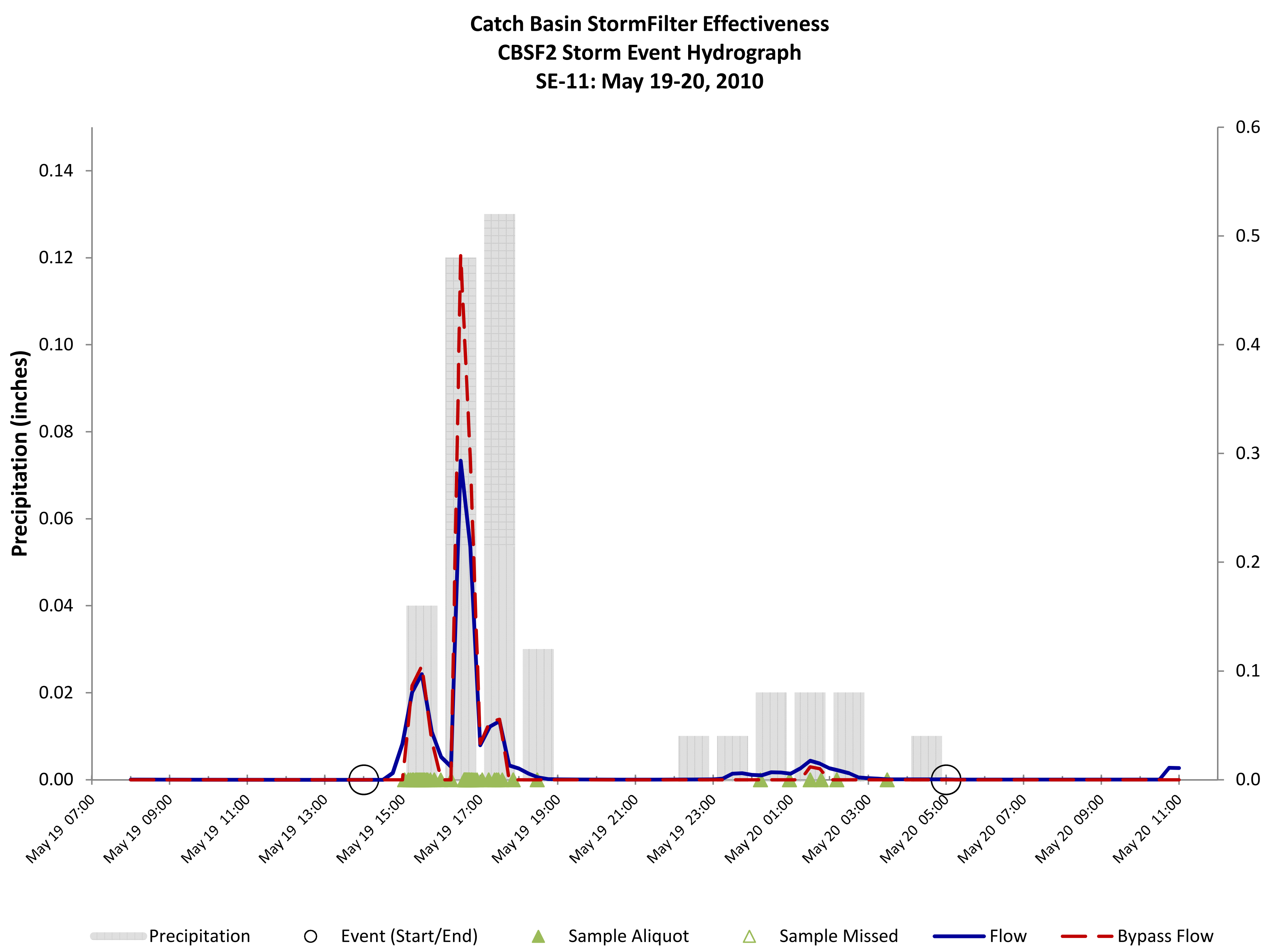


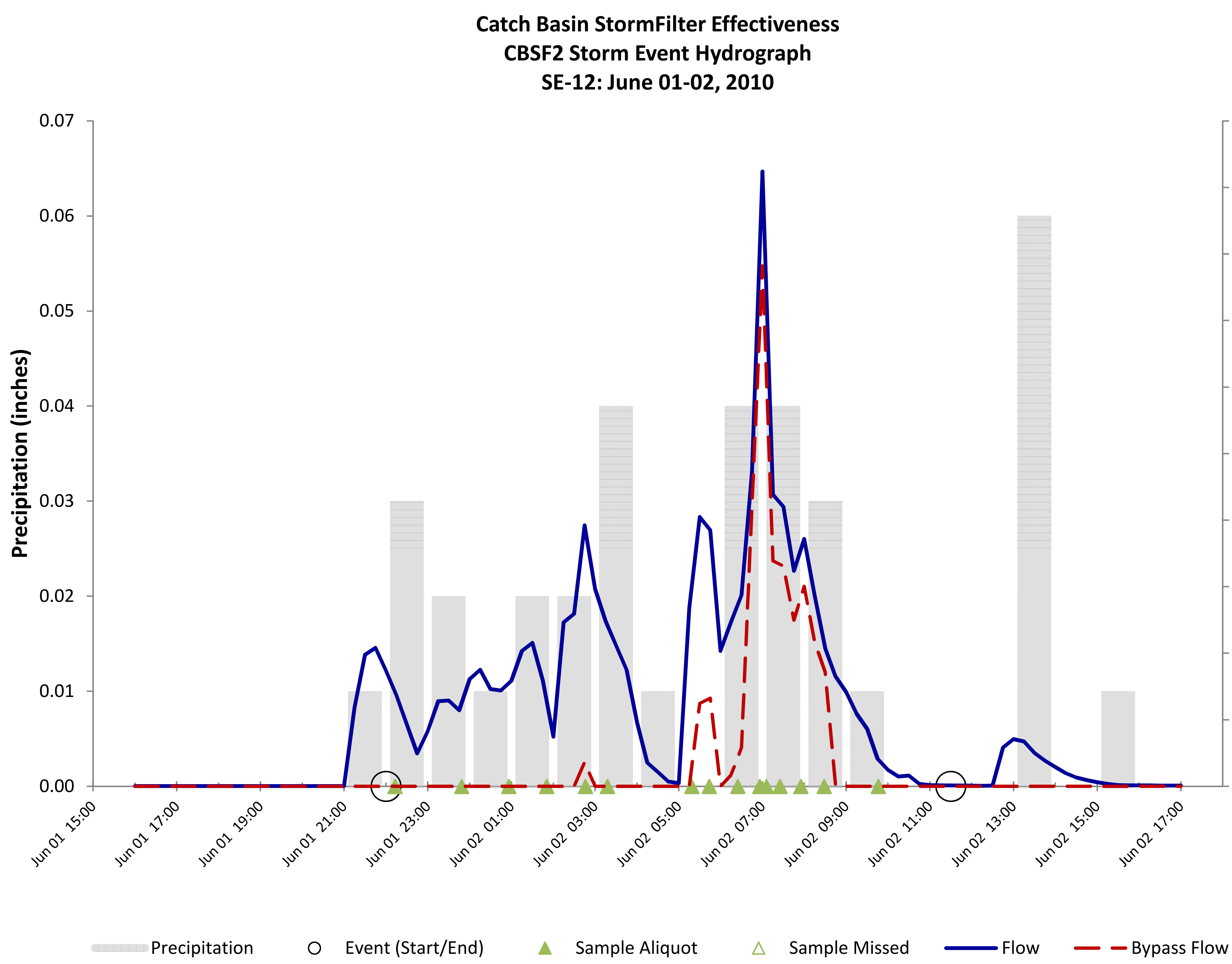


Catch Basin StormFilter Effectiveness
CBSF2 Storm Event Hydrograph
SE-09: March 11, 2010
Precipitation (inches)
Flow (cfs)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.0450
0.0400
0.0350
0.0300
0.0250
0.0200
0.0150
0.0100
0.0050
0.0000
Mar 10 18:00
Mar 10 20:00
Mar 10 22:00
Mar 11 00:00
Mar 11 02:00
Mar 11 04:00
Mar 11 06:00
Mar 11 08:00
Mar 11 10:00
Mar 11 12:00
Mar 11 14:00
Mar 11 16:00
Mar 11 18:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow

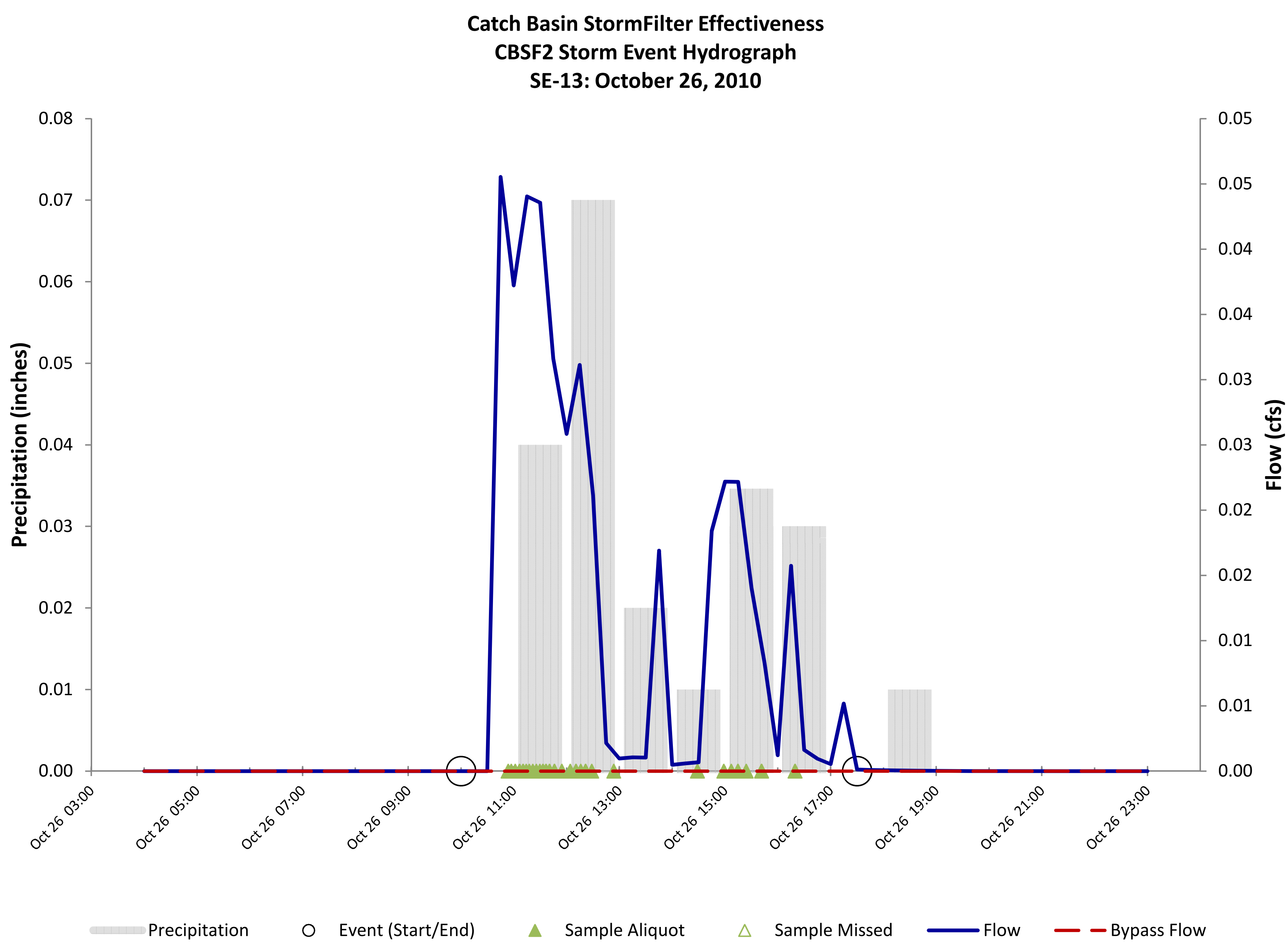


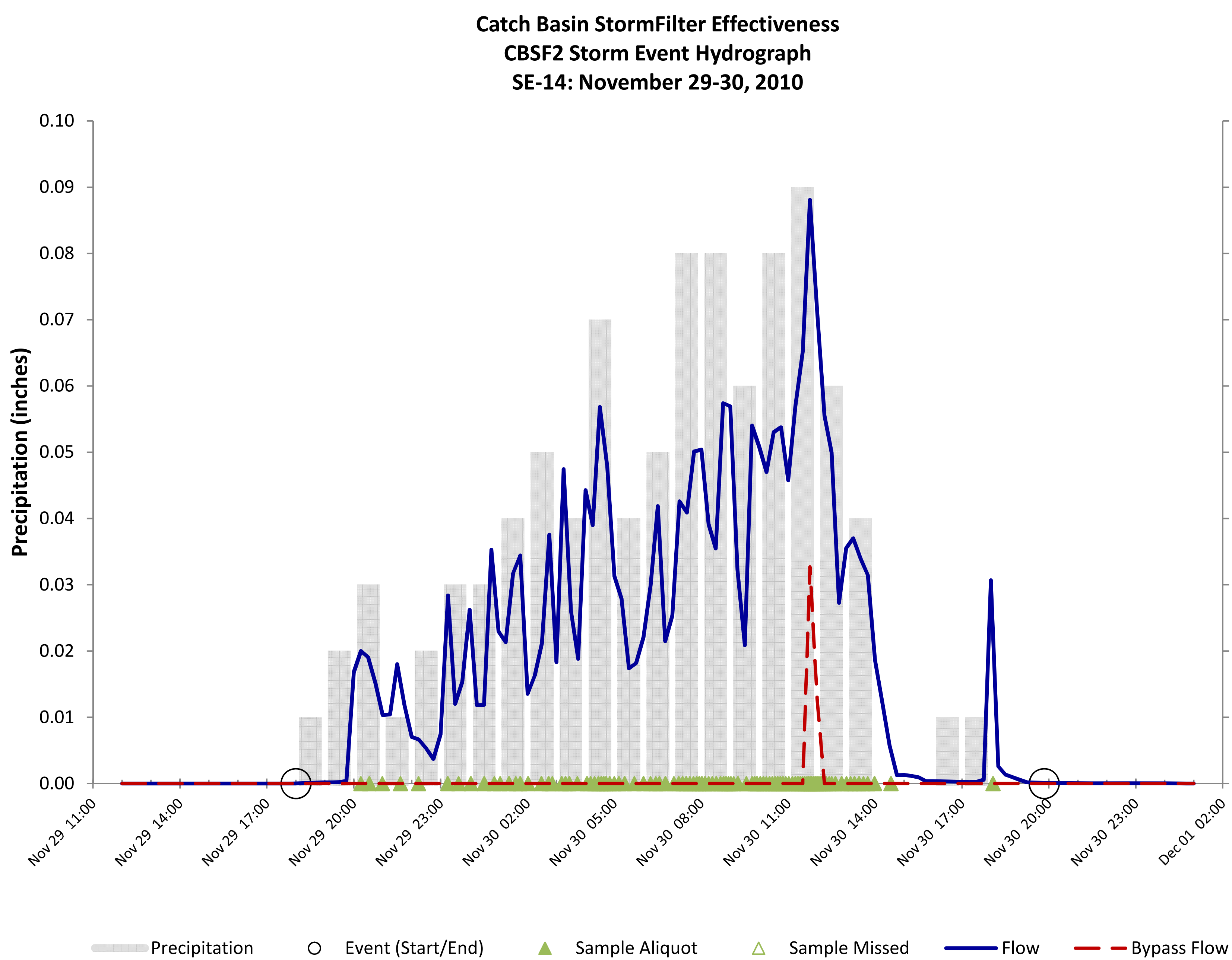
Catch Basin StormFilter Effectiveness
CBSF2 Storm Event Hydrograph
SE-10: March 25-26, 2010
Precipitation (inches)
Flow (cfs)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.25
0.20
0.15
0.10
0.05
0.00
Mar 24 21:00
Mar 25 00:00
Mar 25 03:00
Mar 25 06:00
Mar 25 09:00
Mar 25 12:00
Mar 25 15:00
Mar 25 18:00
Mar 25 21:00
Mar 26 00:00
Mar 26 03:00
Mar 26 06:00
Mar 26 09:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow


Catch Basin StormFilter Effectiveness
CBSF2 Storm Event Hydrograph
SE-11: May 19-20, 2010
Precipitation (inches)
Flow (cfs)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.6
0.5
0.4
0.3
0.2
0.1
0.0
May 19 07:00
May 19 09:00
May 19 11:00
May 19 13:00
May 19 15:00
May 19 17:00
May 19 19:00
May 19 21:00
May 19 23:00
May 20 01:00
May 20 03:00
May 20 05:00
May 20 07:00
May 20 09:00
May 20 11:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow

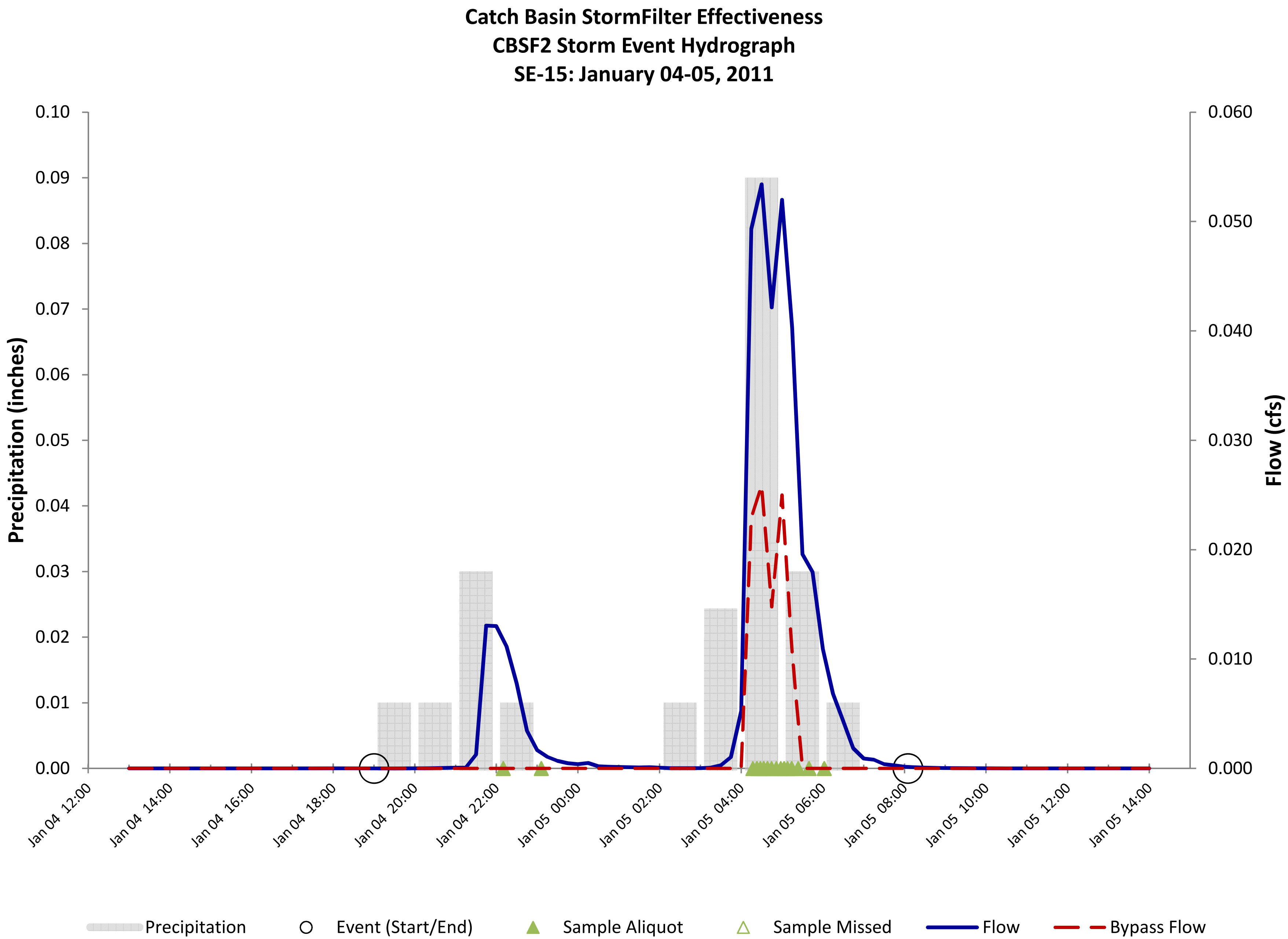


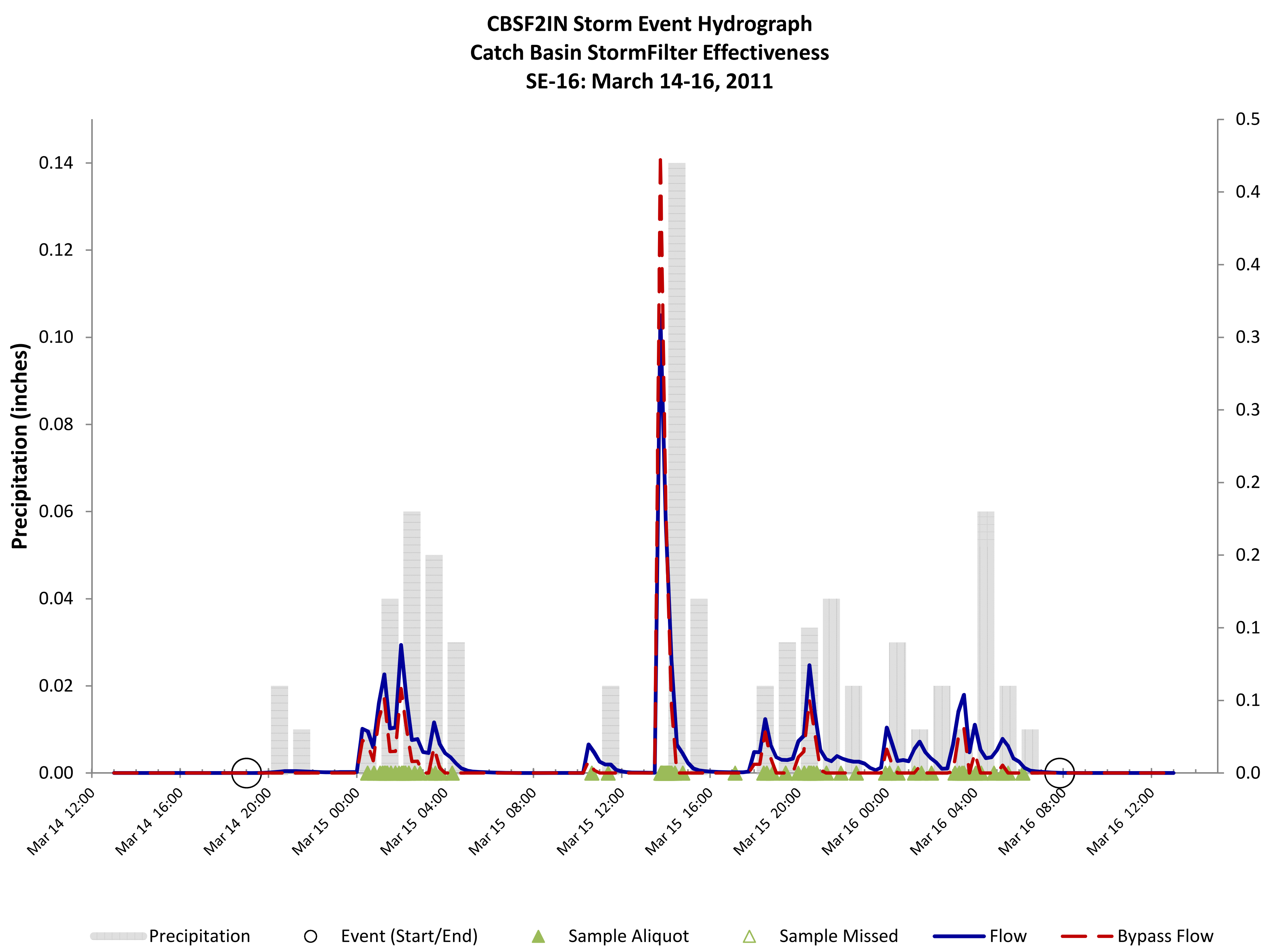
Catch Basin StormFilter Effectiveness
CBSF2 Storm Event Hydrograph
SE-12: June 01-02, 2010
Precipitation (inches)
Flow (cfs)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.05
0.05
0.04
0.04
0.03
0.03
0.02
0.02
0.01
0.01
0.00
Jun 01 15:00
Jun 01 17:00
Jun 01 19:00
Jun 01 21:00
Jun 01 23:00
Jun 02 01:00
Jun 02 03:00
Jun 02 05:00
Jun 02 07:00
Jun 02 09:00
Jun 02 11:00
Jun 02 13:00
Jun 02 15:00
Jun 02 17:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow


Catch Basin StormFilter Effectiveness
CBSF2 Storm Event Hydrograph
SE-13: October 26, 2010
Precipitation (inches)
Flow (cfs)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Oct 26 03:00
Oct 26 05:00
Oct 26 07:00
Oct 26 09:00
Oct 26 11:00
Oct 26 13:00
Oct 26 15:00
Oct 26 17:00
Oct 26 19:00
Oct 26 21:00
Oct 26 23:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow

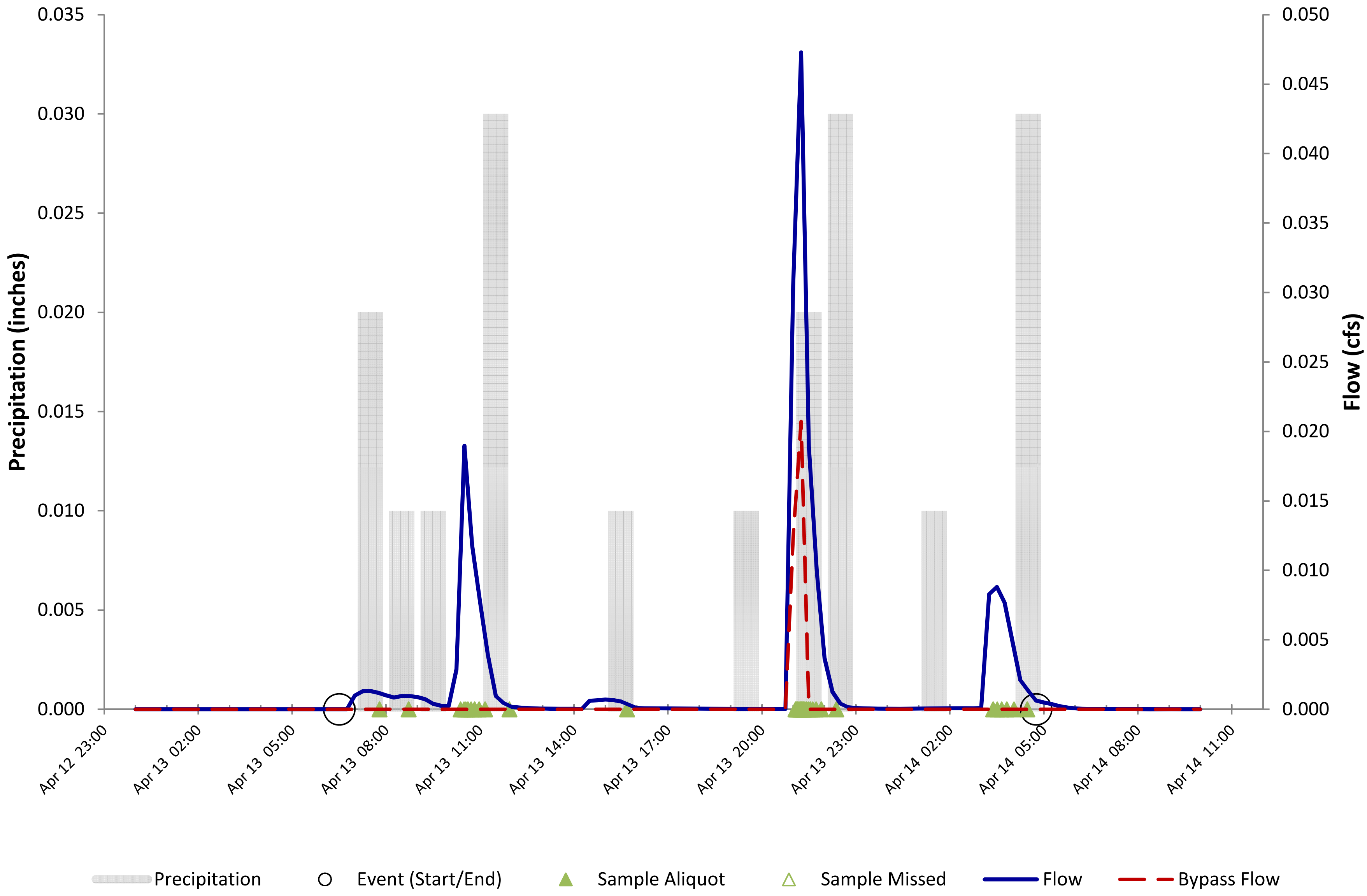


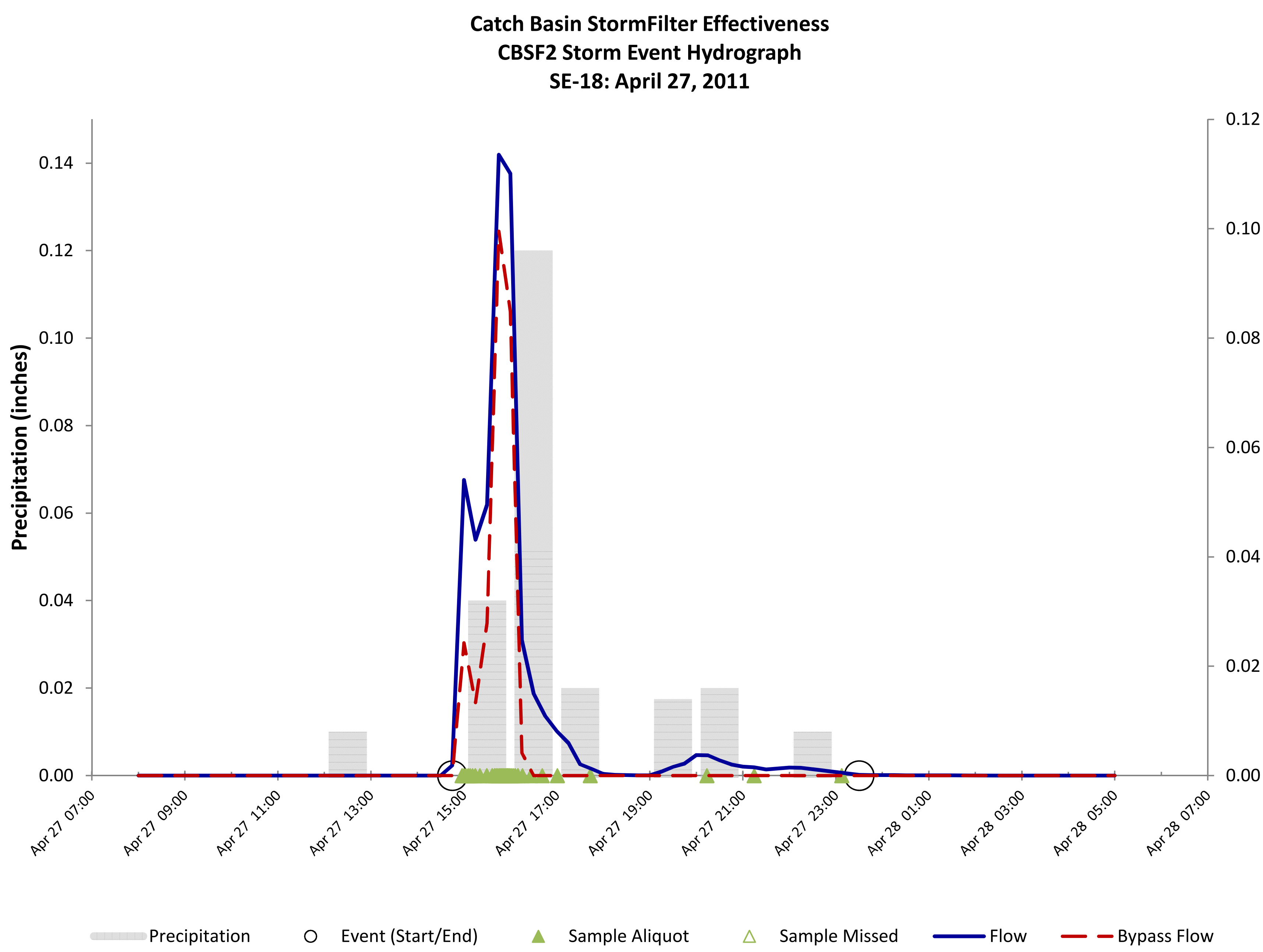
Catch Basin StormFilter Effectiveness
CBSF2 Storm Event Hydrograph
SE-14: November 29-30, 2010
Precipitation (inches)
Flow (cfs)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Nov 29 11:00
Nov 29 14:00
Nov 29 17:00
Nov 29 20:00
Nov 29 23:00
Nov 30 02:00
Nov 30 05:00
Nov 30 08:00
Nov 30 11:00
Nov 30 14:00
Nov 30 17:00
Nov 30 20:00
Nov 30 23:00
Dec 01 02:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow


Catch Basin StormFilter Effectiveness
CBSF2 Storm Event Hydrograph
SE-15: January 04-05, 2011
Precipitation (inches)
Flow (cfs)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.060
0.050
0.040
0.030
0.020
0.010
0.000
Jan 04 12:00
Jan 04 14:00
Jan 04 16:00
Jan 04 18:00
Jan 04 20:00
Jan 04 22:00
Jan 05 00:00
Jan 05 02:00
Jan 05 04:00
Jan 05 06:00
Jan 05 08:00
Jan 05 10:00
Jan 05 12:00
Jan 05 14:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow


CBSF2IN Storm Event Hydrograph
Catch Basin StormFilter Effectiveness
SE-16: March 14-16, 2011
Precipitation (inches)
Flow (cfs)
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.0
0.1
0.1
0.2
0.2
0.3
0.3
0.4
0.4
0.5
Mar 14 12:00
Mar 14 16:00
Mar 14 20:00
Mar 15 00:00
Mar 15 04:00
Mar 15 08:00
Mar 15 12:00
Mar 15 16:00
Mar 15 20:00
Mar 16 00:00
Mar 16 04:00
Mar 16 08:00
Mar 16 12:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow

Catch Basin StormFilter Effectiveness
CBSF2 Storm Event Hydrograph
SE-17: April 13-14, 2011



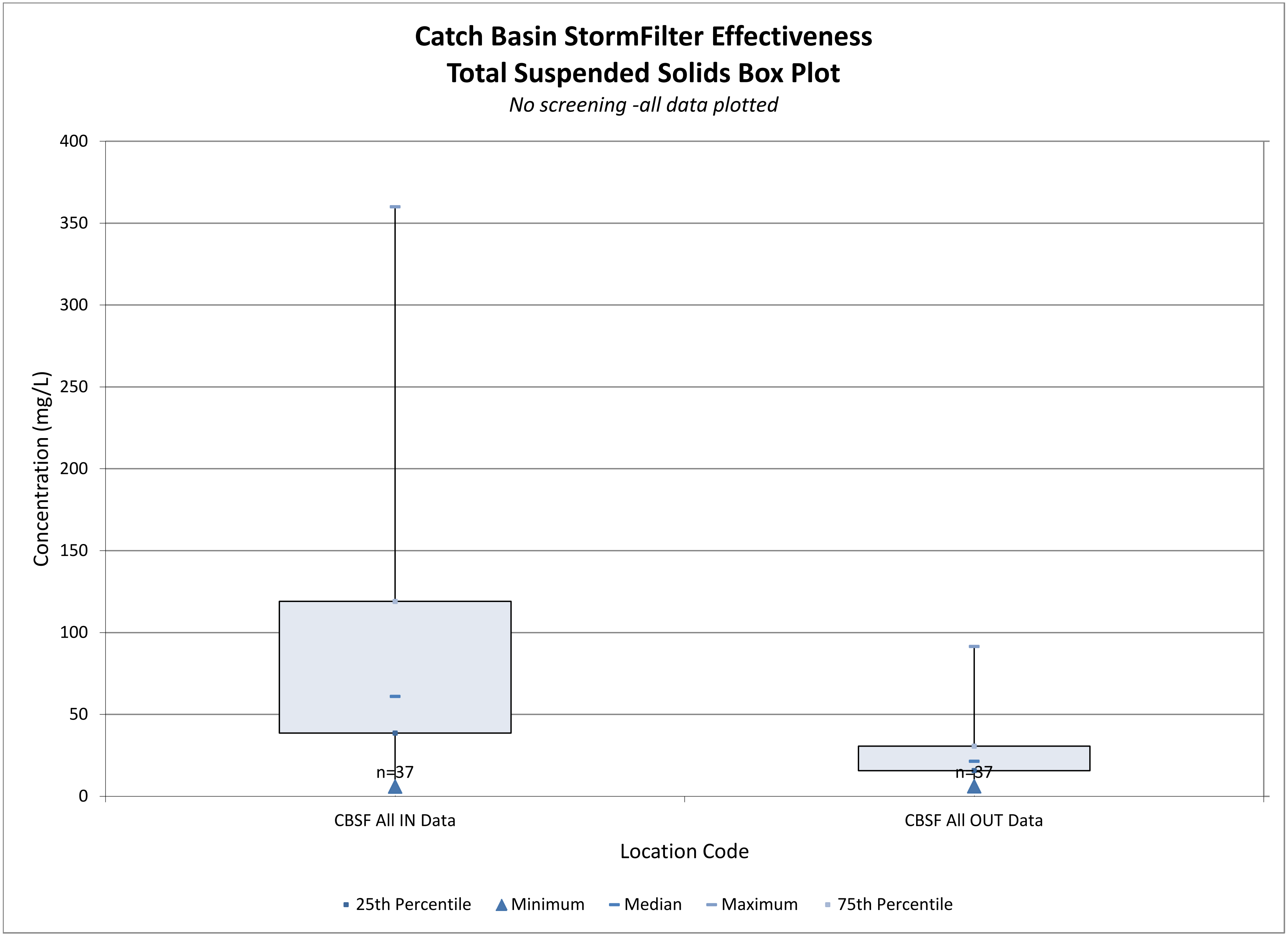


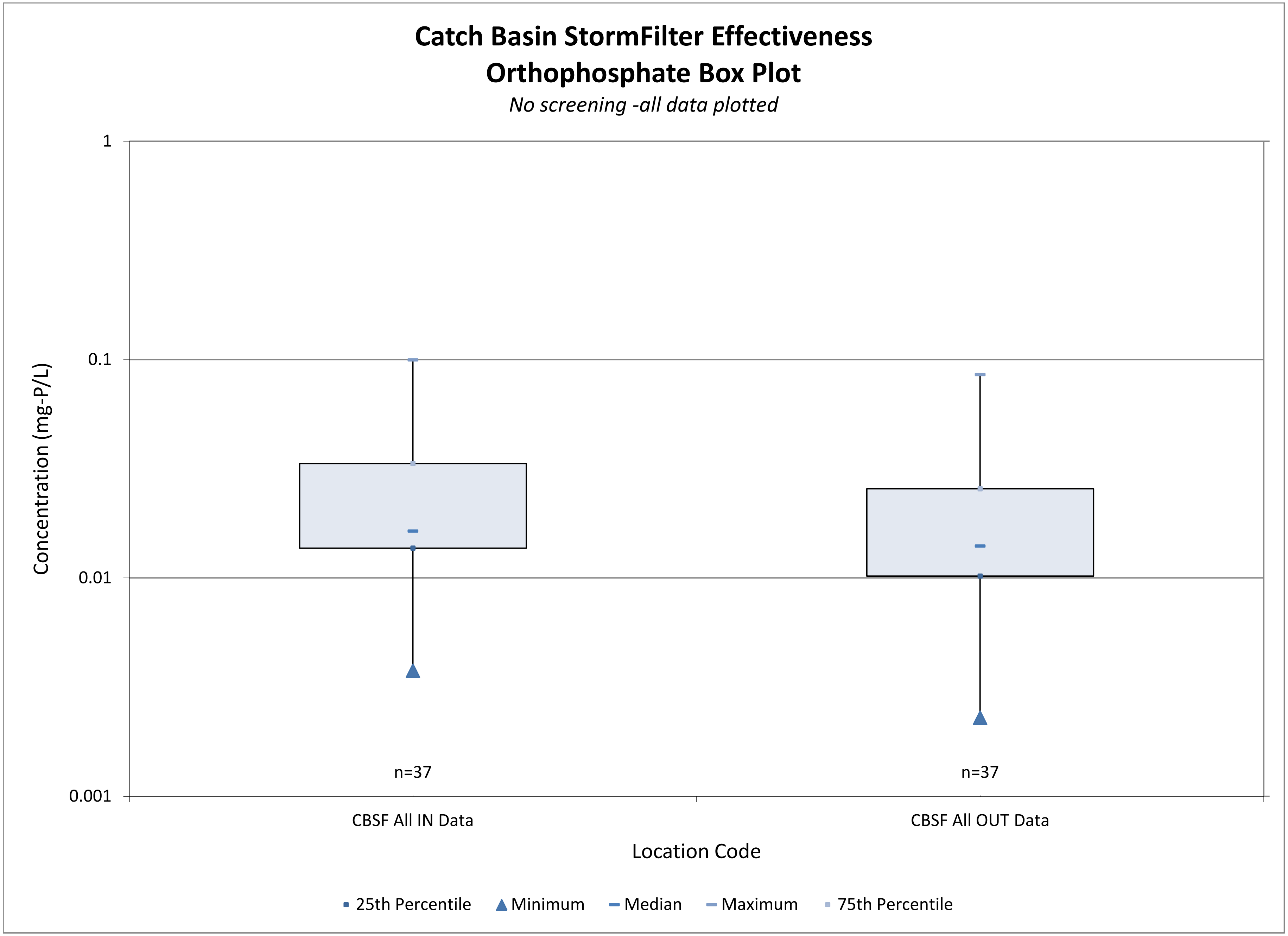
Catch Basin StormFilter Effectiveness
CBSF2 Storm Event Hydrograph
SE-18: April 27, 2011
Precipitation (inches)
Flow (cfs)
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
Apr 27 07:00
Apr 27 09:00
Apr 27 11:00
Apr 27 13:00
Apr 27 15:00
Apr 27 17:00
Apr 27 19:00
Apr 27 21:00
Apr 27 23:00
Apr 28 01:00
Apr 28 03:00
Apr 28 05:00
Apr 28 07:00
Precipitation
Event (Start/End)
Sample Aliquot
Sample Missed
Flow
Bypass Flow

This Page Intentionally Left Blank.

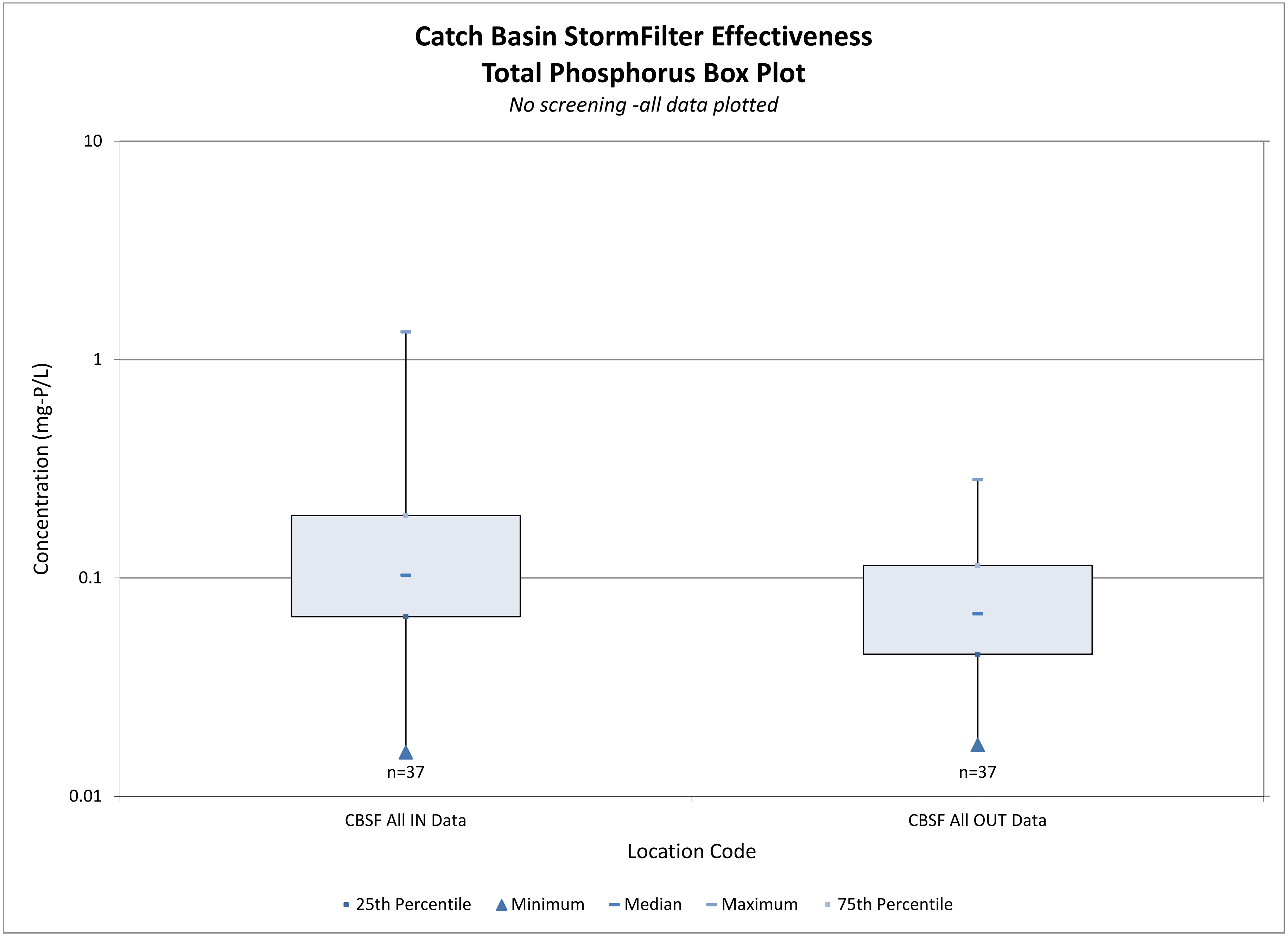
Appendix D BOX PLOTS AND SUMMARY STATISTICS

This Page Intentionally Left Blank.

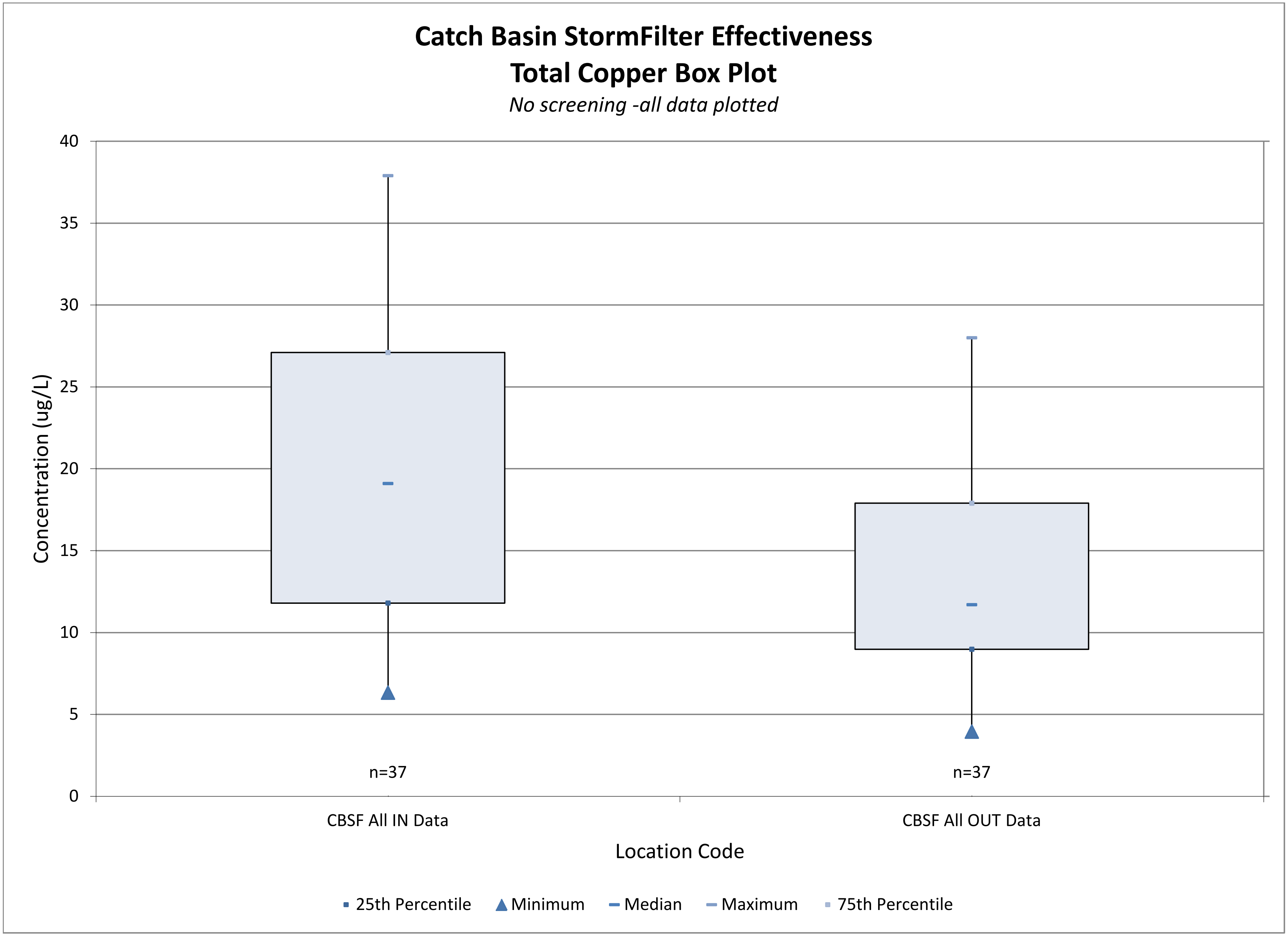

Catch Basin StormFilter Effectiveness
Total Suspended Solids Box Plot
No screening -all data plotted
Concentration (mg/L)
0
50
100
150
200
250
300
350
400
n=37
n=37
CBSF All IN Data
CBSF All OUT Data
Location Code
25th Percentile
Minimum
Median
Maximum
75th Percentile



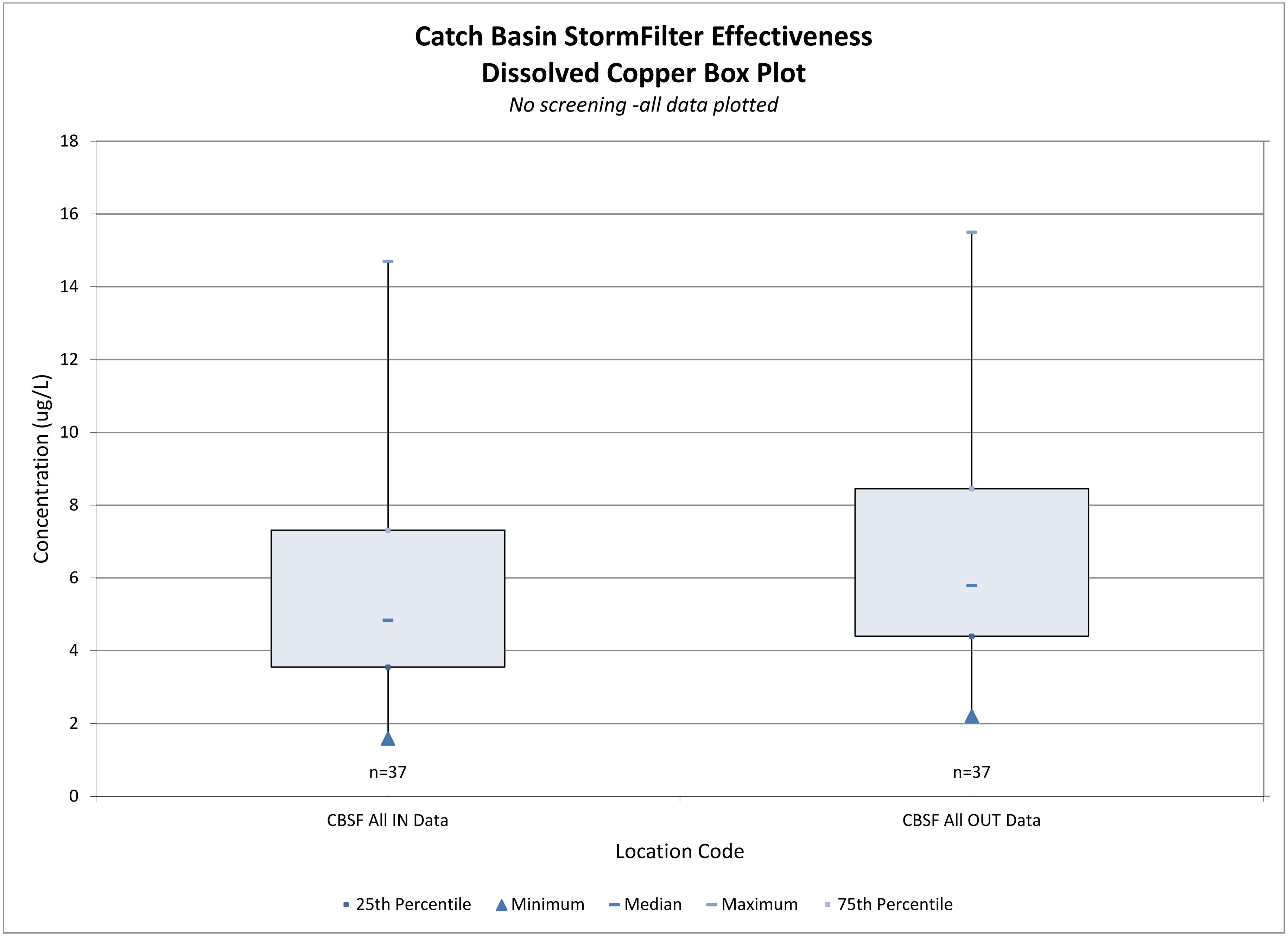
Catch Basin StormFilter Effectiveness
Orthophosphate Box Plot
No screening -all data plotted
1
0.1
0.01
0.001
Concentration (mg-P/L)
n=37
n=37
CBSF All IN Data
CBSF All OUT Data
Location Code
25th Percentile
Minimum
Median
Maximum
75th Percentile



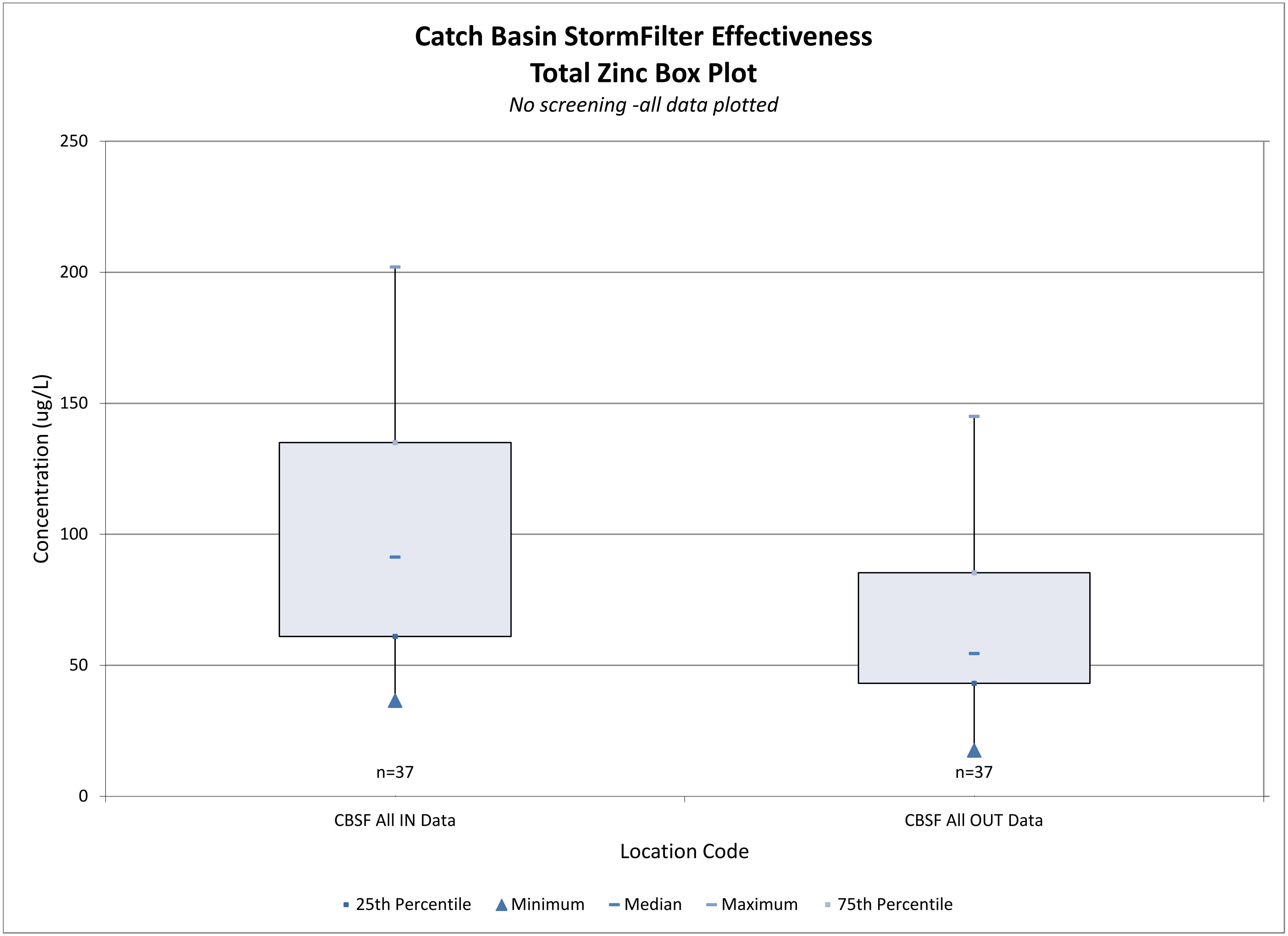
Catch Basin StormFilter Effectiveness
Total Phosphorus Box Plot
No screening -all data plotted
10
1
0.1
0.01
Concentration (mg-P/L)
n=37
n=37
CBSF All IN Data
CBSF All OUT Data
Location Code
25th Percentile
Minimum
Median
Maximum
75th Percentile



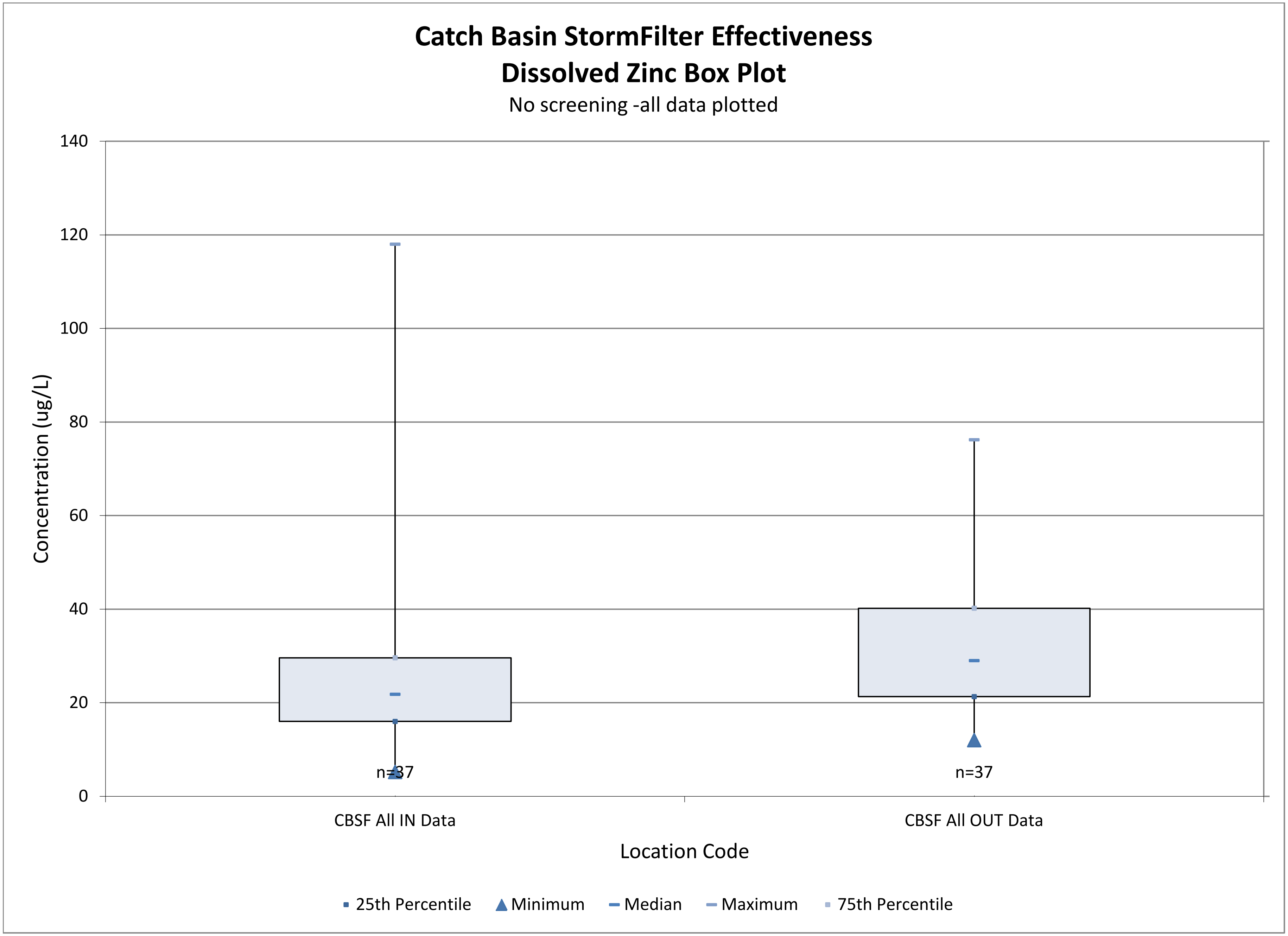
Catch Basin StormFilter Effectiveness
Total Copper Box Plot
No screening -all data plotted
Concentration (ug/L)
40
35
30
25
20
15
10
5
0
n=37
n=37
CBSF All IN Data
CBSF All OUT Data
Location Code
25th Percentile
Minimum
Median
Maximum
75th Percentile



Catch Basin StormFilter Effectiveness
Dissolved Copper Box Plot
No screening -all data plotted
Concentration (ug/L)
18
16
14
12
10
8
6
4
2
0
n=37
n=37
CBSF All IN Data
CBSF All OUT Data
Location Code
25th Percentile
Minimum
Median
Maximum
75th Percentile



Catch Basin StormFilter Effectiveness
Total Zinc Box Plot
No screening -all data plotted
Concentration (ug/L)
250
200
150
100
50
0
n=37
n=37
CBSF All IN Data
CBSF All OUT Data
Location Code
25th Percentile
Minimum
Median
Maximum
75th Percentile



Catch Basin StormFilter Effectiveness
Dissolved Zinc Box Plot
No screening -all data plotted
140
120
100
80
60
40
20
0
Concentration (ug/L)
n=37
n=37
CBSF All IN Data
CBSF All OUT Data
Location Code
25th Percentile
Minimum
Median
Maximum
75th Percentile

Summary Statistics
Catch Basin StormFilter Effectiveness Evaluation

Total Suspended Solids Data (mg/L)

Site	Date	IN	OUT	% Removal [1]
CBSF1	3/2/09	144	64.5	55.2
CBSF1	3/3/09	168	91.5	45.5
CBSF1	10/21/09	92.5	26.5	
CBSF1	10/26/09	93.5	20.9	
CBSF1	11/6/09	54.5	24.4	
CBSF1	12/14/09	105	31.8	69.7
CBSF1	3/11/10	29.5	9.6	
CBSF1	3/26/10	130	6.11	95.3
CBSF1	4/2/10	38.6	6.6	
CBSF1	5/20/10	221	17.5	92.1
CBSF1	6/2/10	30.4	15.5	
CBSF1	6/9/10	96.3	8.4	
CBSF1	10/26/10	77.7	39.3	
CBSF1	11/30/10	141	63.5	55.0
CBSF1	1/5/11	57.5	21.4	
CBSF1	3/8/11	25.6	33.2	
CBSF1	3/16/11	90.4	20.9	
CBSF1	4/14/11	20.9	46.4	
CBSF1	4/27/11	56.3	29.6	
CBSF2	3/2/09	179	72	59.8
CBSF2	3/3/09	116	79.6	31.4
CBSF2	10/26/09	34.8	11.6	
CBSF2	11/6/09	29.3	14.3	
CBSF2	12/14/09	61.0	22.2	
CBSF2	12/17/09	39.5	9.8	
CBSF2	2/5/10	5.95	19.6	
CBSF2	2/11/10	52.2	20.0	
CBSF2	3/11/10	25.6	11.5	
CBSF2	3/26/10	119	16.3	86.3
CBSF2	5/20/10	360	30.6	91.5
CBSF2	6/2/10	44.0	17.2	
CBSF2	10/26/10	37.0	16.0	
CBSF2	11/30/10	185	22.3	87.9
CBSF2	1/5/11	46.4	13.8	
CBSF2	3/16/11	215	21.5	90.0
CBSF2	4/14/11	57.4	28.9	
CBSF2	4/27/11	136	30.2	77.8

[1] Percent removal only calculated for sample pairs where influent concentration was greater than 100.

Total Suspended Solids Summary Statistics

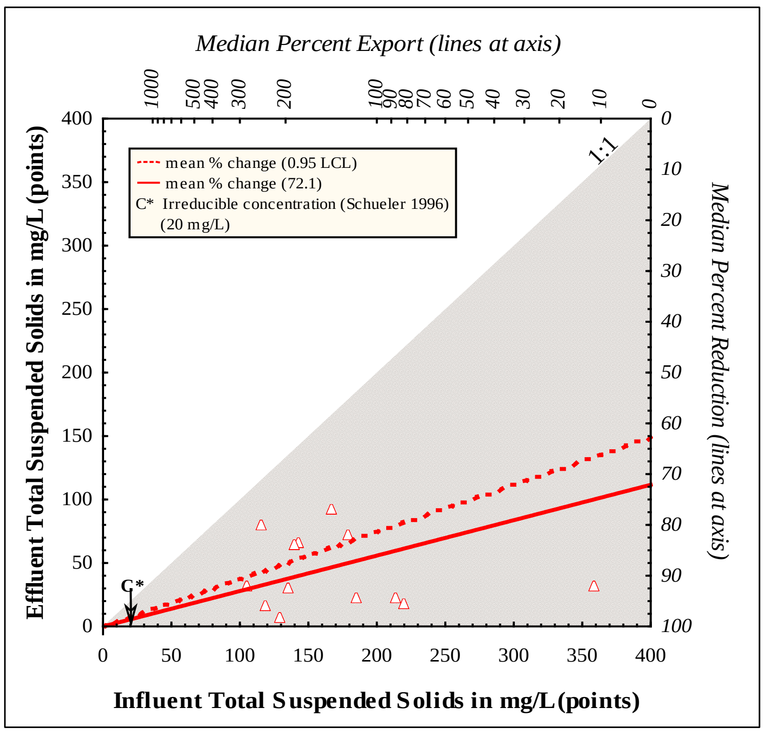
	IN	OUT	% Removal [1]
N	37.0	37.0	13.0
Mean	92.3	28.0	72.1
Minimum	6.0	6.1	31.4
Maximum	360.0	91.5	95.3
Standard Deviation	73.1	20.9	20.9
25th Percentile	38.6	15.5	55.2
Median	61.0	21.4	77.8
75th Percentile	130.0	30.6	90.0
IQR	91.4	15.1	34.8

[1] Percent removal summary statistics only calculated for sample pairs where influent concentration was greater than 100.

Total Suspended Solids Bootstrap Performance Calculations [1]

	IN	OUT	% Removal
N		23	13
Lower 95% CL of mean			62.8
Mean		20.3	72.1
Upper 95% CL of mean		23.6	

[1] Performance calculations based on TAPE 2011 guidelines



Summary Statistics
Catch Basin StormFilter Effectiveness Evaluation

Total Phosphorus Data (µg/L)

Site	Date	IN	OUT	% Removal [1]
CBSF1	3/2/09	412	222	46.1
CBSF1	3/3/09	520	274	
CBSF1	10/21/09	232.0	218.0	6.0
CBSF1	10/26/09	105.0	109.0	-3.8
CBSF1	11/6/09	193.0	212.0	-9.8
CBSF1	12/14/09	211	109	48.3
CBSF1	3/11/10	129.0	86.6	32.9
CBSF1	3/26/10	170	78.2	54.0
CBSF1	4/2/10	66.5	65.6	
CBSF1	5/20/10	268	134	50.0
CBSF1	6/2/10	79.5	41.5	
CBSF1	6/9/10	26.5	57.7	
CBSF1	10/26/10	267.0	282.0	-5.6
CBSF1	11/30/10	459	230.0	49.9
CBSF1	1/5/11	61.1	57.0	
CBSF1	3/8/11	60.9	41.1	
CBSF1	3/16/11	129.0	50.9	60.5
CBSF1	4/14/11	19.8	35.6	
CBSF1	4/27/11	49.1	44.5	
CBSF2	3/2/09	1340	236	
CBSF2	3/3/09	280	236	15.7
CBSF2	10/26/09	103.0	44.7	56.6
CBSF2	11/6/09	125.0	114.0	8.8
CBSF2	12/14/09	117.0	112.0	4.3
CBSF2	12/17/09	73.1	68.5	
CBSF2	2/5/10	15.9	17.8	
CBSF2	2/11/10	86.6	64.2	
CBSF2	3/11/10	78.9	49.3	
CBSF2	3/26/10	97.7	75	
CBSF2	5/20/10	111	77	30.6
CBSF2	6/2/10	44.2	39.8	
CBSF2	10/26/10	94.1	101.0	
CBSF2	11/30/10	170	68.1	59.9
CBSF2	1/5/11	71.8	47.8	
CBSF2	3/16/11	75.7	32.1	
CBSF2	4/14/11	37.9	17.9	
CBSF2	4/27/11	19.4	17.2	

[1] Percent removal only calculated for sample pairs where influent concentration was between 100 and 500.

Total Phosphorus Summary Statistics

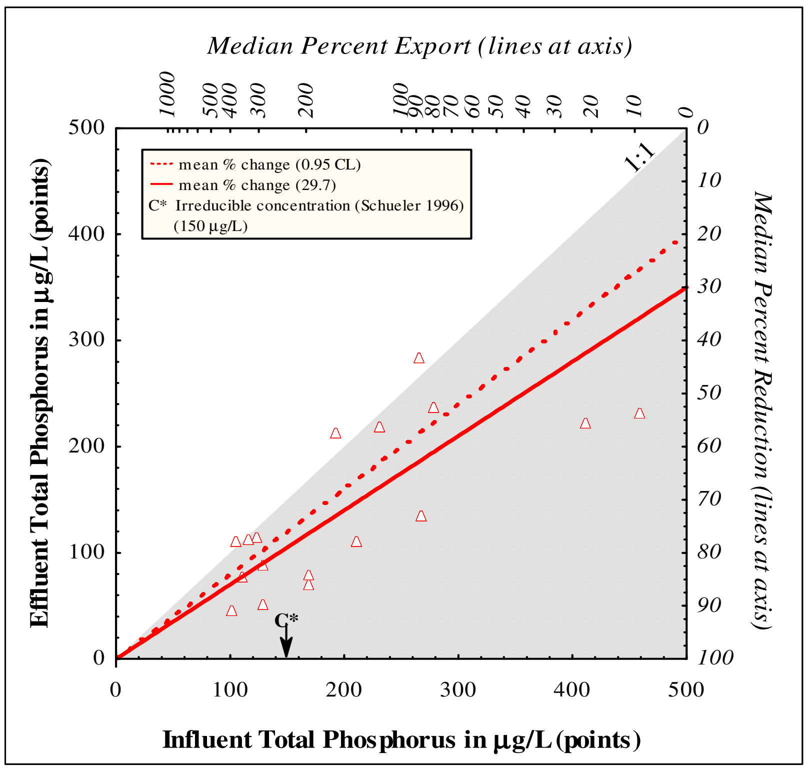
	IN	OUT	% Removal [1]
N	37	37	17
Mean	173.0	101.8	29.7
Minimum	15.9	17.2	-9.8
Maximum	1340.0	282.0	60.5
Standard Deviation	231.2	78.8	25.5
25th Percentile	66.5	44.7	6.0
Median	103.0	68.5	32.9
75th Percentile	193.0	114.0	50.0
IQR	126.5	69.3	44.0

[1] Percent removal summary statistics only calculated for sample pairs where influent concentrations were between 100 and 500.

Total Phosphorus Bootstrap Performance Calculations [1]

	IN	OUT	% Removal
N			17
Lower 95% CL of mean			19.8
Mean			29.7

[1] Performance calculations based on TAPE 2011 guidelines



Summary Statistics
Catch Basin StormFilter Effectiveness Evaluation

Orthophosphorus Data (µg/L)

Site	Date	IN	OUT	% Removal
CBSF1	3/2/09	8	8	0.0
CBSF1	3/3/09	14	13	7.1
CBSF1	10/21/09	96.8	53.5	44.7
CBSF1	10/26/09	39.6	32.7	17.4
CBSF1	11/6/09	76.5	85.4	-11.6
CBSF1	12/14/09	33.4	31.7	5.1
CBSF1	3/11/10	18.8	15.1	19.7
CBSF1	3/26/10	25.9	33.6	-29.7
CBSF1	4/2/10	13.8	18.5	-34.1
CBSF1	5/20/10	99.7	28.6	71.3
CBSF1	6/2/10	5.8	16.1	-179.5
CBSF1	6/9/10	7.2	26.9	-273.6
CBSF1	10/26/10	64.5	67.1	-4.0
CBSF1	11/30/10	16.4	13.7	16.5
CBSF1	1/5/11	25.4	10.2	59.8
CBSF1	3/8/11	20.6	8.8	57.3
CBSF1	3/16/11	13.7	7.2	47.3
CBSF1	4/14/11	3.8	7.5	-98.7
CBSF1	4/27/11	44.0	22.6	48.6
CBSF2	3/2/09	14	11	21.4
CBSF2	3/3/09	16	14	12.5
CBSF2	10/26/09	38.0	23.8	37.4
CBSF2	11/6/09	32.2	38.8	-20.5
CBSF2	12/14/09	43.0	22.3	48.1
CBSF2	12/17/09	12.3	10.6	13.8
CBSF2	2/5/10	8.55	9	-5.3
CBSF2	2/11/10	13.8	10.7	22.5
CBSF2	3/11/10	14.3	11.5	19.6
CBSF2	3/26/10	22.1	17.8	19.5
CBSF2	5/20/10	37.2	20.7	44.4
CBSF2	6/2/10	6.0	2.3	61.9
CBSF2	10/26/10	27.4	25.6	6.6
CBSF2	11/30/10	9.29	6.7	28.3
CBSF2	1/5/11	15.8	10.9	31.0
CBSF2	3/16/11	8.24	4.7	43.3
CBSF2	4/14/11	15.7	11.6	26.1
CBSF2	4/27/11	20.7	2.7	87.0

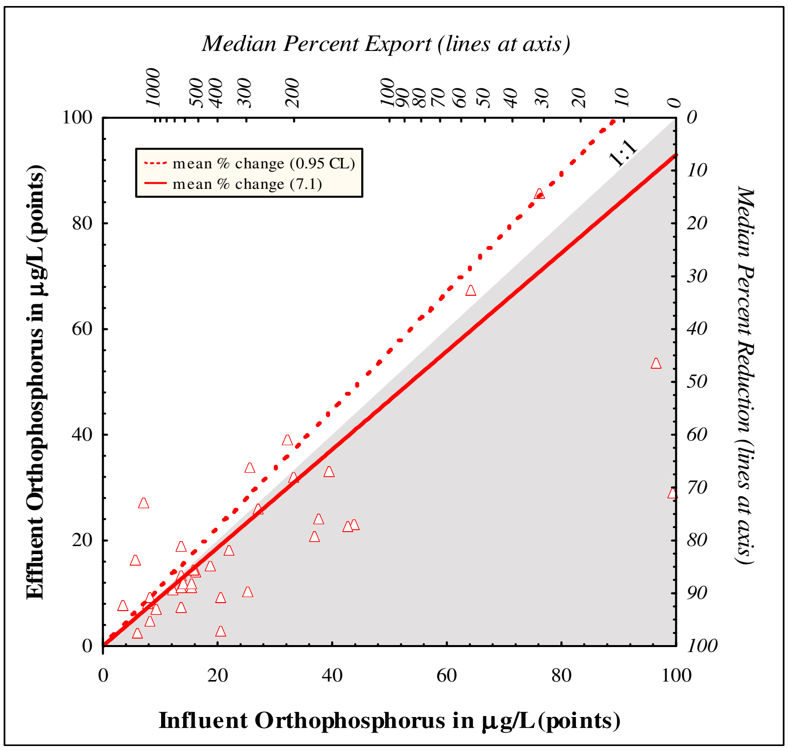
Orthophosphorus Summary Statistics

	IN	OUT	% Removal
N	37	37	37
Mean	26.6	20.4	7.1
Minimum	3.8	2.3	-273.6
Maximum	99.7	85.4	87.0
Standard Deviation	23.6	17.6	66.8
25th Percentile	13.7	10.2	0.0
Median	16.4	14.0	19.6
75th Percentile	33.4	25.6	44.4
IQR	19.7	15.4	44.4

Orthophosphorus Bootstrap Performance Calculations [1]

	IN	OUT	% Removal
N			37
Lower 95% CL of mean			-11.7
Mean			7.1

[1] Performance calculations based on TAPE 2011 guidelines



Summary Statistics
Catch Basin StormFilter Effectiveness Evaluation

Total Copper Data (µg/L)

Site	Date	IN	OUT	% Removal
CBSF1	3/2/09	30.4	17.9	41.1
CBSF1	3/3/09	30.2	19.8	34.4
CBSF1	10/21/09	19.7	15.1	23.4
CBSF1	10/26/09	10.7	6.9	35.7
CBSF1	11/6/09	14.2	11.3	20.4
CBSF1	12/14/09	29.1	17.3	40.5
CBSF1	3/11/10	22.6	11.3	50.0
CBSF1	3/26/10	30.3	15.9	47.5
CBSF1	4/2/10	13.5	8.5	36.8
CBSF1	5/20/10	37.9	19.4	48.8
CBSF1	6/2/10	11.0	8.4	23.5
CBSF1	6/9/10	20.5	11.3	44.9
CBSF1	10/26/10	27.1	28.0	-3.3
CBSF1	11/30/10	37.6	23.3	38.0
CBSF1	1/5/11	14.0	11.7	16.4
CBSF1	3/8/11	11.8	18.9	-60.2
CBSF1	3/16/11	21.5	10.6	50.7
CBSF1	4/14/11	14.2	27.1	-90.8
CBSF1	4/27/11	24.8	22.1	10.9
CBSF2	3/2/09	26.8	16	40.3
CBSF2	3/3/09	17.8	14.8	16.9
CBSF2	10/26/09	7.2	4.0	45.4
CBSF2	11/6/09	9.1	7.7	15.2
CBSF2	12/14/09	19.1	13.5	29.3
CBSF2	12/17/09	11.6	8.3	28.5
CBSF2	2/5/10	6.33	5.23	17.4
CBSF2	2/11/10	14.9	10.9	26.8
CBSF2	3/11/10	10.3	8.7	15.7
CBSF2	3/26/10	20.5	12	41.5
CBSF2	5/20/10	33.7	25.9	23.1
CBSF2	6/2/10	13.1	9.0	31.5
CBSF2	10/26/10	10.5	10.2	2.9
CBSF2	11/30/10	20	10.2	49.0
CBSF2	1/5/11	11.2	9.8	12.3
CBSF2	3/16/11	17.6	8.6	51.2
CBSF2	4/14/11	27.5	19.4	29.5
CBSF2	4/27/11	27.6	16.1	41.7

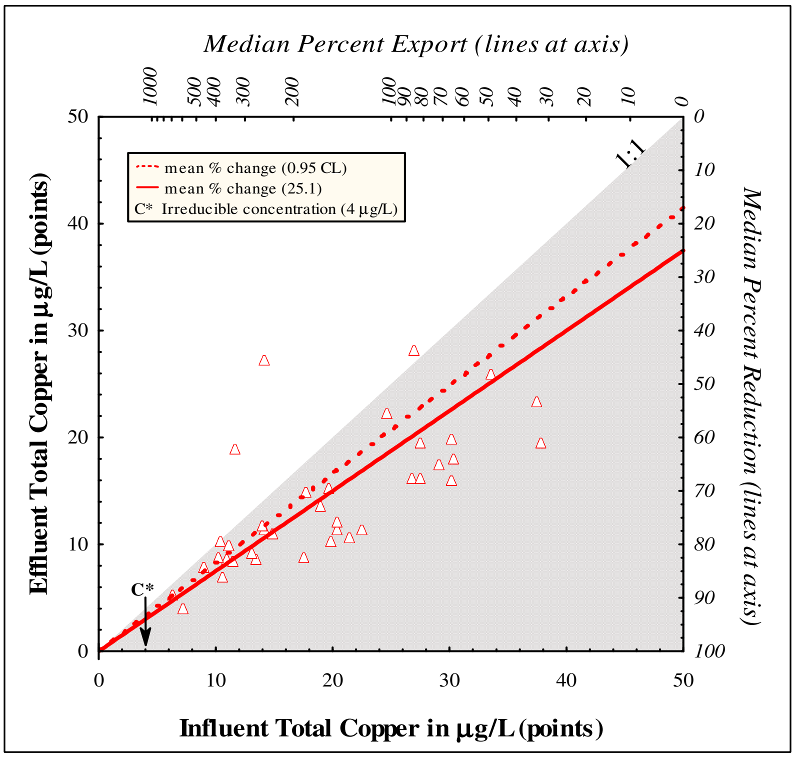
Total Copper Summary Statistics

	IN	OUT	% Removal
N	37	37	37
Mean	19.6	13.9	25.1
Minimum	6.3	4.0	-90.8
Maximum	37.9	28.0	51.2
Standard Deviation	8.7	6.1	28.4
25th Percentile	11.8	9.0	16.9
Median	19.1	11.7	29.5
75th Percentile	27.1	17.9	41.5
IQR	15.3	8.9	24.6

Total Copper Bootstrap Performance Calculations [1]

	IN	OUT	% Removal
N			37
Lower 95% CL of mean			16.9
Mean			25.1

[1] Performance calculations based on TAPE 2011 guidelines



Summary Statistics
Catch Basin StormFilter Effectiveness Evaluation

Dissolved Copper Data (µg/L)

Site	Date	IN	OUT	% Removal [1]
CBSF1	3/2/09	4.6	5.2	
CBSF1	3/3/09	3.7	4.4	
CBSF1	10/21/09	10.4	10.2	1.9
CBSF1	10/26/09	3.5	2.2	
CBSF1	11/6/09	6.2	6.0	2.9
CBSF1	12/14/09	4.59	6.54	
CBSF1	3/11/10	7.5	7.3	1.6
CBSF1	3/26/10	8.78	10.4	-18.5
CBSF1	4/2/10	5.2	5.8	-12.2
CBSF1	5/20/10	14.7	11.8	19.7
CBSF1	6/2/10	7.5	5.5	26.6
CBSF1	6/9/10	6.9	7.8	-12.6
CBSF1	10/26/10	9.4	15.5	-64.2
CBSF1	11/30/10	3.59	5.1	
CBSF1	1/5/11	5.2	5.5	-7.4
CBSF1	3/8/11	6.0	8.8	-45.7
CBSF1	3/16/11	2.7	4.2	
CBSF1	4/14/11	6.1	10.1	-66.9
CBSF1	4/27/11	9.4	12.2	-29.2
CBSF2	3/2/09	2.9	3.8	
CBSF2	3/3/09	2.7	3.2	
CBSF2	10/26/09	2.8	2.3	
CBSF2	11/6/09	3.7	5.1	
CBSF2	12/14/09	7.0	6.7	5.5
CBSF2	12/17/09	3.1	3.7	
CBSF2	2/5/10	2.88	3.34	
CBSF2	2/11/10	4.6	5.5	
CBSF2	3/11/10	4.5	5.7	
CBSF2	3/26/10	4.88	6.88	
CBSF2	5/20/10	7.41	11.3	-52.5
CBSF2	6/2/10	4.8	5.0	
CBSF2	10/26/10	4.2	5.9	
CBSF2	11/30/10	2.18	2.6	
CBSF2	1/5/11	3.6	6.9	
CBSF2	3/16/11	1.59	3.2	
CBSF2	4/14/11	7.6	9.5	-24.2
CBSF2	4/27/11	7.31	8.5	-15.6

[1] Percent removal only calculated for sample pairs where influent concentration was between 100 and 500.

Dissolved Copper Summary Statistics

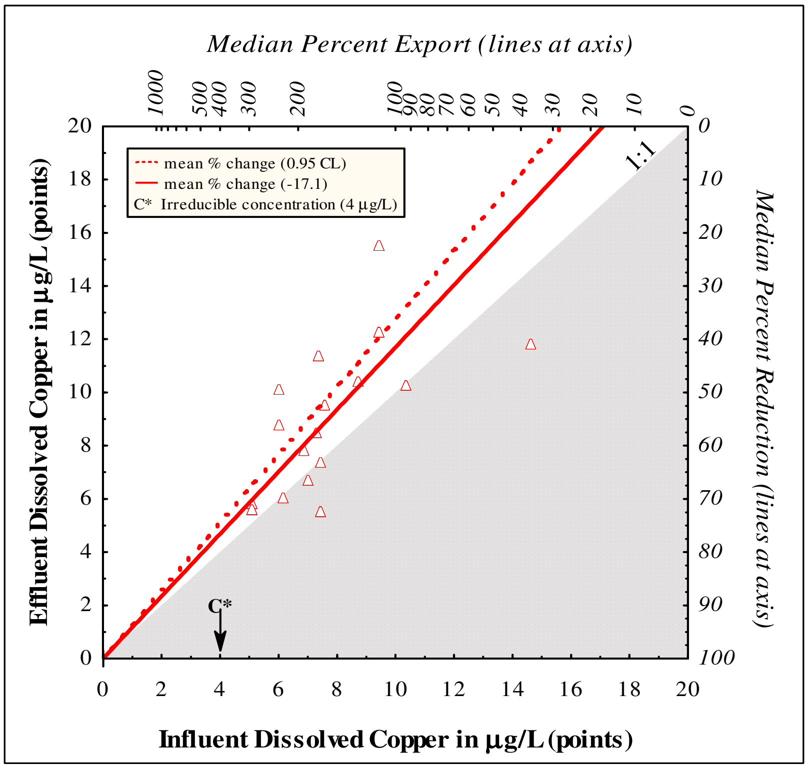
	IN	OUT	% Removal [1]
N	37	37	17
Mean	5.5	6.6	-17.1
Minimum	1.6	2.2	-66.9
Maximum	14.7	15.5	26.6
Standard Deviation	2.7	3.1	27.4
25th Percentile	3.6	4.4	-29.2
Median	4.8	5.8	-12.5
75th Percentile	7.3	8.5	1.9
IQR	3.8	4.1	31.2

[1] Percent removal summary statistics only calculated for sample pairs where influent concentrations were between 100 and 500.

Dissolved Copper Bootstrap Performance Calculations [1]

	IN	OUT	% Removal
N			17
Lower 95% CL of mean			-27.5
Mean			-17.1

[1] Performance calculations based on TAPE 2011 guidelines



Summary Statistics
Catch Basin StormFilter Effectiveness Evaluation

Total Zinc Data (µg/L)

Site	Date	IN	OUT	% Removal
CBSF1	3/2/09	146	125	14.4
CBSF1	3/3/09	158	100	36.7
CBSF1	10/21/09	81.2	55.8	31.3
CBSF1	10/26/09	53.6	30.2	43.7
CBSF1	11/6/09	74.2	49.4	33.4
CBSF1	12/14/09	135	63.1	53.3
CBSF1	3/11/10	68.2	43.1	36.8
CBSF1	3/26/10	136	56.3	58.6
CBSF1	4/2/10	61.0	37.8	38.0
CBSF1	5/20/10	180	96.2	46.6
CBSF1	6/2/10	53.3	42.6	20.1
CBSF1	6/9/10	99.9	62.1	37.8
CBSF1	10/26/10	120.0	89.8	25.2
CBSF1	11/30/10	202	114.0	43.6
CBSF1	1/5/11	67.7	70.0	-3.4
CBSF1	3/8/11	42.4	85.3	-101.2
CBSF1	3/16/11	90.4	52.8	41.6
CBSF1	4/14/11	149.0	145.0	2.7
CBSF1	4/27/11	123.0	88.6	28.0
CBSF2	3/2/09	190	79	58.4
CBSF2	3/3/09	107	80	25.2
CBSF2	10/26/09	36.9	17.5	52.6
CBSF2	11/6/09	47.1	38.2	18.9
CBSF2	12/14/09	91.9	54.5	40.7
CBSF2	12/17/09	48.7	38.2	21.6
CBSF2	2/5/10	36.5	28.6	21.6
CBSF2	2/11/10	80.8	52.9	34.5
CBSF2	3/11/10	52.0	35.6	31.5
CBSF2	3/26/10	121	53.4	55.9
CBSF2	5/20/10	184	91.2	50.4
CBSF2	6/2/10	70.0	43.0	38.6
CBSF2	10/26/10	54.6	50.9	6.8
CBSF2	11/30/10	113	49.5	56.2
CBSF2	1/5/11	78.7	45.1	42.7
CBSF2	3/16/11	91.3	43.1	52.8
CBSF2	4/14/11	112.0	95.6	14.6
CBSF2	4/27/11	147	75.0	49.0

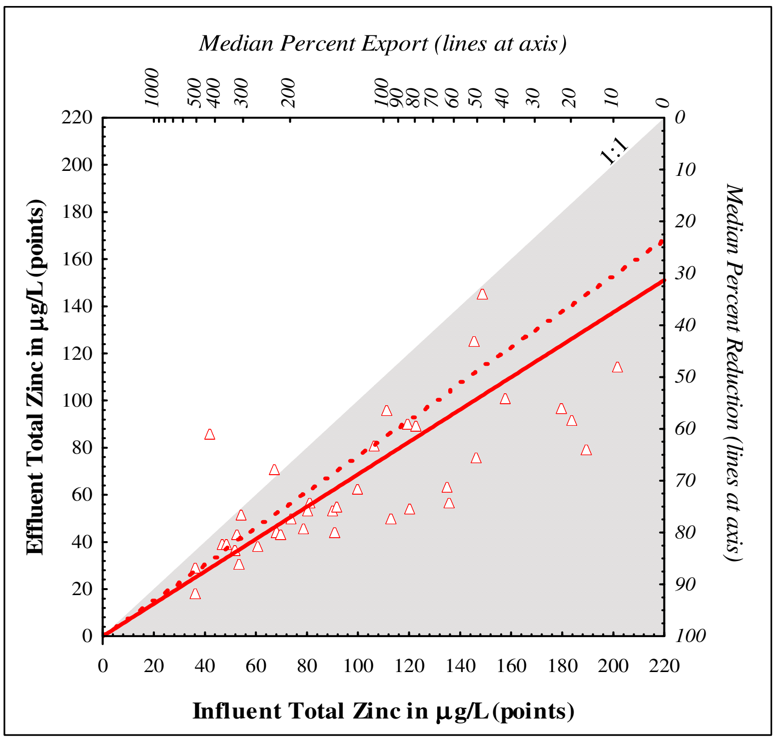
Total Zinc Summary Statistics

	IN	OUT	% Removal
N	37	37	37
Mean	100.1	64.3	31.3
Minimum	36.5	17.5	-101.2
Maximum	202	145	58.6
Standard Deviation	46.6	28.8	27.5
25th Percentile	61	43.1	21.6
Median	91.3	54.5	36.8
75th Percentile	135	85.3	46.6
IQR	74	42.2	24.9

Total Zinc Bootstrap Performance Calculations [1]

	IN	OUT	% Removal
N			37
Lower 95% CL of mean			23.4
Mean			31.3

[1] Performance calculations based on TAPE 2011 guidelines



Summary Statistics
Catch Basin StormFilter Effectiveness Evaluation

Dissolved Zinc Data (µg/L)

Site	Date	IN	OUT	% Removal [1]
CBSF1	3/2/09	16	29	
CBSF1	3/3/09	15	20	
CBSF1	10/21/09	34.1	31.9	6.5
CBSF1	10/26/09	18.8	15.2	
CBSF1	11/6/09	32.3	22.9	29.1
CBSF1	12/14/09	18.5	21.5	
CBSF1	3/11/10	26.7	28.7	-7.5
CBSF1	3/26/10	29.6	40.2	-35.8
CBSF1	4/2/10	22.2	28.8	-29.7
CBSF1	5/20/10	51.5	76.2	-48.0
CBSF1	6/2/10	38.7	35.2	9.0
CBSF1	6/9/10	38.2	54.7	-43.2
CBSF1	10/26/10	37.2	42.1	-13.2
CBSF1	11/30/10	15.8	18.7	
CBSF1	1/5/11	27.6	45.1	-63.4
CBSF1	3/8/11	16.8	53.1	
CBSF1	3/16/11	14.3	25.8	
CBSF1	4/14/11	118.0	72.4	38.6
CBSF1	4/27/11	36.2	48.0	-32.6
CBSF2	3/2/09	11	15	
CBSF2	3/3/09	13	15	
CBSF2	10/26/09	15.7	12.0	
CBSF2	11/6/09	18.5	29.6	
CBSF2	12/14/09	27.1	29.6	-9.2
CBSF2	12/17/09	17.2	19.6	
CBSF2	2/5/10	13.8	21.3	
CBSF2	2/11/10	20.7	28.5	-37.7
CBSF2	3/11/10	19.5	22.4	
CBSF2	3/26/10	22.2	29.1	-31.1
CBSF2	5/20/10	29.4	53.8	-83.0
CBSF2	6/2/10	23.3	26.7	-14.6
CBSF2	10/26/10	21.8	29.6	-35.8
CBSF2	11/30/10	13.1	13.3	
CBSF2	1/5/11	17.3	33.0	
CBSF2	3/16/11	10.4	16.9	
CBSF2	4/14/11	31.2	44.0	-41.0
CBSF2	4/27/11	27.5	37.0	-34.5

[1] Percent removal only calculated for sample pairs where influent concentration was between 100 and 500.

Dissolved Zinc Summary Statistics

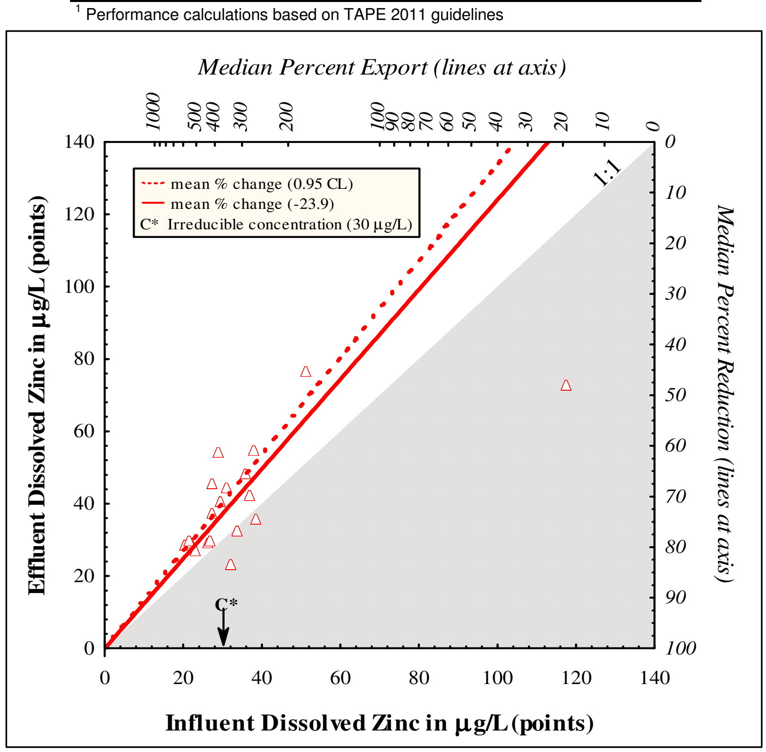
	IN	OUT	% Removal [1]
N	37	37	20
Mean	26.0	32.1	-23.9
Minimum	10.4	12.0	-83.0
Maximum	118.0	76.2	38.6
Standard Deviation	18.2	15.5	29.4
25th Percentile	16.0	21.3	-39.4
Median	21.8	29.0	-31.8
75th Percentile	29.6	40.2	-8.4
IQR	13.6	18.9	31.0

[1] Percent removal summary statistics only calculated for sample pairs where influent concentrations were between 100 and 500.

Dissolved Zinc Bootstrap Performance Calculations [1]

	IN	OUT	% Removal
N			20
Lower 95% CL of mean			-34.2
Mean			-23.9

[1] Performance calculations based on TAPE 2011 guidelines



Appendix E CONTECH STATEMENT

This Page Intentionally Left Blank.

Statement from Contech Construction Products Inc. on the Draft Seattle Public Utilities CatchBasin StormFilter Report (12/13/2011)

Summary

The field evaluation of stormwater best management practices is a challenging endeavor. These types of field evaluations require a tremendous amount of flexibility and adaptability, which may not be well suited for satisfying monitoring requirements associated with Phase 1 permit conditions. The CatchBasin StormFilter™ (CBSF) is even more complicated due to many hydraulic and treatment processes occurring in a very compact footprint. The CBSF receives surface runoff. Runoff enters into a sumped inlet chamber containing a scum/oil baffle and a bypass weir. Water moves from the inlet chamber into a cartridge chamber that contains cartridges elevated over a wet sump. Treated runoff passes through the filter cartridges and then passes through an underdrain manifold into the effluent chamber. Seattle Public Utilities (SPU) has done an extraordinary job with undertaking the evaluation of this unit and characterizing the influent conditions being received by the system under these constraints.

The CBSF systems on California Avenue that were evaluated for this monitoring project were undersized from both a flow-based and mass loading perspective and received annual rainfall totals that were 38% above average. As such, the performance results of these units are very specific to the unique attributes associated within these drainage areas and hydraulic conditions. The results do provide evidence that the CBSF is a robust design that was able to perform well under adverse conditions. Contech Construction Products (Contech) does provide an alternative perspective on the evaluation of the CBSF on California Avenue.

The alternative perspective will focus on the following issues:

Water Quality Design Flow – Contech agrees with the retrospective sizing analysis conducted by SPU and the increased water quality design flow rates for the respective sites.

Net Annual Treated Volume – The 91% of the treated volume analysis neglects to consider that the systems were undersized for the area. Additional analysis could be explored to further evaluate bypass conditions.

Maintenance Frequency – Contech has prepared a cumulative load analysis that can be used to evaluate mass load capacity of the system. Based on the mass load to the system, Contech provided a maintenance frequency estimate for each site.

Mass Load Design – Flow-based BMP designs can be evaluated with mass load design criteria to assist with annual maintenance.

Sediment Accumulation – Contech prepared an additional analysis to accompany the sediment accumulation results provided by SPU. The mass retained by the system on a per cartridge basis exceeded expectations.

Inlet Grate Clogging – Contech will continue to work with SPU on preferred inlet grate design. Contech does suggest that future investigations evaluate TVSS to assist in the characterization of organic material in BMPs.

Dissolved Metals – The dissolved metals data is difficult to interpret due to the frequency and occurrence of very low influent concentrations. There is not enough resolution in the data set to determine when the cation exchange capacity in the media was exhausted.

Water Quality Design Flow

The water quality design flow rate as modeled in the WWHM was much lower than the observed flows in the 2010 and 2011 water years. SPU did a comprehensive analysis comparing actual flow to the theoretical water quality design flow rate. The retrospective sizing analysis and recommended retrospective design flow rate provided by SPU would appear to be appropriate based on the peak flows (frequency and size) for the systems evaluated. Table 1 provides number of StormFilter cartridges (18 inch) that would be required to meet the retrospective design flow rate, when designing with a flow-based method. Based on the observed flow rates and retrospective sizing analysis, the tested systems had 33% less capacity than would be provided by typical designs.

Table 1. Water Quality Design Flow and Retrospective Design Flow Rate

System	Acres	Water Quality Design Flow (cfs)	Retrospective Design Flow Rate by SPU (cfs)	Number of Cartridges Evaluated	Number of Cartridges Required Based on Retrospective Design Flow Rate (cfs)
CBSF1	0.18	0.033	0.045	2	3
CBSF2	0.97	0.067	0.093	4	6

Net Annual Treated Volume

Net annual treated volume (e.g. 91% annual volume) analysis is a challenging endeavor as it is difficult to analyze and interpret data collected:

a) in an above average precipitation year (CBSF1 & CBSF2)
b) a larger drainage area than designed (CBSF2)
c) in an area with above average loading (CBSF1 & CBSF2)
d) with frequent occurrence of flows greater than the water quality design flow rate (CBSF1 & CBSF2)

Net annual treated volume analysis should also include an observed and expected volume comparison to further assist in the explanation of bypass. The higher than expected peak flows (CBSF1 = 42%, CBSF2 = 66% of the storms evaluated) and additional volume (including long flow durations) could be compared to the system's original design capacity. Peak flows listed in Table 4.1a and 4.1b were compared to the water quality design flow rate of the system to determine the percentage of storms evaluated with expected bypass.

All treatment systems have a finite capacity for mass load. When a system's mass load capacity is exceeded, treated flows may decrease, and bypass flows are likely to increase. The mass load entering into the system is not taken into account when determining the net annual treated volume. The treatment system is designed for a targeted water quality flow rate and associated flow volume. It is our recommendation that net annual treated volume analysis should also reflect the mass load capacity of the system to further explain bypass conditions. Although it may be more accurate to integrate mass load analysis into the net annual treated volume calculation, it is likely outside the scope of the permit. Evaluating the cumulative impact of mass load to the system could be considered in a maintenance frequency analysis.

Maintenance Frequency

We can qualitatively assess the cumulative net annual mass load to BMPs to assist with evaluating the maintenance frequency at the site(s). Figure 1 and Figure 2 are a culmination of these efforts. The cumulative monthly rainfall from October 2009 to June 2011 was used along with a runoff volume estimate for each site. The runoff volume for each month was adjusted by taking the calculated rainfall volume and scaling for the Total Flow measured at the site (SPU CBSF Report, Table 5.3.4, pg 61). The cumulative load in Figure 1 used a runoff volume of 54,550 ft^3 (compared to 55,055 ft^3 in Table 5.3.4) and Figure 2 used a runoff volume of 160,600 ft^3 (compared to 161,926 ft^3 in Table 5.3.4). Figure 1 and Figure 2 represent precipitation of 47.57 inches over the first maintenance interval and 44.2 inches for the second maintenance interval.

For determination of the mass load to the site, the particle size distribution (PSD) analysis was selected since it is likely to be more inclusive of the total mass of particles transported in stormwater (e.g. ASTM D3977 was used for >250 microns). The monthly mass load to the system was calculated using the mean PSD value and the adjusted monthly runoff volume calculation. The mean PSD influent data (n=19) for CBSF1 was 128.9 mg/L. The mean PSD influent data (n=16) for CBSF2 was 110.1 mg/L. Two PSD data points were omitted from analysis (spring 2009) as potential outliers from the CBSF2 sample population. Figure 1 and Figure 2 show the monthly PSD mass load data collected between maintenance intervals.

For comparative purposes, TSS analysis is also presented in Figure 1 and Figure 2. The TSS monthly mass load to the system was calculated using the mean TSS value and the adjusted monthly runoff volume calculation. The mean TSS value for CBSF1 was 88.0 mg/L and CBSF2 was 96.8 mg/L. Figure 1 and Figure 2 shows the monthly mass load data as a cumulative load to the system.

The evaluation of the two CBSF systems did occur in above average water years. In addition the systems were undersized based on the "Retrospective Sizing Analysis" and recommended retrospective design flow rates by SPU. Table 2 and Table 3 show the recommended maintenance frequency based on the annual load received by each system during the evaluation period as well as the adjusted annual mass load to account for the average water year.

CBSF1 was tested with 2 cartridges; however the unit installed has up to a 4 cartridge capacity. Figure 1 displays two dashed lines (a red small-dashed line, and a blue long-dashed line) that represent the recommended mass load capacity for a 2 and 4 cartridge system respectively. The average mass load ((244+195)/2) to the CBSF1 system during the evaluation period was 219 pounds. Since CBSF1 has capacity for up to 4 cartridges, an estimated maintenance frequency for this system based on the number of cartridges has been provided in Table 2.

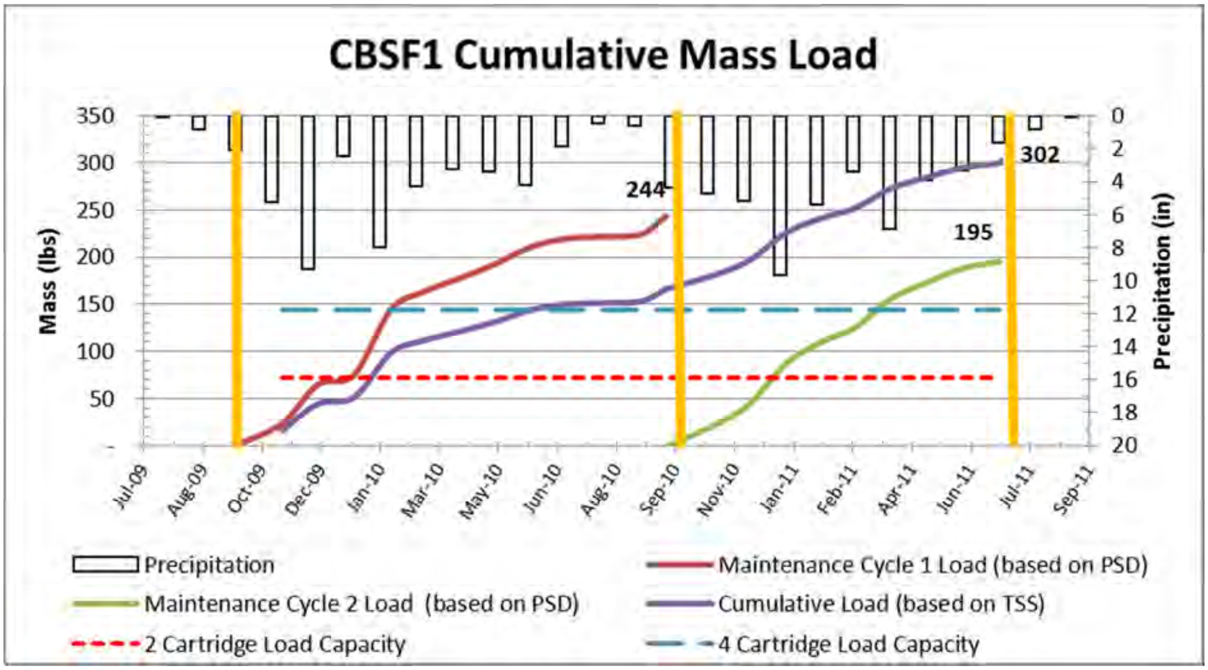


Figure 1. Estimated cumulative mass load received by CBSF1.

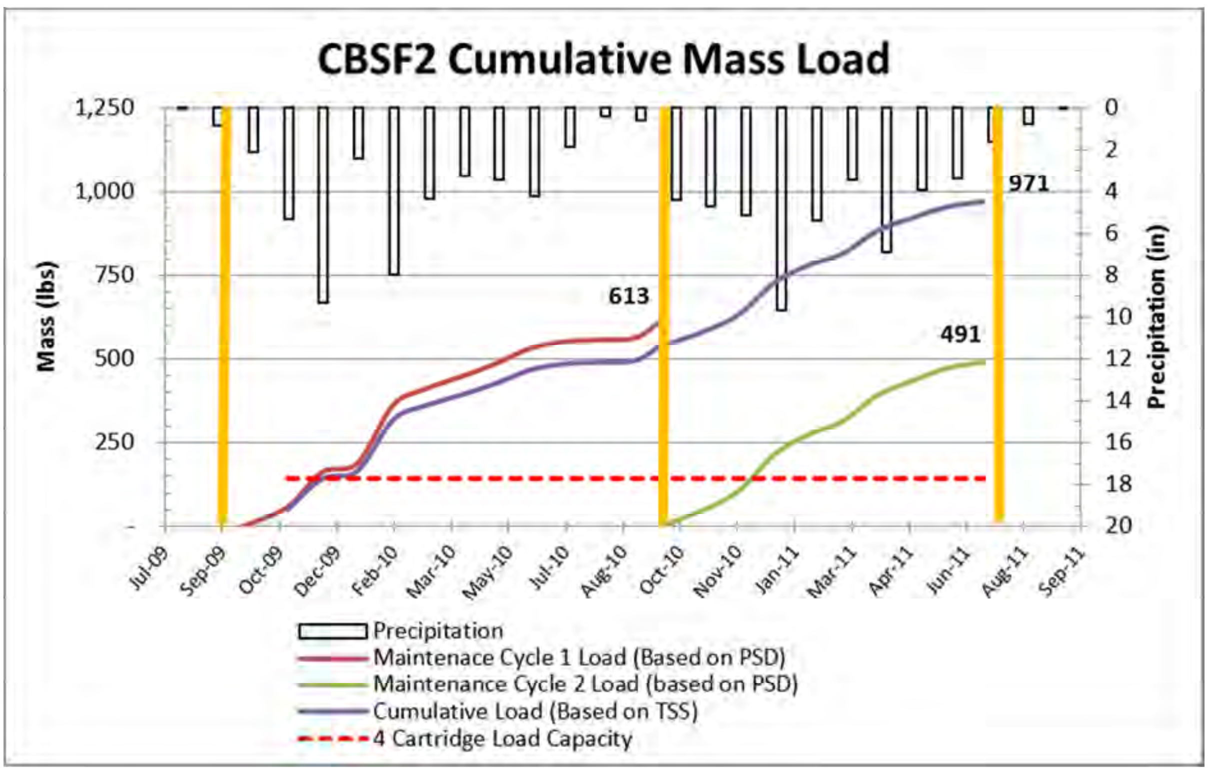


Figure 2. Estimated cumulative mass load received by CBSF2.

Table 2. CBSF1 Maintenance Intervals

CatchBasin StormFilter (capacity)	Manufacturer Recommended Sediment Load Capacity (lbs)	Maintenance Frequency to Accommodate Annual Mass Load of 219 lbs (months)	Maintenance Frequency to Accommodate Annual Mass Load of 158 lbs (months)
2 cartridges	72	4	5
3 cartridges	96	5	7
4 cartridges	144	8	11

The average mass load ((613+491)/2) to the CBSF2 system during the evaluation period was 552 pounds. Since the CBSF2 is 4 cartridges, an estimated maintenance frequency for this system based on the 4 cartridges has been provided in Table 3.

Table 3. CBSF2 Maintenance Intervals

CatchBasin StormFilter	Manufacturer Recommended Sediment Load Capacity (lbs)	Maintenance Frequency to Accommodate Annual Mass Load of 552 lbs (months)	Maintenance Frequency to Accommodate Annual Mass Load of 397 lbs (months)
4 cartridges	144	3	4

The systems did receive a volume that was 38% greater than the mean annual precipitation over the two-year period. The evaluation period was over the course of 21 months, and the mean annual precipitation was estimated to be 28% greater during this time frame (1/26/2012 e-mail communication). Assuming that the mass load could be reduced by 28% (219 lbs*(1 - 0.28) = 158 lbs), CBSF1 with 4 cartridges (144 lbs) is estimated to reach its mass load capacity at approximately 11 months. As CBSF2 is very undersized for the drainage area, the system will require frequent maintenance during an average annual precipitation year. Assuming that the mass load could be reduced by 28%, (552 lbs* (1 - 0.28) = 397 lbs), CBSF2 with 4 cartridges (144 lbs) is estimated to reach its mass load capacity at approximately 4 months. The manufacturer recommended mass load capacity (144 lbs) could be further adjusted based on the sediment accumulation results in Table 6 and 7. The results in Tables 6 and 7 indicate a mass load capacity of approximately 93 pounds for CBSF1 with 2 cartridges and 282 pounds for CBSF2 with 4 cartridges.

Mass Load Design

A majority of the runoff models (WWHM, MGS Flood, etc.) used in Washington do not typically adjust for or incorporate an estimate for the annual mass load of sediment being received by the BMP. For systems downstream of detention, Contech typically provides recommendation for a design that accounts for annual mass load to assist with determining longevity (e.g. ensure annual maintenance) in the field. Currently the regulated requirement is to design a system downstream of detention to meet the two-year release rate (simply a flow-based design). Typically, flow-based designs do not undergo a mass load analysis to estimate longevity and maintenance requirements.

Through field data collection we can calibrate a flow-based design to accommodate annual mass loading considerations. For most sites in Washington State the default influent solids concentrations are assumed to be approximately 30-60 mg/L, which is substantiated by multiple investigations by Contech (and others) in the Northwest. Northwest field data per TAPE (2002) are presented in Table 4 showing the median TSS or SSC<500 event mean concentration. Ecology currently does not have any guidance for stormwater treatment BMPs to integrate mass load design considerations for ensuring annual (or longer) maintenance intervals.

Table 4. Median Event Mean Concentrations in the Northwest

Site	Land Use	Median TSS or SSC<500 um (mg/L)	Reference
Bellingham, WA	Roadway	34	Contech, 2011
Everett, WA	Roadway	95	Contech, 2004
Tacoma, WA	Roadway	54	City of Tacoma, 2008
Olympia, WA	Commercial	27	Contech, 2005
University Place, WA	Commercial	30	Contech, 2007
Vancouver, WA	Commercial	32	Contech, 2004b
Portland, OR	Commercial	35	Contech, 2011
	Roadway Average	61	
	Commercial Average	31	
	CBSF1 Mean TSS	88	
	CBSF2 Mean TSS	97	

For comparative purposes, if these systems (CBSF1 and CBSF2) were retrospectively designed for the above average water years, longer flow durations, increased water quality design storm, and with mass loading considerations using PSD values to ensure an annual maintenance cycle:

- Site 1 (0.18 acres) design recommendation would be for 7 cartridges. (219 lbs per site/36 lbs per cartridge)
- Site 2 (0.97 acres) design recommendation would be for 16 cartridges. (552 lbs/36 lbs per cartridge)

Sediment Accumulation

The units evaluated were put under a fair amount of stress from a combination of long flow durations and higher peak flows than the modeled design flows, in addition to a fairly high mass load. Yet these systems showed robust performance. Sediment accumulation is often an overlooked measurement, and we appreciate the additional level of detail provided by SPU.

Table 5. Average Sediment Accumulated Data Table

Table 4.3.1d. Average Sediment Accumulation Data Table (WY 2009, WY2010, WY2011)

Location	ID	Average Sediment Depth (ft)	Sediment Volume (CF)	Wet Density (lbs/cf)	Dry Density (lbs/CF)	Wet Sediment Mass (kg)	Wet Sediment Mass (lbs)	Dry Sediment Mass (kg)	Dry Sediment Mass (lbs)	Total Wet Sediment Mass per unit (lbs)	Total Dry Sediment Mass per Unit (lbs)	Accumulation Period (Days)
CBSF1-Influent	CBSF1-Sed 1	0.45	1.82	61.85	18.25	56.13	123.75	21.60	47.62			
CBSF1-Filter	CBSF1-Sed 2	0.09	0.69	72.75	18.65	24.93	54.97	16.37	36.08	186	57	241
CBSF1-Effluent	CBSF1-Sed 3	0.09	0.10	71.55	18.75	3.20	7.05	2.00	4.41			
CBSF2 Influent	CBSF2-Sed 1	1.24	5.01	78.73	28.37	179.10	394.85	93.43	205.99			
CBSF2 Filter	CBSF2-Sed 2	0.12	1.79	81.93	34.97	66.53	146.68	38.80	85.54	554	210	283
CBSF2-Effluent	CBSF2-Sed 3	0.12	0.12	101.80	43.90	5.73	12.64	4.30	9.48			

The SPU CBSF Report, Section 4.3.1 - Sediment Accumulation Monitoring Results contain results from the mass retained in the system for 2 ¼ years (WY 2009, WY2010, WY2011). The "total mass retained in the system" in the report does not include the mass retained by the filter cartridges. Water Year 2009 results represent only a fraction of the year as it was cleaned out before analysis. CBSF1 in Water Year 2011 is slightly underestimated as some material was dislodged during a flow calibration test. The SPU CBSF Report contains a table for each Water Year (Tables 4.3.1a –c). Table 5 (Table 4.3.1d) is an average of the sediment accumulated from the data available. Table 5 was modified to include total pounds rather than kilograms. Table 5 was not included in the SPU report, but is recommended for inclusion as Table 4.3.1d.

From Table 5 we can compare the mass load retained by the system (observed) to the mass load recommended by Contech (expected). Table 6 highlights the mass retained by the system and compares it to the recommended mass load design capacity. Since the ZPG media in the cartridges were not included in the mass load analysis, Contech has estimated that the filter cartridges have each retained approximately 18 pounds of sediment. This 18 pound value was determined from laboratory loading tests conducted by Contech (Contech, 2005b) that suggest approximately 50% of the load is retained in the cartridges and 50% of the load is on the floor as captured by the system (50% x 36 lbs = 18 lbs).

Table 6. Observed and Expected Load Retained

System	Acres	Number of Cartridges Evaluated	Average Retained Wet Sediment Mass per System (lbs)[a]	Average Retained Dry Sediment per System (lbs)[a]	Estimated Mass Retained (With Cartridges)[b]	Recommended Mass Sediment Retained Per System (lbs)[c]	Difference (lbs)
CBSF1	0.18	2	186	57	93	72	21
CBSF2	0.97	4	554	210	282	144	138

a – Sediment retained in the system without weighing cartridge media.
b – Sediment retained including an estimated mass retained by the cartridge media. Cartridge mass load retained was estimated to be 18 lbs per cartridge per Contech laboratory loading study.
c – Recommended mass retained by system is based on Contech laboratory loading study at 36 lbs per cartridge.

The average sediment accumulation per system can also be evaluated on a per cartridge basis. The design recommendation from Contech is that each cartridge has a mass load capacity of 36 pounds, distributed between the media the precast vault floor. Table 7 is recommended to be included in the report as Table 4.3.1e. The data indicate that CBSF1 mass loading was approximately 131% and CBSF2 mass loading was 192% of the manufacturer design recommendation, on a per cartridge basis.

Table 7. Average Sediment Accumulation per Cartridge

Table 4.3.1e. Average Sediment Accumulation per Cartridge

	Total Wet Sediment Mass per Cartridge (lbs)	Total Dry Sediment Mass per Cartridge (lbs)	Estimated Dry Sediment Mass Per Cartridge (lbs)
CBSF 1 (2 cartridges)	93	29	47
CBSF 2 (4 cartridges)	139	52	69

The results presented in Table 5, 6 and 7 have likely underrepresented the entire load retained by the system on an annual basis as previously discussed. The sediment accumulation data does suggest that the CBSF at both sites have certainly exceeded the manufacturer's expectations. The data may indicate that the recommended mass load capacity may be too conservative for the site and/or possibly for the CBSF.

Grated Inlet Clogging

There is a significant challenge ahead for all best management practices (BMPs) in dealing with large amounts of coarse particulate organic matter (CPOM) such as leaves, bud shatter, etc. Contech will continue to work with the SPU in the design of structures that can meet the challenges associated with CPOM and grit build-up in the grates. This challenge is likely to be much more prevalent as the regulatory requirements move to incorporate more vegetated BMPs.

Additional research is required to understand the fate, transport, and mobilization of CPOM, Fine Particulate Organic Matter (FPOM) and its long term effects on BMP design. Due to the high volume of CPOM exhibited at these sites it would be suggested that further studies evaluate either Total Organic Carbon (TOC) or Total Volatile Suspended Solids (TVSS) data to assist in characterization of the incoming and exiting loads. Our preference has been to collect TVSS as a surrogate to assist in understanding the fate, transport, and mobilization of CPOM and FPOM.

Dissolved Metals

In general the dissolved metals concentrations at the site were very low. The difficulty with field collection and the inherent margin of error (flow, sample equipment, analytical laboratory, etc.) makes it difficult to rely on or to interpret removal efficiency of a BMP experiencing low influent concentrations.

We do know that these sites received higher than anticipated runoff volumes, longer flow durations, higher peak flows, substantial solid loads, and large amount of Coarse Particulate Organic Matter (CPOM). All of these factors impact long term performance of the system. The zeolite within the ZPG media does have a finite capacity. Once the cation exchange capacity is exhausted, the media is no longer able to uptake soluble metals. The median influent dissolved copper for CBSF1 was 6 ug/L, and CBSF2 was 4.3 ug/L. The median influent dissolved zinc for CBSF1 was 27.6 ug/L and CBSF2 was 19.5 ug/L. Total zinc and total copper were consistently removed throughout the entire evaluation period.

The results from September 2009 to September 2010 appear to be fairly representative of the StormFilter with ZPG media at low influent concentrations. The September 2010 to June 2010 appear that the media exhausted its cation exchange capacity soon after maintenance occurred. Unfortunately, there is not enough resolution in the data set to determine exactly when the cation exchange capacity was exhausted in the media (e.g. breakthrough).

References

CONTECH Stormwater Solutions Inc. (2004). Lake Stevens North Field Evaluation: Stormwater Management StormFilter with ZPG Media (Document PE-E012). Portland, Oregon: Author.

CONTECH Stormwater Solutions Inc (2004b). Heritage Marketplace Field Evaluation: Stormwater Management StormFilter with ZPG Media (Document PE-E081). Portland, Oregon: Author.

CONTECH Stormwater Solutions Inc. (2005). The Daily Olympian Field Evaluation: Stormwater Management StormFilter with Perlite/MetalRx Media (Document PE-F030). Portland, Oregon: Author.

CONTECH Stormwater Solutions Inc. (2005). Evaluation of the Lifecycle Loading Characteristics of the Stormwater Management StormFilter® Cartridge: ZPG StormFilter cartridge at 28 L/min (7.5 gpm) and Sandy Loam (Document PE-F090). Portland, Oregon: Author.

CONTECH Stormwater Solutions Inc. (2007). Fred Meyer Stormwater Treatment System Field Evaluation: The Stormwater Management StormFilter with Perlite Media at 57 L/min/cart (Document PE-H100). Portland, Oregon: Author.

CONTECH Stormwater Solutions Inc. (2011). West Hills Plaza Stormwater Treatment System Field Evaluation: The Stormwater Management StormFilter with Perlite Media at 28 L/min/cart. Portland, Oregon: Author.

CONTECH Stormwater Solutions Inc. (2011). Cable Street Stormwater Management StormFilter® Field Evaluation Project: Portland, Oregon: Author.

City of Tacoma and Taylor Associates, Inc. (2008). EvTEC Ultra-Urban Stormwater Technology Evaluation Stormwater Management StormFilter® Final Report. Tacoma, Washington: Author.