

**STUDY PHASE ENGINEERING AGREEMENT
BETWEEN PBS&J AND HARRIS COUNTY
to Provide Professional Engineering Services
and Monitoring to Study the Effects of
Permanent Stormwater Quality Features**

**DRAFT
Basin K542-00-00
Phase I Evaluation**

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Acronyms and Abbreviations

ANOVA	Analysis of Variance
ASCE	American Society of Civil Engineers
AVFM	area velocity flow meter
BDL	below detection limit
BMP	Best Management Practices
BOD ₅	biochemical oxygen demand 5-day
CMP	corrugated metal pipe
COD	chemical oxygen demand
CV	coefficient of variation
DQO	Data Quality Objective
EMC	event mean concentration
EPA	Environmental Protection Agency
FS	flow station
HCFC	Harris County Flood Control District
HCSWQ	Harris County Public Infrastructure Department Storm Water Quality Section
H-GAC	Houston-Galveston Area Council
H&H	hydrology and hydraulic
ID	inside diameter
MS	monitoring station
NPDES	National Pollutant Discharge Elimination System
NURP	Nationwide Urban Runoff Program
O&M	operation and maintenance
PSD	particle size distribution
SPSS	Statistical Package for the Social Sciences
SSC	suspended sediment concentration
SWMP	Storm Water Management Program
SWQMP	Storm Water Quality Management Plan
TDS	total dissolved solids
TKN	total Kjeldahl nitrogen
TSS	total suspended solids

1.0 INTRODUCTION

1.1 CONTRACT

On February 17, 2004, Harris County retained PBS&J under an Agreement for Engineering Services (Harris County Purchase Order No. P071730, Request No. 143956) to initiate and perform long-term systematic stormwater quality monitoring at a detention facility serving a single residential subdivision that will ultimately operate in three outlet design configurations during the entire monitoring program. This report describes the nature of the monitoring program and presents the results of the first phase of monitoring activities. Twenty-six storm events were successfully monitored, resulting in the collection of 25 composite samples and four grab samples during the period from May 2005 to July 2006.

1.2 BACKGROUND

Under its National Pollutant Discharge Elimination System ("NPDES") stormwater permit, Harris County must develop and implement a Storm Water Management Program ("SWMP") that addresses pollutant discharges from areas of New Development and Significant Redevelopment. To address these discharges, the County requires land developers to design and implement Storm Water Quality Management Plans ("SWQMP") for new properties that sometimes include the use of stormwater quality ponds or basins as stormwater best management practices ("BMP"). However, the effectiveness of these facilities has not been evaluated in Harris County through systematic BMP performance monitoring.

In order to address concerns over local BMP effectiveness, the Harris County Public Infrastructure Department Storm Water Quality Section ("HCSWQ") contracted PBS&J to conduct long-term systematic stormwater quality monitoring at detention basin K542-00-00 serving the Lakewood Oaks Estates subdivision. Basin K542-00-00 was selected as the most suitable monitoring candidate from a group of 18 detention basins located within Harris County (PBS&J, 2004b).

PBS&J conducted monitoring activities to meet the requirements of the first phase of the three-phase program. This report serves as the report of the Phase I monitoring results called for in Section II.G of Amendment 2 to the February 17, 2004, contract.

1.3 MONITORING PHASES AND GOALS

HCSWQ desires comparative performance information for three different outlet design configurations. To reduce the number of variables that might impact water quality performance, a single facility was chosen for monitoring. This will allow comparison of performance data without varying watershed characteristics, such as soils, imperviousness, and land use. For this monitoring program, Basin K542-00-00 will ultimately operate in three outlet design configurations, including:

- Standard detention – designed to control the peak flow arising from a 100-year storm.
- Water quality pond system – designed to capture and slowly release the first ½-inch of runoff.
- Combined detention – designed to capture floatables and control the peak flow arising from both a 10-year and a 100-year storm.

The first phase of the program, for which the results are herein presented, was performed for the first outlet design configuration listed above. The information obtained from this and all other phases associated with this long-term systematic monitoring program should allow Harris County to evaluate the relative performance of each outlet configuration. The results of all three monitoring phases will assist HCSWQ in reviewing their existing criteria for new development BMP's.

1.4 ORGANIZATION OF DOCUMENT

This document is organized into nine sections as follows:

Section 1 – Introduction: Section 1.0 provides the background of the agreement between Harris County and PBS&J, the purpose of the project including the three monitoring phases and goals, and document organization.

Section 2 – Site Information: Section 2.0 discusses the basin location, watershed characteristics, precipitation and hydrology information, and the basin purpose and design.

Section 3 – Sampling Activities: Section 3.0 summarizes the sampling and analytical methods used in this study.

Section 4 – Monitoring Results: Section 4.0 summarizes the storm event data, the laboratory results, and the quality assurance findings of the monitoring activities.

Section 5 – Statistical Analysis: Section 5.0 presents the statistical analysis of the results, including summary statistics, analysis of variance, box-whisker plots, effluent probability plots, and grouped analysis.

Section 6 – Discussion of Results: Section 6.0 discusses the results of the statistical analysis and grouped analysis, including numerical and seasonal comparisons.

Section 7 – Future Work: Section 7.0 summarizes Phase II, Phase III, and the final report of the project.

Section 8 – Summary: Section 8.0 provides an overview of the report.

Section 9 – References: Section 9.0 provides a comprehensive list of references cited in this report.

2.0 SITE INFORMATION

This section summarizes the site selection process and describes the detention basin, K542-00-00, and its contributing watershed.

2.1 SITE SELECTION

The *Study Phase Engineering Agreement Between PBS&J and Harris County to Provide Professional Engineering Services and Monitoring to Study the Effects of Permanent Storm Water Quality Features: Site Selection Report* (PBS&J, 2004b) describes the efforts undertaken to identify a stormwater basin suitable for long-term systematic monitoring of the three design modes outlined in Section 1.3. It was determined that the selected basin and contributing drainage area needed to possess attributes that were representative of the majority of basin drainage area systems within Harris County and that it serve a residential drainage area. A comprehensive set of site selection criteria were established to filter out unique basin systems that would not perform similarly to other basins within the county. The Site Selection Criteria are included in Appendix A.

Eighteen candidate basins were reviewed against the site selection criteria based upon Harris County Public Infrastructure knowledge of the basins, as-built plans, storm sewer layout, drainage area plans, and site visits. An outline of candidate basins evaluated and justification for elimination are summarized in the Summary of Harris County Flood Control District ("HCFCD") Basin Candidate Evaluations included in Appendix A.

Basins K542-00-00 and B504-00-00 met all of the site selection criteria and were compared to each other based upon ranking of the priority of each criteria and the level to which each criteria was met. This is summarized in the Site Selection Criteria Comparison of Basins B504-03-00 and K542-00-00 in Appendix A.

PBS&J performed preliminary hydrology and hydraulic ("H&H") modeling on the two remaining basins. The H&H analysis was performed to determine with a reasonable degree of certainty whether the basins would operate adequately during the planned project retrofit conditions without over-excavation or downstream flooding with proper design and construction of the retrofit outlets. The analysis for each basin was performed as follows:

- The drainage area and storm sewer layout plan sheets for each development draining to the basin were used to determine the total drainage area to the basin.
- The 10-year and 100-year runoff hydrographs were generated using the small watershed method.

- A MIKE-SWMM model was built using the as-built plan sheets, the generated hydrographs, and anticipated tailwater conditions.
- The model consisted of a storage junction connected to a secondary junction by an orifice and a weir with a pipe outfalling to the third junction at Faulkey Gully.
- The model was run and the results were evaluated.

Model results indicated that both basins would likely perform adequately under the planned retrofit conditions and similar to their original design. Results also indicated that neither should require any over-excavation, assuming the retrofitted outlets are properly designed and constructed to prevent downstream flooding and erosion of the basin and channel.

Basin K542-00-00 was selected over Basin B504-03-00 for the following reasons:

- B504-03-00 had two inlets, which would have made sampling more costly and the evaluation of results more difficult.
- A significant amount of undeveloped land was located adjacent to B504-03-00. While specific plans were not identified for development within the property or future storm sewer connection from the property to the facility, the possibility did exist.
- B504-03-00 was being considered by HCFCD for monitoring under a grant from the General Land Office.

2.2 SITE LOCATION

Basin K542-00-00 is located in northwest Harris County approximately 1,300 feet south of the intersection of Spring-Cypress Road and Faulkey Gully (HCFCD Unit K142-00-00). Figure 2-1 presents a vicinity map of the basin location.

2.3 SITE CLIMATE

Basin K542-00-00 is located in the flat Coastal Plains, about 60 miles from the Gulf of Mexico and about 35 miles from Galveston Bay. The climate is predominantly marine. The terrain includes numerous small streams and bayous that together with the nearness of Galveston Bay favor the development of both ground and advective fogs. Prevailing winds are from the southeast and south, except in January when frequent passages of high-pressure areas bring invasions of polar air and prevailing northerly winds (USDA, 1976).

Temperatures are moderated by the influence of winds from the Gulf. Another effect of being close to the Gulf is abundant rainfall, except for rare extended dry periods. Rainfall records (1971-2000 data from NCDC, 2002) from the atmospheric monitoring station located at Houston Bush Intercontinental Airport report a typical total rainfall amount of 47.84 inches per year.

2.4 WATERSHED CHARACTERISTICS

The total drainage area contributing stormwater flow to the basin is approximately 116 acres. Based on review of aerial imagery (H-GAC, 2002), the land use is almost completely residential and is fully built-out, with the exception of one small undeveloped commercial lot in the northwestern corner of the drainage area. Impervious surfaces are estimated to comprise 30 to 50 percent of the drainage area. Remaining surface area is primarily resident managed lawn. Topography in the area is generally flat, ranging from 140 to 150 feet above mean sea level. The basin and drainage area boundaries are shown in Figure 2-1.

Basin K542-00-00 is principally underlain by Gessner complex (Gs) soil, which is nearly level, poorly drained, and moderately permeable sandy clay loam. The contributing drainage area is underlain by Gessner complex and Wockley fine sandy loam (Wo). Wockley fine sandy loam is a nearly level, sandy clay that is identified as being somewhat poorly drained and having moderately slow permeability. Both Gessner complex and Wockley fine sandy loam are typical soil types found within northwest Harris County (USDA, 1976).

2.5 BASIN DESCRIPTION AND FUNCTION

Basin K542-00-00 is located on approximately 7 acres of property owned by HCFCD. The current detention basin layout represents a standard detention basin that is designed to control the peak flow arising from a 100-year storm. This is the required layout of the first phase of monitoring activities as described in Section 1.3. The current layout is illustrated in Figure 2-2. Stormwater runoff from the Lakewood Oaks Estates subdivision enters the detention basin through a 96-inch corrugated metal pipe ("CMP"). A plunge pool has formed in the vicinity of the inlet pipe due to inflow scouring. The original design of the basin included a 12-foot-wide concrete pilot channel to direct water to the outlet pipe, but the scouring at the inlet destroyed a section of the pilot channel and lead to the sedimentation of the remaining portion of the pilot channel.

A 66-inch CMP outlet is located approximately 375 feet from the inlet. Water flows through the outlet pipe for approximately 180 feet before discharging into Faulkey Gully. Water may also enter the basin from Faulkey Gully ("reverse flow") due to the slight slope of the outlet pipe. This situation occurs when the water surface elevation in the gully exceeds the water surface elevation in the basin.

Figure 2-2
System Layout for Basin K542-00-00

A second inlet is located in the northwest corner of the basin. The inlet structure is a 24-inch CMP. The inlet serves a drainage area of less than 1 acre, which is comprised of a 14-foot wide utility easement and a 20- to 25-foot drainage swale that borders the lots surrounding Victory Court in the Lakewood Oaks Estates subdivision (CLR, 1997). A portion of the undeveloped 4-acre lot north of the drainage swale that is not part of the Lakewood Oaks Estates subdivision may also drain to the swale and then to the inlet. Inflow to the basin from the second inlet was considered insignificant with respect to the inflow from the 96-inch inlet and was not monitored.

A summary of the basin design information is provided in Table 2-1. The applicable basin record drawings depicting the basin slopes and flow lines are provided in Appendix B.

Table 2-1
Basin K542-00-00 Design Summary

<ol style="list-style-type: none"> 1. AREA SERVICED = 115.50 ACRES 2. DETENTION STORAGE RATE = $C_s = 0.56$ ACRE-FEET/ACRE 3. DETENTION STORAGE VOLUME REQUIRED = 64.68 ACRE-FEET 4. DETENTION STORAGE VOLUME PROVIDED = 64.78 ACRE-FEET 5. MAXIMUM DESIGN WATER SERVICE ELEVATION = 140.48 FEET 6. MAXIMUM OUTFALL RATE ALLOWED = 172 CFS 7. MAXIMUM OUTFALL RATE PROVIDED = 172 CFS 8. RESTRICTOR SIZE = 66 INCHES <p style="margin-top: 10px; font-size: small;">Source: CLR, 1997</p>
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In March 2005, monitoring stations were installed at the inlet and outlet storm sewer pipes. The locations are shown in Figure 2-3. The station located at the 96-inch CMP inlet was Monitoring Station 1 (MS-1). The station located at the 66-inch CMP outlet was Monitoring Station 2 (MS-2). MS-2 consisted of two separate sampling stations that were used to evaluate the quantity and quality of: (1) detained water leaving the basin ("outflow"); and (2) water entering the basin from Faulkey Gully ("reverse flow"). All of the sampling stations included automated sampling instruments ("auto-samplers") for collecting samples from within the storm sewer pipes. The instruments also recorded flow data collected by area velocity flow meters ("AVFM") located within the storm sewer pipes. A rain gauge was located at MS-2 at the outlet of the basin.

Figure 2-3
Monitoring Station Layout for Basin K542-00-00

2.6 BASIN OPERATION AND MAINTENANCE

HCFCFCD routinely conducts operation and maintenance ("O&M") activities at Basin K542-00-00. HCFCFCD O&M activities included:

- Basin mowing
- Erosion repair
- Herbicide/pesticide application

By maintaining the routine maintenance schedule, monitoring data better represented the typical treatment effectiveness of the basin.

In addition to the routine O&M procedures, it was necessary to perform some basin maintenance prior to the start of monitoring activities for each outlet configuration. Pre-monitoring maintenance included vegetation thinning within the basin and erosion repair around the inlet and outlet pipes. It is important to ensure that the basin is in similar condition at the start of each monitoring phase.

2.7 INTERNATIONAL STORMWATER BMP DATABASE

Basin information and data from the monitoring study will be transferred and handled in Microsoft Access using the database structure of the International BMP Database prepared by the American Society of Civil Engineers ("ASCE") and the United States Environmental Protection Agency ("EPA"). The general structure of the database is presented in Figure 2-4. The completed database forms for this phase of the monitoring study are included in Appendix C.

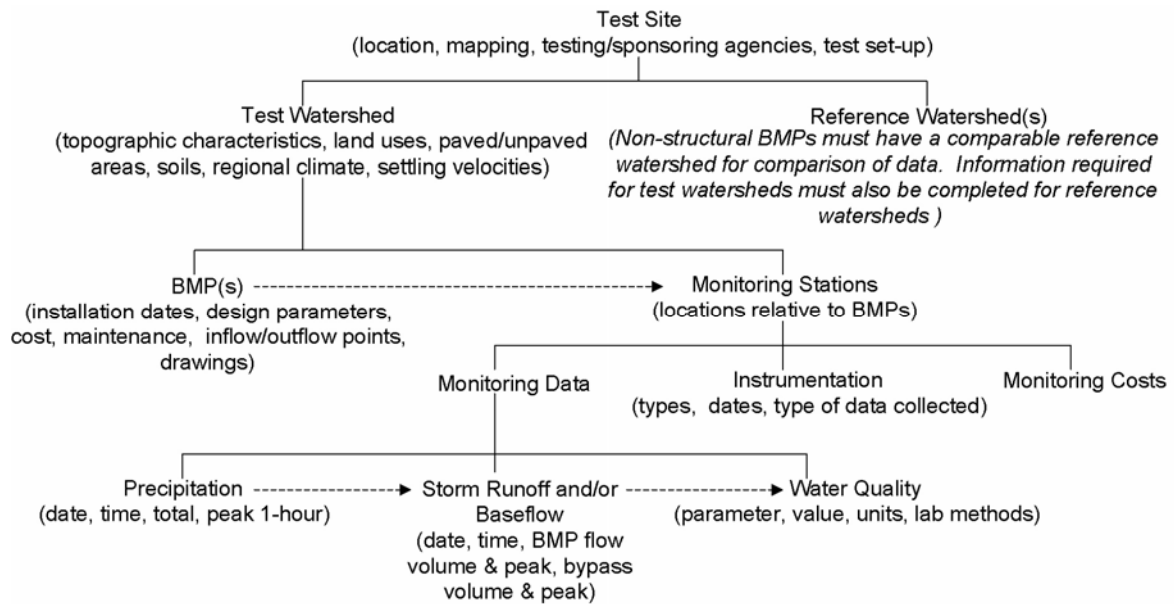


Figure 2-4
Database Structure (Source: ASCE, 2002)

3.0 SAMPLING ACTIVITIES

This section summarizes the sampling and analytical methods used as described in the *Study Phase Engineering Agreement Between PBS&J and Harris County to Provide Professional Engineering Services and Monitoring to Study the Effects of Permanent Storm Water Quality Features: Monitoring Plan and Quality Assurance Project Plan* (PBS&J, 2004a).

3.1 INTRODUCTION

Water quality and flow data were collected from 26 storm events at the project site from May 2005 to July 2006.

3.2 GENERAL SAMPLING METHOD

Basin K542-00-00 inflow, outflow, and reverse flow were sampled multiple times on a flow-proportional basis to obtain the event mean concentration ("EMC") from each qualified storm event as defined below. The EMC result was obtained at the sampling locations by analyzing a flow-weighted composite sample consisting of a qualified number of sub-samples collected by an automatic sampling device. The EMC is a statistical parameter used to represent the flow-proportional average concentration of a given parameter during a storm event.

Only storms meeting the criteria for qualifying storms were sampled for all constituents. Meteorological conditions were monitored in order to anticipate qualifying rain events. When qualified rain events were expected, staff members were deployed to the site for the collection of samples. The qualifying event criteria were defined in the monitoring plan as follows:

1. Rainfall Volume: 0.10 inch minimum
2. Antecedent Dry Period: 24 hours minimum

A total of four sets of grab samples were collected from four storm events at the inlet and the outlet. Grab samples were collected whether or not the storm met the qualifying conditions outlined above. The grab sample sets were collected across the storm hydrograph as follows:

- One first flush sample
- One sample along the rising limb of the hydrograph
- One sample near the peak of the hydrograph
- One sample along the falling limb of the hydrograph

The monitoring team utilized a depth staff as well as the level and flow sensors at each monitoring station to determine the occurrence of the first flush, rising limb, peak, and falling limb of the hydrograph.

Sample collection checklists were developed to guide the sampling activities at Basin K542-00-00. The sample collection checklists are provided in Appendix D.

3.3 SAMPLING EQUIPMENT

Monitoring Stations 1 and 2 were comprised of Sampling Stations SS-1, SS-2, and SS-3, which collected water quality samples from inlet, outlet, and reverse flows, respectively. The locations of the monitoring stations are shown in Figure 2-3. The sampling stations utilized ISCO 6712FR refrigerated automated sampling instruments. These instruments allowed the collection of flow-proportional samples of up to 5 gallons using a peristaltic pump. The ISCO 6712FR has a programmable controller with a data logger and memory to allow the collection and storage of rainfall, level, velocity, and sample collection data. A CDMA digital cellular modem was used to remotely communicate with the ISCO 6712FR controller and to download data stored within the data logger. The ISCO 6712FR and cellular modem were housed within secure, vented shelters.

Flow Stations FS-1, FS-2, and FS-3 were located at Sampling Stations SS-1, SS-2, and SS-3, respectively. Level and velocity data were collected at the flow stations. Each station consisted of ISCO SPA 1074 low profile area velocity sensors connected to the ISCO 6712FR controllers through ISCO 750 series modules. One rain station, RS-1, was located at SS-2 and consisted of an ISCO 674 rain gauge connected directly to the ISCO 6712FR controller.

Aliquot samples were collected via a 3/8-inch diameter ("ID") Teflon™ suction line that extended from the collection point through a remote pump to the composite bottle at the ISCO 6712FR. The sample collection point was slightly elevated off the bottom of the CMP with the intake tube opening facing downstream. At SS-1, a stainless steel floatables excluder was installed to prevent debris, such as pine needles, mulch, and other yard waste, from entering and clogging the suction line. A photo of the floatables excluder is included in Appendix E. The floatables excluder's mesh allowed particles less than 200 µm to enter the suction line.

The auto-samplers purged the 3/8-inch Teflon tubing before and after aliquot samples were collected by reverse pumping air through the line. The auto-sampler was programmed with four different activity modes: Inhibited, Enabled, Active, and Shut Down.

The auto-sampler began in "Inhibited" mode. When the area velocity meter measured level at a specific depth, the auto-sampler switched from "Inhibited" to "Enabled" mode. Once the area velocity meter measured a qualifying volume of runoff flow, the auto-sampler became "Active" and collected an aliquot. The ISCO 6712FR collected an aliquot every time an additional qualifying volume of flow was measured.

The auto-sampler automatically "Shut Down" whenever the sample container became full or was manually "Shut Down" at the end of the flow event.

During the collection of grab samples, pH and temperature data were recorded at SS-1 and SS-2 using a YSI 600XLM Multiprobe. The measurements were taken from the center of flow at the mouth of the 96-inch and 66-inch CMP's. The YSI 600XLM Multiprobe was calibrated prior to collecting measurements in the flow stream.

3.4 SAMPLING EQUIPMENT MAINTENANCE

Maintenance on the sampling equipment at Basin K542-00-00 was performed after each storm event. Maintenance checklists were developed to guide the maintenance activities and are provided in Appendix D.

Major maintenance activities included inspecting the sample intake ports, replacing defective suction tubing, addressing vandalism to the sample shelters, cleaning the condenser coil and air filter on the ISCO 6712FR's, checking all connections to the ISCO 6712FR controller, replacing defective pump tubing, cleaning the strainer and the floatables excluder, and addressing error messages on the ISCO 6712FR controller.

3.5 MONITORING CONSTITUENTS

Constituents monitored at the project site are listed in Table 3-1.

Grab samples were collected at SS-1 and SS-2. No grab samples were collected at SS-3. Grab samples were analyzed by the laboratory whether or not the storm met the qualifying conditions. The grab samples were collected across the storm hydrograph as described in Section 3.2.

Bacteria samples were collected using a sterilized dipping cup. Samples were collected from the surface of the center of the flow at the 96-inch and 66-inch CMP's located at MS-1 and MS-2. Sample water was poured into a 120-mL plastic container preserved with $\text{Na}_2\text{S}_2\text{O}_3$ and ice in accordance with the analytical methods (see Table 3-2).

**Table 3-1
Constituents Monitored at Basin K542-00-00**

Sample Type	Constituent	STORET Code
Composite (SS-1, SS-2, and SS-3)	Total Suspended Solids (TSS)	00530
	Total Dissolved Solids (TDS)	70300
	Suspended Sediment Conc. (SSC)	80154
	Specific Gravity of Solids ¹	82205
	Percent Clay, Silt, and Sand (<0.0039 mm) ¹	82009
	Percent Silt (<0.0625 mm) ¹	82008
	Percent Sand (<2.0 mm) ¹	89991
	Percent Gravel (72.0 mm) ¹	80256
	Particle Size Distribution	80250-80255
	Total Phosphorous	00665
	Dissolved Phosphorous	00666
	Ortho-Phosphate	70507
	Total Kjeldahl Nitrogen	00625
	Nitrate and Nitrite Nitrogen	00630
	Metals, Total	
	Zinc	01092
	Lead	01051
	Copper	01042
	Cadmium	01027
	Silver	01077
	Nickel	01067
	Mercury	71900
	Cyanide, Free (amenable to chlorination)	00722
	Cyanide, Total	00720
	Biochemical Oxygen Demand (BOD ₅)	80082
	Chemical Oxygen Demand (COD)	00335/00340 ²
Total Hardness	00900	
Pesticides/Herbicides	N/A	
2,4,5-T Dalapon	N/A	
2,4,5-TP Dichloroprop		
2,4-D MCPA		
2,4-DB MCPP		
Dicamba		
Grab (SS-1 and SS-2)	Bacteria	
	Fecal Coliform	31613
	Fecal Enterococci	31701
	Escherichia coli	31699
	pH	00403
	Oil and Grease	00552
Field Measurement (SS-1 and SS-2)	pH	00406
	Temperature	00011

1 No data was collected for these constituents. The amount of suspended sediment in the samples was insufficient for laboratory analysis.

2 Based on the concentration of K₂Cr₂O₇ used, 0.025N: 0035; 0.25N 00340

Oil and grease samples were collected by partially submerging the sampling container directly into the flow stream. Samples were collected from surface of the center of the flow at the 96-inch and 66-inch CMP's located at MS-1 and MS-2. The sample containers were removed from the water flow as soon as they were completely filled. The oil and grease containers were preserved with H₂SO₄ to reduce the sample pH to 2, and were sealed with a PTFE-lined cap in accordance with the analytical methods (see Table 3-2).

The pH samples were collected using a sterilized dipping cup from the center of flow at the 96-inch and 66-inch CMP's. Sample water was poured into 100-mL plastic containers in accordance with the analytical methods (see Table 3-2).

Grab samples were placed on ice and shipped to the laboratory within the required analytical holding time. Xenco Laboratories was used to analyze all of the constituents, excluding bacteria and particle size distribution. Bacteria samples were analyzed by Hygeia Laboratories, Inc., and particle size distribution analyses were conducted by Spectrex, Inc.

**Table 3-2
Grab Sample Containers and Preservatives**

Constituent	Analytical Method EPA Method, (40 CFR 136)	Container Specifications			Holding Times
		Size	(G) – Glass; or (P) - Plastic	Preservative	
Fecal Coliform Escherichia coli Enterococci	SM9222D SM9223B SM9230D	120 mL	P	Na ₂ S ₂ O ₃ Ice	6 hours
Oil and Grease	E1664	1000 mL	G	H ₂ SO ₄ Ice	28 days
pH	E150.1	100 mL	P	Ice	Immediately

During the collection of grab samples, pH and temperature measurements were collected using a YSI Multiprobe. The measurements were taken from the center of flow at the 96-inch and 66-inch CMP's located at MS-1 and MS-2. The YSI Multiprobe was calibrated prior to collecting measurements in the flow stream.

3.6 QA/QC FIELD ACTIVITIES

Quality assurance/quality control ("QA/QC") of field samples were performed as defined in the *Study Phase Engineering Agreement Between PBS&J and Harris County to Provide Professional Engineering Services and Monitoring to Study the Effects of Permanent Storm Water Quality Features: Monitoring Plan and Quality Assurance Project Plan* (PBS&J, 2004a). QA/QC field samples included field duplicates, equipment blanks, and equipment calibration.

4.0 MONITORING RESULTS

This section presents the data obtained during the sampling activities. The data includes monitoring equipment measurements and laboratory results.

4.1 STORM EVENT DATA

Storm event data was recorded by a tipping bucket rain gauge using Rainfall Station RS-1 (see Section 3.3) or RS-2 for all 26 storm events. RS-2 was the back-up rain gauge operated by the Harris County Office of Emergency Management located at the intersection of Little Cypress Creek (L100-00-00) and Kluge Road. The storm characteristics of each sampling event and significant reference storm events are presented in Table 4-1.

A comparison of the average monthly rainfall totals recorded at RS-1 located at Basin K542-00-00 to the average monthly rainfall totals recorded for Houston at George Bush Intercontinental Airport (IAH) from 1971-2000 (NCDC, 2002) are shown in Figure 4-1.

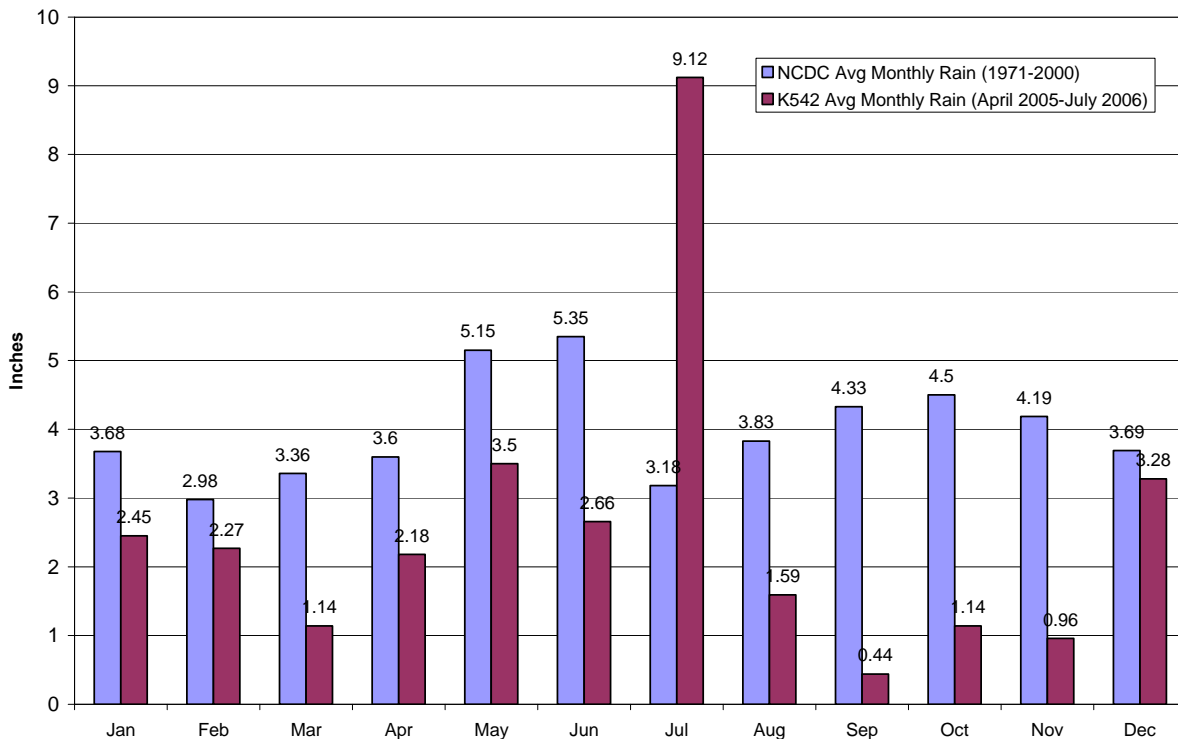


Figure 4-1
Comparison of Monthly Rainfall Patterns

**Table 4-1
Storm Characteristics of Sampling Events**

Event Number	Date	Rainfall Total (in)	Peak 1-hr Rate (in/hr)	Antecedent Dry Period (hrs)	Rain Station
001	05/29/05	0.46	0.44	62	RS-1
002	06/01/05	0.90	0.09	53	RS-1
003	07/07/05	0.72	0.71	527	RS-1
004	07/15/05	0.12	0.10	24	RS-1
005	07/20/05	1.12	1.05	71	RS-1
006	08/22/05	0.27	0.27	74	RS-1
007	10/10/05	0.84	0.28	382	RS-1
008	10/31/05	1.26	1.00	508	RS-2
009	11/15/05	0.46	0.35	173	RS-1
010*	12/07/05	0.09	0.04	64	RS-1
011	12/14/05	2.80	0.95	161	RS-1
012	12/17/05	0.26	0.04	52	RS-1
013	01/16/06	0.61	0.55	96	RS-1
014	01/28/06	0.40	0.25	141	RS-1
015	02/01/06	0.27	0.23	94	RS-1
016	02/10/06	0.38	0.18	206	RS-1
017	03/20/06	0.20	0.17	91	RS-1
018	03/28/06	0.65	0.19	190	RS-1
019	03/29/06	0.12	0.12	24	RS-2
020	04/21/06	0.85	0.85	442	RS-1
021	04/26/06	0.47	0.39	115	RS-1
022	04/29/06	1.27	1.07	73	RS-1
023	05/04/06	0.45	0.45	127	RS-1
024	05/30/06	0.37	0.35	26	RS-1
025	06/17/06	1.70	0.76	43	RS-2
026	07/22/06	2.10	2.10	378	RS-2
Reference Storm Events (HCFCD, 2002)					
Return Period	Duration	Rainfall (inches)			
2-year	1 hour	1.9			
5-year	1 hour	2.5			
100-year	1 hour	4.2			

* Only grab samples were collected and analyzed for this event as it did not meet the qualifying conditions for collection of composite samples.

4.2 WATER QUALITY DATA

Water quality EMC data associated with the 26 storm events are summarized in Tables 4-2 through 4-13. Inlet values represent data collected at the inlet pipe entering the basin; outlet values represent data collected at the outlet pipe leaving the basin; and reverse flow values represent data collected at the outlet pipe entering the basin from Faulkey Gully. Water quality grab sample and field instrument data

associated with Events 008 through 011 are summarized in Tables 4-14 and 4-15. Particle size distribution results for each storm event are provided in Appendix F.

**Table 4-2
Water Quality EMC Data – Total Hardness and Total Dissolved Solids**

Event ID	Total Hardness (mg/L CaCO ₃)			Total Dissolved Solids (mg/L)		
	Inlet	Outlet	Reverse Flow	Inlet	Outlet	Reverse Flow
001	16	18	--	198	226	--
002	25	40	--	245	205	--
003	160	32	38	294	360	218
004	29	49	--	325	518	--
005	12	8	--	150	106	--
006	155	155	--	223	427	--
007	49	36	--	285	584	--
008	16	28	--	175	284	--
009	30	54	--	303	408	--
010	--	--	--	--	--	--
011	38	15	--	153	207	--
012	33	35	--	373	<5	--
013	18	22	--	162	231	--
014	40	48	--	182	246	--
015	20	50	--	407	720	--
016	41	35	--	225	301	--
017	34	35	--	229	471	--
018	26	25	--	348	400	--
019	24	40	--	237	493	--
020	25	19	35	185	176	344
021	18	22	--	285	372	--
022	12	12	--	264	152	--
023	18	22	24	190	214	148
024	24	24	--	356	353	--
025	34	14	--	248	194	--
026	20	6	--	226	78	--

**Table 4-3
Water Quality EMC Data – Suspended Solids and Sediments**

Event ID	TSS (mg/L)			SSC (mg/L)		
	Inlet	Outlet	Reverse Flow	Inlet	Outlet	Reverse Flow
001	19.0	21.0	--	18.8	21.0	--
002	<5.0	33.0	--	3.0	33.1	--
003	866.0	70.0	324.0	877.0	70.7	328.0
004	13.0	14.0	--	13.1	14.1	--
005	18.0	47.0	--	18.1	47.3	--
006	19.0	31.0	--	19.1	31.2	--
007	12.4	19.6	--	12.4	19.7	--
008	24.0	33.2	--	24.1	33.4	--
009	10.0	34.0	--	10.0	34.0	--
010	--	--	--	--	--	--
011	84.8	51.6	--	346.0	63.2	--
012	17.2	116.0	--	17.2	62.6	--
013	97.2	190.0	--	154.0	235.0	--
014	24.0	51.0	--	33.2	75.2	--
015	39.6	117.0	--	32.8	94.2	--
016	14.8	14.0	--	43.0	28.8	--
017	245.0	30.0	--	288.0	29.5	--
018	47.2	24.0	--	51.2	27.3	--
019	45.2	107.0	--	46.4	109.0	--
020	139.0	90.0	552.0	267.0	90.2	569.0
021	38.8	29.2	--	52.1	33.2	--
022	38.8	39.6	--	50.0	41.8	--
023	75.0	104.0	420.0	111.0	123.0	501.0
024	83.0	96.0	--	176.0	141.0	--
025	26.0	28.0	--	27.2	29.0	--
026	42.0	59.0	--	48.6	63.3	--

**Table 4-4
Water Quality EMC Data – Total Cadmium, Total Copper, and Total Lead**

Event ID	Cadmium, Total (µg/L)			Copper, Total (µg/L)			Lead, Total (µg/L)		
	Inlet	Outlet	Reverse Flow	Inlet	Outlet	Reverse Flow	Inlet	Outlet	Reverse Flow
001	<1.00	<1.00	--	21.9	13.5	--	<2.00	<2.00	--
002	<1.00	<1.00	--	28.8	33.4	--	<2.00	<2.00	--
003	1.50	<1.00	<1.00	607.0	24.0	13.9	31.80	3.10	10.20
004	<1.00	<1.00	--	37.7	28.7	--	<2.00	1.70	--
005	<1.00	<1.00	--	15.7	7.4	--	<2.00	<2.00	--
006	<1.00	<1.00	--	15.4	17.6	--	1.90	1.70	--
007	<1.00	<1.00	--	24.2	25.5	--	<2.00	<2.00	--
008	<1.00	<1.00	--	12.7	13.1	--	2.70	1.80	--
009	<1.00	<1.00	--	20.6	24.3	--	<2.00	<2.00	--
010	--	--	--	--	--	--	--	--	--
011	<1.00	<1.00	--	29.0	14.0	--	2.70	1.80	--
012	<1.00	<1.00	--	20.6	19.2	--	<2.00	2.00	--
013	<1.00	<1.00	--	21.1	32.0	--	3.40	4.90	--
014	<1.00	<1.00	--	15.0	11.9	--	2.00	<2.00	--
015	<1.00	<1.00	--	20.7	21.3	--	<2.00	2.00	--
016	<1.00	<1.00	--	15.6	19.2	--	<2.00	<2.00	--
017	<1.00	<1.00	--	63.6	31.0	--	2.50	<2.00	--
018	<1.00	<1.00	--	24.5	20.7	--	<2.00	<2.00	--
019	<1.00	<1.00	--	27.5	31.2	--	2.70	3.40	--
020	<1.00	<1.00	<1.00	59.6	31.2	13.9	3.50	2.90	10.30
021	<1.00	<1.00	--	20.3	17.8	--	<2.00	<2.00	--
022	<1.00	<1.00	--	13.7	12.1	--	<2.00	<2.00	--
023	<1.00	<1.00	<1.00	19.4	14.0	6.0	<2.00	2.40	2.90
024	<1.00	<1.00	--	23.1	19.4	--	2.30	2.40	--
025	<1.00	<1.00	--	45.2	8.1	--	3.58	1.82	--
026	<1.00	<1.00	--	15.0	6.6	--	<2.00	<2.00	--

**Table 4-5
Water Quality EMC Data – Total Mercury and Total Nickel**

Event ID	Mercury, Total (µg/L)			Nickel, Total (µg/L)		
	Inlet	Outlet	Reverse Flow	Inlet	Outlet	Reverse Flow
001	<0.4000	<0.4000	--	2.9	1.9	--
002	<0.4000	<0.4000	--	2.7	3.3	--
003	<0.4000	<0.4000	<0.4000	12.5	2.9	6.2
004	<0.4000	<0.4000	--	1.8	2.7	--
005	<0.4000	<0.4000	--	1.4	1.3	--
006	<0.4000	<0.4000	--	3.5	2.7	--
007	<0.4000	<0.4000	--	<10.0	<10.0	--
008	0.6000	<0.4000	--	<10.0	<10.0	--
009	<0.4000	<0.4000	--	1.4	1.6	--
010	--	--	--	--	--	--
011	<0.4000	<0.4000	--	3.2	2.5	--
012	<0.4000	<0.4000	--	2.7	2.8	--
013	<0.4000	<0.4000	--	<10.0	<10.0	--
014	<0.4000	<0.4000	--	1.9	<10.0	--
015	<0.4000	<0.4000	--	2.4	2.7	--
016	<0.4000	<0.4000	--	2	2.3	--
017	<0.4000	<0.4000	--	4.5	4.8	--
018	<0.4000	<0.4000	--	2.7	3.0	--
019	<0.4000	<0.4000	--	3.3	4.2	--
020	<0.4000	<0.4000	<0.4000	3.6	3.0	8.4
021	<0.4000	<0.4000	--	1.9	1.8	--
022	<0.4000	<0.4000	--	1.6	1.4	--
023	<0.4000	<0.4000	<0.4000	1.6	2.3	2.5
024	<0.4000	<0.4000	--	<10.0	<10.0	--
025	<0.4000	<0.4000	--	4.3	<10.0	--
026	<0.4000	<0.4000	--	1.5	<10.0	--

**Table 4-6
Water Quality EMC Data – Total Silver and Total Zinc**

Event ID	Silver, Total (µg/L)			Zinc, Total (µg/L)		
	Inlet	Outlet	Reverse Flow	Inlet	Outlet	Reverse Flow
001	<10.0	<10.0	--	28.1	18.1	--
002	<10.0	<10.0	--	24.5	26.2	--
003	<10.0	<10.0	<10.0	881.0	30.7	33.7
004	<10.0	<10.0	--	30.2	25.2	--
005	<10.0	<10.0	--	27.3	15.0	--
006	<10.0	<10.0	--	30.2	21.9	--
007	<10.0	<10.0	--	41.4	21.4	--
008	<10.0	<10.0	--	18.7	11.7	--
009	<10.0	<10.0	--	21.5	14.6	--
010	--	--	--	--	--	--
011	<10.0	<10.0	--	66.9	19.2	--
012	<10.0	<10.0	--	25.6	23.7	--
013	<10.0	<10.0	--	43.2	43.8	--
014	<10.0	<10.0	--	22.9	24.1	--
015	<10.0	<10.0	--	27.2	21.3	--
016	<10.0	<10.0	--	22.7	17.9	--
017	<10.0	<10.0	--	48.3	17.0	--
018	<10.0	<10.0	--	32.3	18.0	--
019	<10.0	<10.0	--	38.1	32.5	--
020	<10.0	<10.0	<10.0	66.8	36.3	33.1
021	<10.0	<10.0	--	16.9	20.9	--
022	<10.0	<10.0	--	21.1	18.8	--
023	<10.0	<10.0	<10.0	26.7	17.6	15.9
024	<10.0	<10.0	--	23.2	16.5	--
025	<10.0	<10.0	--	49.5	10.8	--
026	<10.0	<10.0	--	17.1	13.5	--

**Table 4-7
Water Quality EMC Data – Nitrogen**

Event ID	Nitrate as N (mg/L)			Nitrite as N (mg/L)			Nitrogen, Total Kjeldahl (mg/L)		
	Inlet	Outlet	Reverse Flow	Inlet	Outlet	Reverse Flow	Inlet	Outlet	Reverse Flow
001	--	--	--	--	--	--	2.41	2.76	--
002	0.914	0.827	--	1.980	3.740	--	1.45	4.02	--
003	--	1.330	1.790	--	2.320	1.280	--	4.18	3.95
004	0.605	0.655	--	<0.760	2.590	--	3.75	5.10	--
005	0.748	0.385	--	1.270	<0.760	--	1.69	1.24	--
006	0.757	0.988	--	<0.760	<0.760	--	3.70	1.84	--
007	0.763	0.849	--	<0.760	<0.760	--	2.61	3.37	--
008	1.280	1.470	--	1.460	2.800	--	2.65	4.10	--
009	0.460	0.500	--	0.120	0.120	--	2.92	3.47	--
010	--	--	--	--	--	--	--	--	--
011	0.495	0.583	--	<0.760	<0.760	--	0.92	4.03	--
012	0.745	0.767	--	<0.760	0.082	--	5.61	4.29	--
013	0.541	0.515	--	<0.760	<0.760	--	1.16	1.05	--
014	0.428	0.524	--	<0.760	<0.760	--	0.52	0.30	--
015	0.758	0.810	--	<0.760	0.096	--	<0.500	<1.00	--
016	0.797	0.179	--	<0.760	0.016	--	2.20	2.50	--
017	1.150	1.160	--	1.190	1.390	--	5.65	3.80	--
018	0.860	1.060	--	0.237	0.260	--	3.93	4.45	--
019	0.738	1.030	--	0.091	0.222	--	3.01	4.31	--
020	1.020	0.859	1.950	<0.760	<0.760	<0.760	4.55	3.62	7.12
021	0.711	0.766	--	<0.760	0.078	--	3.54	3.33	--
022	0.483	0.449	--	<0.760	<0.760	--	2.76	2.46	--
023	0.626	0.693	0.741	0.088	0.078	<0.760	1.12	0.89	0.75
024	0.581	0.510	--	0.075	<0.760	--	5.06	3.54	--
025	0.589	0.409	--	<0.760	<0.760	--	11.40	11.00	--
026	0.707	0.547	--	<0.760	<0.760	--	5.55	2.70	--

**Table 4-8
Water Quality EMC Data – Phosphorus**

Event ID	Ortho-Phosphate (mg/L)			Phosphorus (mg/L)		
	Inlet	Outlet	Reverse Flow	Inlet	Outlet	Reverse Flow
001	--	--	--	15.100	14.100	--
002	0.67	0.91	--	21.400	35.200	--
003	--	2.05	3.74	--	17.100	18.400
004	<2.50	1.90	--	0.520	0.604	--
005	<2.50	<2.50	--	0.561	0.397	--
006	<2.50	2.24	--	0.780	0.882	--
007	<2.50	<2.50	--	0.735	0.948	--
008	2.23	3.03	--	1.090	1.250	--
009	0.36	0.49	--	0.879	0.684	--
010	--	--	--	--	--	--
011	1.25	1.20	--	3.800	3.300	--
012	1.45	0.79	--	10.300	8.480	--
013	0.79	0.70	--	91.000	40.800	--
014	1.02	0.93	--	3.000	3.800	--
015	<2.50	0.64	--	1.340	61.400	--
016	0.84	0.12	--	43.800	39.300	--
017	2.56	3.97	--	7.950	9.200	--
018	2.62	2.95	--	7.950	11.900	--
019	0.76	4.45	--	4.880	18.200	--
020	1.92	1.50	11.00	1.400	1.330	5.470
021	0.96	1.14	--	19.500	0.950	--
022	1.41	1.05	--	27.100	15.400	--
023	0.74	0.98	1.25	15.100	31.100	54.700
024	0.98	1.05	--	15.000	13.800	--
025	<2.50	0.82	--	4.250	5.750	--
026	1.00	<2.50	--	0.960	0.620	--

Table 4-9
Water Quality EMC Data – Biochemical Oxygen Demand (BOD₅)
and Chemical Oxygen Demand (COD)

Event ID	BOD ₅ (mg/L)			COD (mg/L)		
	Inlet	Outlet	Reverse Flow	Inlet	Outlet	Reverse Flow
001	--	--	--	39.0	59.0	--
002	7.63	5.79	--	35.0	52.0	--
003	--	15.00	14.00	--	61.0	48.0
004	7.14	7.78	--	34.0	127.0	--
005	7.81	7.22	--	28.0	21.0	--
006	8.93	13.80	--	88.0	96.0	--
007	6.86	17.70	--	98.0	114.0	--
008	11.50	10.70	--	62.0	54.0	--
009	8.44	7.23	--	33.0	38.0	--
010	--	--	--	--	--	--
011	6.63	5.99	--	58.0	55.0	--
012	5.53	4.76	--	55.0	55.0	--
013	10.80	12.30	--	70.0	65.0	--
014	9.84	10.10	--	72.0	73.0	--
015	8.65	9.40	--	36.0	42.0	--
016	7.14	6.34	--	55.0	49.0	--
017	44.00	13.00	--	178.0	82.0	--
018	8.78	8.93	--	84.0	80.0	--
019	8.43	12.50	--	80.0	105.0	--
020	16.80	16.00	16.40	119.0	89.0	87.0
021	8.07	7.00	--	88.0	59.0	--
022	10.50	8.70	--	87.0	78.0	--
023	11.60	6.67	7.41	54.0	45.0	26.0
024	18.20	9.62	--	127.0	94.0	--
025	5.93*	5.23*	--	75.0	58.0	--
026	5.62	5.96	--	60.0	39.0	--

*Analyzed outside of the holding time.

Table 4-10
Water Quality EMC Data – Cyanide

Event ID	Cyanide, Amenable (µg/L)			Cyanide, Total (µg/L)		
	Inlet	Outlet	Reverse Flow	Inlet	Outlet	Reverse Flow
001	<20.0	<20.0	--	<20.0	<20.0	--
002	<20.0	<20.0	--	<20.0	<20.0	--
003	--	<20.0	<20.0	--	<20.0	<20.0
004	<20.0	<20.0	--	<20.0	<20.0	--
005	<20.0	<20.0	--	<20.0	12.0	--
006	<20.0	<20.0	--	<20.0	<20.0	--
007	<20.0	<20.0	--	<20.0	<20.0	--
008	<20.0	<20.0	--	<20.0	<20.0	--
009	<20.0	<20.0	--	<20.0	<20.0	--
010	--	--	--	--	--	--
011	<20.0	<20.0	--	<20.0	<20.0	--
012	<20.0	<20.0	--	<20.0	<20.0	--
013	<20.0	<20.0	--	<20.0	<20.0	--
014	<20.0	<20.0	--	<20.0	<20.0	--
015	<20.0	<20.0	--	<20.0	<20.0	--
016	<20.0	<20.0	--	<20.0	<20.0	--
017	<20.0	<20.0	--	<20.0	<20.0	--
018	<20.0	<20.0	--	<20.0	<20.0	--
019	<20.0	<20.0	--	<20.0	<20.0	--
020	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0
021	<20.0	<20.0	--	<20.0	<20.0	--
022	<20.0	<20.0	--	<20.0	<20.0	--
023	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0
024	<20.0	<20.0	--	<20.0	<20.0	--
025	<20.0	<20.0	--	<20.0	<20.0	--
026	<20.0	<20.0	--	<20.0	<20.0	--

Table 4-11
Water Quality EMC Data – 2,4,5-T, 2,4,5-TP, and 2,4-D

Event ID	2,4,5-T (µg/L)			2,4,5-TP (µg/L)			2,4-D (µg/L)		
	Inlet	Outlet	Reverse Flow	Inlet	Outlet	Reverse Flow	Inlet	Outlet	Reverse Flow
001	<0.694	<0.667	--	<0.694	<0.667	--	<1.39	<1.33	--
002	<0.820	<0.694	--	<0.820	<0.694	--	<1.64	<1.39	--
003	--	<0.625	<0.658	--	<0.625	<0.658	--	<1.25	<1.32
004	0.714	<0.625	--	<0.625	<0.625	--	1.05	<1.25	--
005	2.050	0.251	--	<0.500	<0.500	--	0.64	0.41	--
006	<0.625	<0.625	--	<0.625	<0.625	--	0.27	<1.25	--
007	<0.500	<0.500	--	<0.500	0.110	--	8.98	8.85	--
008	<0.500	0.133	--	<0.500	<0.500	--	<1.00	0.19	--
009	0.127	<0.694	--	<0.685	<0.694	--	<1.37	<1.39	--
010	--	--	--	--	--	--	--	--	--
011	<0.667	<0.641	--	<0.667	<0.641	--	1.34	0.82	--
012	<0.549	<0.562	--	<0.549	<0.562	--	<1.10	<1.12	--
013	<0.500	<0.500	--	<0.500	<0.500	--	<1.00	<1.00	--
014	<0.500	<0.500	--	0.120	<0.500	--	1.40	0.99	--
015	<0.625	<0.544	--	<0.625	<0.544	--	<1.25	<1.09	--
016	<0.500	<0.500	--	0.155	<0.500	--	<1.00	<1.00	--
017	0.089	<0.500	--	<0.500	<0.500	--	0.14	0.36	--
018	<0.500	<0.500	--	<0.500	<0.500	--	1.10	1.12	--
019	<0.500	<0.556	--	<0.500	<0.556	--	0.28	0.41	--
020	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	<1.00	<1.00	<1.00
021	<0.500	<0.500	--	<0.500	<0.500	--	<1.00	<1.00	--
022	<0.500	<0.500	--	<0.500	<0.500	--	<1.00	<1.00	--
023	<0.500	<0.500	<0.500	<0.500	<0.500	<0.500	1.01	1.30	1.19
024	<0.625	<0.625	--	<0.625	<0.625	--	0.37	0.60	--
025	<0.625	<0.625	--	0.107	<0.625	--	0.40	0.16	--
026	<0.500	--	--	<0.500	--	--	<1.00	--	--

Table 4-12
Water Quality EMC Data – 2,4-DB, Dicamba, and Dalapon

Event ID	2,4-DB (µg/L)			Dicamba (µg/L)			Dalapon (µg/L)		
	Inlet	Outlet	Reverse Flow	Inlet	Outlet	Reverse Flow	Inlet	Outlet	Reverse Flow
001	<6.94	<6.67	--	<0.694	<0.667	--	<6.94	<6.67	--
002	0.32	<6.94	--	<0.820	<0.694	--	<8.20	<6.94	--
003	--	<6.25	<6.58	--	<0.625	<0.658	--	1.96	<1.32
004	1.05	0.86	--	<0.625	<0.625	--	<1.25	<1.25	--
005	<5.00	<5.00	--	<0.500	<0.500	--	<1.00	0.31	--
006	<6.25	<6.25	--	<0.625	<0.625	--	0.29	<1.25	--
007	<5.00	<5.00	--	<0.500	<0.500	--	0.78	1.96	--
008	<5.00	0.67	--	<0.500	<0.500	--	<1.00	<1.00	--
009	<6.85	<6.94	--	<0.685	<0.694	--	<1.37	<6.94	--
010	--	--	--	--	--	--	--	--	--
011	<6.67	<6.41	--	<0.667	0.666	--	<1.33	<1.28	--
012	<5.49	<5.62	--	<0.549	<0.562	--	<1.10	<1.12	--
013	0.78	<5.00	--	<0.500	<0.500	--	<1.00	<1.00	--
014	<5.00	<5.00	--	0.531	<0.500	--	<1.00	<1.00	--
015	<6.25	<5.44	--	<0.625	<0.544	--	<1.25	<1.09	--
016	<5.00	<5.00	--	0.937	0.618	--	<1.00	<1.00	--
017	0.20	<5.00	--	<0.500	<0.500	--	<1.00	<1.00	--
018	<5.00	<5.00	--	<0.500	<0.500	--	<1.00	<1.00	--
019	<5.00	<5.56	--	<0.500	<0.556	--	<1.00	<1.11	--
020	<5.00	<5.00	<5.00	<0.500	<0.500	<0.500	<1.00	<1.00	<1.00
021	<5.00	<5.00	--	<0.500	<0.500	--	<1.00	<1.00	--
022	<5.00	<5.00	--	<0.500	<0.500	--	<1.00	<1.00	--
023	1.25	0.79	0.74	<0.500	<0.500	<0.500	<1.00	<1.00	<1.00
024	<6.25	<6.25	--	<0.625	<0.625	--	0.69	0.37	--
025	<6.25	<6.25	--	<0.625	<0.625	--	<1.25	<1.25	--
026	<5.00	--	--	<0.500	--	--	<1.00	--	--

**Table 4-13
Water Quality EMC Data – Dichloroprop, MCPA, and MCPP**

Event ID	Dichloroprop (µg/L)			MCPA (µg/L)			MCPP (µg/L)		
	Inlet	Outlet	Reverse Flow	Inlet	Outlet	Reverse Flow	Inlet	Outlet	Reverse Flow
001	<1.39	<1.33	--	<278	<267	--	<278	45	--
002	<1.64	<1.39	--	<328	<278	--	<328	<278	--
003	--	<1.25	<1.32	--	<250	<263	--	<250	<263
004	<1.25	<1.25	--	<250	66	--	72	<250	--
005	<1.00	<1.00	--	<200	<200	--	<200	<200	--
006	<1.25	<1.25	--	<250	<250	--	45	<250	--
007	<1.00	0.32	--	<200	<200	--	<200	<200	--
008	0.19	0.16	--	<200	<200	--	<200	<200	--
009	<1.37	<1.39	--	<274	<278	--	<274	<278	--
010	--	--	--	--	--	--	--	--	--
011	<1.33	<1.28	--	<267	<256	--	<267	<256	--
012	<1.10	<1.12	--	<220	<225	--	<220	<225	--
013	<1.00	<1.00	--	<200	<200	--	<200	<200	--
014	0.46	<1.00	--	<200	<200	--	<200	<200	--
015	0.40	<1.09	--	<250	<217	--	<250	<217	--
016	<1.00	<1.00	--	<200	<200	--	<200	<200	--
017	0.14	0.09	--	<200	<200	--	<200	39	--
018	<1.00	<1.00	--	<200	<200	--	<200	<200	--
019	<1.00	<1.11	--	<200	<222	--	<200	<222	--
020	<1.00	<1.00	<1.00	<200	<200	<200	<200	<200	<200
021	<1.00	<1.00	--	<200	<200	--	<200	<200	--
022	<1.00	<1.00	--	<200	<200	--	<200	<200	--
023	<1.00	<1.00	<1.00	<200	<200	<200	<200	<200	<200
024	<1.25	<1.25	--	<250	<250	--	<250	<250	--
025	<1.25	<1.25	--	<250	<250	--	<250	<250	--
026	<1.00	--	--	<200	--	--	<200	--	--

Table 4-14
Grab Sample Water Quality Data – pH, Temperature, and Oil and Grease

Event ID	Sample Type	pH (su)		Temperature (°C)		Oil & Grease (mg/L)	
		Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
008	First Flush	8.45	7.65	--	--	<5.00	<5.00
	Rising Limb	8.49	7.55	--	--	2.07	8.55
	Peak	8.89	7.86	--	--	<5.00	2.47
	Falling Limb	8.91	8.56	--	--	<5.00	3.46
	YSI	8.48	8.34	20.06	19.28	--	--
009	First Flush	8.89	7.58	--	--	<5.00	<5.00
	Rising Limb	8.77	7.79	--	--	<5.00	5.26
	Peak	8.30	8.35	--	--	7.56	4.64
	Falling Limb	6.72	8.35	--	--	<5.00	3.17
	YSI	6.55	--	24.42	--	--	--
010*	First Flush	8.22	7.70	--	--	<5.00	7.70
	Rising Limb	8.24	7.68	--	--	4.32	6.55
	Peak	8.20	7.83	--	--	<5.00	7.93
	Falling Limb	8.20	7.84	--	--	9.89	6.24
	YSI -First Flush	8.00	7.57	13.26	11.45	--	--
	YSI - Rising Limb	8.10	7.44	13.41	11.54	--	--
	YSI - Peak	8.16	7.66	16.40	12.63	--	--
	YSI - Falling Limb	8.16	7.66	16.37	12.63	--	--
011	First Flush	8.29	8.15	--	--	2.22	<5.00
	Rising Limb	8.44	8.29	--	--	2.25	2.93
	Peak	8.38	8.36	--	--	<5.00	4.67
	Falling Limb	7.59	7.45	--	--	10.70	9.10
	YSI -First Flush	7.98	7.60	18.34	15.98	--	--
	YSI - Rising Limb	8.08	7.69	18.27	16.72	--	--
	YSI - Peak	7.88	7.90	18.16	18.42	--	--
	YSI - Falling Limb	7.89	7.86	17.59	18.37	--	--

* Only grab samples were collected and analyzed for this event as it was not a qualifying event due to insufficient rainfall.

**Table 4-15
Grab Sample Water Quality Data – Bacteria**

Event ID	Sample Type	Fecal Coliform (CFU/100mL)		Enterococci (MPN/100mL)		Escherichia coli (MPN/100mL)	
		Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
008	First Flush	20,000	300,000	5,630	104,620	7,590	241,900
	Rising Limb	10,000	110,000	61,310	104,620	11,980	241,900
	Peak	300,000	10,000	241,960	51,720	129,970	43,520
	Falling Limb	90,000	70,000	64,880	120,330	64,880	81,640
009	First Flush	6,000	700,000	1,986	9,590	2,330	241,960
	Rising Limb	19,000	690,000	7,080	5,780	29,090	241,960
	Peak	160,000	140,000	10,460	7,590	2,420	141,360
	Falling Limb	600,000	120,000	27,230	21,870	241,960	198,630
010*	First Flush	11,000	450,000	1,850	104,620	2,420	98,040
	Rising Limb	20,000	700,000	3,170	198,630	2,030	141,360
	Peak	20,000	1,000,000	4,890	104,620	5,200	173,290
	Falling Limb	20,000	680,000	4,430	198,630	5,910	155,310
011	First Flush	470,000	200,000	3,880	1,011	7,330	38,730
	Rising Limb	50,000	120,000	13,540	43,600	14,830	81,640
	Peak	480,000	180,000	62,940	81,640	81,640	64,880
	Falling Limb	220,000	310,000	18,420	72,700	32,550	46,110

* Only grab samples were collected and analyzed for this event as it was not a qualifying event due to insufficient rainfall.

4.3 QUALITY ASSURANCE FINDINGS

Data validation procedures defined in the QAPP were performed. These included laboratory data quality objectives ("DQO's"), collection of QA/QC field samples, laboratory quality control checks, QA samples, and verification of holding times. Laboratory DQO's are listed in the *Study Phase Engineering Agreement Between PBS&J and Harris County to Provide Professional Engineering Services and Monitoring to Study the Effects of Permanent Storm Water Quality Features: Monitoring Plan and Quality Assurance Project Plan* (PBS&J, 2004a). QA/QC field samples included field duplicates and equipment blanks. Laboratory quality control checks and QA samples included laboratory equipment blanks, method blanks, laboratory duplicates, internal standards, and matrix spike and matrix spike duplicates. The BOD₅ results for Event 025 were rejected under this quality assurance program because the sample was analyzed outside of the holding time. All other analytical results were accepted under this quality assurance program.

Table 4-16 presents the duplicate results of the composite samples collected for Events 007, 018, and 023, and the duplicate results of the grab samples collected for Event 009. The duplicate particle size distribution results for Events 007, 018, and 023 are presented in Appendix G.

Table 4-16
Duplicate Comparison

The results of all equipment blanks conducted during the monitoring period are presented in Table 4-17. The equipment blank particle size results for Events 003, 015, and 017 are presented in Appendix G. Low levels of oil and grease and an elevated pH were detected in the sample container blanks for Event 010 as shown in Table 4-17. According to Clesceri, et al. (1998), the pH of DI water is rarely detected at 7.0 due to the difficulty in measuring pH in a solution with an absence of ions. A search was performed for the source of the oil and grease in the blank. Possible sources that were identified were the sample collection method and contaminated equipment blanks or DI water.

Table 4-17
Water Quality Data – Basin K542-00-00 Equipment Blank Results

	LOE-003	LOE-010	LOE-015	LOE-017	
	5-Gallon Composite Blank	Grab Sample Container Blanks	Cone Splitter Blank	5-Gallon Composite Blank	
Parameter Name	Value	Value	Value	Value	Unit
Hardness (CaCO3)	<4.00	--	<4.00	<4.00	mg/L
TDS	7.00	--	20.00	<5.00	mg/L
TSS	<5.00	--	<5.00	<5.00	mg/L
SSC	2.01	--	0.71	Undetected	mg/L
Silver, Total	<10.0	--	<10.0	<10.0	µg/L
Nickel, Total	<10.0	--	<10.0	1.5 J	µg/L
Mercury, Total	<0.4000	--	<0.4000	<0.4000	µg/L
Copper, Total	<10.0	--	<10.0	<10.0	µg/L
Cadmium, Total	<1.00	--	<1.00	<1.00	µg/L
Lead, Total	<2.00	--	<2.00	<2.00	µg/L
Zinc, Total	7.9 J	--	<10.0	<10.0	µg/L
Nitrate as N	<0.113	--	<0.113	<0.565	mg/L
Nitrite as N	<0.152	--	<0.152	<1.00	mg/L
Ortho-Phosphate	<0.500	--	<0.500	<2.50	mg/L
TKN	<1.00	--	<0.500	0.173 J	mg/L
Phosphorus	0.016 J	--	0.067	<0.050	mg/L
2,4,5-T	<0.694	--	<0.500	<0.500	µg/L
2,4,5-TP (Silvex)	<0.694	--	<0.500	<0.500	µg/L
2,4-D	<1.39	--	<1.00	<1.00	µg/L
2,4-DB	<6.94	--	<5.00	<5.00	µg/L
Dicamba	<0.694	--	<0.500	<0.500	µg/L
Dalapon	<1.39	--	<1.00	<1.00	µg/L
Dichloroprop	<1.39	--	<1.00	<1.00	µg/L
MCPA	<278	--	<200	<200	µg/L
MCPP	<278	--	<200	<200	µg/L
Cyanide, Free	<20.0	--	<20.0	<20.0	µg/L
Cyanide, Total	<20.0	--	<20.0	<20.0	µg/L
BOD ₅	<2.00	--	6.37	<2.00	mg/L
COD	<10.0	--	<10.0	<10.0	mg/L
Fecal Coliform	--	<1	--	--	CFU/100 mL
Enterococci	--	<1	--	--	MPN/100 mL
Escherichia coli	--	<1	--	--	MPN/100 mL
pH	--	8.35	--	--	su
Oil and Grease	--	5.22	--	--	mg/L

J - The target analyte was positively identified below the detection limit.

Xenco Laboratories utilized samples from Basin K542-00-00 for the matrix spike and matrix spike duplicate analyses for Events 009, 014, 018, and 023. These results are presented in Appendix G.

5.0 STATISTICAL ANALYSIS

Statistical analysis of the results, including summary statistics, analysis of variance, box-whisker plots, and effluent probability plots, are presented in this section. Statistical Package for the Social Sciences ("SPSS"), Version 14.0, available from SPSS, Inc., Chicago, Illinois, and SYSTAT®, Version 11, available from Systat Software, Inc., Point Richmond, California, were used to perform the statistical analysis.

Total cadmium, total mercury, total silver, 2,4,5-T, 2,4,5-TP, 2,4-DB, Dicamba, Dalapon, Dichloroprop, MCPA, MCPP, amenable cyanide, and total cyanide were not included in the statistical analysis because either the constituent was not detected from any event or was not detected in 75 percent or greater of the samples. These results were reported from the lab as below detection limit ("BDL"). Half of the detection limit was used in the analysis for results reported from the lab as BDL for all other constituents.

Data was included from all events regardless of the presence of missing data that prevented complete paired sample sets in some cases. The BOD₅ results for Event 025 were not included in the statistical analysis due to the sample being analyzed outside of the holding time.

5.1 CALCULATION OF EMC VALUES FOR GRAB AND PROBE CONSTITUENTS

Grab samples were collected according to the methods described in Section 3.2. Data collected using the YSI 600XLM for storm Events 010 and 011 were also collected according to the methods described in Section 3.2. Numerical and graphical methods were used to estimate the EMC results for this data based upon the corresponding flow hydrographs recorded at SS-1 and SS-2 for Events 008 through 011. Best engineering judgment was used to fill gaps and to smooth flow hydrographs of errant readings recorded by the velocity or level meters. Missing data was interpolated using linear interpolation and by plotting best-fit curves to the hydrograph on graphical paper. The flow hydrographs for Events 008 through 011 depicting the areas that were smoothed or interpolated using best engineering judgment are shown in Appendix H.

EMC values were calculated as defined by EPA (1983):

$$EMC = \frac{\sum_i^n V_i C_i}{\sum_i^n V_i}$$

where,

V: volume of flow during period *i*
 C: average concentration associated with period *i*
 n: total number of measurements taken during event

For temperature and pH (collected by the YSI 600XLM), only one data point was collected at the inlet and outlet for Event 008 and at the inlet for Event 009. An EMC value could not be calculated for these parameters for these two events, so the values themselves were used as estimations of the EMC value (URS, 1999).

The calculated EMC values associated with Events 008 through 011 are summarized in Tables 5-1 and 5-2.

Table 5-1
Calculated EMC Values of Grab and Probe Constituents

Event ID	Oil & Grease (mg/L)		pH (su)		Temperature (°C) – YSI		pH (su) - YSI	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
008	2.38	3.20	8.78	7.95	20.06	19.28	8.48	8.34
009	3.88	3.66	7.82	8.28	24.42	--	6.55	--
010	3.50	6.60	8.22	7.82	14.26	12.52	8.07	7.64
011	3.39	8.01	8.30	7.67	18.12	18.35	7.92	7.87

Table 5-2
Calculated EMC Values of Grab Constituents

Event ID	Fecal Coliform (CFU/100mL)		Enterococci (MPN/100mL)		Escherichia coli (MPN/100mL)	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
008	110,304	182,145	100,160	103,562	62,611	168,897
009	289,965	193,353	25,174	17,406	171,223	193,766
010	15,226	741,198	2,963	180,071	2,994	156,971
011	381,180	277,864	48,365	74,036	63,345	50,888

5.2 SUMMARY STATISTICS

Summary statistics of the inlet, outlet, and reverse flow EMC values over all sampling events are presented in Tables 5-3 through 5-5. The analyses include statistics suggested in the *Storm Water Quality Pond Monitoring Protocol Version 1.0* (PBS&J, 2002). The disqualified data discussed in Section 4.3 were removed from the summary statistics analysis.

**Table 5-3
Inlet (SS-1) EMC Summary Statistics**

Parameter	N	Mean	Geometric Mean	Median	Variance	Standard Deviation	Coefficient of Variation
2,4-D	24	0.99	0.64	0.53	3.00	1.73	1.74
BOD ₅	22	10.86	9.51	8.55	64.72	8.05	0.74
COD	24	71.5	64.3	66.0	1221.5	34.9	0.49
Copper	25	48.7	26.2	21.1	13,701.7	117.1	2.40
E. coli	4	75,040	37,760	62,980	4.911 x 10 ⁹	70,080	0.93
Enterococci	4	44,170	24,520	36,770	1.737 x 10 ⁹	41,680	0.94
Fecal Coliform	4	199,170	116,730	200,140	2.770 x 10 ¹⁰	166,440	0.84
Lead	25	2.92	1.70	1.00	37.05	6.09	2.08
Nickel	25	3.3	2.9	2.7	5.2	2.3	0.68
Nitrate as N	23	0.729	0.701	0.738	0.046	0.214	0.29
Nitrite as N	23	0.514	0.367	0.380	0.232	0.482	0.94
Nitrogen, Total Kjeldahl	24	3.27	2.48	2.84	5.58	2.36	0.72
Oil & Grease	4	3.29	3.24	3.45	0.41	0.64	0.19
Ortho-Phosphate	23	1.26	1.15	1.25	0.33	0.58	0.46
pH	8	8.02	7.99	8.15	0.45	0.67	0.08
Phosphorus, Total	24	12.433	4.569	4.565	393.447	19.835	1.60
SSC	25	110	46	43	34,559	186	1.70
Temperature	4	19.22	18.86	19.09	17.85	4.23	0.22
TDS	25	251	241	237	5172	72	0.29
Total Hardness	25	37	28	25	1,413	38	1.02
TSS	25	82	36	39	29,424	172	2.10
Zinc	25	66.1	34.0	27.3	29,014.7	170.3	2.58

**Table 5-4
Outlet (SS-2) EMC Summary Statistics**

Parameter	N	Mean	Geometric Mean	Median	Variance	Standard Deviation	Coefficient of Variation
2,4-D	24	0.95	0.62	0.58	2.90	1.70	1.80
BOD ₅	23	9.67	9.07	8.93	13.09	3.62	0.37
COD	25	67.6	62.8	59.0	664.8	25.8	0.38
Copper	25	19.9	18.1	19.2	67.5	8.2	0.41
E. coli	4	142,630	127,160	162,930	3.976 x 10 ⁹	63,050	0.44
Enterococci	4	93,770	70,020	88,800	4.588 x 10 ⁹	67,740	0.72
Fecal Coliform	4	348,640	291,830	235,610	7.032 x 10 ¹⁰	265,170	0.76
Lead	25	1.76	1.55	1.70	0.98	0.99	0.56
Nickel	25	3.3	3.0	2.9	1.8	1.3	0.40
Nitrate as N	24	0.744	0.678	0.730	0.098	0.313	0.42
Nitrite as N	24	0.749	0.350	0.380	1.050	1.024	1.37
Nitrogen, Total Kjeldahl	25	3.31	2.64	3.47	4.37	2.09	0.63
Oil & Grease	4	5.37	4.99	5.13	5.37	2.32	0.43
Ortho-Phosphate	24	1.53	1.20	1.17	1.19	1.09	0.71
pH	7	7.94	7.93	7.87	0.08	0.28	0.03
Phosphorus, Total	25	13.460	5.227	8.480	261.253	16.163	1.20
SSC	25	62	49	42	2,468	50	0.80
Temperature	3	16.72	16.42	18.35	13.43	3.66	0.22
TDS	25	309	234	284	28366	168	0.54
Total Hardness	25	34	27	28	818	29	0.85
TSS	25	58	45	40	1,870	43	0.75
Zinc	25	21.5	20.3	19.2	60.2	7.8	0.36

**Table 5-5
Reverse Flow (SS-3) EMC Summary Statistics**

Parameter	N	Mean	Geometric Mean	Median	Variance	Standard Deviation	Coefficient of Variation
2,4-D	3	0.78	0.73	0.66	0.13	0.36	0.55
BOD ₅	3	12.60	11.94	14.00	21.67	4.65	0.33
COD	3	53.7	47.7	48.0	954.3	30.9	0.64
Copper	3	11.3	10.5	13.9	20.8	4.6	0.33
Lead	3	7.80	6.73	10.20	18.01	4.24	0.42
Nickel	3	5.7	5.1	6.2	8.9	3.0	0.48
Nitrate as N	3	1.494	1.373	1.790	0.431	0.657	0.37
Nitrite as N	3	0.680	0.570	0.380	0.270	0.520	1.37
Nitrogen, Total Kjeldahl	3	3.94	2.77	3.95	10.14	3.18	0.81
Ortho-Phosphate	3	5.33	3.72	3.74	25.66	5.07	1.35
Phosphorus, Total	3	26.190	17.658	18.400	651.411	25.523	1.39
SSC	3	466	454	501	15,439	124	0.25
TDS	3	237	223	218	9,865	99	0.46
Total Hardness	3	32	32	35	54	7	0.21
TSS	3	432	422	420	13,104	114	0.27
Zinc	3	27.6	26.1	33.1	102.2	10.1	0.31

5.3 NOTCHED BOX-WHISKER PLOTS

Notched box-whisker plots were created from the EMC values in order to summarize the median, upper, and lower quartiles, minimum and maximum data values, and 95 percent confidence levels of the median. The disqualified data discussed in Section 4.3 were removed from the notched box-whisker plot analysis. Figure 5-1 demonstrates the statistics shown by the box-whisker plot. The boxes represent the middle 50 percent of the data drawn between the lower and upper quartiles following Tukey (1977). Notches on the box demonstrate the 95 percent confidence level following McGill, et al. (1978). The whiskers are vertical lines drawn from the top and bottom of the boxes to the nearest data point that is less than 1.5 times the interquartile range from the bottom of the box, or more than 1.5 times the interquartile range from the top of the box. These data points are represented by horizontal dashes "⊥" or "⌊" at the top or bottom of the line. Suspected outliers and outliers are also represented in the box-whisker plot. Suspected outliers are designated by asterisks (*) and are identified as points that are more than 1.5 times the interquartile range from the top of the box, or less than 1.5 times the interquartile range from the bottom of the box. Outliers are designated by circles (o) and are identified as points that are more than three times the interquartile range from the top of the box, or less than three times the interquartile range from the bottom of the box.

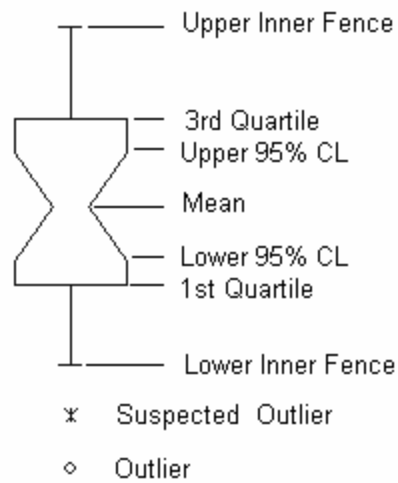


Figure 5-1
Box-Whisker Plot Legend

The box-whisker plots display, from left to right, the results obtained from samples collected from the basin inlet (SS-1), outlet (SS-2), and reverse flow (SS-3) monitoring locations as shown in Figures 5-2 through 5-23. The box-whisker plots for E.coli, Enterococci, fecal coliform, oil and grease, pH, and temperature display only the results obtained from samples collected from the basin inlet (SS-1) and outlet (SS-2).

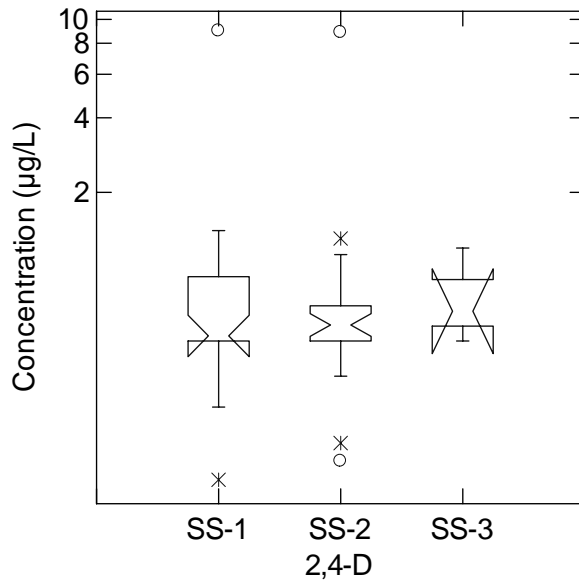


Figure 5-2
Box-Whisker Plot – 2,4-D

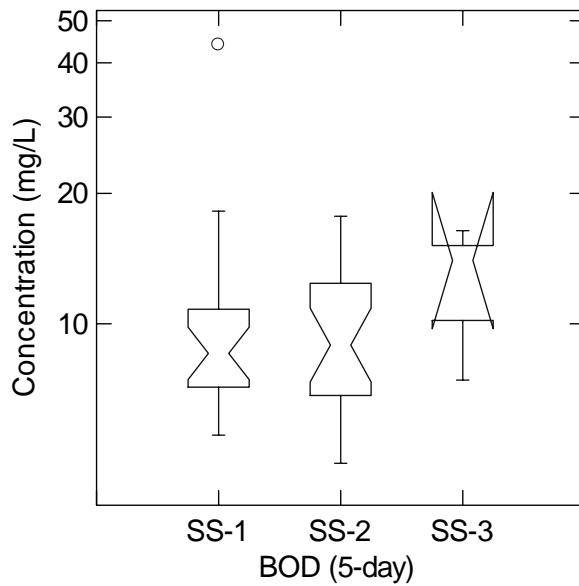


Figure 5-3
Box-Whisker Plot – BOD₅

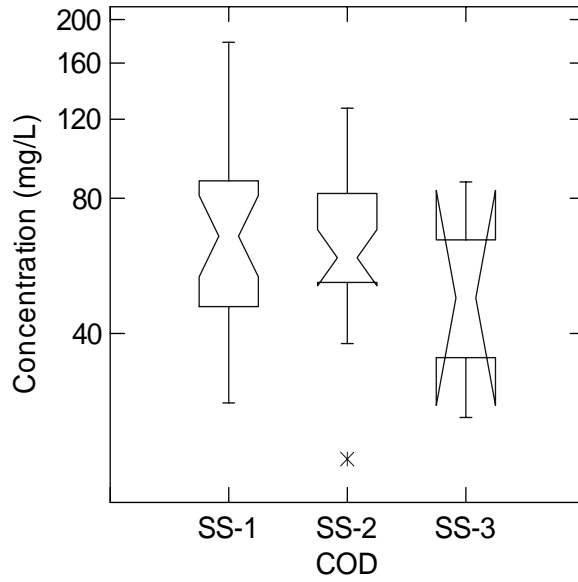


Figure 5-4
Box-Whisker Plot – COD

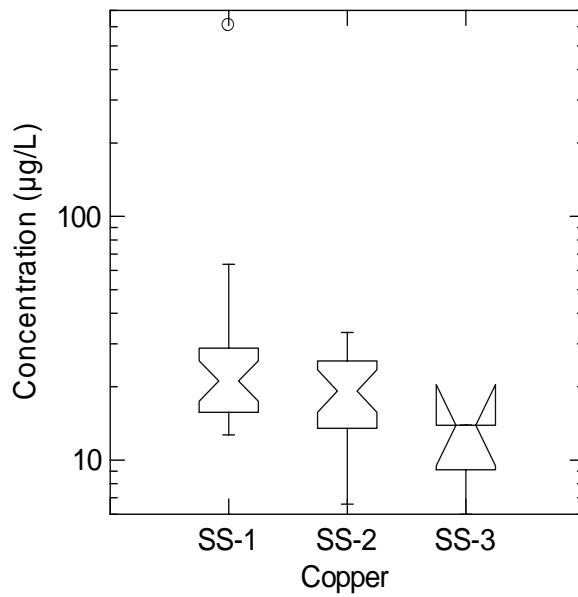


Figure 5-5
Box-Whisker Plot – Copper

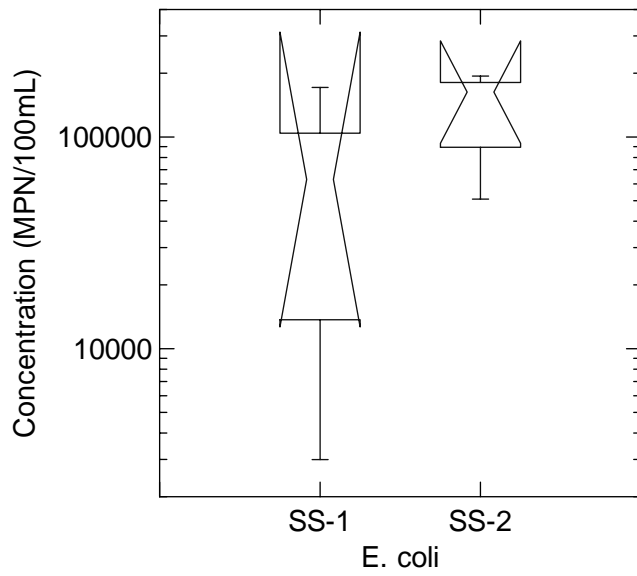


Figure 5-6
Box-Whisker Plot – E. coli

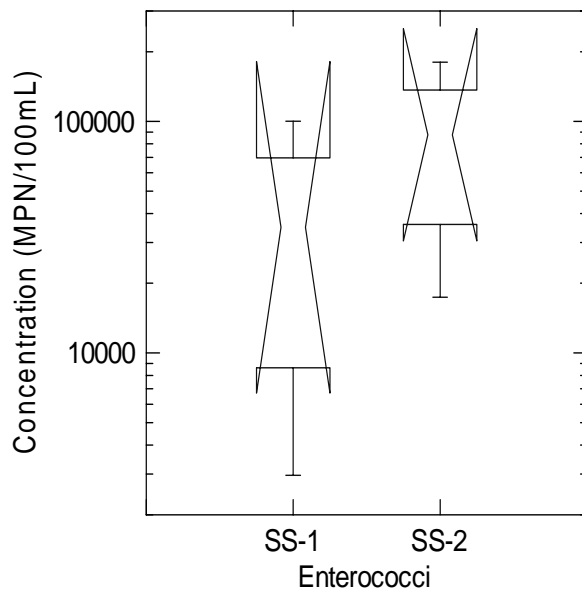


Figure 5-7
Box-Whisker Plot – Enterococci

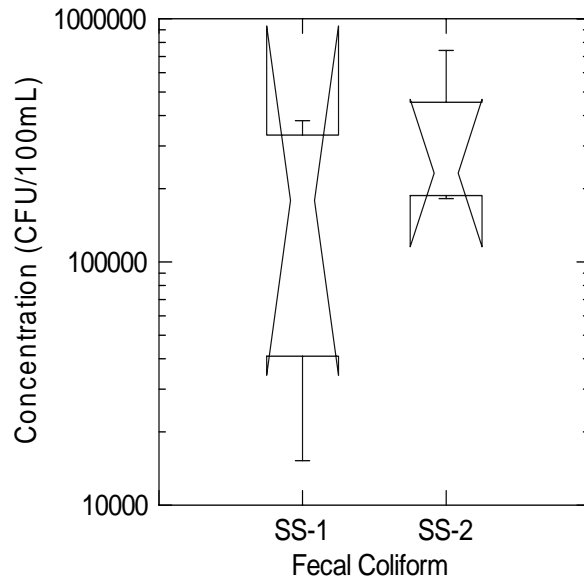


Figure 5-8
Box-Whisker Plot – Fecal Coliform

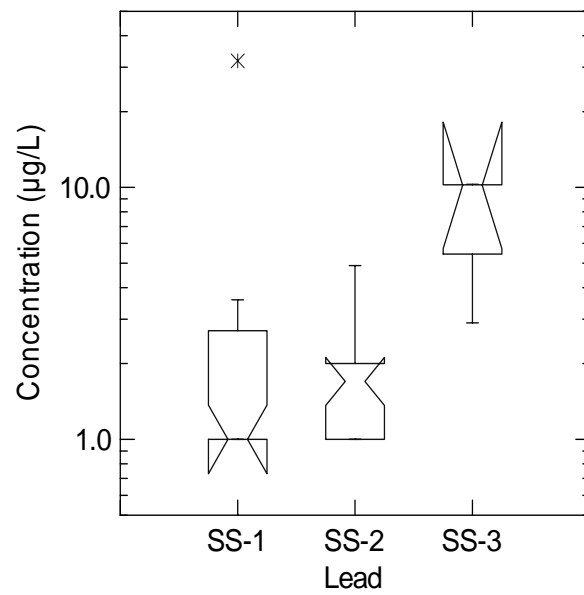


Figure 5-9
Box-Whisker Plot – Lead

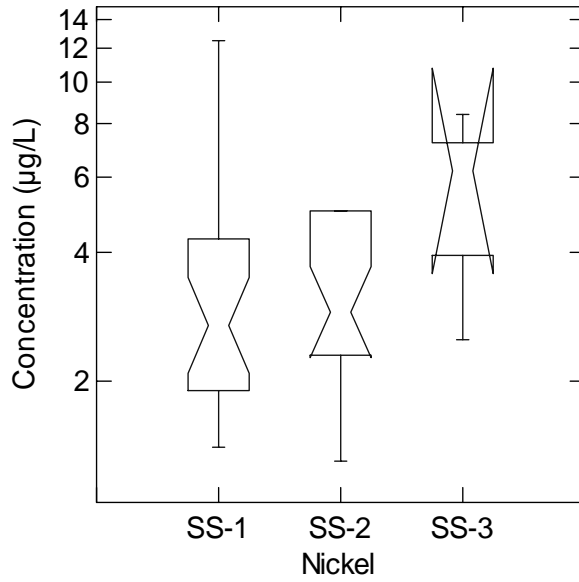


Figure 5-10
Box-Whisker Plot – Nickel

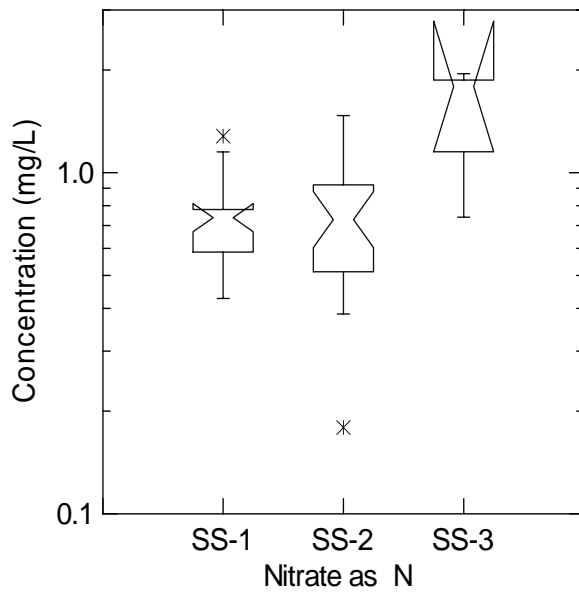


Figure 5-11
Box-Whisker Plot – Nitrate as N

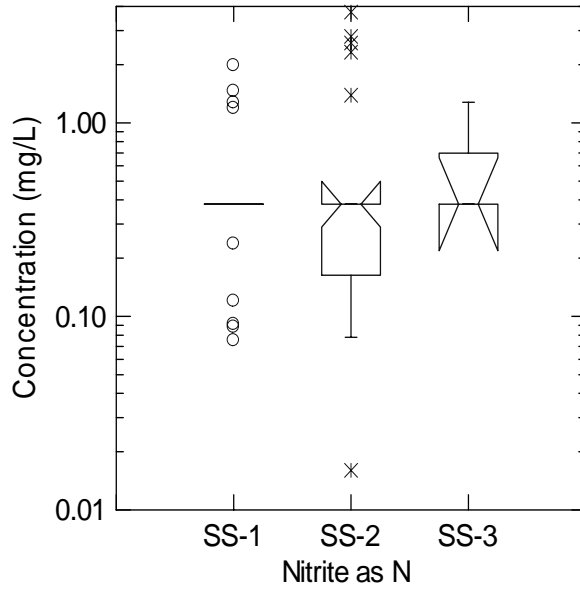


Figure 5-12
Box-Whisker Plot – Nitrite as N

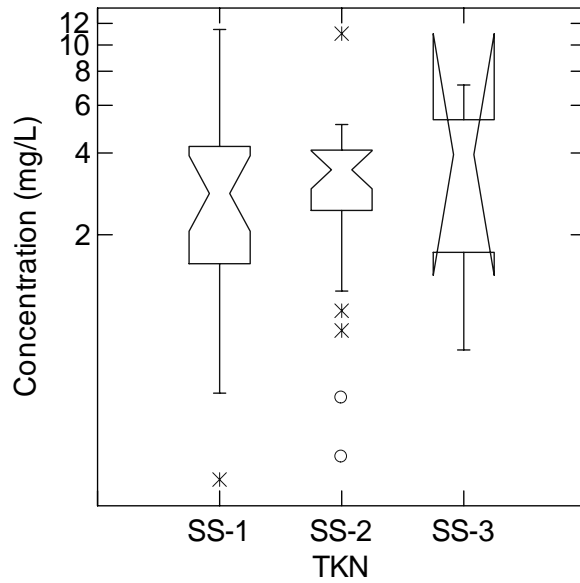


Figure 5-13
Box-Whisker Plot – TKN

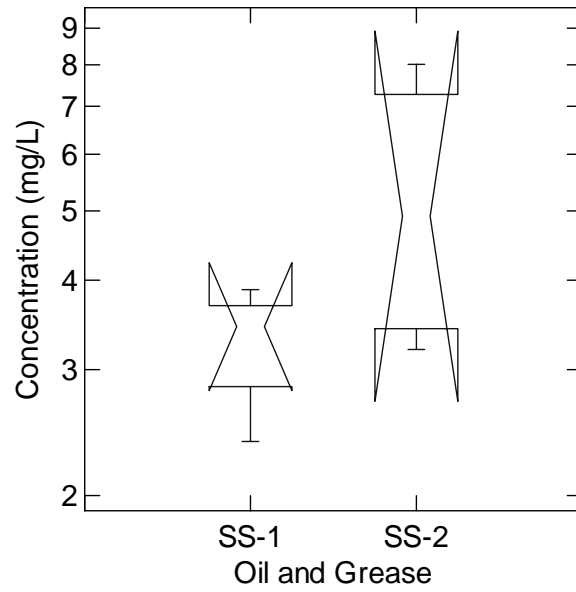


Figure 5-14
Box-Whisker Plot – Oil and Grease

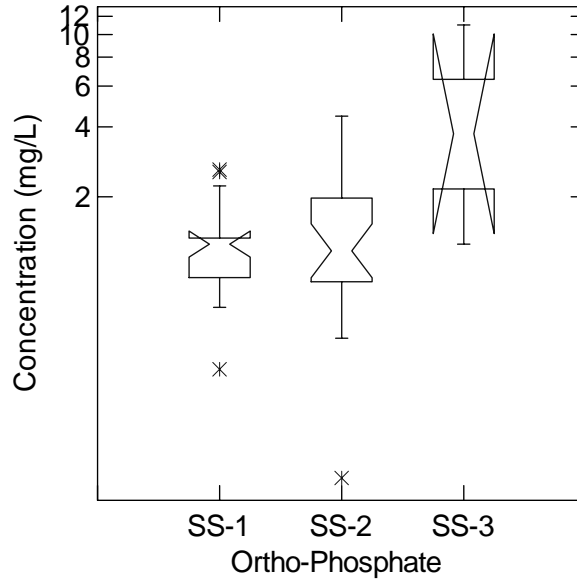


Figure 5-15
Box-Whisker Plot – Ortho-Phosphate

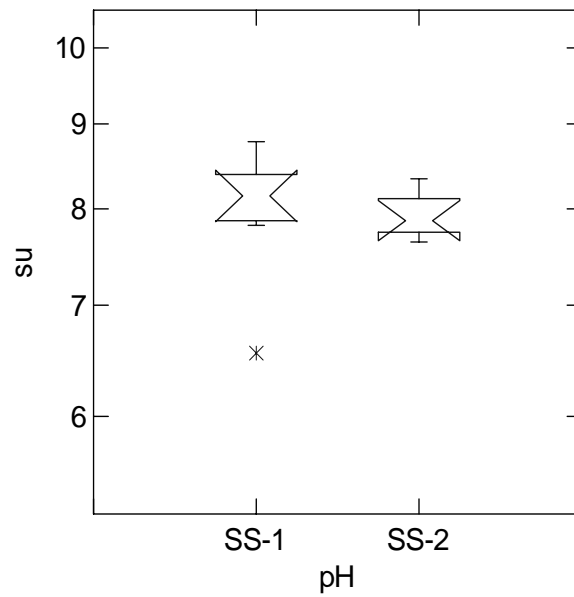


Figure 5-16
Box-Whisker Plot – pH

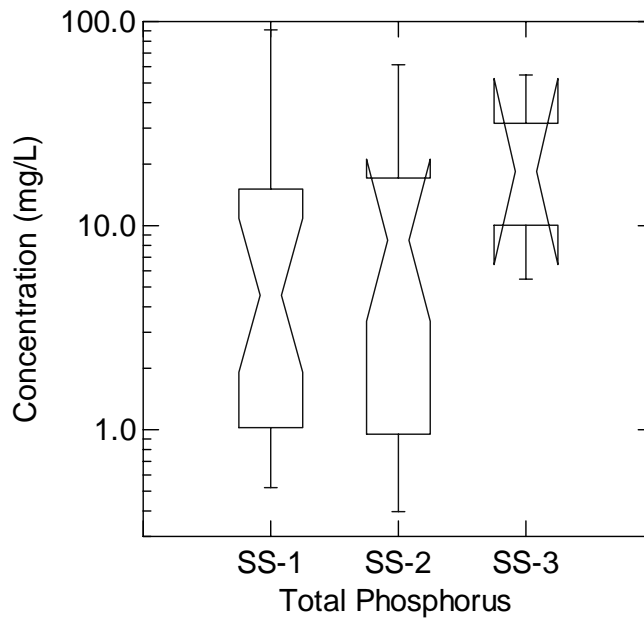


Figure 5-17
Box-Whisker Plot – Total Phosphorus

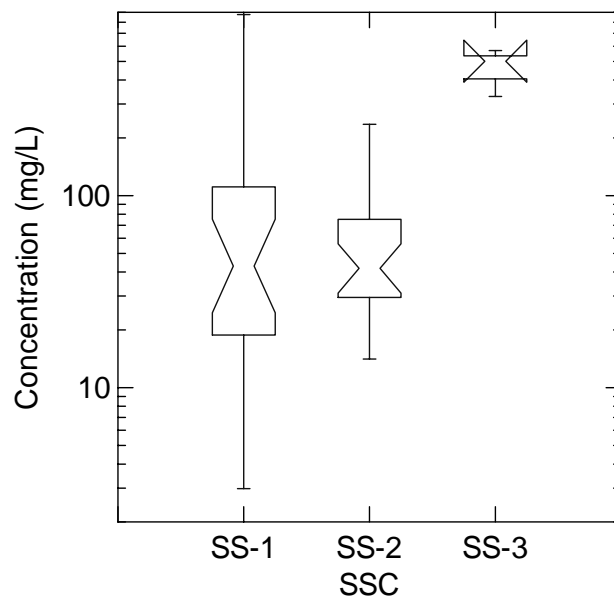


Figure 5-18
Box-Whisker Plot – SSC

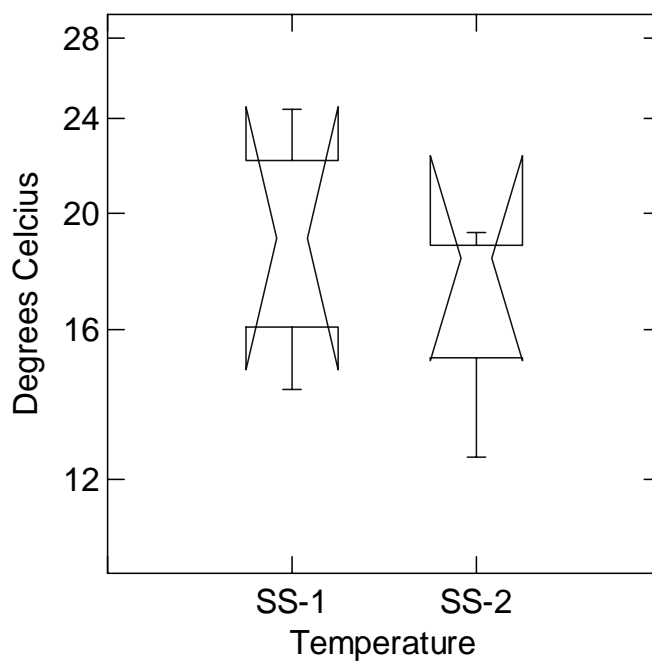


Figure 5-19
Box-Whisker Plot – Temperature

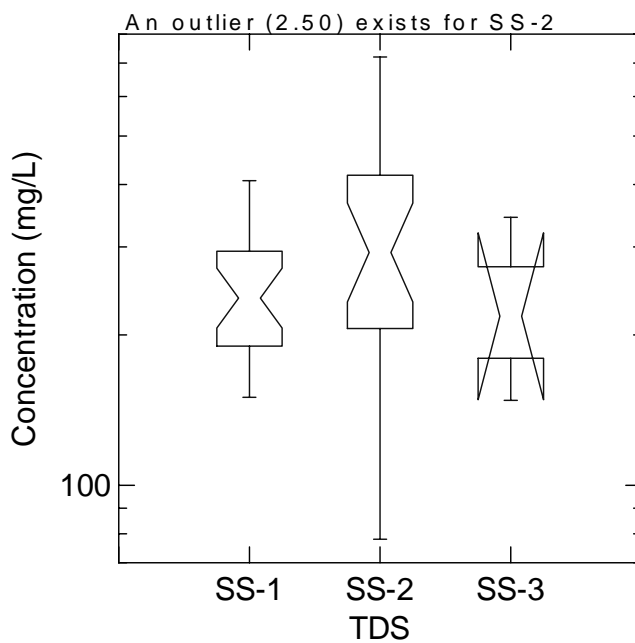


Figure 5-20
Box-Whisker Plot – TDS

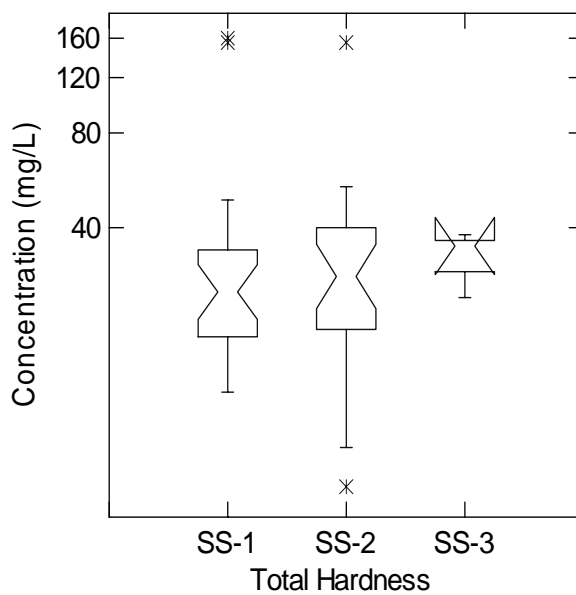


Figure 5-21
Box-Whisker Plot – Total Hardness

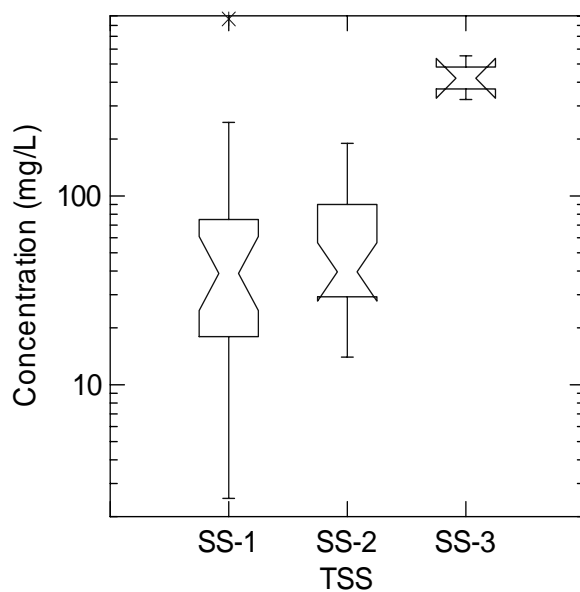


Figure 5-22
Box-Whisker Plot – TSS

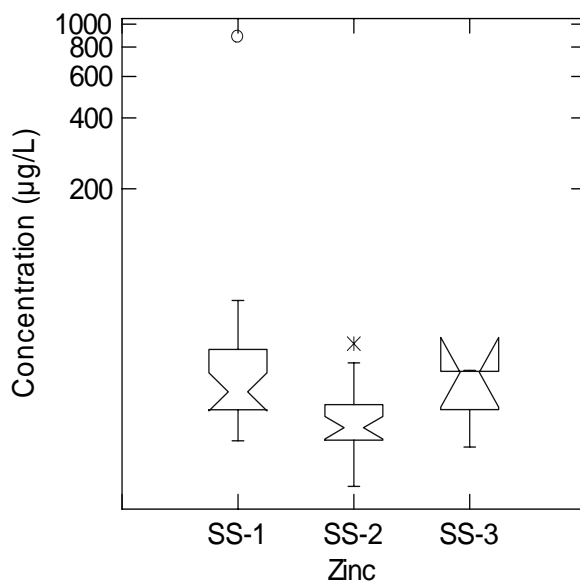


Figure 5-23
Box-Whisker Plot – Zinc

5.4 PROBABILITY PLOTS

Studies have shown that the effluent probability method is an effective tool for BMP water quality monitoring data analysis (ASCE, 2002; Burton and Pitt, 2001; PBS&J, 2002). The probability plot displays information about how well the data is represented by a log-normal distribution, the mean and standard deviation of the log-normal distribution, and the presence of outliers. Overlaying data sets to create effluent probability plots displays the information mentioned above for each data set as well as the degree of removal present, if any. The information depicted in a properly developed effluent probability plot includes:

- **Log-norm Distribution:** The degree to which the data forms a straight line depicts how well the data fits a log-normal distribution. A perfect log-normal distribution would be represented by a straight line.
- **Variance:** The variance of the data is depicted by the steepness of the plot. A steep slope indicates a low variance while a flat slope indicates a high variance. The probability plot allows the comparison of the variances between the inlet, outlet, and reverse flow sampling stations on the same plot for each parameter.
- **Median:** The median is represented by the location the plot crosses the horizontal line of 0.50 fraction less than.
- **Differences among Sampling Locations:** Statistically significant differences are depicted by the distance between the plots for the inlet, outlet, and reverse flow sampling stations. Statistically significant differences appear as separate lines for each sampling station with greater distances between the lines indicating larger differences.
- **Concentration Dependent Difference among Sampling Locations:** Divergent plots indicate that statistically significant differences exist at higher or lower concentrations. If there is a statistically significant difference between the inlet, outlet, or reverse flow at low concentrations only, then the lines will be separated at low concentrations shown on the left side of the plots and overlap at high concentrations shown on the right side of the plots. If there is a statistically significant difference between the inlet, outlet, or reverse flow at high concentrations only, then the lines will overlap at high concentrations on the right side of the plots and diverge at low concentrations on the left side of the plots.

Figures 5-23 through 5-44 show the probability plots of the inlet, outlet, and reverse flow EMC values. The disqualified data discussed in Section 4.3 were removed from the probability plot analysis.

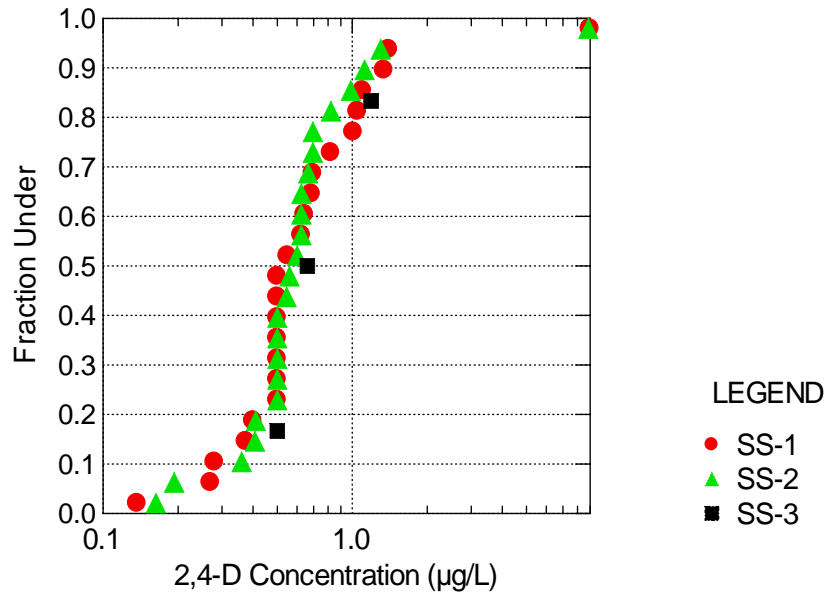


Figure 5-24
Probability Plot for 2,4-D

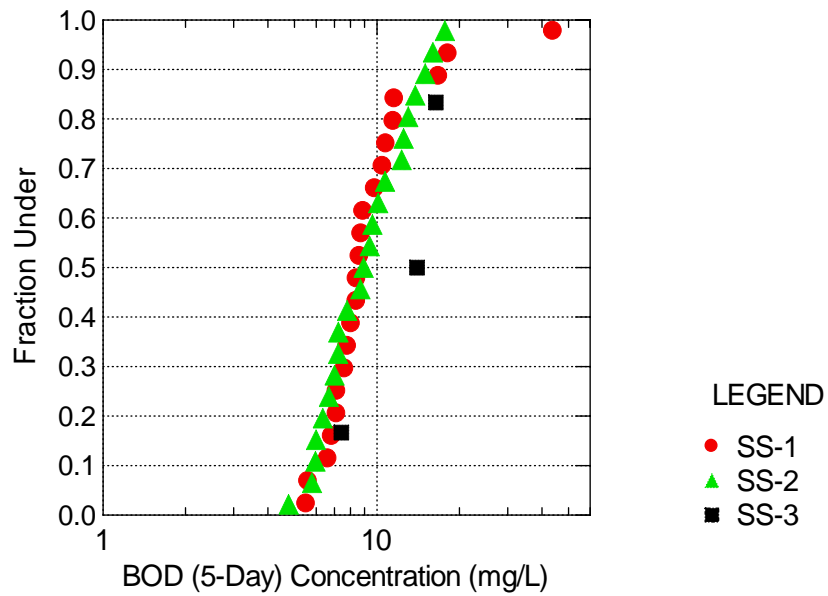


Figure 5-25
Probability Plot for BOD₅

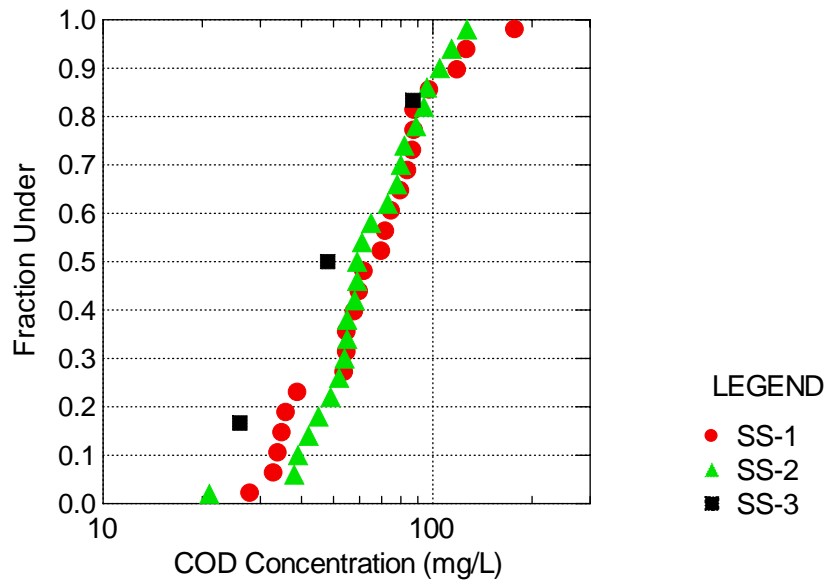


Figure 5-26
Probability Plot for COD

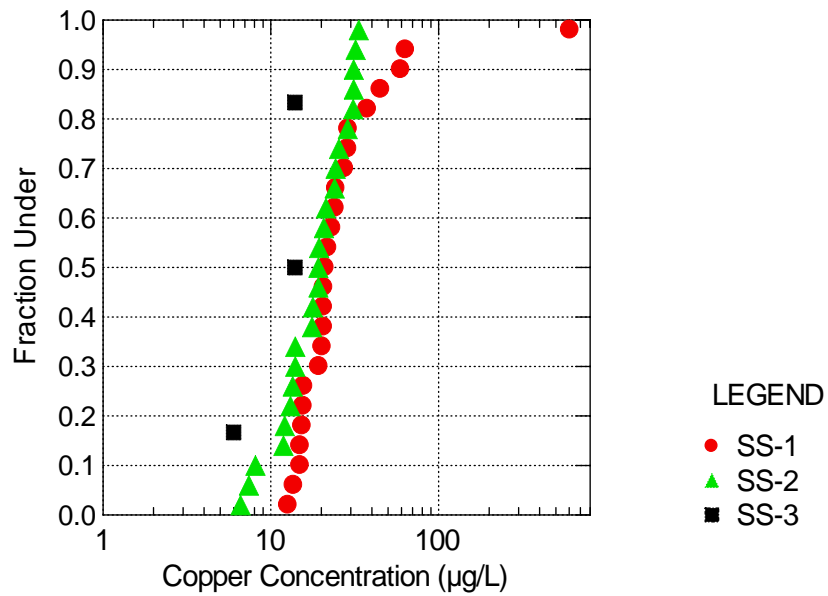


Figure 5-27
Probability Plot for Copper

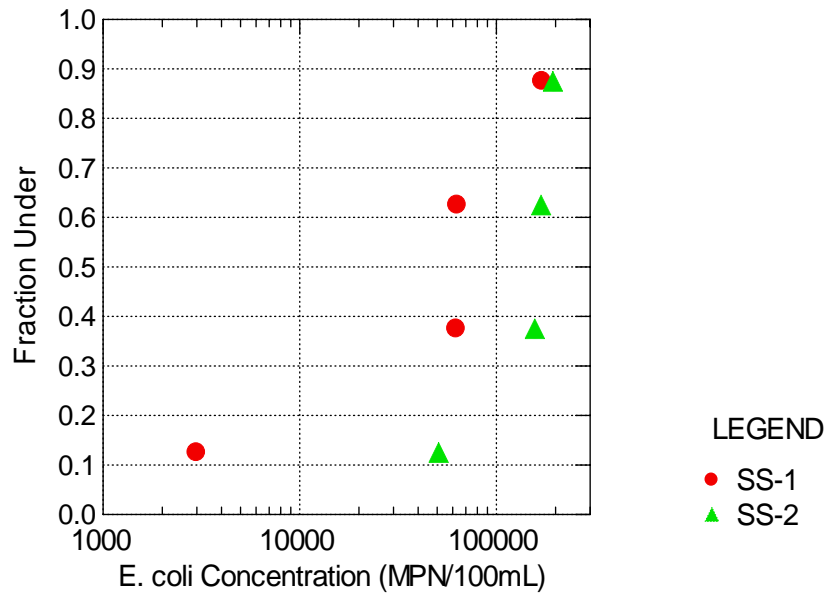


Figure 5-28
Probability Plot for E. coli

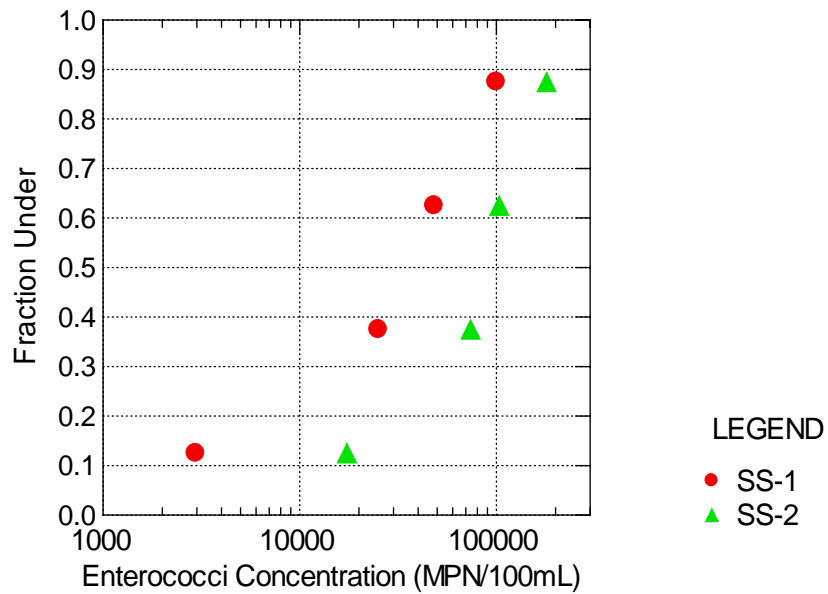


Figure 5-29
Probability Plot for Enterococci

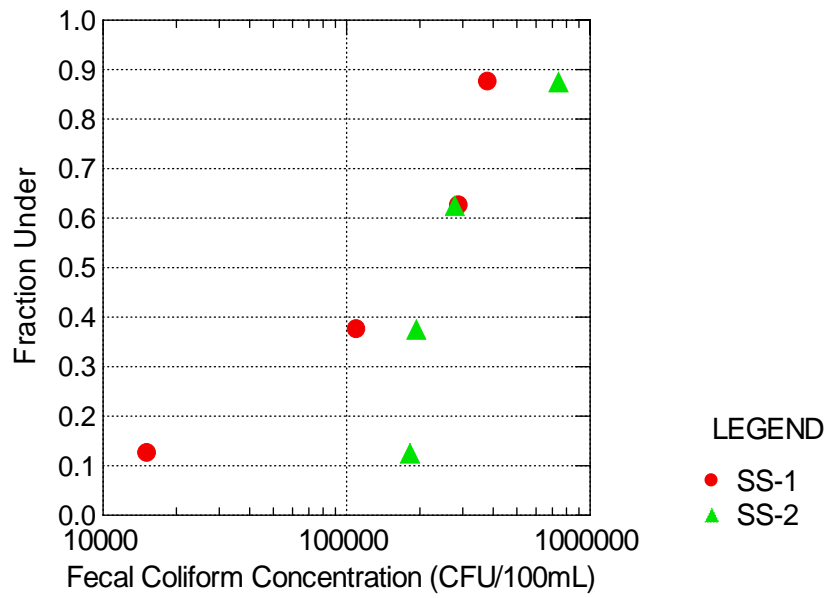


Figure 5-30
Probability Plot for Fecal Coliform

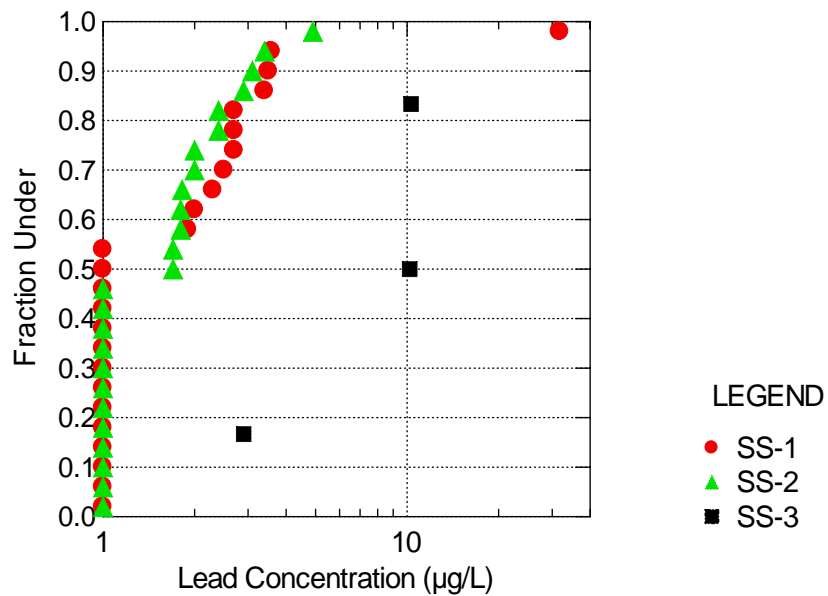


Figure 5-31
Probability Plot for Lead

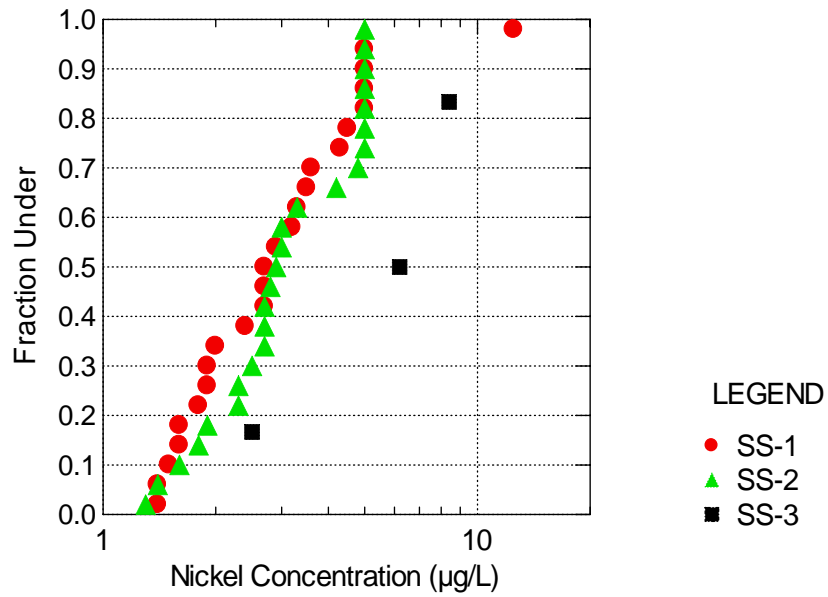


Figure 5-32
Probability Plot for Nickel

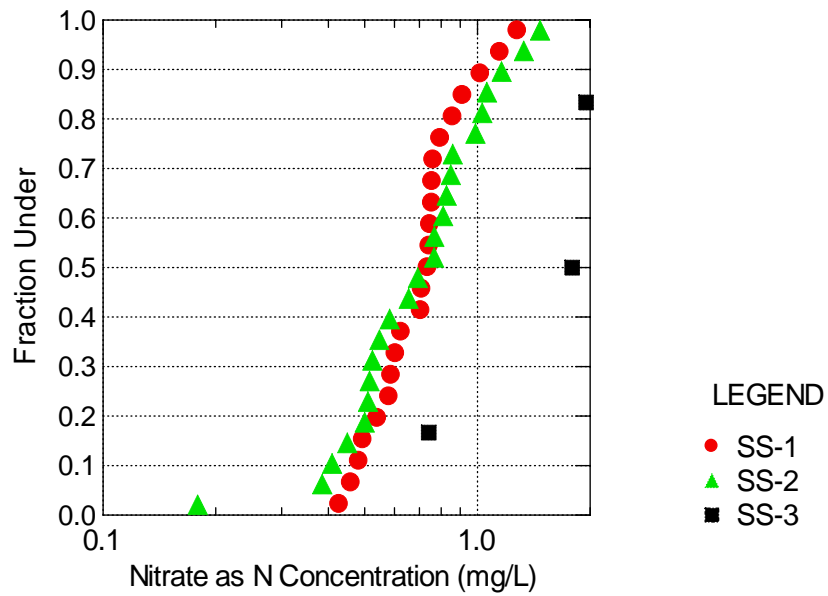


Figure 5-33
Probability Plot for Nitrate N

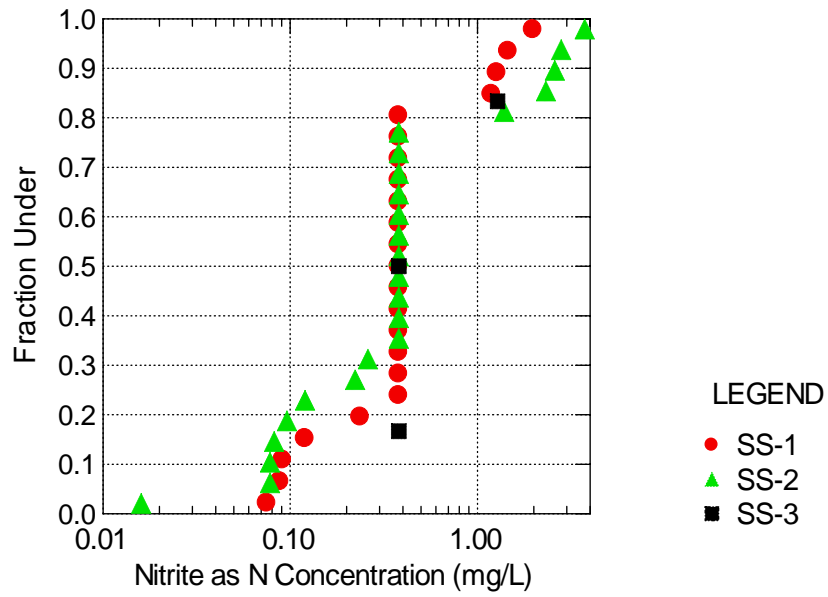


Figure 5-34
Probability Plot for Nitrite N

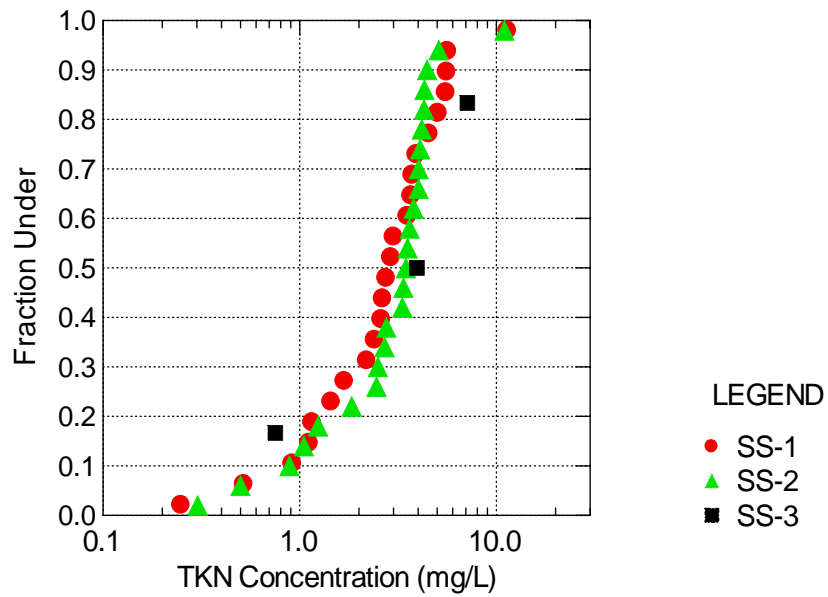


Figure 5-35
Probability Plot for TKN

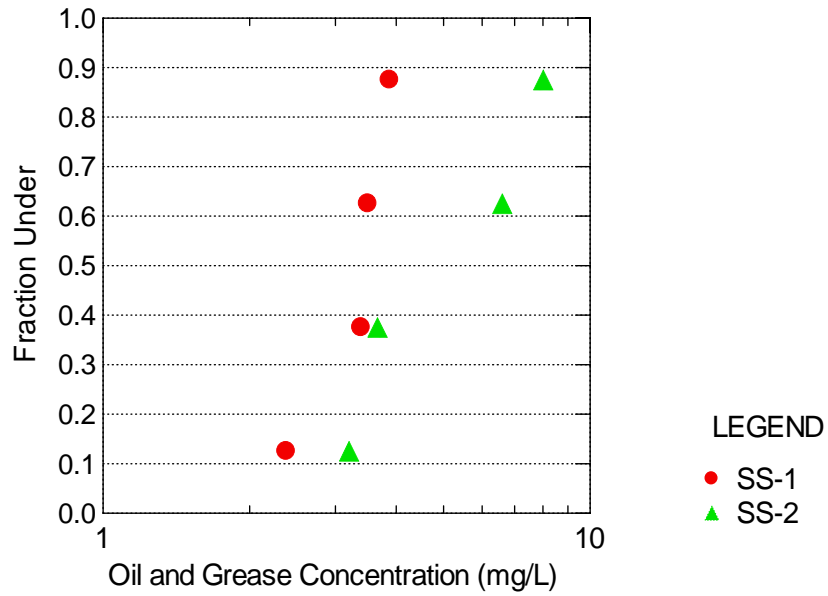


Figure 5-36
Probability Plot for Oil and Grease

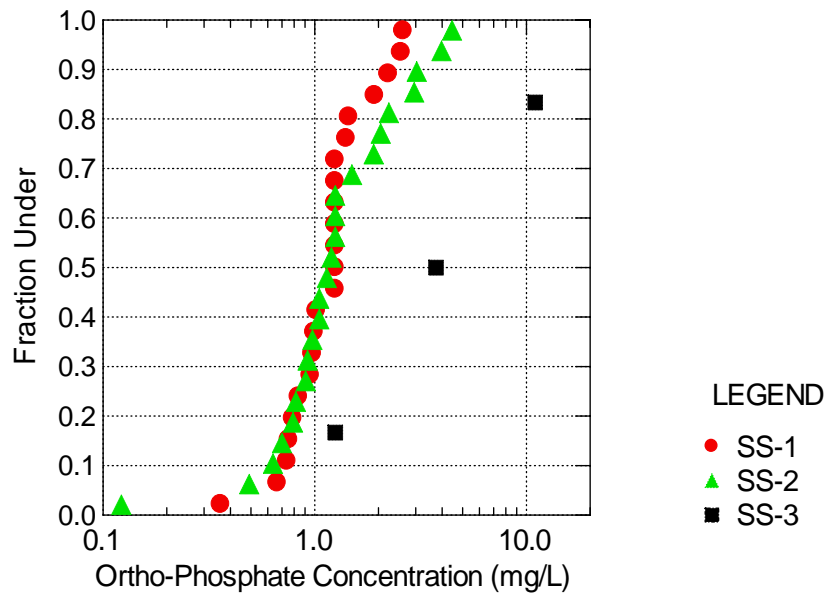


Figure 5-37
Probability Plot for Ortho-Phosphate

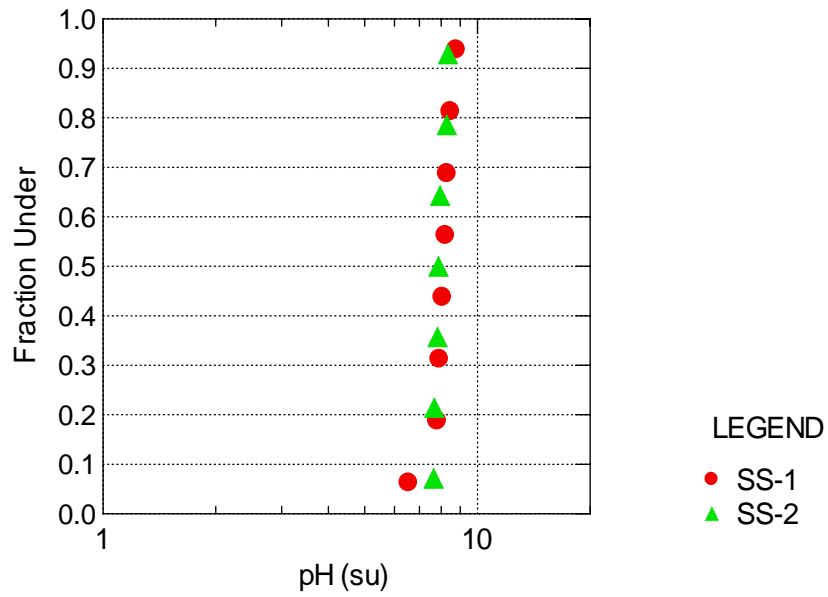


Figure 5-38
Probability Plot for pH

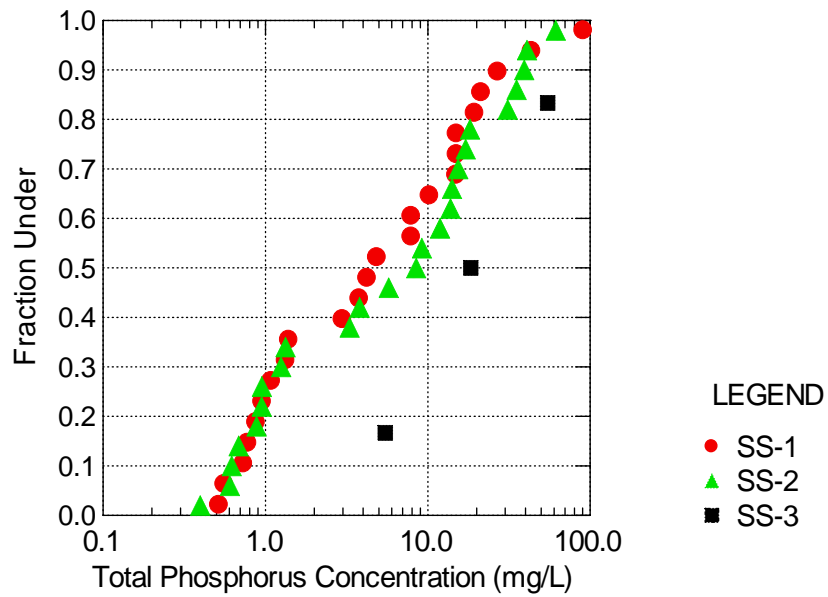


Figure 5-39
Probability Plot for Total Phosphorus

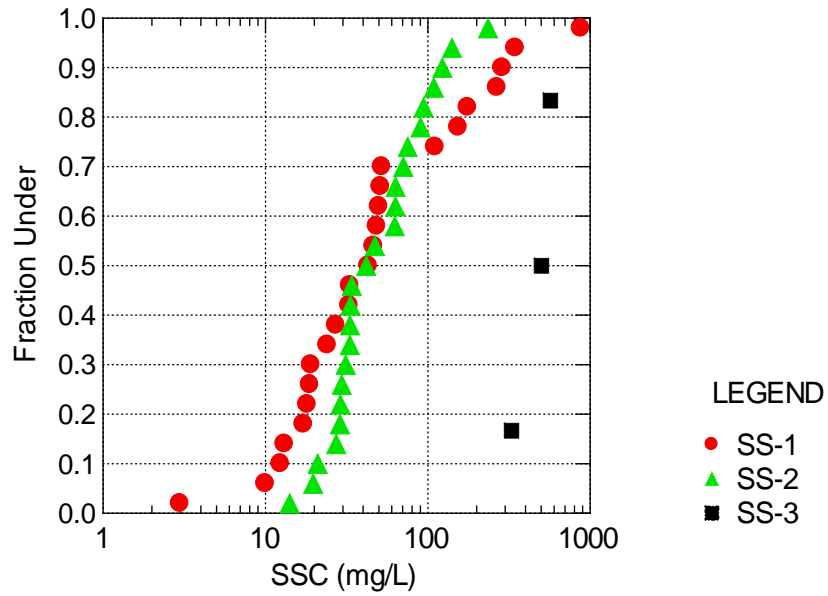


Figure 5-40
Probability Plot for SSC

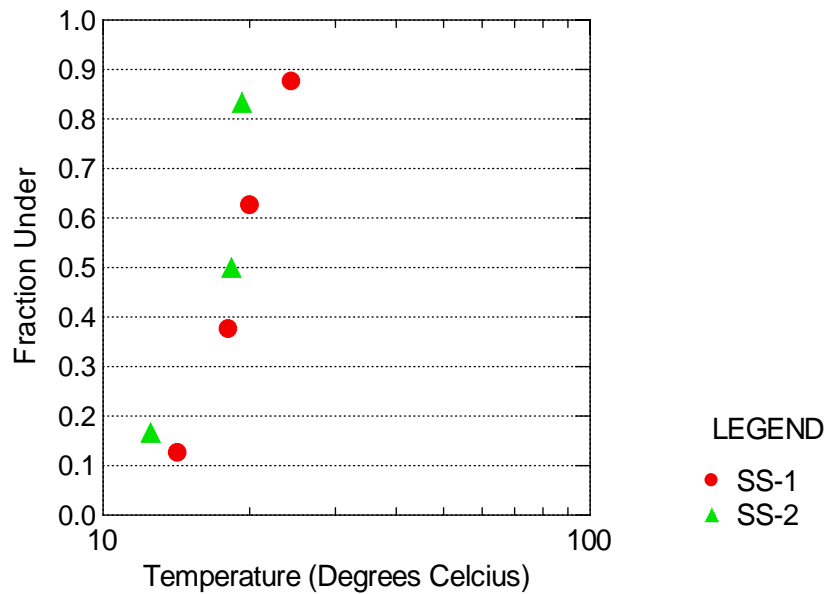


Figure 5-41
Probability Plot for Temperature

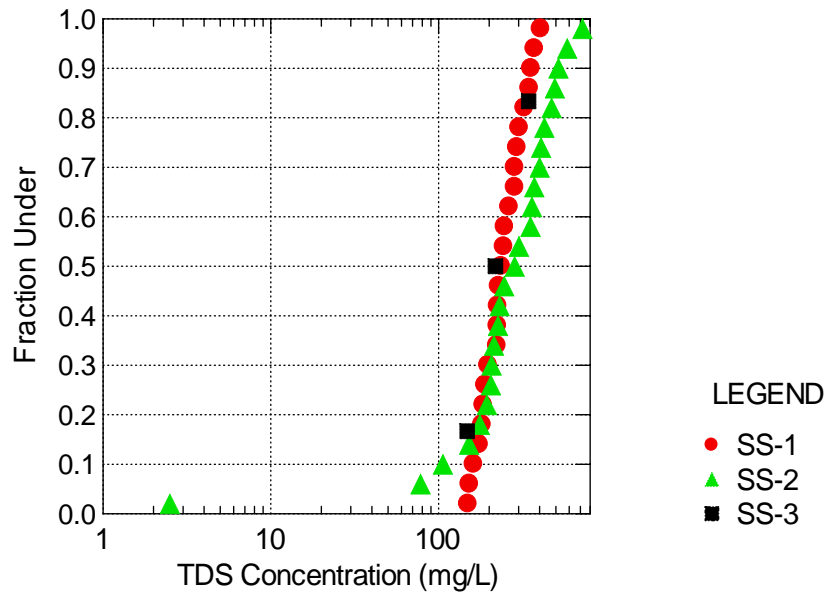


Figure 5-42
Probability Plot for TDS

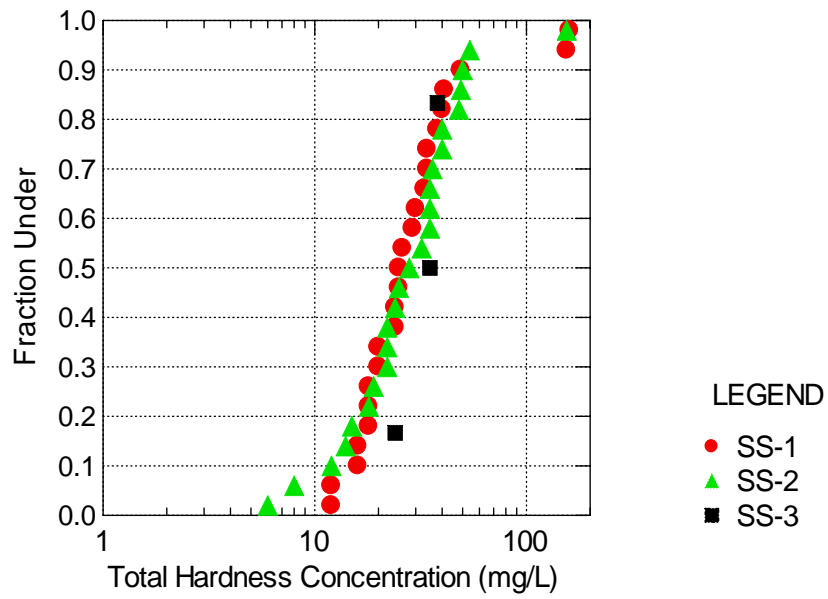


Figure 5-43
Probability Plot for Total Hardness

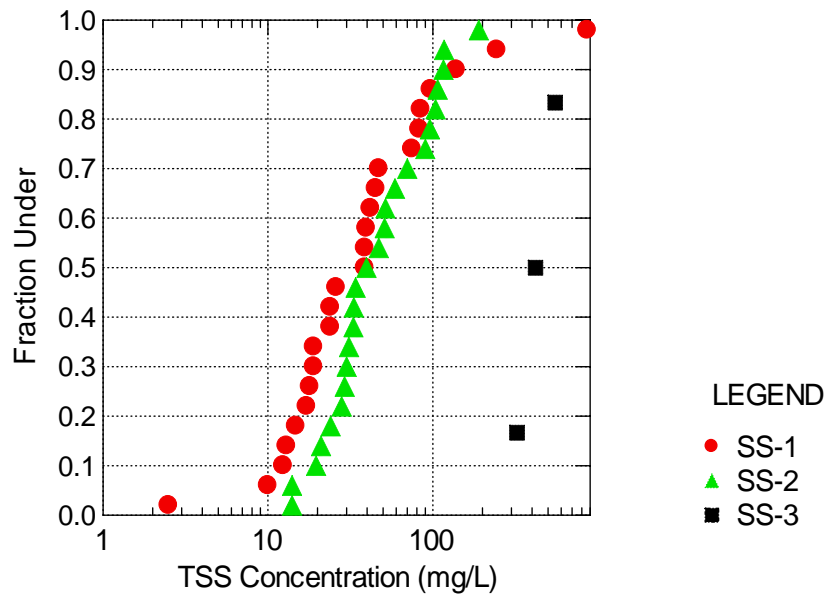


Figure 5-44
Probability Plot for TSS

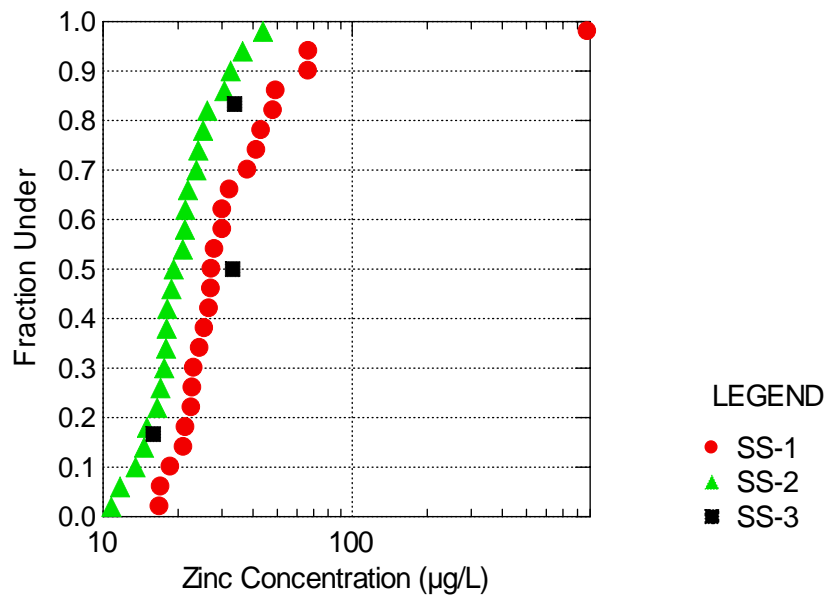


Figure 5-45
Probability Plot for Zinc

5.5 INLET, OUTLET, AND REVERSE FLOW COMPARISON

The EMC values were transformed logarithmically (LN) for this statistical analysis based upon the probability plots in Section 5.4 and the tendency of water quality concentration data to have a log-normal distribution (EPA, 1983). The outliers identified in Section 5.3 were not removed from the analysis; however, the disqualified data discussed in Section 4.3 were removed from the analysis.

Inlet, outlet, and reverse flow mean values were statistically compared to each other to determine if there was a statistically significant difference in the mean values calculated at the inlet, outlet, and reverse flow sampling locations. The one-way analysis of variance ("ANOVA") test of statistical significance was used to compare the inlet, outlet, and reverse flow means to each other. The hypothesis for the ANOVA test was that the inlet, outlet, and reverse flow values were derived from the same population and had equal means. ANOVA also assumed that the variances were equal across the groups. The variances between all of the inlet, outlet, and reverse flow EMC's for each parameter were compared using the Levene test for equality of variances. The results of the Levene test for each parameter are provided in Appendix I. Oil and grease and SSC were the only parameters that did not meet the equal variances assumption. ANOVA compared the inlet, outlet, and reverse flow mean values for statistically significant differences at a confidence level of 95 percent. The sample sizes, means, variances, and "P" values from the ANOVA tests for each parameter are summarized in Table 5-6. If the "P" value was less than 0.05, then there was a statistical difference between one of the groups (inlet, outlet, and reverse flow). The complete results of the ANOVA tests for each parameter are provided in Appendix J.

Table 5-6
ANOVA "P" Values for Comparing Parameter Means at
Inlet, Outlet, and Reverse Flow Sampling Locations

Parameter	Statistic	Inlet	Outlet	Reverse Flow	ANOVA "P" Value
2,4-D	Sample Size	24	24	3	0.927
	Mean	-0.45	-0.48	-0.31	
	Variance	0.60	0.54	0.20	
BOD ₅	Sample Size	22	23	3	0.553
	Mean	2.25	2.20	2.48	
	Variance	0.21	0.13	0.18	
COD	Sample Size	24	25	3	0.553
	Mean	4.16	4.14	3.87	
	Variance	0.22	0.16	0.36	
Copper	Sample Size	25	25	3	0.025
	Mean	3.27	2.89	2.35	
	Variance	0.61	0.22	0.24	
E. coli	Sample Size	4	4	--	0.239
	Mean	10.54	11.75	--	
	Variance	3.08	0.38	--	
Enterococci	Sample Size	4	4	--	0.292
	Mean	10.11	11.16	--	
	Variance	2.30	1.00	--	
Fecal Coliform	Sample Size	4	4	--	0.295
	Mean	11.67	12.58	--	
	Variance	2.13	0.42	--	
Lead	Sample Size	25	25	3	0.003
	Mean	0.53	0.44	1.91	
	Variance	0.62	0.24	0.53	
Nickel	Sample Size	25	25	3	0.175
	Mean	1.05	1.10	1.62	
	Variance	0.28	0.19	0.40	
Nitrate as N	Sample Size	23	24	3	0.018
	Mean	-0.36	-0.39	0.32	
	Variance	0.08	0.22	0.29	
Nitrite as N	Sample Size	23	24	3	0.764
	Mean	-1.00	-1.05	-0.56	
	Variance	0.71	1.68	0.49	
TKN	Sample Size	24	25	3	0.955
	Mean	0.91	0.97	1.02	
	Variance	0.71	0.61	1.36	
Oil and Grease	Sample Size	4	4	--	0.130
	Mean	1.17	1.61	--	
	Variance	0.05	0.20	--	
Ortho-Phosphate	Sample Size	23	24	3	0.017
	Mean	0.14	0.19	1.31	
	Variance	0.21	0.57	1.18	
pH	Sample Size	8	7	--	0.845
	Mean	2.08	2.07	--	
	Variance	0.01	0.00	--	
Phosphorus, Total	Sample Size	24	25	3	0.369
	Mean	1.52	1.65	2.87	
	Variance	2.31	2.57	1.33	
SSC	Sample Size	25	25	3	0.002
	Mean	3.83	3.89	6.12	
	Variance	1.70	0.48	0.08	
Temperature	Sample Size	4	3	--	0.464
	Mean	2.94	2.80	--	
	Variance	0.05	0.06	--	
TDS	Sample Size	25	25	3	0.983
	Mean	5.49	5.46	5.41	
	Variance	0.08	1.17	0.18	
Total Hardness	Sample Size	25	25	3	0.902
	Mean	3.34	3.29	3.46	
	Variance	0.40	0.45	0.06	
TSS	Sample Size	25	25	3	0.000
	Mean	3.58	3.82	6.04	
	Variance	1.36	0.50	0.07	
Zinc	Sample Size	25	25	3	0.013
	Mean	3.53	3.01	3.26	
	Variance	0.60	0.11	0.18	

Copper, lead, nitrate N, ortho-phosphate, SSC, TSS, and zinc exhibited "P" values less than 0.05. These parameters along with oil and grease, which did not meet the equal variance assumption, were examined further using the non-parametric, Kruskal Wallis test and parametric ANOVA contrast tests. The discussion of those tests is presented in Appendix K.

The Kruskal Wallis tests reaffirmed the findings of the ANOVA tests for oil and grease, SSC, and lead, which all exhibited non-parametric characteristics. The statistical analyses presented in Appendix K revealed that for SSC, lead, nitrate as N, ortho-phosphate, and TSS, the reverse flow mean was statistically different from the inlet and outlet means at a confidence level of 95 percent. It was also shown that for copper the inlet mean was statistically different from the outlet and reverse flow means, and that for zinc the inlet and outlet means were statistically different at a confidence level of 95 percent.

5.6 GROUPED ANALYSIS – ANTECEDENT DRY PERIODS

The EMC values were transformed logarithmically (LN) for this statistical analysis based upon the probability plots in Section 5.4 and the tendency of water quality concentration data to have a log-normal distribution (EPA, 1983). The outliers identified in Section 5.3 were not removed from the analysis; however, the disqualified data discussed in Section 4.3 were removed from the analysis.

The antecedent dry periods for all events listed in Table 4-1 were sorted into three categories: (1) greater than or equal to 24 hours and less than 72 hours, (2) greater than or equal to 72 hours and less than 168 hours, and (3) greater than or equal to 168 hours. Twenty-four hours was selected as the minimum cut-off point because no storms were sampled for this study that had an antecedent dry period of less than 24 hours. At 72 hours, storms may be sampled to fulfill the requirements of an NPDES permit, and at 168 hours a pollutant build-up time of one week has occurred.

The antecedent dry period categories and inlet values for each parameter were statistically compared to each other to determine if a relationship existed between antecedent dry period and the pollutant load entering the basin. The ANOVA test was used to compare the inlet values grouped into the three antecedent dry period categories to each other. The hypothesis for the ANOVA test of statistical significance was that the inlet values for each antecedent dry period category were derived from the same population and had equal means. ANOVA also assumed that the variances were equal across the groups. The variances among the inlet values for each antecedent dry period category and each parameter were compared using the Levene test for equality of variances. The results of the Levene test for each parameter are provided in Appendix L. The Levene test could not be performed for E. coli, Enterococci, fecal coliform, oil and grease, and temperature because the sample size for each category was not large enough. All of the remaining tests met the assumption of equal variances through the Levene test.

The ANOVA test was used to evaluate the hypothesis of equal means among the antecedent dry period categories for all parameters except E. coli, Enterococci, fecal coliform, oil and grease, and temperature. These parameters were excluded from this comparison due to the lack of data necessary to obtain a statistically significant result. ANOVA compared the inlet values with each antecedent dry period category for statistically significant differences at a confidence level of 95 percent. The sample sizes, means, variances, and "P" values from the ANOVA tests for each parameter are summarized in Table 5-7. If the "P" value was less than 0.05, then there was a statistical difference between one of the antecedent dry period categories. The complete results of the ANOVA tests for each parameter are provided in Appendix M.

Table 5-7
ANOVA "P" Values for Comparing Parameter Means
Belonging to Three Different Antecedent Dry Period Groups

Parameter	Statistic	Group 1 ≥24 hrs, <72 hrs	Group 2 ≥72 hrs, <168 hrs	Group 3 ≥168 hrs	ANOVA "P" Value
2,4-D	Sample Size	8	9	7	0.431
	Mean	-0.59	-0.58	-0.12	
	Variance	0.19	0.56	1.13	
BOD ₅	Sample Size	6	9	7	0.478
	Mean	2.13	2.40	2.17	
	Variance	0.16	0.30	0.13	
COD	Sample Size	8	9	7	0.297
	Mean	3.95	4.31	4.22	
	Variance	0.27	0.19	0.18	
Copper	Sample Size	8	9	8	0.565
	Mean	3.27	3.07	3.49	
	Variance	0.12	0.22	1.62	
Lead	Sample Size	8	9	8	0.720
	Mean	0.39	0.50	0.71	
	Variance	0.30	0.25	1.49	
Nickel	Sample Size	8	9	8	0.698
	Mean	1.03	0.96	1.18	
	Variance	0.18	0.19	0.54	
Nitrate as N	Sample Size	7	9	7	0.241
	Mean	-0.36	-0.46	-0.21	
	Variance	0.03	0.09	0.10	
Nitrite as N	Sample Size	7	9	7	1.000
	Mean	-1.00	-1.00	-1.01	
	Variance	1.48	0.43	0.56	
TKN	Sample Size	8	9	7	0.053
	Mean	1.25	0.38	1.20	
	Variance	0.46	1.05	0.11	
Ortho-Phosphate	Sample Size	7	9	7	0.813
	Mean	0.05	0.15	0.21	
	Variance	0.09	0.14	0.47	
pH	Sample Size	2	2	4	0.900
	Mean	2.10	2.09	2.06	
	Variance	0.00	0.00	0.02	
Phosphorus, Total	Sample Size	8	9	7	0.318
	Mean	1.58	2.01	0.83	
	Variance	2.14	2.33	2.34	
SSC	Sample Size	8	9	8	0.124
	Mean	3.08	4.34	3.99	
	Variance	1.33	1.04	2.29	
TDS	Sample Size	8	9	8	0.582
	Mean	5.55	5.41	5.52	
	Variance	0.10	0.10	0.06	
Total Hardness	Sample Size	8	9	8	0.494
	Mean	3.15	3.34	3.54	
	Variance	0.13	0.58	0.51	
TSS	Sample Size	8	9	8	0.169
	Mean	2.96	3.99	3.75	
	Variance	1.04	0.63	2.22	
Zinc	Sample Size	8	9	8	0.587
	Mean	3.40	3.43	3.77	
	Variance	0.06	0.19	1.69	

No parameter exhibited "P" values less than 0.05 indicating that there was no statistically significant difference between the antecedent dry period groups and the inlet values for any parameter at a confidence level of 95%.

5.7 GROUPED ANALYSIS – STORM EVENT SIZE

The EMC values were transformed logarithmically (LN) for this statistical analysis based upon the probability plots in Section 5.4 and the tendency of water quality concentration data to have a log-normal distribution (EPA, 1983). The outliers identified in Section 5.3 were not removed from the analysis; however, the disqualified data discussed in Section 4.3 were removed from the analysis.

The storm events listed in Table 4-1 were sorted into two categories: (1) Less than or equal to 0.47 inch, and (2) greater than 0.47 inch. The amount 0.47 inch was the median rainfall of the qualifying storms presented in Table 4-1 and was selected as the cut-off point for the categories. The median value allowed the rainfall categories to be equally distributed. Storms below 0.47 inch were considered small storm events and storms above 0.47 inch were considered large storm events.

The two storm event categories and inlet values for each parameter were statistically compared to each other to determine if a relationship existed between storm size and the mean pollutant concentration entering the basin. The ANOVA test was used to compare the inlet values grouped into the two storm size categories to each other. The hypothesis for the ANOVA test of statistical significance was that the inlet values for each storm size category were derived from the same population and had equal means. ANOVA also assumed that the variances were equal across the groups. The variances among the inlet values for each storm size and each parameter were compared using the Levene test for equality of variances. The results of the Levene test for each parameter are provided in Appendix N. All parameters met the assumption of equal variances through the Levene test except E. coli, Enterococci, fecal coliform, oil and grease, and temperature.

The ANOVA test was used to evaluate the hypothesis of equal parameter means between the two storm event categories for all parameters except E. coli, Enterococci, fecal coliform, oil and grease, and temperature. These parameters were excluded from this comparison due to the lack of data necessary to accomplish a statistically significant result. ANOVA compared the mean inlet values belonging to both storm size categories for statistically significant differences at a confidence level of 95 percent. The sample sizes, means, variances, and "P" values from the ANOVA tests for each parameter are summarized in Table 5-8. If the "P" value was less than 0.05, then there was a statistical difference between the means belonging to the two storm event size categories. The complete results of the ANOVA tests for each parameter are provided in Appendix O.

Table 5-8
ANOVA "P" Values for Comparing Parameter Means
Belonging to Two Storm Event Size Categories

Parameter	Statistic	Small Storms	Large Storms	ANOVA "P" Value
2,4-D	Sample Size	13	11	0.189
	Mean	-0.64	-0.22	
	Variance	0.40	0.78	
BOD ₅	Sample Size	12	10	0.504
	Mean	2.31	2.18	
	Variance	0.30	0.10	
COD	Sample Size	13	11	0.863
	Mean	4.15	4.18	
	Variance	0.27	0.18	
Copper	Sample Size	13	12	0.342
	Mean	3.12	3.42	
	Variance	0.16	1.10	
Lead	Sample Size	13	12	0.157
	Mean	0.31	0.77	
	Variance	0.18	1.05	
Nickel	Sample Size	13	12	0.174
	Mean	0.91	1.20	
	Variance	0.16	0.39	
Nitrate as N	Sample Size	12	11	0.514
	Mean	-0.39	-0.31	
	Variance	0.07	0.10	
Nitrite as N	Sample Size	12	11	0.039
	Mean	-1.34	-0.63	
	Variance	0.70	0.49	
TKN	Sample Size	13	11	0.659
	Mean	0.84	0.99	
	Variance	0.89	0.55	
Ortho-Phosphate	Sample Size	12	11	0.174
	Mean	0.01	0.27	
	Variance	0.22	0.17	
pH	Sample Size	4	4	0.157
	Mean	2.03	2.12	
	Variance	0.01	0.00	
Phosphorus, Total	Sample Size	13	11	0.698
	Mean	1.63	1.38	
	Variance	2.04	2.83	
SSC	Sample Size	13	12	0.540
	Mean	3.67	4.00	
	Variance	1.02	2.52	
TDS	Sample Size	13	12	0.121
	Mean	5.57	5.39	
	Variance	0.07	0.08	
Total Hardness	Sample Size	13	12	0.682
	Mean	3.40	3.29	
	Variance	0.34	0.50	
TSS	Sample Size	13	12	0.566
	Mean	3.45	3.73	
	Variance	0.81	2.05	
Zinc	Sample Size	13	12	0.118
	Mean	3.29	3.78	
	Variance	0.07	1.11	

Nitrite as N exhibited a "P" value less than 0.05 and was examined further using a box-whisker plot, probability plot, and the non-parametric Kruskal Wallis test. The discussion of these tests is presented in Appendix P. The Kruskal Wallis test found that there was no statistical difference between the means belonging to the small and large storm event categories for nitrite as N at a confidence level of 95 percent.

5.8 GROUPED ANALYSIS – SUSPENDED SEDIMENT AND METALS

The EMC values were transformed logarithmically (LN) for this statistical analysis based upon the probability plots in Section 5.4 and the tendency of water quality concentration data to have a log-normal distribution (EPA, 1983). The outliers identified in Section 5.3 were not removed from the analysis.

TSS and SSC EMC results were sorted into four categories: (1) less than or equal to 25 percent of the data; (2) greater than 25 to less than or equal to 50 percent of the data; (3) greater than 50 to less than or equal to 75 percent of the data; and (4) greater than 75 percent of the data. These groupings were selected to allow TSS and SSC to be ranked in ascending groups of equal size for comparison to the metals data.

The mean metals concentration associated with each of the four suspended sediment categories were statistically compared to each other for each metal parameter to determine if a relationship existed between increasing suspended sediment concentration and the concentration of metals detected at the inlet, outlet, and in the reverse flow sampling locations. The ANOVA test was used to compare the mean metals concentration belonging to each of the four TSS and SSC categories to each other. The hypothesis for the ANOVA test of statistical significance was that the mean metal parameter values belonging to each of the sediment categories were derived from the same population and had equal means. ANOVA also assumed that the variances were equal across the groups. The variances among the means belonging to each sediment concentration category were compared using the Levene test for equality of variances. The results of the Levene test are provided in Appendix Q for TSS and Appendix R for SSC. All metal parameters met the assumption of equal variances through the Levene test for both the TSS and SSC groupings.

The ANOVA test was used to evaluate the hypothesis of equal means among the four TSS and SSC categories. ANOVA compared the mean metal parameter values belonging to each of the TSS and SSC categories for statistically significant differences at a confidence level of 95 percent. The sample sizes, means, variances, and "P" values from the ANOVA tests for each parameter are summarized in Table 5-9 for TSS and Table 5-10 for SSC. If the "P" value was less than 0.05, then there was a statistical difference in metals concentrations belonging to the TSS categories. The complete results of the ANOVA tests for each parameter are provided in Appendix S for TSS and Appendix T for SSC.

Table 5-9
ANOVA "P" Values for Comparing Mean Metal Concentration Belonging to TSS Groups

Parameter	Statistic	Group 1 TSS ≤25%	Group 2 TSS >25% to ≤50%	Group 3 TSS >50% to ≤75%	Group 4 TSS >75%	ANOVA "P" Value
Copper	Sample Size	16	10	14	13	0.306
	Mean	3.00	3.00	2.85	3.33	
	Variance	0.09	0.26	0.24	1.25	
Lead	Sample Size	16	10	14	13	0.000
	Mean	0.18	0.30	0.40	1.43	
	Variance	0.11	0.19	0.25	0.66	
Nickel	Sample Size	16	10	14	13	0.014
	Mean	0.96	1.06	0.97	1.49	
	Variance	0.17	0.24	0.22	0.24	
Zinc	Sample Size	16	10	14	13	0.046
	Mean	3.18	2.95	3.24	3.66	
	Variance	0.05	0.19	0.18	1.08	

Table 5-10
ANOVA "P" Values for Comparing Mean Metal Concentration Belonging to SSC Groups

Parameter	Statistic	Group 1 SSC ≤25%	Group 2 SSC >25% to ≤50%	Group 3 SSC >50% to ≤75%	Group 4 SSC >75%	ANOVA "P" Value
Copper	Sample Size	13	14	12	14	0.146
	Mean	3.10	2.92	2.76	3.34	
	Variance	0.15	0.15	0.23	1.15	
Lead	Sample Size	13	14	12	14	0.000
	Mean	0.27	0.24	0.35	1.35	
	Variance	0.200	0.13	0.21	0.72	
Nickel	Sample Size	13	14	12	14	0.014
	Mean	1.04	0.98	0.93	1.47	
	Variance	0.21	0.18	0.18	0.28	
Zinc	Sample Size	13	14	12	14	0.008
	Mean	3.29	2.98	3.07	3.71	
	Variance	0.08	0.11	0.10	1.00	

Lead, nickel, and zinc exhibited "P" values less than 0.05 and were examined further using box-whisker plots, probability plots, and non-parametric Kruskal Wallis tests. The discussion of these tests is presented in Appendix U. The statistical analyses revealed that for lead, nickel, and zinc, the means belonging to Groups 1, 2, and 3 were statistically different from the mean belonging to Group 4 for both TSS and SSC groupings at a confidence level of 95 percent.

5.9 PARTICLE SIZE COMPARISON

The results of the particle size distribution analyses for each storm event are presented in Appendix F. Two statistics were calculated from the results of these analyses and used for comparison: event mean particle size and event median diameter (d50). These two characteristics represent an average particle size. The d50 was calculated for each event and station as:

$$S = 2^{\log_2(S^-) + [0.5 - P^-] * \frac{[\log_2(S^+) - \log_2(S^-)]}{[P^+ - P^-]}}$$

where,

S = Size

S^+ = Size at the top of the range

S^- = Size at the bottom of the range

P^+ = Percent of particles smaller than S^+

P^- = Percent of particles smaller than S^-

The event mean and d50 associated with the 26 storm events are summarized in Table 5-11.

Table 5-11
Particle Size Distribution Summary Data

Event ID	Event Mean (µm)			d50 (µm)		
	Inlet	Outlet	Reverse Flow	Inlet	Outlet	Reverse Flow
001	1.99	3.05		1.67	2.25	
002	1.92	2.57		1.69	1.57	
003	5.33	3.14	2.41	3.10	2.61	2.41
004	2.21	1.77		1.92	1.50	
005	1.86	1.93		1.67	1.80	
006	2.22	2.28		1.72	1.97	
007	1.58	2.91		1.37	1.88	
008	1.89	1.82		1.61	1.60	
009	2.72	2.20		2.03	1.82	
011	2.57	3.76		1.81	2.20	
012	2.09	3.29		1.85	2.24	
013	6.44	7.67		3.84	4.13	
014	3.43	4.26		2.75	2.95	
015	4.22	6.75		3.27	4.10	
016	3.18	2.98		2.59	2.35	
017	5.97	2.65		2.94	2.28	
018	3.27	2.79		2.55	2.35	
019	3.21	4.07		2.39	2.67	
020	5.69	4.29	3.35	2.86	2.57	2.46
021	3.11	2.72		2.18	2.07	
022	2.50	2.12		1.90	1.88	
023	1.94	2.59	2.32	1.37	2.37	2.32
024	3.13	2.53		2.23	2.27	
025	3.27	2.63		2.26	1.92	
026	1.90	2.53		1.82	2.14	

The summary statistics of the inlet, outlet, and reverse flow event mean and d50 particle sizes are presented in Table 5-12.

Table 5-12
Particle Size Distribution Summary Statistics

Station	Statistic	Event Mean	d50
Inlet	N	25	25
	Mean	3.11	2.22
	Geometric Mean	2.86	2.13
	Median	2.72	2.03
	Variance	1.94	0.40
	Standard Deviation	1.39	0.63
	Coefficient of Variation	0.45	0.29
Outlet	N	25	25
	Mean	3.11	2.22
	Geometric Mean	2.86	2.13
	Median	2.72	2.03
	Variance	1.94	0.40
	Standard Deviation	1.39	0.63
	Coefficient of Variation	0.45	0.29
Reverse Flow	N	3	3
	Mean	2.70	2.40
	Geometric Mean	2.66	2.40
	Median	2.41	2.41
	Variance	0.32	0.01
	Standard Deviation	0.57	0.07
	Coefficient of Variation	0.21	0.03

Box-whisker plots for the event mean and d50 particle sizes categorized by inlet, outlet, and reverse flow are shown in Figures 5-46 and 5-47.

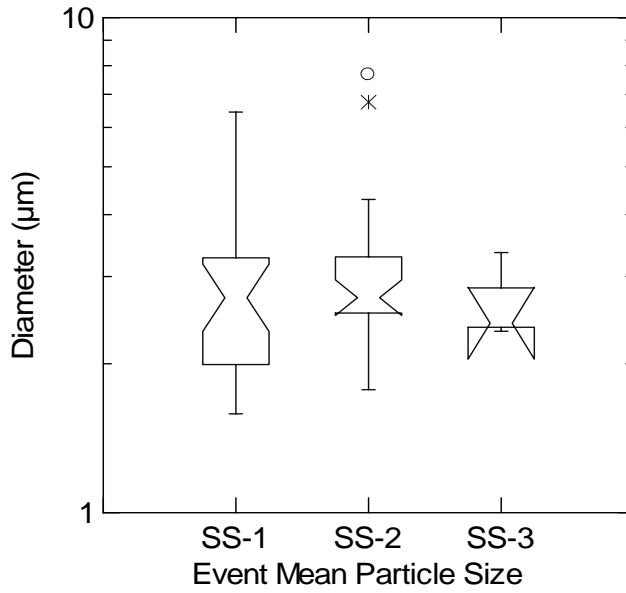


Figure 5-46
Box-Whisker Plot – Event Mean Particle Size

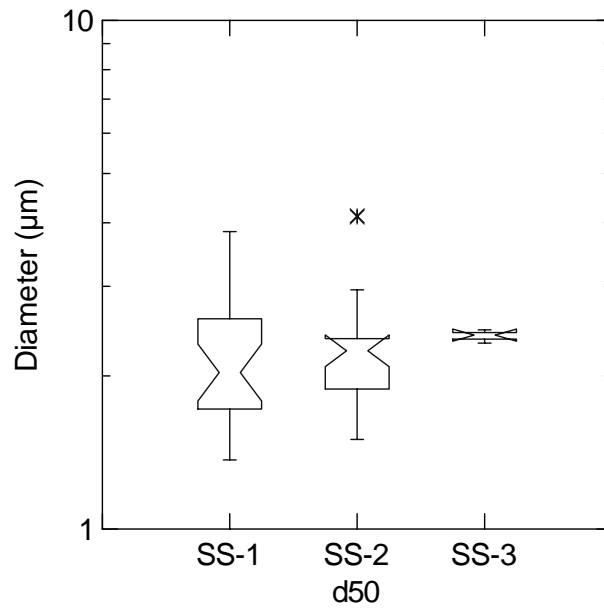


Figure 5-47
Box-Whisker Plot – d50

Figures 5-48 and 5-49 show the probability plots of the inlet, outlet, and reverse flow values for the event mean and d50.

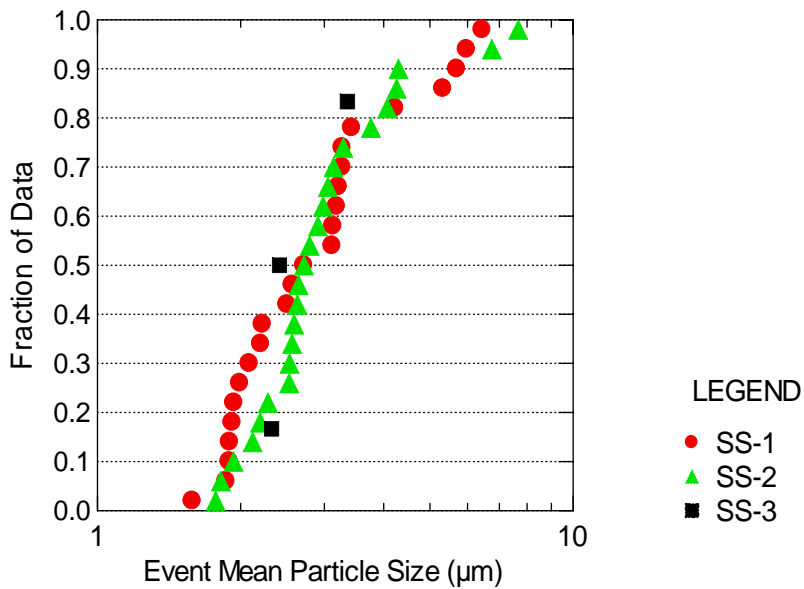


Figure 5-48
Probability Plot for Event Mean Particle Size

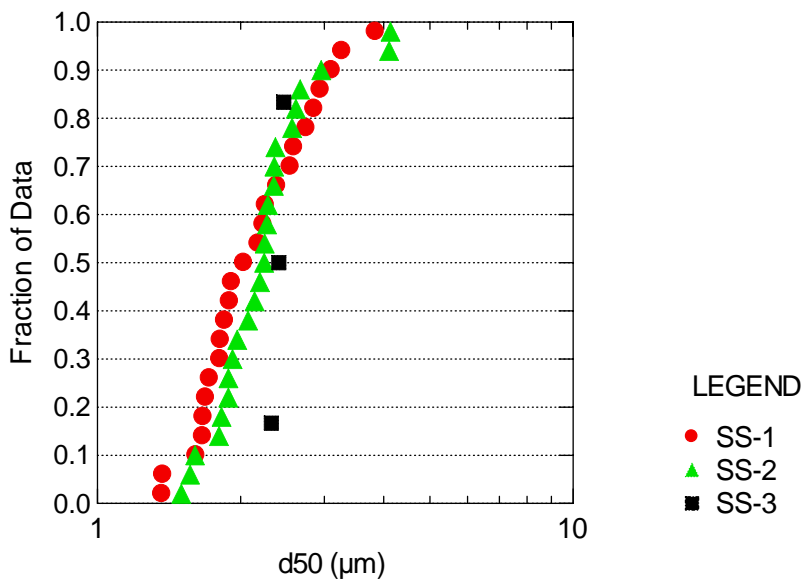


Figure 5-49
Probability Plot for d50

The inlet, outlet, and reverse flow values for event mean and event median particle size were statistically compared to each other to determine if any statistically significant change occurred among the three

different sampling locations. The EMC values were transformed logarithmically (LN) for this statistical analysis based upon the probability plots and the tendency of water quality concentration data to have a log-normal distribution (EPA, 1983). The ANOVA test was used to compare the mean particle size values at each sampling location to each other. The hypothesis for the ANOVA test of statistical significance was that all values for event mean and event median (d50) particle size were derived from the same population and had equal means. ANOVA also assumed that the variances were equal at each sampling location. The variances between the values for event mean and d50 particle sizes were compared using the Levene test for equality of variances. The results of the Levene tests are provided in Appendix V. Both event mean and d50 met the assumption of equal variances.

The ANOVA test was used to evaluate the hypothesis of equal means among the sampling locations for event mean and d50 particle sizes. ANOVA compared the inlet, outlet, and reverse flow values for both event mean and d50 particle size for statistically significant differences at a confidence level of 95 percent. The sample sizes, means, variances, and "P" values from the ANOVA tests for both event mean and d50 are summarized in Table 5-13. If the "P" value was less than 0.05, then there was a statistical difference between one of the categories. The complete results of the ANOVA tests for each parameter are provided in Appendix W.

Table 5-13
ANOVA "P" Values for Comparing Particle Size among Inlet, Outlet and Reverse Flow

Parameter	Statistic	Inlet	Outlet	Reverse Flow	ANOVA "P" Value
Event Mean	Sample Size	25	25	3	0.879
	Mean	1.05	1.08	0.98	
	Variance	0.16	0.13	0.04	
Event Median/d50	Sample Size	25	25	3	0.699
	Mean	0.76	0.80	0.87	
	Variance	0.08	0.06	0.00	

The event mean and the d50 particle size did not exhibit "P" values less than 0.05, indicating that there was no statistically significant difference between the inlet, outlet, and reverse flow values at a confidence level of 95 percent.

6.0 DISCUSSION OF RESULTS

Statistical analyses were performed for each constituent to determine concentration differences among sampling locations, constituent variability and mean values, the effect of antecedent dry period on the inlet concentrations, the effect of storm event size on the inlet concentrations, and relationships between suspended sediment and metals. A comparison of the monitoring results to the EPA Nationwide Urban Runoff Program ("NURP") study (EPA, 1983) was also conducted.

Efforts were made to minimize variations in the sampling procedures among the inlet, outlet, and reverse flow configurations and to maximize the amount of suspended sediment collected at all stations. However, a stainless steel floatables excluder was installed at the inlet to prevent clogging of the auto-sampler. The floatables excluder's mesh prevented particles greater than 200 μm from entering the suction line. The sample intake points at all of the sampling stations were located near the bottom of the CMP, yet auto-samplers have been shown to be inefficient at characterizing bed load due to the limitations of the auto-samplers to collect larger particles (Bent, et al., 2001).

Additionally, the monthly rainfall patterns that occurred over the monitoring period differed from the long-term averages as shown in Figure 4-1. The majority of rainfall was during the month of July, while during the remaining months rainfall was less than the long-term monthly averages.

6.1 COMPARISON OF VARIABILITY AND MEANS

Constituents with a low variability are easier to remove through BMP's due to the enhanced ability of designing an accurate and appropriate BMP suited to the level of constituent removal desired. BMP performance evaluations can be skewed by constituent variability from either the influent or effluent. The variability may mask an underlying removal process, such as the efficient removal of high concentrations of a constituent.

Standard deviation is a measure of how variable data are and how much individual results vary from the mean of the results. Bacteria had high standard deviations at both the inlet and outlet suggesting that the concentrations were quite different among storm events at both stations.

The coefficient of variation ("CV") allowed the comparison of variability among the constituents and between values entering and leaving the basin. The constituents 2,4-D and total phosphorus exhibited a high CV at both the inlet and outlet demonstrating that these constituents were highly variable. The CV's for 2,4-D, nitrate as N, nitrite as N, oil and grease, and TDS were larger leaving the basin than entering the basin (inlet and reverse flow), suggesting that the concentrations of these constituents entering the basin were less variable than the concentrations leaving. The CV's for COD, bacteria, nickel, TKN, pH, and total phosphorus were smaller leaving the basin compared to entering (inlet and reverse flow),

suggesting that the concentrations of these constituents entering the basin were more variable than the concentrations leaving. The constituents BOD₅, copper, lead, orth-phosphate, SSC, total hardness, TSS, and zinc had variable CV's between values entering (inlet and reverse flow) and leaving the basin. The changes in CV between values entering and leaving the basin indicate that processes did occur within the basin that affected the levels of those constituents.

Due to the tendency of water quality concentration data to have a log-normal distribution (EPA, 1983), the geometric means were compared between values entering and leaving the basin. The constituents 2,4-D, BOD₅, pH, total hardness, temperature, and zinc exhibited a decrease in the geometric mean between values entering (inlet and reverse flow) and leaving the basin suggesting a removal process was occurring in the basin. Bacteria and oil and grease exhibited an increase in the geometric mean between values entering the basin (inlet and reverse flow) and leaving the basin, suggesting the basin was a source of these constituents. COD, copper, lead, nickel, nitrate as N, nitrite as N, TKN, ortho-phosphate, total phosphorus, and TDS exhibited variable geometric means between the inlet, outlet, and reverse flow values. TSS and SSC exhibited a substantially higher geometric mean in the reverse flow than at both the inlet and outlet, suggesting that flow from Faulkey Gully contained higher levels of suspended sediment than flow entering and leaving the basin.

6.2 NOTCHED BOX-WHISKER PLOTS

The notched box-whisker plots displayed the inlet, outlet, and reverse flow EMC concentrations for each parameter. The BOD₅, copper, lead, nickel, nitrate as N, ortho-phosphate, SSC, TSS, and zinc box-whisker plots displayed confidence intervals for one or more of the groups that did not overlap with the other groups. The box-whisker plots allowed visual inspection for significant differences between the groupings and provided guidance for further statistical analysis.

For BOD₅, nickel, nitrate as N, ortho-phosphate, SSC, and TSS, the box-whisker plots indicated that reverse flow values were higher than the inlet and outlet values. For copper, the box-whisker plot indicated that the reverse flow values were less than the inlet and outlet values. The plots also indicated that for lead the outlet values were higher than the inlet values, and for zinc the outlet values were less than the inlet values. The notched box-whisker plots did not provide evidence of differences between the inlet, outlet, and reverse flow values for 2,4-D, COD, bacteria, nitrite as N, TKN, oil and grease, pH, total phosphorus, temperature, TDS, and total hardness.

6.3 PROBABILITY PLOTS

The probability plots allowed a further graphical comparison between the inlet, outlet, and reverse flow EMC data for each constituent. The 2,4-D, lead, nickel, nitrite N, and ortho-phosphate probability plots illustrated the high proportions of non-detects within the data as evidenced by the vertical orientation around a specific value in the data. For the constituents 2,4-D, nickel, nitrite as N, and ortho-phosphate,

there were many instances of positive detections below the detection limit, which cause the vertical plotting line around the non-detects to be located at a mid-point in the probability plot as opposed to near the y-axis. Copper, lead, pH, and zinc showed a tendency to be removed (outlet values less than inlet values) across the entire range of observed concentrations with the relationship being especially true for zinc. Total hardness, TDS, nitrate, and nitrite N showed a tendency to be removed more efficiently at low concentrations, while TSS and SSC showed a tendency to be removed more efficiently at high concentrations. BOD₅, COD, copper, nitrate as N, pH, total phosphorus, TDS, total hardness, TSS, and zinc exhibited clear characteristics of log-normal distributions.

6.4 INLET, OUTLET, AND REVERSE FLOW COMPARISON

The reverse flow EMC values for lead, nitrate N, ortho-phosphate, TSS, and SSC were statistically higher than the inlet and outlet values. Water entering the basin from Faulkey Gully was expected to contain higher levels of these constituents due to the developing contributing watershed. The difference in the geometric mean between the reverse flow and outlet value for lead was 5.18 µg/L, for nitrate as N was 0.695 mg/L, for ortho-phosphate was 2.52 mg/L, for TSS was 377 mg/L, and for SSC was 405 mg/L.

The inlet values for copper were statistically higher than the outlet values. The difference in the geometric mean between the inlet and outlet for copper was 8.1 µg/L. There was no statistical difference between the outlet and reverse flow values for copper, and the geometric mean for reverse flow was lower than the geometric mean for the outlet by 7.6 µg/L. The inlet value for zinc was statistically higher than the outlet value. The difference in the geometric mean between the inlet and outlet for zinc was 13.7 µg/L.

6.5 ANTECEDENT DRY PERIODS

The inlet mean EMC values belonging to three antecedent dry period categories: (1) greater than or equal to 24 hours and less than 72 hours, (2) greater than or equal to 72 hours and less than 168 hours, and (3) greater than or equal to 168 hours were statistically compared for all parameters. No statistical difference was observed among the categories for any parameter, which suggests that antecedent dry period and inlet concentrations were not correlated.

6.6 STORM EVENT SIZE

The inlet mean EMC values belonging to two storm event size categories: (1) less than or equal to 0.47 inch, and (2) greater than 0.47 inch were statistically compared for all parameters. No statistical difference was observed between the categories for any parameter, which suggests that storm event size did not play a significant role in changing the inlet levels for any parameter although the rainfall totals over the study period were generally less than the long-term averages, which may have weighted the analysis with small rain events.

6.7 SUSPENDED SEDIMENT AND METALS

TSS and SSC were used to determine how much suspended sediment influenced the levels of total metals. TSS and SSC influenced the level of metals in identical ways and will be referred to simply as "suspended sediment." High levels of suspended sediment (the top 25 percent of all suspended sediment samples) were correlated with high levels of total lead, nickel, and zinc. This finding demonstrates that a relationship does exist between levels of these constituents and the levels of suspended sediment in stormwater, but it is only evident when examining high levels of suspended sediment.

6.8 PARTICLE SIZE

The event mean and event median (d50) particle size at the inlet, outlet, and reverse flow sampling locations were compared through summary statistics, notched box-whisker plots, probability plots, and the ANOVA test of statistical significance and were not shown to be statistically different among the inlet, outlet, and reverse flow locations.

6.9 COMPARISON TO NURP DATA

Table 6-1 illustrates the average inlet and outlet EMC and CV from this study compared with the NURP EMC and CV values. The average concentration of TSS and zinc observed entering and leaving the basin were lower than the NURP values, although the inlet CV for both of these constituents was higher than the NURP CV. The average concentration of nutrients observed entering and leaving the basin were higher than the NURP values. Of the nutrients, only total phosphorus exhibited a higher CV than the NURP CV at both the inlet and outlet. The average concentration and CV of copper observed entering the basin was higher than the NURP value, while the average concentration and CV observed leaving the basin was lower than the NURP value.

Table 6-1
NURP Comparison

Parameter	Average K542 Inlet EMC	Average K542 Outlet EMC	Average NURP EMC	K542 Inlet CV	K542 Outlet CV	NURP CV
TSS (mg/L)	82	58	180	2.10	0.75	1.5
Total Phosphorus (mg/L)	12.433	13.460	0.420	1.60	1.20	0.75
Soluble Phosphorus (mg/L)	1.26	1.53	0.15	0.46	0.71	0.75
TKN (mg/L)	3.27	3.31	1.90	0.72	0.63	0.75
Total Copper (µg/L)	48.7	19.9	43.0	2.40	0.41	0.75
Total Zinc (µg/L)	66.1	21.5	202.0	2.58	0.36	0.75

6.10 BMP PERFORMANCE (PHASE I MONITORING)

The Phase I basin design, although not intended to treat pollutants, revealed statistically significant removal of zinc and copper.

Although the Phase I Basin K542-00-00 design was not intended to treat pollutants, the levels of zinc and copper entering the basin at the inlet were reduced at the outlet. The reduction of these metals could be explained by the area of vegetation established between the plunge pool and the outlet. Partially submerged plants are known to reduce levels of metals in water, although the majority of the reduction occurs through the settling of suspended solids, which was not observed in the basin (Sinicrope, et al., 1992). Side slope erosion of the basin berm and bottom were observed and may have contributed to the increase in the geometric means between the inlet and outlet for suspended sediments. Furthermore, the levels of lead, nitrate as N, ortho-phosphate, TSS, and SSC entering the basin in the reverse flow were reduced at the outlet, suggesting that constituent removal processes did take place in the basin during periods of reverse flow, which may have increased the detention time within the basin, allowing suspended sediments to settle. The levels of most constituents observed entering and leaving the basin were within the levels observed in typical urban runoff by the NURP study.

7.0 FUTURE WORK

HCSWQ plans to conduct two additional monitoring phases at Basin K542-00-00. HCSWQ plans to develop a final report for Phase II monitoring work and at the conclusion of Phase III. The planned final report will present the results of all three phases of the monitoring program.

7.1 OUTLET DESIGN CONFIGURATIONS

The three outlet design configurations are planned to be evaluated at Basin K542-00-00 include:

- Phase I – A standard detention facility designed to control the peak flow arising from a 100-year storm.
- Phase II – A water quality pond system designed to capture and slowly release the first ½ inch of runoff.
- Phase III – A combined detention facility designed to capture floatables and control the peak flow arising from both a 10-year and a 100-year storm.

The first phase of the monitoring program has been completed and the results presented herein. The information obtained from this and all other phases associated with this long-term systematic monitoring program should allow Harris County to evaluate the relative performance of each design configuration.

7.2 FINAL REPORT

A final report summarizing all three phases of the monitoring program is planned at the end of the program. The report will compare the efficiency of each outlet design configuration at removing stormwater pollutants and may provide recommendations for adjusting the County's New Development and Significant Redevelopment program if needed.

8.0 SUMMARY

On February 17, 2004, Harris County retained PBS&J under an Agreement for Engineering Services (Harris County Purchase Order No. P071730, Request No. 143956) to initiate and perform long-term systematic stormwater quality monitoring at a single detention facility serving a residential subdivision. The facility will ultimately operate in three outlet design configurations during the entire monitoring program. Twenty-six storm events were successfully monitored, resulting in the collection of 25 composite samples and four grab samples during the period from May 2005 to July 2006.

This report describes the monitoring program and presents the results of the first phase of monitoring activities conducted by PBS&J from May 2005 to July 2006 at Basin K542-00-00 located in northwest Harris County. The data from these activities was analyzed using summary statistics, box-whisker plots, probability plots, and statistical comparisons of means. These analyses revealed that of all the parameters monitored at the site, only zinc and copper showed a statistically significant reduction between the inlet and the outlet. Reverse flow mean values for SSC, lead, nitrate N, ortho-phosphate, and TSS were statistically significantly higher than the inlet and outlet values demonstrating that water quality processes did take place in the basin during periods of reverse flow.

Harris County plans to continue the monitoring efforts at this site. The information obtained from this and all other phases associated with this long-term systematic monitoring program should allow Harris County to evaluate the relative performance of varying outlet design configurations. The information obtained from the systematic monitoring of the three outlet design configurations should allow the County to evaluate their relative performance and, if needed, to make adjustments to the County's federally mandated New Development and Significant Redevelopment program.

9.0 REFERENCES

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Appendix A

Site Selection Report Tables

Summary of HCFCB Basin Candidate Evaluations

Basin ID	Watershed	HCPID Preliminary Assessment	Basin As-built Review	Site Visit	Gather Additional Data	H&H Results
B504-03-00	Armand Bayou	High	✓	✓	✓	✓
K542-00-00	Cypress Creek	High	✓	✓	✓	✓
C500-02-00	Sims Bayou	Moderate	✓	✓	<u>Eliminated</u> Drainage area not residential	
K524-02-00	Cypress Creek	Moderate	Plans initially not found	✓	<u>Eliminated</u> High frequency storm water bypass	
B504-04-00	Armand Bayou	Moderate	✓	<u>Eliminated</u> Small drainage area		
K520-01-00	Cypress Creek	Moderate	✓	<u>Eliminated</u> Small drainage area		
K524-01-00	Cypress Creek	Moderate	✓	<u>Eliminated</u> 2 inlets and 2 outlets		
P530-01-00	Greens Bayou	Moderate	✓	<u>Eliminated</u> 3 inlets and 2 outlets		
K533-01-00	Cypress Creek	Moderate	<u>Eliminated</u> Drainage area not residential			
A518-01-00	Clear Creek	<u>Eliminated</u> Low				
A519-02-00	Clear Creek	<u>Eliminated</u> Low				
B504-01-00	Armand Bayou	<u>Eliminated</u> Low				
B516-01-00	Armand Bayou	<u>Eliminated</u> Low				
D518-02-00	Brays Bayou	<u>Eliminated</u> Low				
K500-03-00	Cypress Creek	<u>Eliminated</u> Low				
K531-03-00	Cypress Creek	<u>Eliminated</u> Low				
T500-01-00	Barker Reservoir	<u>Eliminated</u> Low				
U506-04-00	Addicks Reservoir	<u>Eliminated</u> Low				

Site Selection Criteria

Minimum Requirements

1. Basin must be owned and operated by HCFCD.
2. Basin must operate as a flood control basin designed to control 100-year flow at project initiation.
3. Contributing drainage areas must be fully developed with no active construction.
4. All runoff must pass through the basin (in-line configuration).
5. Basin must be suitable for identified retrofit conditions/designs.
6. Adequate access must be available for monitoring and retrofitting.

Desired Basin Characteristics

1. Basin should have no additional inlets or outlets.
2. Ample freeboard should remain at peak holding volume to allow 10/100 retrofit.
3. Design storage volume should not include storm sewers or streets.
4. Maximum flow discharge rate during 100-year storm should be well below pre-development peak flow.
5. Basin should be located near power supply.
6. Side slopes should match typical regional designs.
7. Pond volume should match typical regional designs.
8. Hydraulic residence time with water quality outlet should match typical regional designs.
9. Length to width ratio of the basin should match typical regional designs.
10. Groundwater elevation should be less than basin floor.
11. Outlet structure should have little to no backwater effect.

Desired Watershed Characteristics

1. Land use should match typical residential subdivision.
2. Surface soils should match typical residential subdivision.
3. Watershed size should match the typical contributing area of basins serving residential subdivisions.
4. Level of imperviousness should match typical residential subdivision.
5. Residential land use should match typical residential areas of Harris County.

Desired Basin Conditions

1. Banks and bottom should have little to no erosion.
2. Banks and bottom should have well-established grassy vegetation.
3. Basin should have no standing water after design drain time.
4. Sediment depth should be less than half of removal trigger depth.
5. Inlet and outlet pipes should be structurally sound with minimal deformation or evidence of clogging.

Appendix B
K542 Record Drawings

Appendix C

ASCE/EPA Guidance Manual for BMP Monitoring Forms

Appendix D

Sample Collection and Maintenance Checklists

Appendix E

**Stainless Steel
Floatables Excluder**

Appendix F

Particle Size Distribution

Appendix G
Quality Assurance/Quality Control Results

Appendix H

EMC Calculation Flow Hydrographs

Appendix I

Results of the Levene Tests of Homogeneity of Variances

Appendix J
Results of the ANOVA Tests

Appendix K

Inlet, Outlet, and Reverse Flow Statistical Comparisons

Appendix L

Results of the Levene Tests of Homogeneity of Variances for Antecedent Dry Period Comparison

Appendix M

**Results of the ANOVA Tests
for Antecedent Dry Period Comparison**

Appendix N

Results of the Levene Tests of Homogeneity of Variances for Storm Size Comparison

Appendix O

Results of the ANOVA Tests for Storm Size Comparison



Appendix P

**Storm Event Size
Statistical Comparisons**

Appendix Q

Results of the Levene Tests of Homogeneity of Variances for TSS Comparison

Appendix R

Results of the Levene Tests of Homogeneity of Variances for SSC Comparison

Appendix S

Results of the ANOVA Tests for TSS Comparison

Appendix T

Results of the ANOVA Tests for SSC Comparison

Appendix U

Suspended Sediment and Metals Statistical Comparisons

Appendix V

Results of the Levene Tests of Homogeneity of Variances for Particle Size Comparison

Appendix W

Results of the ANOVA Tests for Particle Size Comparison