Field Verification Report for the Up-Flo™ Filter

by

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April 2006

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1.0 INTRODUCTION

1.1 History and Background

Most stormwater requires treatment to prevent harm either to surface or ground waters. Stormwater from "critical source areas" such as paved parking and storage areas has been observed to be contaminated with higher-than-average concentrations of many critical pollutants (Bannerman, *et al.* 1993; Pitt, *et al.* 1995; Claytor and Schueler 1996). One approach is to treat the runoff from critical source areas before it mixes with the runoff from less polluted areas. The general features of a "critical source area" appear to be large paved areas, heavy vehicular traffic, and outdoor use or storage of problem pollutants.

Numerous proprietary devices have been manufactured to treat stormwater runoff. Many of these devices have been designed to treat one or more of the common stormwater pollutants – solids, metals, oils and grease, nutrients, and bacteria. Few have been designed to treat a broad range of pollutants with a single device. In addition, several of these devices provide inconsistent performance from one installation to another. Treatment of runoff from critical source areas requires a device with robust removal capabilities and the capability of operating in a situation having grossly contaminated waters containing large amounts of debris and floatable materials. There are a wide range of stormwater control practices, but all are not suitable in every situation. It is important to understand which controls are suitable for the site conditions and can also achieve the required treatment objectives.

Upflow filtration for stormwater treatment applications was examined during Phase I research of a Small Business Innovative Research (SBIR) project. Upflow filtration was examined mainly because downflow filters quickly clog, reducing their treatment flow rate and overall treatment capacity.

This research was conducted as part of a Phase II US EPA Small Business Innovative Research (SBIR) project. The scope of this Phase II research included the design, fabrication and field installation and field testing of a prototype upflow filtration device, the Up-Flo™ Filter, designed to treat stormwater runoff from critical source areas.

1.2 Objectives

The objective of this monitoring program was to determine the hydraulic capacity and the pollutant removal capabilities of a prototype upflow filtration device, the Up-Flo™ Filter, in a field installation under both controlled and actual runoff conditions.

2.0 TECHNOLOGY DESCRIPTION

2.1 Description of the Treatment System

The Up-Flo™ Filter is a compact stormwater quality treatment system that integrates multiple components of a treatment train into a single, small-footprint device. Pollutant removal mechanisms in the Up-Flo™ Filter include several processes:

- Buoyant trash is captured by flotation in the chamber and retained by the floatables baffle during high-flow bypassing
- Coarse solids and debris are removed by sedimentation and settle into the sump
- Capture of intermediate solids by sedimentation in sump resulting from controlled discharge rates
- Neutrally buoyant materials are screened out by the angled screens
- Fine solids are captured in the filtration media
- Dissolved pollutants are removed by sorption and ion-exchange in the filtration media

The basic removal of solids is dependent on physical sedimentation in the sump, and by filtration in the filter media. The following discusses these primary removal processes. Figure 2-1 is a schematic showing the main components of the Up-Flo™ Filter prototype used in this field monitoring program and the treatment flow path through the unit.

1. **Filtration Chamber**
2. **Bypass with Floatables Baffle**
3. **Media Housing**
4. **Filtration Media**
5. **Angled Screen**
6. **Sump**
7. **Baffle Wall**
8. **Effluent Chamber**
9. **Outlet Pipe**
10. **Weep Tubes** (not pictured)

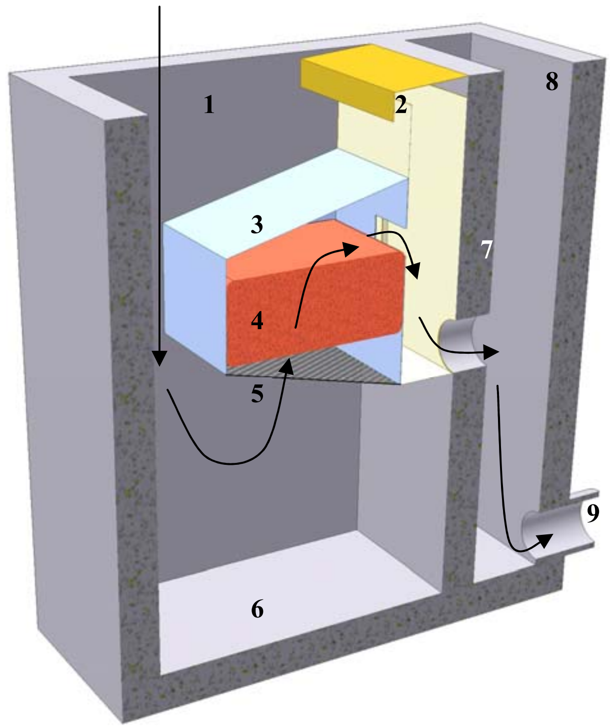

Figure 2-1: Schematic of Up-Flo™ Filter prototype.

2.1.1 Coarse Screening of Litter and Debris

As shown in Figure 2-1, a coarse screen is fitted to the bottom of the filter housing. This screen is at an incline angle and the water passes through the screen in an upflow direction. The apertures of the screen in the prototype unit are 5/16 inches in diameter (about 8 mm, or 8,000 µm). Debris larger than this size cannot penetrate the Up-Flo™ Filter and will be trapped in the catchbasin sump.

Earlier research conducted by Pitt (1979) found that debris and leaves captured in a catchbasin sump away from the flowing water were permanently trapped and later tests (Pitt 1985) found that the overlying water was not significantly degraded compared to the runoff. Pitt (1985) also found that about one foot of standing water above the debris, at least, was needed to prevent the previously collected material from being scoured during subsequent events. These observations were taken into account in the design of the angled screen utilized in the Up-Flo™ Filter.

The incline angle of the screen and upward flow through the screen prevent material from accumulating on the screen and forcing subsequent water through the trapped material. During previous catchbasin screening tests (Pitt and Field 1998), flows through previously captured material (mostly organic material, such as leaves) were found to degrade the material and increase the discharge of suspended solids and nutrients. The design of this angled screen is intended to minimize the potential for this to occur. In the rare case that the screen clogs with debris and blinds, the high capacity bypass is protected from floatable washout by an overhanging floatables baffle.

2.1.2 Sediment Capture in Catchbasin Sump
As noted above, coarse grit and debris will be removed from stormwater runoff by sedimentation. These particles settle out of influent water into the sump. Sediment particles in the <30 micron range are generally deemed unsettleable, meaning the time required for these particles to settle out is far longer than the typical residence time in catch basins even at very low flows.

Phase I SBIR research by Pitt showed that the incorporation of a sump increases the efficacy of an upflow filter. Coarse grit and debris settle out in the sump before influent waters enter the filtration media. The result is less frequent clogging and a longer life of the filtration media compared to an upflow filtration device that incorporates no pre-settling sump.

2.1.3 Filtration and Ion Exchange in Filter Media
Filtration is defined as an interaction between a suspension and a filter material (Ives 1990). Pollutants are removed from the solution when they become attached to the media or to previously captured particles. In general, the three key properties of a filter are surface area, depth and profile. Filtration media that is polar (has a high cation-exchange capacity) typically has a high specific adsorption capacity for pollutants of concern and will remove those pollutants of concern from stormwater runoff by the principles of ion-exchange. Whereas the filtering of solids is dependent on physical properties such as grain size and pore size, removal of pollutants by ion-exchange is highly dependent on the length of contact time between the pollutant and the filtration media.

2.2 Up-Flo™ Filter Prototype
A schematic of the Up-Flo™ Filter prototype used in this monitoring program is shown in Figure 2-1. The prototype Up-Flo™ Filter was constructed to fit in the modified inlet at the City Hall parking lot in Tuscaloosa, AL. Figure 2-2 through 2-8 are photographs of the prototype Up-Flo™ Filter, and the media being installed for the field tests.

Figure 2-2: Bottom of Up-Flo™ Filter prototype shown without angled screen - at left, the large holes serve as an inlet to the filtration chamber and at right, a finer screen sits over weep hole tubes for blockage protection.

Figure 2-3: Looking down into Up-Flo™ Filter, with main filtration chamber to the left, the dividing wall with weir, the secondary filter chamber and overflow chamber.


Figure 2-4: Front view of Up-Flo™ chamber.

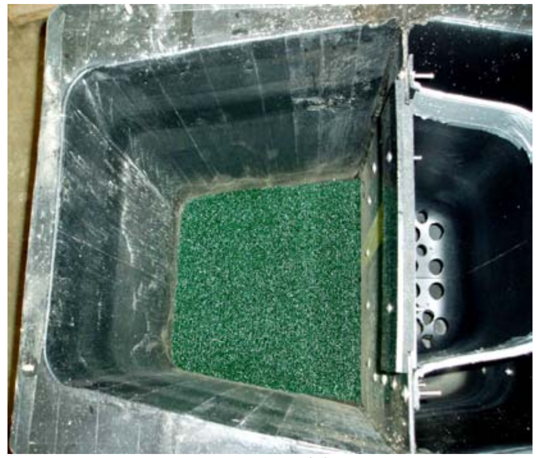
Figure 2-5: Bottom layer of flow distributing media placed in filtration chamber.


Figure 2-6: Bottom bag of filter balls placed in filtration chamber to fill excess space.


Figure 2-7: Filter bag being filled with CPZ Mix™

3.0 TEST SITE DESCRIPTION

3.1 Location and Land Use

The test site was a catch basin located in the parking lot of the Tuscaloosa City Hall, Alabama. The catch basin receives flows from the 0.9 acre drainage area within the red border shown in Figure 3-1. The grated inlet to the catch basin is denoted by the blue dot. The site is comprised of parking, roofs, and adjacent storage areas (Figure 3-2 to 3-6).

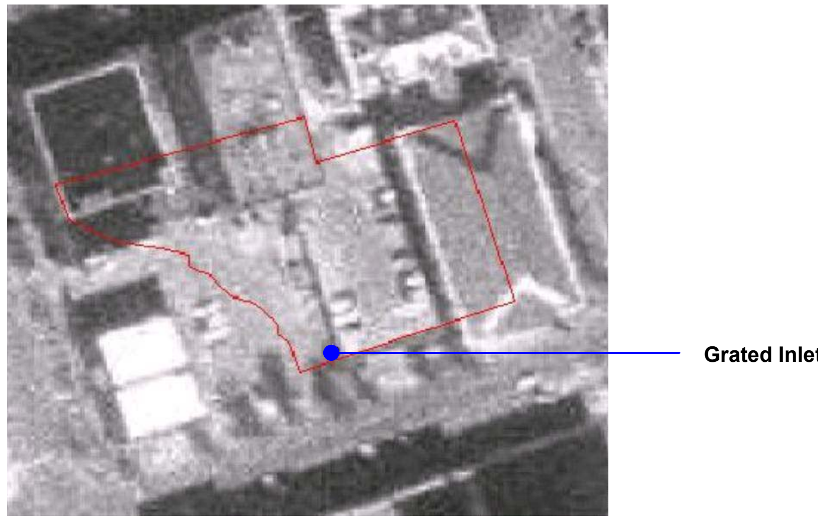

Figure 3-1: Drainage area for the test catch basin shown on an enlarged aerial photo (blue dot denotes inlet location).

Figure 3-2: Elevated parking and city hall roof with roof drains to test area.

Figure 3-3: One area of building debris storage in small drainage area.

Figure 3-4: Impervious areas of the drainage site

Figure 3-5: Garbage disposal containers and paved area of the drainage area

The depth of the catch basin system was 5-ft, rendering it adequate for a retrofit installation of the Up-Flo™ Filter prototype. A 3-in thick baffle wall was retrofitted to divide the catch basin into a filtration chamber and an effluent chamber (Figure 3-6). After the installation of the baffle wall, the Up-Flo™ Filter prototype was retrofitted onto the baffle wall in the filtration chamber. After retrofit installation, the filtration chamber had a sump depth (the depth between the inlet to the filtration media and the floor of the filtration chamber) of 2.5 ft. A full-size inlet grating was installed to allow access to the entire inlet area to the filtration chamber (Figure 3-7).

Figure 3-6: Inlet box with forms removed from baffle divider showing main outlet.

Figure 3-7: Completed modified inlet with new inlet grating.

3.2 Test Site Rainfall and Runoff Conditions

3.2.1 Theoretical Rainfall and Runoff Characteristics for Tuscaloosa, Alabama

Figure 3-8 is a Tuscaloosa, AL, IDF (intensity-duration-frequency) curve that describes the characteristics of rare rain events at the test site, normally used for drainage design, prepared using the *Alabama Rainfall Atlas* software program developed by Dr. S. Rocky Durrans of the University of Alabama. For Tuscaloosa, these rainfall intensities can be quite large, ranging from about 6 in/hr for rains having about a 50% chance of occurring in any one year (the so-called “2-year” storm), to about 10 in/hr for rains that may only occur with a 1% chance in any one year (the “100-year” storm). Except for the smallest events, these design storms are usually not suitable for water quality treatment, but the inlet and any inserts must be capable of accommodating the peak flow rates that may be expected for the designated critical design storm for the site.

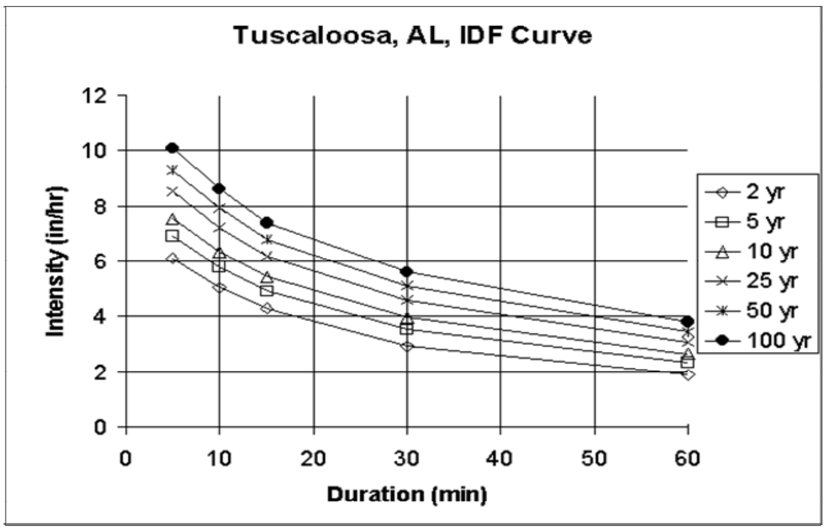

Figure 3-8: Tuscaloosa, AL, IDF curve (R. Durrans, Alabama Rainfall Atlas).

Figure 3-9 is a plot showing estimated peak runoff rates for different rainfall intensities and paved drainage areas, while Figure 3-10 is a similar plot for average runoff rates for rains having different total rain depths. The peak runoff rates are estimated using the Rational formula, while the average runoff rates are estimated using volumetric runoff coefficients and typical rain durations for these sized rains in the region.

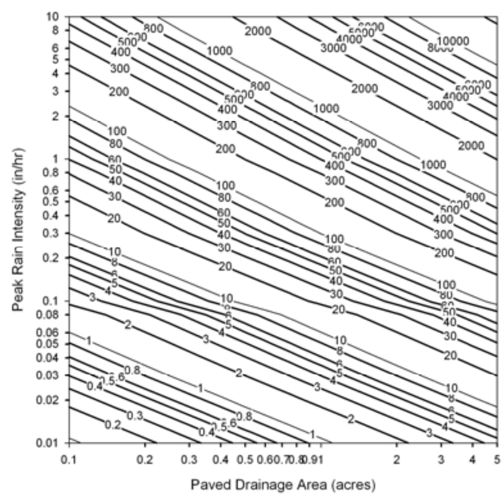

Figure 3-9: Calculated peak runoff rates (gallons/minute) for different peak rain intensities and drainage areas for paved areas.

The test site is quite large for the prototype Up-Flo™ Filter. This however allowed for a wide range of flow conditions during a smaller set of monitored events. The test site has about 0.9 acres of pavement and roof area and is expected to produce peak flow rates of 25 gal/min (the expected filtration capacity for the prototype Up-Flo™ Filter) for short periods of rainfall intensities of about 0.1 in/hr, and peak 50 gal/min flow rates for short periods of rain intensities of about 0.2 in/hr. Average 25 gal/min flows would be expected during about 0.75 inch rains, and average 50 gal/min flows would be expected during about 2 inch rains (Figure 3-10). These rain conditions are expected to commonly occur at the test site during the monitoring period. Peak flow rates (associated with short-term rain intensities of 6 to 10 in/hr) would be about 2,500 to 5,000 gal/min during the 2 to 100-year design storms. Table 3-1 shows the computed site runoff volumes for rain events at varying intensities.

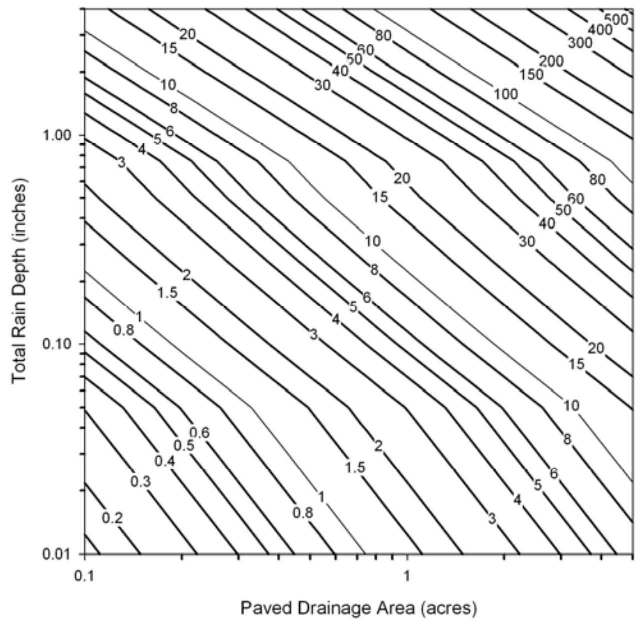

Figure 3-10: Average runoff rates (gallons/minute) for different total event rain depths and paved drainage areas.

Table 3.1: Runoff Volumes (ft^3) and Average Flow Rate (gal/min) for Different Sized Rains at Test Area

Rain Total (inches)	Runoff volume (ft^3)				Average Flow Rate (gal/min)	Rv
	Pitched Roof	Flat Roofs	Paved Parking	Land Use Totals		
0.01	0	0	2	2	0.08	0.07
0.05	10	1	44	55	0.8	0.33
0.1	38	11	110	159	2	0.49
0.25	119	61	343	523	5	0.64
0.5	256	142	787	1185	10	0.73
0.75	391	224	1278	1894	13	0.77
1	529	306	1824	2658	19	0.81
1.5	800	477	3010	4288	31	0.87
2	1078	654	4207	5940	42	0.91
2.5	1348	832	5389	7568	54	0.93
3	1617	1020	6556	9193	65	0.94
4	2156	1380	8878	12414	88	0.95

3.2.2 Characterization of Stormwater Runoff from Tuscaloosa City Hall Inlet Site, before Up-Flo™ Filter Installation

Pre-installation runoff monitoring was conducted to characterize the runoff from the test site drainage area. Figure 3-11 is the particle size distribution measured at the test site during preliminary monitoring. Runoff samples were taken manually at the inlet using a dipper sampler to collect water that was cascading from the gutter into the inlet, ensuring that all particulates would be captured in the sample. The sample was sieved using a 1500 µm screen to remove any large material. This large material was then washed from the screen and analyzed separately. The rest of the sample was split using a Dekaport/USGS cone sample splitter and the separate split fractions were sieved using a 200 µm sieve and a 0.45 µm filter. The sample fraction between 0.45 and 200 µm was analyzed using a Coulter Counter Multisizer 3. The size information was then combined to produce this plot which is only for finer particulate matter and did not include any large debris (leaves or litter) larger than 1500 µm, or dissolved solids less than 0.45 µm. The median particle size of the particulate matter in the runoff was about 25 µm, and about 15% of the particulates were larger than 250 µm (but smaller than 1500 µm). During the initial testing in late fall, a substantial amount of leaves (about 5 ft^3), and several large pieces of litter (soda cans, plastic bags, and Styrofoam cups) were accumulated in the sump. The mass of the large debris was relatively small compared to the amount of runoff that flowed through the system, and would have had an insignificant effect on the particle size distribution.

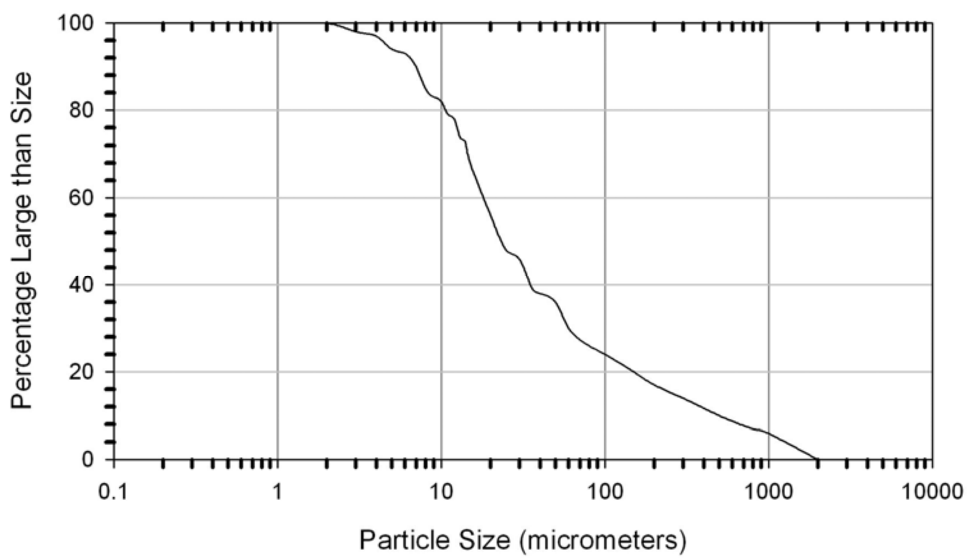

Figure 3-11: Observed particulate matter size distribution in runoff water at Tuscaloosa test site.

From the 3rd week of October, 2004 until the 2nd week of November, 2004 YSI 6600 Sondes were deployed in the inlet at the City Hall, Tuscaloosa location to determine their consistency and drift for an extended deployment. The sondes were calibrated in the laboratory before their deployment and were tested on the same standards after their deployment to measure any change before they were re-calibrated. Tables 3-2 and 3-3 show that the drifts of the parameters over this 20 day "turned on" plus 10 day "idle" period was very low, especially considering that the sondes were dry much of the time. The drifts were less than 3% during this period, well within a useable range.

Table 3-2: Drift in sonde -1 on November 18, 2004 after one month field deployment

	pH	pH	D.O. %	DO (mg/L)	Depth (ft)
Before new calibration (20th Oct 2004 prior calibration)	7.09	4.09	97.7	8.96	0.028
After new calibration 18th Nov 2004	7.00	4.00	100.1	9.18	0
% change	1.3%	2.3%	2.4%	2.4%	n/a

Table 3-3: Drift in sonde -2 on November 18, 2004 after one month field deployment

	pH	pH	DO %	D.O. (mg/L)	Depth (ft)
Before new calibration (20th Oct 2004 prior calibration)	7.11	4.11	98.7	9.05	0.025
After new calibration 18th Nov 2004	7.00	4.00	100.0	9.16	0
% change	1.6%	2.8%	1.3%	1.2%	n/a

A total of 1,920 data points (collected at 15minute intervals) were obtained. The various parameters that were logged were temperature, specific conductivity, DO, pH, ORP and turbidity. There were very large variations in the turbidity data indicating the runoff conditions at this site. The turbidity range has a maximum of about 1,100 NTU and the water periodically exceeded this value. During this 20 day period, two large storms occurred that were monitored, but most of the time the sondes were dry (Table 3-4 summarizes the rain characteristics for the two events).

Table 3-4: Summary of rain events during the initial sonde deployment

Event	Duration (hr : min)	Peak 5-min Intensity (in/hr)	Total Rainfall (in)
Event 1 (10/23/04)	3:15	4.17	0.84
Event 2 (11/3/04)	5:25	4.24	1.18

3.2.3 Storm Sample Analysis

Table 3-5 lists data for the first storm sampled at the Tuscaloosa City Hall parking area test inlet on August 20 – 22, 2004, a very intense and large rain. Samples CH1 and CH2 are duplicates of the first portion of the storm that occurred within the first 30 minutes of this very intense and long rain. Samples CH3 and CH4 are duplicates collected two days later for the same event, after substantial runoff. CH1 was affected by ethylene glycol (radiator coolant) that had recently been blown from vehicle air conditioner heat exchangers on this very hot day. By the time the second sample (CH2) was collected a few minutes later, the color of the water was substantially reduced. The other notable effect is that the bacteria remained at very high levels throughout this event, in the obvious absence of sanitary sewage sources, while the other concentrations were greatly reduced (notably for TSS, conductivity, turbidity, COD, and phosphates).

Table 3-5a: Analysis data for the storm events during August 20 – 22, 2004

Sample #	Sampling date	Total Coliform (MPN/100 mL)	E-coli (MPN/100 mL)	Enterococci (MPN/100 mL)	TSS (mg/L)	pH
CH 1	20-Aug	>2419.2	1732.87	1046.24	136	6.72
CH 2	20-Aug	>2419.2	145	71.4	106	6.35
CH 3	22-Aug	>2419.2	>2419.2	1986.28	4	6.44
CH 4	22-Aug	>2419.2	>2419.2	>2419.2	3	6.35

Table 3-5b: Analysis data for the storm events during August 20 – 22, 2004 (cont)

Sample #	Sampling date	Conductivity (µs/cm)	Turbidity (NTU)	Color (HACH color units)	COD (mg/L)
CH 1	20-Aug	123	134	No match	184
CH 2	20-Aug	118	59	95	233
CH 3	22-Aug	8	3	5	39
CH 4	22-Aug	13	2	5	44

Table 3-5c: Chemical analysis data for the storm events during August 20 – 22, 2004 (cont)

Sample #	Sampling date	Phosphates (mg/L)	Ammonia (mg/L)
CH 1	20-Aug	1.94	0.19
CH 2	20-Aug	1.35	0.07
CH 3	22-Aug	0.09	0.03
CH 4	22-Aug	0.15	0.01

4.0 PERFORMANCE EVALUATION

4.1 Evaluation of Filtration Rate

4.1.1 Introduction

This series of tests served to evaluate the filtration rate of the CPZ Mix™ filter media, a proprietary mixture of granular activated carbon, bone char activated carbon, and manganese coated zeolite. Based on results of earlier lab scale testing, the mixed media was expected to have high pollutant removal at relatively high filtration rates (25 to 30 gpm). The prototype Up-Flo™ Filter that was tested was fitted with two media bags, each filled with an equal volume of CPZ Mix™.

4.1.2 Methodology for the Evaluation of Filtration Rate

Flow tests were conducted in the field with the cooperation of the Tuscaloosa Water Department by using a fire hose connected to a fire hydrant adjacent to the test site. The flows were measured using the Water Department's calibrated meter, and also checked at the test rates by timing the filling of large containers at relatively low flows. The maximum filtration rate through the Up-Flo™ Filter, using the CPZ Mix™ media ranged from 29 to 31 gpm (about 20 gal/min/ft^2). The preliminary flow test results are shown in Table 4-1. The flow rates were determined with clean media. Figure 4-1 shows various pictures in which 300 gpm of flow is handled by the empty Up-Flo™ Filter without any bypass over flow. Table 4-2 shows a more comprehensive characteristic of the filtration capacity versus the required height of driving head for the CPZ Mix™ media. Figures 5-2 to 5-5 show the filtration rate vs. driving head plots.

Effluent pouring onto sonde and sample intake

300 gpm showing overflow bypass

300 gpm into empty chamber with no overflow

31 gpm flow with Mixed media at capacity

Figure 4-1: Various pictures showing Up-Flo™ Filter at different influent flow rates.

Table 4-1: Preliminary test results for filtration capacity of the CPZ Mix™

Media (2 Bags)	Head (in)	Flow Rate (GPM) for 1.5 ft^2 filter area	Comments
CPZ Mix™	22.5	29 to 31	Clean media

Table 4-2: Filtration Rate measurements with available head for CPZ Mix™ media

Flow Type	CPZ Mix™ Media	
	Head (in)	Flow (gpm)
Low	3.5	5.8
Medium	6	15.3
High	22.5	27

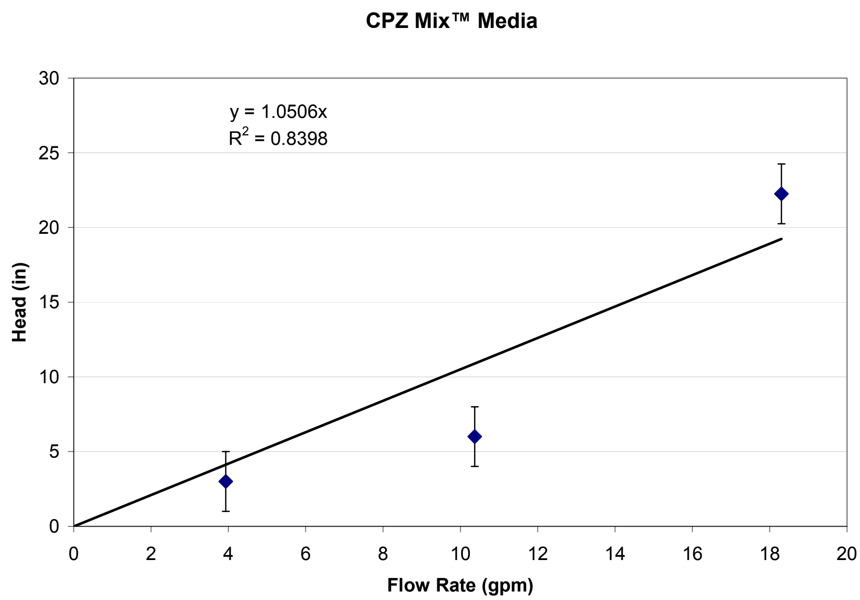

Figure 4-2: Flow vs. head graph for mixed media

4.2 Controlled TSS Testing

4.2.1 Introduction

Historically, the performance of filters has been measured during controlled laboratory experiments. Controlled tests enable precise measurements of filter behavior under repeatable conditions. However, the major disadvantage of controlled testing is that they do not account for unusual and over-range conditions, such as bypass flows which may control filter performance during actual storm events. Also, actual stormwater is rarely used during controlled laboratory tests, with questionable transferability to real conditions. Idealized flow can be determined in the absence of clogging particulates, but pollutant retention measurements are difficult. The recent use of ground silicas available from the U.S. Silica Co., have enabled more accurate filter tests under controlled conditions particularly for particulate solids and their associated pollutants. However, the removal capability for other pollutants such as those in solution requires the use of actual stormwater as a test solution (Pitt, *et al.* 1999; Clark 1999; Clark and Pitt 1999; Johnson, *et al*. 2003; etc.).

4.2.2 Particle Size Distribution of Tested Media and Test Sediment

The test sediment in the stormwater stimulant was based on the following mixture: Sil-Co-Sil 250, Sil-Co-Sil 106 (both from the U.S. Silica Co.), and coarse and fine concrete sands. The mixture was made by using equal weight fractions of each of the four components. The test sediment particle sizes therefore ranged from 0.45 µm to 2000 µm. Two different batches of the test sediment were prepared and the particle size distributions for each of the batches were determined. Figures 4-3 and 4-4 show the particles size distributions of the two test sediment batches.

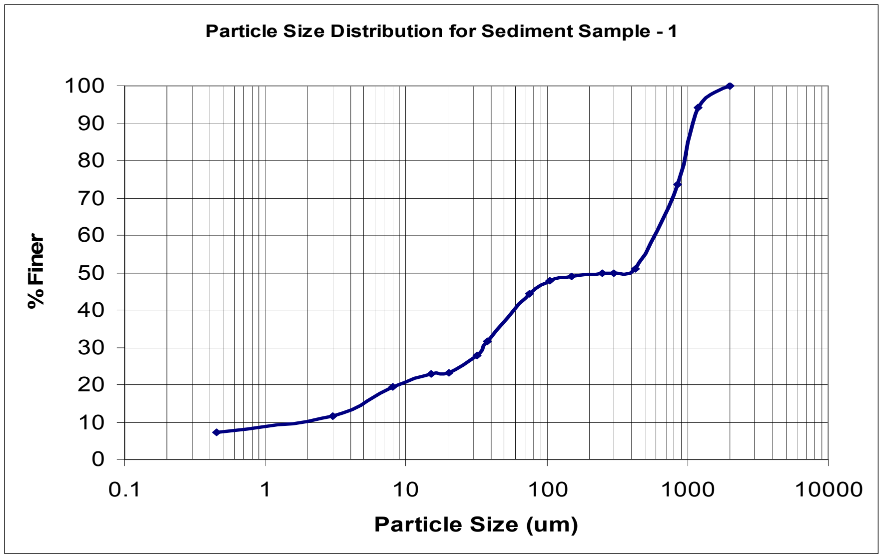

Figure 4-3: PSD curve for test sediment sample 1.

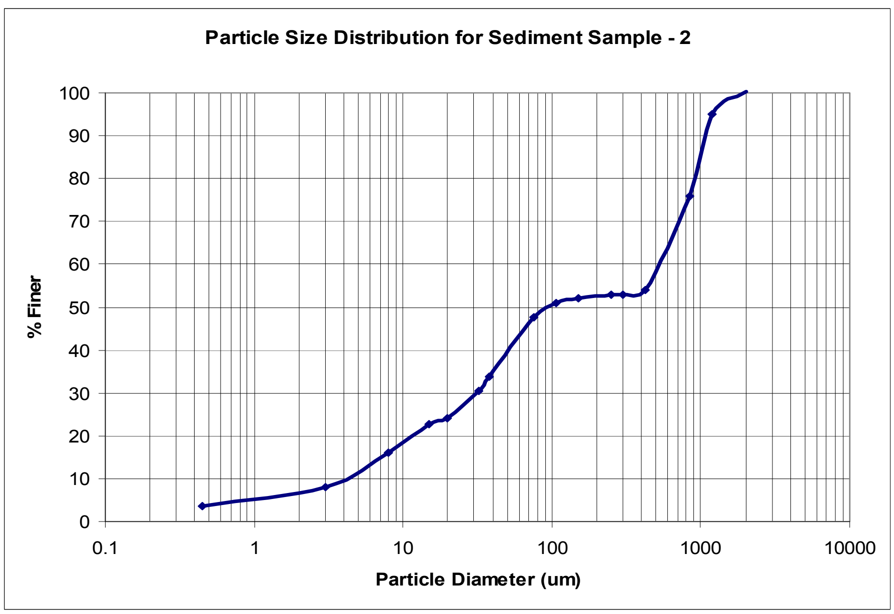

Figure 4-4: PSD curve for test sediment sample 2.

4.2.3 Test Methodology for Controlled Sediment Capture Tests

A known concentration of particulate solids was used as the influent at three different flow rates. The "high" flow rate was about 27 gpm - the flow rate at the largest height of driving head available before bypassing. The "medium" flow was about 15 gpm, and the "low" flow was about 5 gpm. The solids mixture was made up of a specific combination of ground silica and sieved sand, covering the particle size range from about 0.45 to 2,000 µm, as noted above. The high flows were 46 gpm for the activated carbon media, and 51 gpm for the bone char media. Each experiment was conducted for 30 minutes, during which time measured aliquots of the dry sediment were carefully and constantly poured into the influent "clean" flow from the fire hydrant. An initial blank sample was collected from the Up-Flo™ effluent location before any sediment was added to measure the background solids in the test water. A sample was collected using a dipper grab sampler every 1 minute and composited in a churn sample splitter for the 30-minute test period. Using the churn splitter, three samples of 1000 ml each were collected for each experiment for laboratory analyses. Samples of the added solids were also collected to verify the particle size distributions.

In preparation for the tests, the test sediment was pre-weighed in several 50 mL polyethylene bottles. The sediment was manually feed into the influent water over the whole period of each experiment, according to the desired particulate solids concentration for the specific flow rate for each test. Depth readings of the water levels were also taken during each experiment to determine the head loss for the Up-Flo™ Filter operation. Also, after completion of each experiment, flow and depth readings were taken to determine the final flow rate and available head to detect any change in filtration rate during the test.

A fire hydrant located close to the test site was used as the influent water source. Before starting any experiment, the highest flow (as bypass just starts for the Up-Flo™ Filter) for the CPZ Mix™ media was determined and then the medium and low flow rates were set at about one-half and one-fourth of that highest flow rate. The total amount of sediment (and the corresponding number of sediment bottles) required for each experiment was calculated at the beginning of each experiment once the flow rates were determined.

For the CPZ Mix™ media, four different influent sediment concentrations were tested. The concentrations tested were 500 mg/L, 250 mg/L, 100 mg/L, and 50 mg/L. At each one of these four concentrations, three separate experiments were conducted at high, medium, and low flow rates. The highest flow tested for the mixed media was 29 gpm, close to what was measured as the overflow/bypass rate observed during actual storms. Figures 4-5 to 4-10 are photographs from the controlled tests.

Figure 4-5: Steady state filtration rate at the height of the bypass weir

Figure 4-6: Effluent sample collection

Figure 4-7: The feed pollutant is added manually

Figure 4-8: Picture showing sediment addition

Figure 4-9: Feed pollutant dispersing through filtration chamber

Figure 4-10: Sample splitting using churn splitter

4.2.4 Sample Handling and Analysis

A total of 21 separate controlled experiments were conducted resulting in the collection of 84 samples, including the blank samples for each experiment. Total solids, suspended solids, total dissolved solids (by difference), and particle size distribution (PSD) analyses were carried out for each sample and its duplicate. Therefore, the total number of samples analyzed during the controlled tests was 168. Before conducting the analyses, each sample was split into 10 equal volumes of 100 mL each using the Decaport/USGS cone splitter shown in Figure 4-11. These split subsamples were analyzed for total solids, suspended solids, and PSD.

Figure 4-11: Decaport cone splitter.

4.2.5 Results from Controlled Sediment Capture Tests

The maximum flow rate for the available driving head in the system was about 20 gal/min-ft^2 for the CPZ Mix™ media. The effluent TSS concentrations were lower during lower influent tests compared to the higher concentration tests, indicating that irreducible concentrations were not strictly being observed. The effluent concentration was lower during the lower flow rate tests than for the higher flow tests, but the differences were small (Figures 4-12 and 4-13).

Figures 4-12 and 4-13 show the performance plots for the controlled flow Sil-Co-Sil challenge tests. These plots are for the CPZ Mix™ (Mn-coated zeolite, bone char, and peat mixture) tests which provided maximum flow rates of about 25 gal/min/ft^2 (38 gal/min). During actual storms, treatment rates ranging from 35 to 50 gal/min were observed for the prototype Up-Flo™ Filter. These plots show excellent control of solids by the prototype Up-Flo™ Filter for a wide range of flow and concentration conditions.

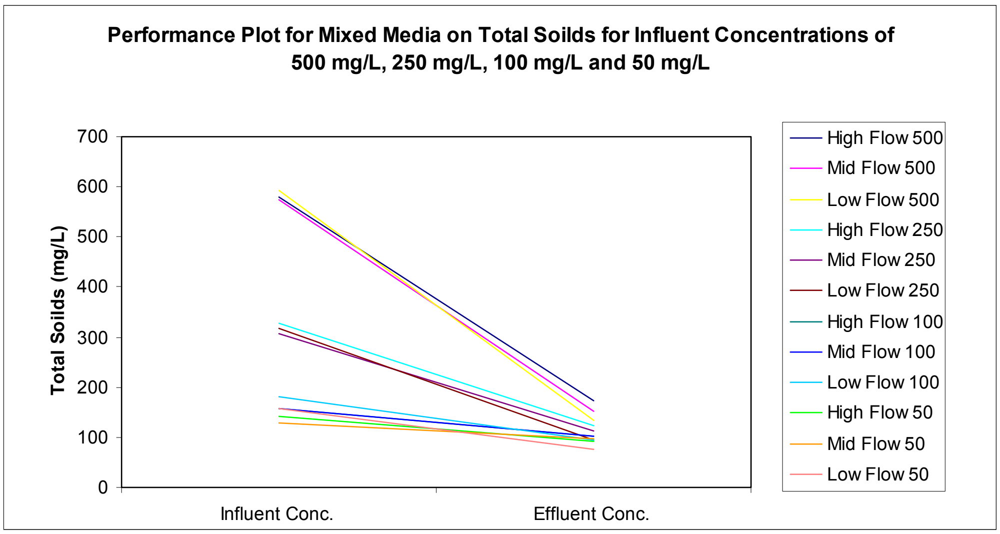

Figure 4-12: Performance plot for mixed media for total solids at influent concentrations of 500 mg/L, 250 mg/L, 100 mg/L and 50 mg/L.

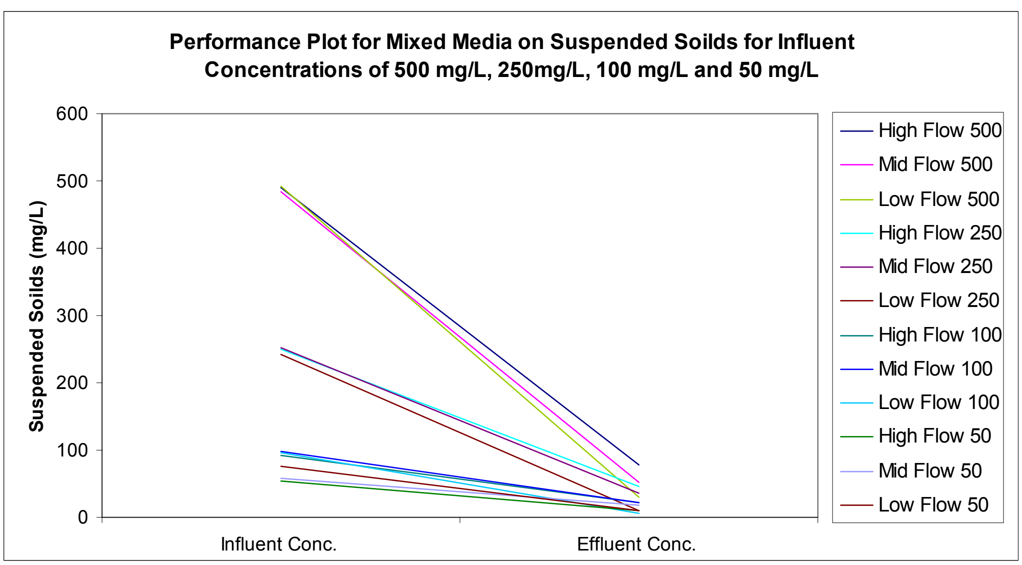

Figure 4-13. Performance plot for mixed media for suspended solids at influent concentrations of 500 mg/L, 250 mg/L, 100 mg/L and 50 mg/L.

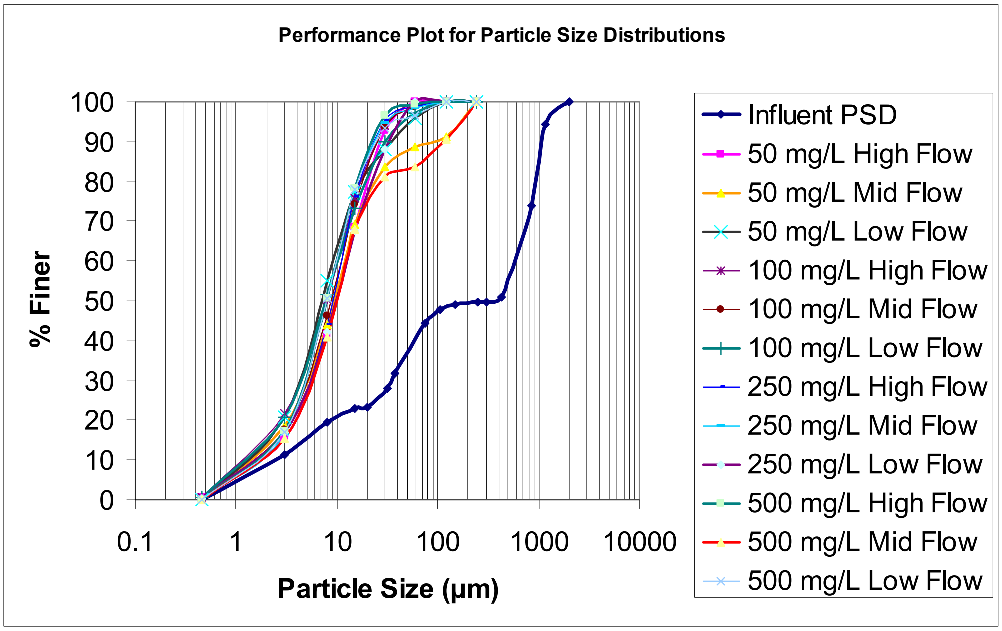

Figure 4-14: Performance plot of particle size distribution for mixed media

The percentage reductions for suspended solids for the CPZ Mix™ media at high influent concentrations (485 to 492 mg/L) were 84 to 94%, with effluent concentrations ranging from 31 to 79 mg/L for filtration rates ranging from 15 to 30 gal/min. During the low concentration tests (54 to 76 mg/L), the reductions ranged from 68 to 86%, with effluent concentrations ranging from 11 to 19 mg/L. The flow rates therefore seem to be important in determining particulate solids capture. The results of these tests are presented in Tables 4-3 and 4-4.

Table 4-3: Suspended Solids for CPZ Mix™ media

Media	Flow	Effluent Blank 1/2	Effluent Blank 2/2	sample 1-1	sample 1-2	Sample 2-1	Sample 2-2	Sample 3-1	Sample 3-2	% SS reduction 1	% SS reduction 2	Avg % SS reduction
Mix + Mix 500	High	3	3	79	80	79	79	75	81	85	84.20	84.44
Mix + Mix 500	Mid	2	3	62	60	59	62	10	60	91	87.95	89.71
Mix + Mix 500	Low	10	11	32	32	29	32	30	30	96	95.67	95.78
Mix + Mix 250	High	8	6	51	53	41	50	28	55	86	81.23	83.84
Mix + Mix 250	Mid	7	10	30	32	46	43	45	27	87	89.55	88.25
Mix + Mix 250	Low	3	7	3	3	18	16	10	8	98	98.31	98.03
Mix + Mix 100	High	8	10	34	30	22	11	9	23	85	85.21	85.01
Mix + Mix 100	Mid	13	17	26	22	23	26	11	24	94	89.27	91.66
Mix + Mix 100	Low	8	4	2	6	7	2	6	14	100	98.54	99.27
Mix + Mix 50	High	18	2	2	3	17	16	19	9	94	100.00	96.95
Mix + Mix 50	Mid	8	14	17	17	41	19	7	13	78	88.97	83.46
Mix + Mix 50	Low	17	5	14	24	2	1	15	9	100	99.49	99.74

The influent suspended solids concentration is assumed to be zero. All units in mg/L

Table 4-4: Total Solids for CPZ Mix™ media

Media	Flow	Effluent Blank 1/2	Effluent Blank 2/2	sample 1-1	sample 1-2	Sample 2-1	Sample 2-2	Sample 3-1	Sample 3-2	% TS reductio n 1	% TS reductio n 2	Avg % TS reduction
Mix + Mix 500	High	91	95	175	170	178	175	168	170	83	83.86	83.65
Mix + Mix 500	Mid	93	90	159	163	167	154	114	162	89	85.88	87.23
Mix + Mix 500	Low	112	111	135	134	135	135	131	130	95	95.54	95.47
Mix + Mix 250	High	88	84	125	121	132	130	113	123	85	84.11	84.38
Mix + Mix 250	Mid	75	51	114	101	104	113	122	120	79	80.19	79.78
Mix + Mix 250	Low	82	77	82	93	99	101	98	99	94	92.33	93.32
Mix + Mix 100	High	76	73	95	101	91	106	104	109	73	63.02	68.22
Mix + Mix 100	Mid	61	84	102	104	104	91	111	92	60	72.39	66.43
Mix + Mix 100	Low	96	83	93	93	103	91	97	90	91	97.99	94.52
Mix + Mix 50	High	99	98	96	96	102	100	78	77	100	100.00	100.00
Mix + Mix 50	Mid	85	76	97	105	82	106	98	102	76	50.72	63.12
Mix + Mix 50	Low	90	96	0	99	92	81	88	89	100	100.00	100.00

4.3 Up-Flo™ Filter Performance Testing during Actual Rainfall Events

4.3.1 Introduction

The intent of these tests was to quantify the behavior of the Up-Flo™ Filter during actual rains and to verify the results from the controlled tests. The following section describes the field sampling methodology, sample selection, sample handling, sample analysis, and the results from these monitoring activities.

4.3.2 Sampling Equipment, Installation and Methodology

Sampling at the test site was conducted using two ISCO 6712 automatic samplers. The flow rates were determined using two ISCO 4250 area-velocity meters which also measured the stage both in the influent sump (the catchbasin sump) and in the effluent pipe. These were calibrated during the controlled flow tests described in Section 4. The rainfall intensity and amount was measured using a standard tipping bucket rain gauge. A small totalizing rain gauge was also used as a check. YSI 6600 water quality sondes were used to measure the real time water quality data (temperature, dissolved oxygen, pH, ORP, turbidity, conductivity, and water depth) of the influent and the effluent flows at 1minute intervals during storm flows and at 5 minute intervals during inter-event periods. The sampling equipment is shown on Figures 4-15 through 4-17.

Figure 4-15: From bottom left to right 1) ISCO 6712 automatic sampler 2) YSI 6600 Sonde 3) ISCO 4250 Flow Meter 4) ISCO 674 Tipping bucket rain gauge 5) YSI Sonde data logger.

Figure 4-16: YSI 6600 sondes and data logger, Inset – Close look at the sensors.

Figure 4-17: ISCO Propack, Propack holder and Nalgene bottle used to store samples.

With the cooperation of the City of Tuscaloosa, sampling equipment was installed onsite during February 2005. Installation photos of the samplers are shown in Figures 4-18 to 4-23.


Figure 4-18: Samplers and flow meters in sampling shelter.

Figure 4-19: Sampler shelter.


Figure 4-20: Area-velocity sensor installed in effluent pipe.

Figure 4-21: Tipping bucket and standard rain gauges installed at monitoring site.


Figure 4-22: Prototype Up-Flo™ Filter and sampling gear installed in catch basin.


Figure 4-23: Installed prototype Up-Flo™ Filter (no media) with sampling and monitoring lines

From the known site physical characteristics, measurable runoff was expected after about 0.03 inches of rainfall. Once the rain gauge records a rainfall of 0.03 inches (3 tips of the tipping buckets) within a 30 minute period, a pulse is sent to the flow meter which is in turn connected to the automatic samplers to initiate the programmed sampling sequence.

The influent sample is collected from a half-pipe plastic tray (Figure 4-24 and 4-25) that has been placed at the filtration chamber entrance where the inflowing water cascades from the gutter. The influent real time water quality data is collected using the YSI sonde in the same tray. The tray is emptied after each event (debris poured in the catchbasin sump) and the sonde is placed in a perforated plastic pipe harness suspended into the influent sump in order to monitor water quality in the sump between rain events. When an event is expected, the sonde is moved from the catchbasin sump back into the tray. The effluent sonde is located at the same location where the effluent sample is collected, at the back side of the divider wall under the cascading water discharged from the Up-Flo™ Filter (Figure 4-26). The effluent flow is measured in the effluent pipe exiting from the bottom of the catchbasin. The Up-Flo™ Filter discharge location is 2.5 feet above the original catchbasin effluent pipe, the sump is therefore 2.5 ft deep.

Figure 4-24: Picture showing the influent sample tray and the sonde.

Figure 4-25: YSI Sondes installed in sump (another is behind baffle wall for effluent)

Figure 4-26: Sonde in the effluent chamber.

The automatic sampler allows the collection of 24 separate one liter samples. The sampler was therefore programmed for sub sampling multiple samples into each bottle to enable frequent sampling during the runoff event. In the first one hour of the storm, a 500 mL subsample is collected every 5 minutes, filling a one L bottle every 10 minutes, or 6 bottles in the first hour. After the first hour of sampling, the sampler collects a 250 mL subsample every 15 minutes, filling up one bottle every one hour until the flow ceases, or all the bottles are filled. This sampling configuration allows sampling to occur continuously for 19 hours. For longer duration storms, additional sampler tubs outfitted with empty sample bottles (Figure 4-17) are replaced with the filled sample tubs. The samplers are automatically disabled if the rainfall is less than 0.03 inches in a 30 minute period. It is common for the samplers to be disabled and enabled several times during a storm. Every time the samplers are re-initiated, they start where they had previously stopped. Both samplers operate together; they both start and stop at the same time. For example, if a sampler was stopped at the beginning of the 2nd subsample of the 4th bottle, the next subsample would start at the 2nd sub sample of the 4th bottle when the sampler is re-initiated.

Once the samplers stop at the end of the runoff event, sampling reports (Figure 4-27), and data from the flow meters and the sondes (Figure 4-28) were retrieved. Also, all the samples were retrieved from the samplers and placed into clean Nalgene bottles. The ISCO propacks (Figure 4-17), which are polyethylene one-time use sample bags, were replaced with new ones in the sampler bases. The samplers were then reset to automatically start at the next storm, along with the sondes. The flow meters were not reset, as they continuously take readings.

```
SAMPLER ID# 1071576858  18:19  7-JUL-05
  Hardware: A1       Software: 2.10
*********** SAMPLING RESULTS ***********
   SITE: FBAFFLE001
PROGRAM: CITYHALL02
Program Started at 11:54 WE 29-JUN-05
PART 'A' Nominal Sample Volume =  500 ml
PART 'B' Nominal Sample Volume =  250 ml
                                   COUNT
                                      TO
SAMPLE  BOTTLE TIME  SOURCE ERROR LIQUID
------- ------ ----        -- --  ------
               11:54  'A' DISABLED
               11:54  'B' DISABLED
------------- TU 05-JUL-05 -------------
               13:43  'A' ENABLED
  1,2      1   13:44  'A' T            0
  2,2      1   13:49  'A' T            0
  1,2      2   13:54  'A' T            0
  2,2      2   13:59  'A' T            0
  1,2      3   14:04  'A' T            0
  2,2      3   14:09  'A' T            0
  1,2      4   14:14  'A' T            0
               14:18  'A' DISABLED
               17:14  MANUAL PAUSE
               17:16  MANUAL RESUME
------------- WE 06-JUL-05 -------------
               06:16  'A' ENABLED
  2,2      4   06:19  'A' T            0
               06:22  'A' DISABLED
               06:24  'A' ENABLED
  1,2      5   06:29  'A' T            0
  2,2      5   06:34  'A' T            0
  1,2      6   06:39  'A' T            0
  2,2      6   06:44  'A' T            0
               06:44  'A' DONE 06-JUL
               06:45  'B' ENABLED
  1,4      7   07:00  'B' T            0
  2,4      7   07:15  'B' T            0
  3,4      7   07:30  'B' T            0
  4,4      7   07:45  'B' T            0
  1,4      8   08:00  'B' T            0
               08:01  'B' DISABLED
               10:46  'B' ENABLED
  2,4      8   11:01  'B' T            0
               11:10  'B' DISABLED
               11:12  'B' ENABLED
               11:16  'B' DISABLED
               11:21  'B' ENABLED
```

Figure 4-27: Example sampler report.

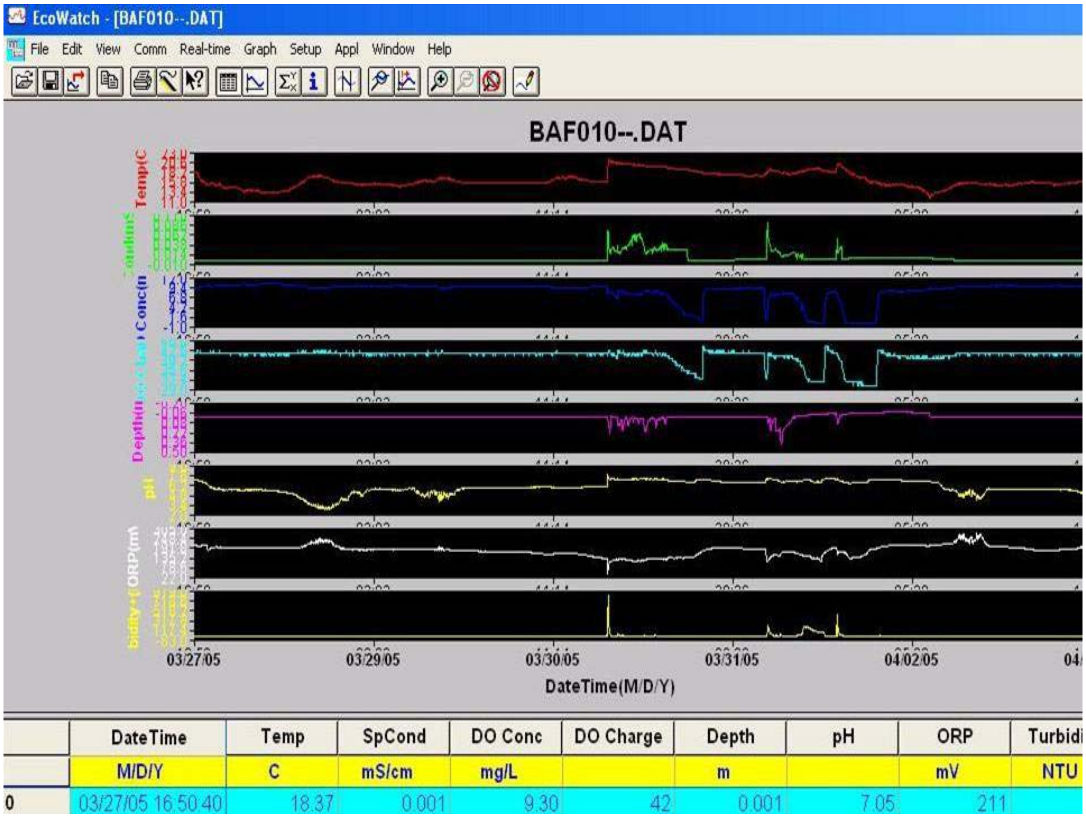

Figure 4-28: Screen shot of sonde data analysis screen.

There are two methods used for selecting appropriate samples for laboratory analyses. Because the monitoring site generates more runoff than can be treated by the prototype Up-Flo™ Filter, many samples are collected when large amounts of water are bypassing the filtration unit. Only paired samples representing periods when the water was treated were evaluated. The first method used to identify sampling periods when runoff was being treated was to use the stage data from the sump flow sensor. The height of the baffle wall and the overflow lip is 49", hence any sample collected when the height of the water in the catchbasin is more than 49" deep is affected by a blend of treated water and bypassed water and was not analyzed (with a few exceptions when the overflow was very small). These samples are identified by overlapping the time data report from the sampler and the stage data. The second method used to identify partially treated water was to use the flow data from the effluent pipe flow sensor. Any flow causing a filter bypass can be directly identified based on the stage-flow relationships of the catchbasin and filter combination. Both of these methods were normally used to identify the samples for analysis. On occasions, the Up-Flo™ Filter treated higher flows than expected. This was possibly due to bed expansion of the filter media and also due to the inherent elasticity of the material used to construct the Up-Flo™ Filter. Normally, the overflow rates were close to the originally determined treatment capacity. Once the appropriate samples were selected for analyses, the bacteria testing (*E. coli* and total coliforms) was conducted. In most cases, the bacterial testing started within 6 hrs after the storm ended.

Once the appropriate samples were selected for analyses, the samples were divided using a Dekaport/USGS cone splitter (Rickly Hydrological Company). As shown in Table 4-6, a minimum sample volume of 400 mL was required to conduct the analyses. All the constituents shown in Table 4-6 were measured for both paired influent and effluent samples.

Table 4-5: Sample volumes required for physical and chemical analyses.

S.No	Analytical Parameter	Volume Needed (mL)	Holding Time
1	Total solids	100	n/a
2	Suspended solids	100	n/a
3	E-Coli and Total Coliforms	10 for 1 in 10 dilution 20 for 1 in 5 dilution	6-10 hrs
4	COD	1	28days with acid preservation
5	Ammonia	2	48hrs
6	Nitrates	25	28 days, cool 4^{o} C
7	Phosphorus	5+5	28 days, cool 4^{o} C
8	Microtox toxicity screening	40	7 days, cool 4^{o} C
9	Heavy metals	45	6 months once digested
10	Particle size distribution	50	n/a
	Total Volume Required	**400**	

Every storm evaluated had a hyetograph (rainfall pattern) and hydrograph (runoff pattern) prepared with the treatment flow capacity marked for that particular event. An example is shown in Figure 4-29.

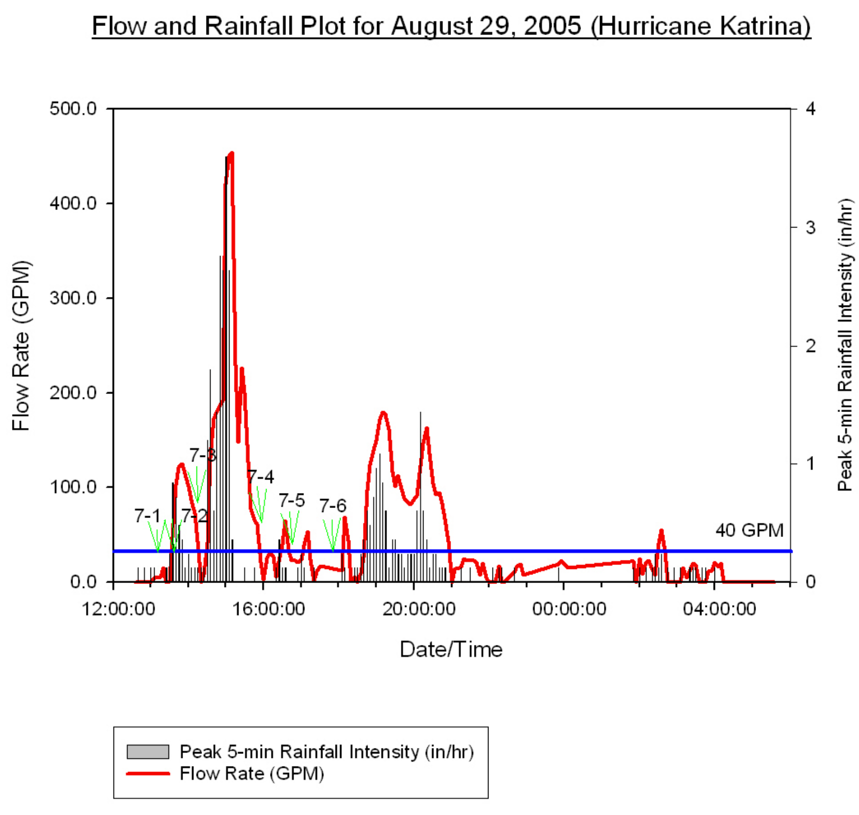

Figure 4-29: Hydrograph and Hyetograph for Hurricane Katrina

4.3.3 Sampling Results

Rains and Flows during Monitoring Period

Thirty-one separate rains occurred during the 10 month monitoring period from February 2 to November 21, 2005, as shown on Table 4-6. The monitoring period started off unusually dry in the late winter to early summer months. However, the mid summer was notable for severe thunderstorms having peak rain intensities (5-min) of up to 4 inches per hour. The late summer was also notable for several hurricanes, including Hurricane Katrina on August 29, 2005 that delivered about 3 inches of rain over a 15 hour period, having peak rain intensities as high as 1 in/hr in the Tuscaloosa area.

Figure 4-30 is a plot showing the relationship between the observed 5-minute peak rain intensities and the instantaneous peak runoff rates for this 0.9 acre site. As noted earlier, the time of concentration for this site is very short (< 5 minutes) and there is no significant hydraulic routing of the flows to the inlet. Most of the flows occur as sheetflows and shallow concentrated flows, with the roof drainage coming off the City Hall roof in large downspouts. The steep roof does not provide any storage, so excess flows would cascade over the rain gutters directly to the elevated concrete parking deck. The flows across the concrete parking deck are mostly as sheetflows and enter several downspouts to the lower asphalt parking area, and the inlet. This simple drainage pattern resulted in a fairly consistent relationship between rain intensity and runoff rate. The Rational formula coefficient "C" shown on this plot is about 0.35. The volumetric runoff coefficient (the ratio of the runoff volume to the rain volume) is about 0.65. Both of these coefficients are smaller than one would expect for the site conditions. The 3.5 to 4.5 in/hr 5-min rain intensities observed during the most intense events were associated with rainfalls in the Tuscaloosa area that would be expected to occur several times a year, according to the local IDF curves, as they did occur. The 2-year event has a 5-min peak rain intensity of about 6 in/hr, while the 25-yr event has a 5-min peak rain intensity of about 8.5 in/hr. It is likely the runoff coefficients would increase as these design storm conditions are reached. What was most unusual about the monitoring period was the absence of typical smaller events, with only these larger events occurring. The hurricanes did not result in such high rainfall intensities in the Tuscaloosa area, but they lasted for very long periods with moderate intensities. With larger drainage areas and longer times of concentration, they were responsible for design storm flows. As an example, the 3.6 inch/hr peak rain intensity observed during Katrina would be associated with a 25-yr design storm if the time of concentration was about 40 minutes (assuming this peak lasted for this duration), which would be the case for many of the local urban streams.

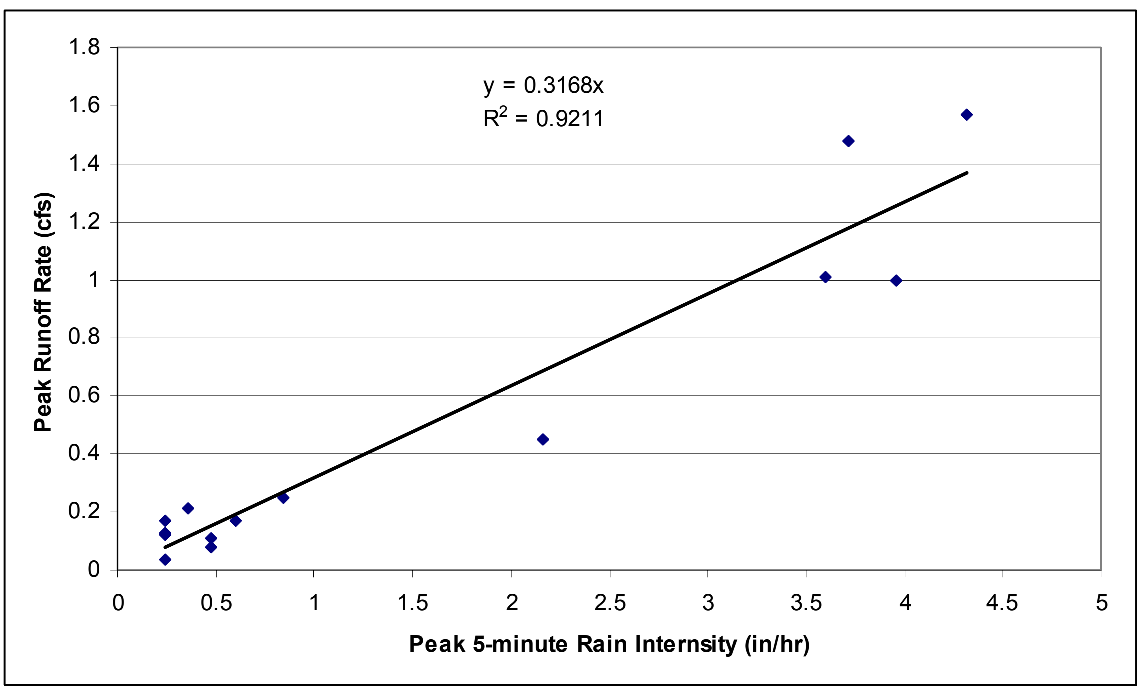

Figure 4-30: Peak 5-minute rain intensities and peak runoff rates observed.

Table 4-6a: Rains during Monitoring Period

Storm Number	Sampled Storm Number	Date	Total Rain Depth (inches)	Beginning and Ending time of Rain	Rainfall Duration (hrs)	Average Rain Intensity (in/hr)	Peak 5-min Rain Intensity (in/hr)	Instantaneous Peak Runoff Rate (cfs)	Peak Runoff Rate (gal/min	Number of Sample Pairs Evaluated per Event	peak/avg flow ratio	treatment flow rate (gal/min)
1		2-Feb-05	0.61	5.00pm-10.30pm	5.5	0.11	0.60	0.07	31	0	1.3	
2		27-Feb-05	0.53	9.45am-7.00pm	9.3	0.06	0.48	0.05	22	0	1.8	
3		7-Mar-05	1.42	12.00pm – 10.15pm	10.3	0.14	1.20	0.12	54	0	1.5	
4		22-Mar-05	0.52	8.45pm-11.55pm	3.2	0.16	1.20	0.41	184	0	5.1	
5	1	26-Mar-05	0.74	7.15pm – 11.25pm	4.2	0.18	1.08	0.27	121	1	2.9	n/a
6	2	1-Apr-05	0.11	3.35pm – 3.55pm	0.3	0.37	0.96	0.28	126	2	2.3	47
7	3	26-Apr-05	1.04	4am-6.30am and 9am-12.25pm	5.9	0.17	1.56	0.26	117	2	2.7	58
8	4	30-Apr-05	0.64	4.15am – 5.20am	1.1	0.59	3.72	0.31	139	2	1.1	70
9		8-Jun-05	0.82	5.30pm-0.30am	7.0	0.12	1.80	0.38	171	0	6.1	
10		9-Jun-05	0.26	5.00pm-6.45pm	1.8	0.15	1.32	0.24	108	0	3.8	
11		10-Jun-05	1.11	2.50pm-6.40pm	3.8	0.29	3.00	0.57	256	0	3.5	
12		11-Jun-05	2.42	9.00am-8.00am(12-Jun-05)	23.0	0.11	0.84	0.3	135	0	4.6	
13		28-Jun-05	0.45	2.00pm-7.20pm	5.3	0.08	2.40	0.33	148	0	8.0	
14	5	5-Jul-05	0.2	2.45pm – 3.30pm	0.8	0.26	0.48	0.13	58	2	1.3	40
15	6	6-Jul-05	0.51	7.00am -2.45pm	7.8	0.06	0.24	0.12	54	5	3.7	32
16		7-Aug-05	0.57	1.25pm-3.30pm	2.1	0.27	2.52	0.42	188	0	3.1	
17		9-Aug-05	0.02	12.30pm-1.30pm	2.0	0.01	0.12	n/a	n/a	0	n/a	
18		10-Aug-05	2.27	5.00pm-10.00pm	5.0	0.45	4.32	1.57	705	0	5.6	
19		13-Aug-05	2.09	4.30pm-7.30pm	3.0	0.70	3.72	1.48	664	0	3.5	
20		21-Aug-05	0.1	5.00pm-7.00pm	2.0	0.05	0.48	0.08	36	0	4.9	
21		23-Aug-05	0.08	6.45pm-7.45pm	1.0	0.08	0.24	0.12	54	0	5.0	

Table 4-6b: Rains during Monitoring Period (cont.)

Storm Number	Sampled Storm Number	Date	Total Rain Depth (inches)	Beginning and Ending time of Rain	Rainfall Duration (hrs)	Average Rain Intensity (in/hr)	Peak 5-min Rain Intensity (in/hr)	Instantaneous Peak Runoff Rate (cfs)	Peak Runoff Rate (gal/min	Number of Sample Pairs Evaluated per Event	peak/avg flow ratio	treatment flow rate (gal/min)
22	7	29-Aug-05	3.2	12.35pm – 4.00am (29th aug - 30th aug)	15.4	0.21	3.60	1.01	453	6	7.7	40
23	8	16-Sep-05	0.12	1.45pm-2.45pm	1.0	0.12	0.24	0.17	76	2	4.0	30
24		24-Sep-05	0.22	3.55pm-6.30pm	2.6	0.09	0.60	0.17	76	0	5.2	
25	9	25-Sep-05	1.47	5.15pm - 12.00am (25th Sep - 26th Sep)	6.8	0.22	3.96	1	449	1	7.9	35
26	10	6-Oct-05	0.11	8.15pm - 11.15pm	3.0	0.04	0.24	0.037	17	1	3.1	n/a
27		1-Nov-05	0.12	7.40pm-8.55pm	1.3	0.10	0.48	0.112	50	0	3.3	
28		5-Nov-05	0.05	3.55pm-4.30pm	0.6	0.09	0.24	0.13	58	0	6.8	
29		14-Nov-05	0.12	3.10pm-4.10pm	1.0	0.12	0.84	0.25	112	0	5.8	
30		15-Nov-05	0.57	10.25pm-12.00am	2.1	0.27	2.16	0.45	202	0	3.3	
31		21-Nov-05	0.51	4.25am-2.05pm	7.7	0.07	0.36	0.21	94	0	6.4	
		sum	23.00		145.4					24		352
		average	0.74		4.7	0.18	1.45	0.3683	165		4.2	44
		median	0.52		3.0	0.12	0.96	0.26	114		3.7	40.00
		min	0.02		0.3	0.01	0.12	0.04	17		1.1	30.00
		max	3.20		23.0	0.70	4.32	1.57	705		8.0	70.00
		standard dev	0.80		4.8	0.16	1.31	0.39	176		2.0	13.80
		COV	1.08		1.0	0.86	0.90	1.07	1		0.5	0.31

Treatment Flow Rate during Monitoring Period

An important aspect of a treatment system for stormwater is the change in the treatment flow rate through the device with time. Table 4-6 included the observed maximum flows during the monitored events right at the Up-Flo™ Filter overflow elevation. These data are plotted in Figures 4-31 through 4-33, relating the decreasing flow rate with rain depth, treated runoff, and suspended solids treated. These plots show that the filter was always greater than the specified 25 gpm treatment flow rate during the 10 month period. It is estimated that the 25 gpm treatment flow would be reached after about 30 inches of rainfall (in an area having 0.9 acre of impervious surfaces), or after about 45,000 ft^3 of runoff, or after about 160 lbs of suspended solids, was treated by the filter.

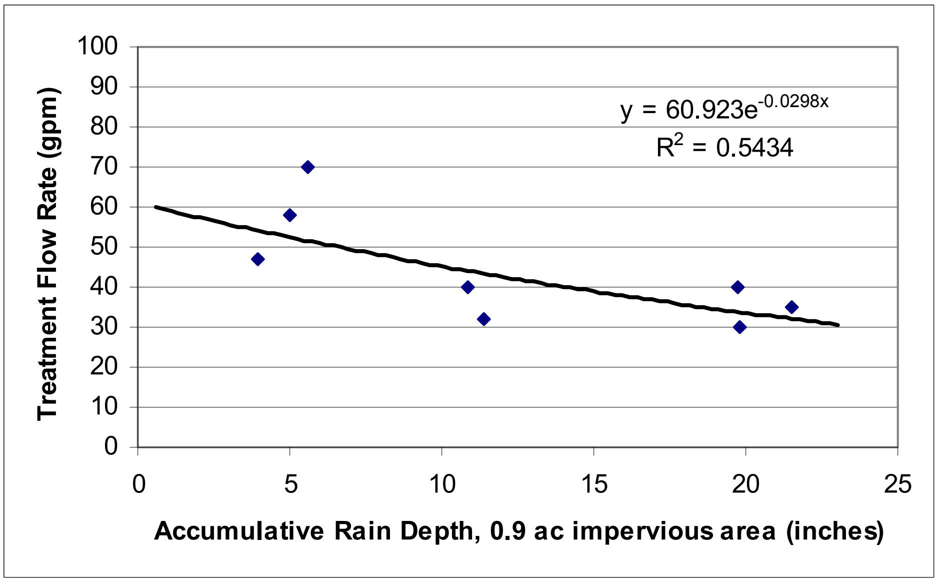

Figure 4-31: Up-Flo™ Filter treatment rate with rain depth.

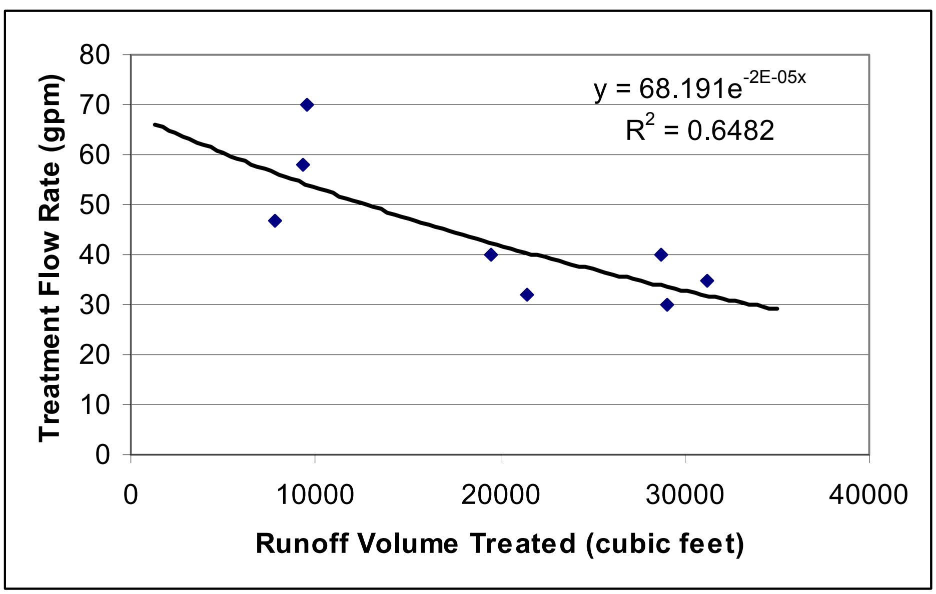

Figure 4-32: Up-Flo™ Filter treatment rate with runoff volume treated.

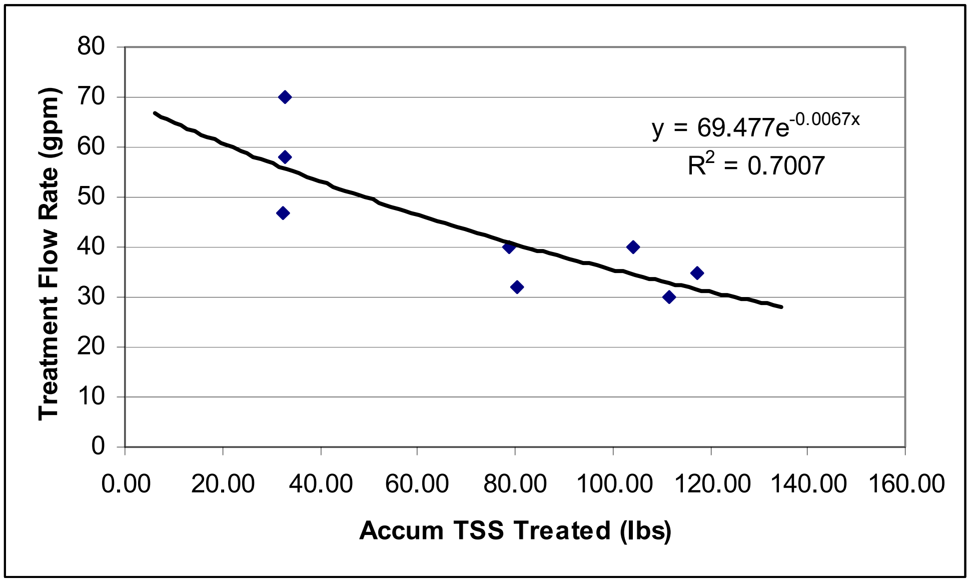

Figure 4-33: Up-Flo™ Filter treatment rate with suspended solids treated.

5.0 DISCUSSIONS

5.1 Annual Flow Treated by Up-Flo™ Filter Prototype

Figure 5-1 is a plot showing the amount of the annual flow associated with different percentage values for the Tuscaloosa, AL, test site. These were calculated using WinSLAMM for the 0.9 acre test site (0.4 acre roof and 0.5 acre paved parking), and for the first nine months of the 1999 rain year. The continuous simulation calculated the flows for every 6 minute increments during this period. With a treatment flow rate of 44 gpm (the average value for the observed events), the total events that would be treated if the peak flows were less than this value. During periods of peak flows greater than this value, the base 44 gpm would be treated by the Up-Flo™ Filter, while higher flows would bypass the filter unit. About 25 to 30% of the annual flows are expected to be less than or equal to the observed 44 gpm treatment flow rate, as shown on Figure 5-1. However, a larger fraction of the annual flows were actually treated at the test site. Figure 5-2 is a plot of the expected fraction of the annual flows that would be treated by the Up-Flo™ Filter for different treatment flow rates. For the observed 44 gpm treatment flow rate, about 60% of the annual flows were likely treated during the test period, and about 40% of the runoff volume bypassed the filter unit. This value compares favorably to the estimates made using the observed hydrographs. In order to treat about 90% of the annual flows at this site, the treatment flow rate should be about 100 gpm. Therefore, the prototype unit was about ¼ the optimal size, assuming a 25 gpm design flow rate.

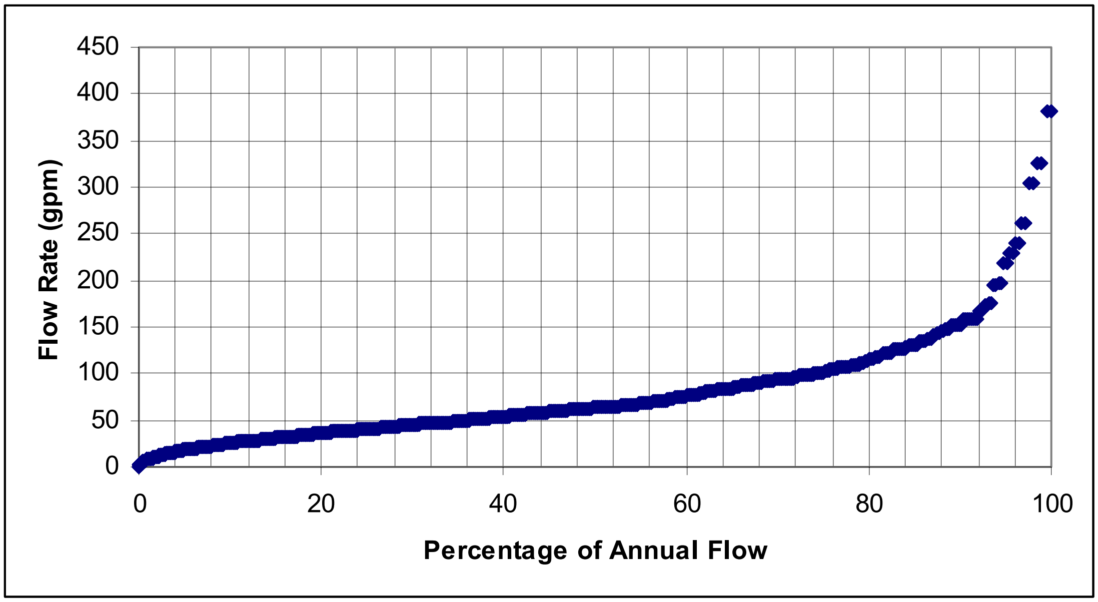

Figure 5-1: Percentage of annual flows at Tuscaloosa test site.

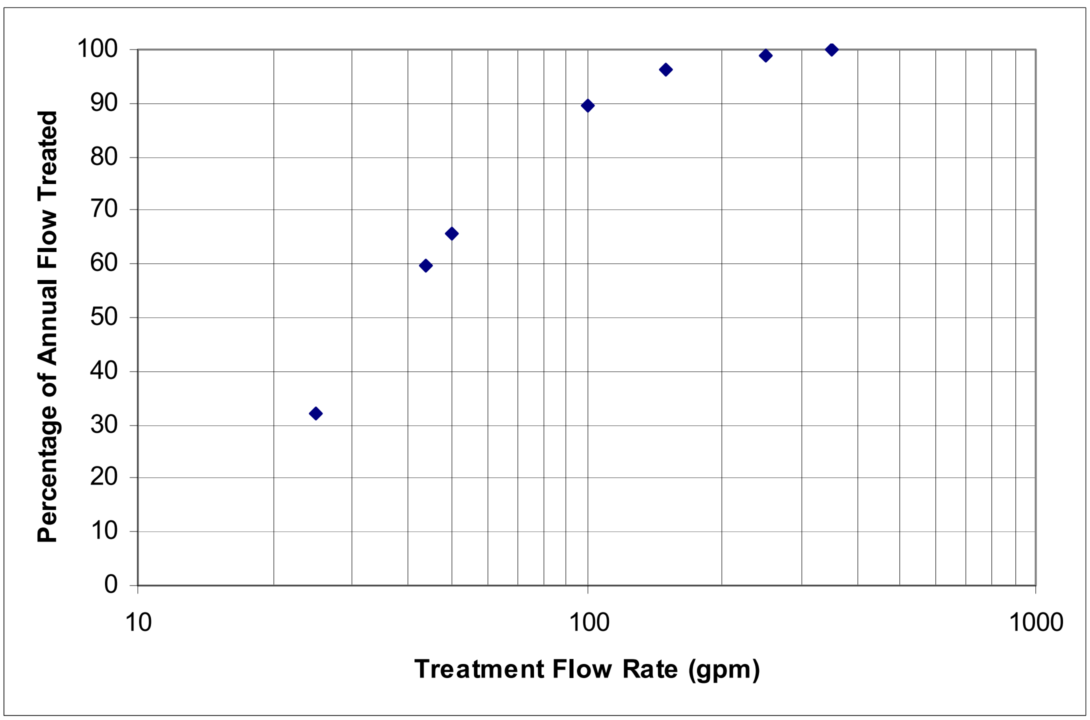

Figure 5-2: Treatment flow rate and percentage of annual flow treated for Tuscaloosa, AL, test site.

5.2 Suspended and Dissolved Material Pollutant Removal

5.2.1 Material in Influent and Effluent Samples

The Up-Flo™ Filter removes pollutants using several mechanisms. The sump, along with the coarse screens and overflow guards, trap the large debris that enter the inlet (including grit and other coarse solids, along with the floatables). Some of the finer material is also trapped by the sump, while additional finer material and some of the dissolved constituents are removed by the filtration media. After the flows cease, the water levels drops in the Up-Flo™ Filter through the small downdrain orifices. As the water drains from the filter media, some of the finer material trapped in the media, along with any floatables trapped against the coarse screen, fall into the sump. The automatic samplers used to measure the performance of the Up-Flo™ Filter do not collect the coarse solids and floatables in the samples, as they are too large for the sample line intake, or have a settling velocity approaching the sample velocity in the intake line. Figures 5-3 and 5-4 are particle size distribution plots of the solids collected by the influent and effluent automatic samplers. In both cases, less than 15% of the sampled material is larger than 100 µm. The median particle sizes of the influent samples averaged about 20 µm, but ranged from about 8 to about 55 µm. The median particle sizes of the effluent samples were smaller, averaging about 10 µm, and ranged from about 3.5 to 50 µm. The following discussion on the Up-Flo™ Filter performance only addresses these "finer suspended solids" particle fractions. The next subsections also discuss the larger material trapped in the sump, and the overall performance of the device.

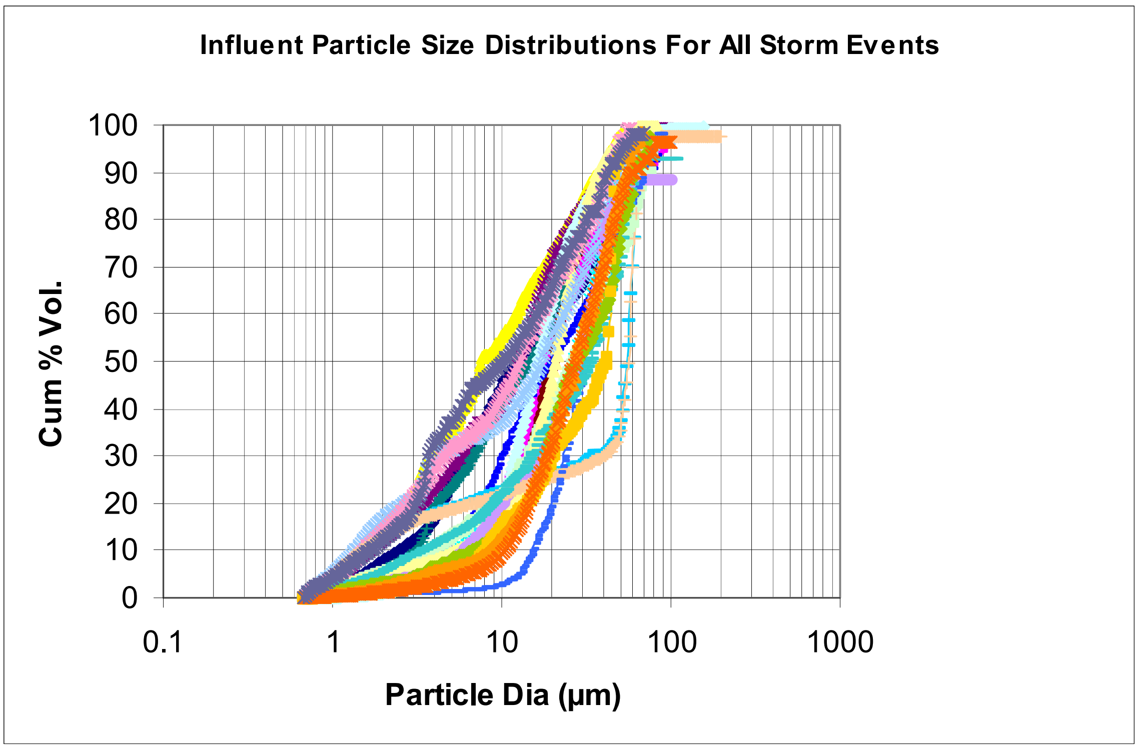

Figure 5-3: Influent particle size distribution for all storm events.

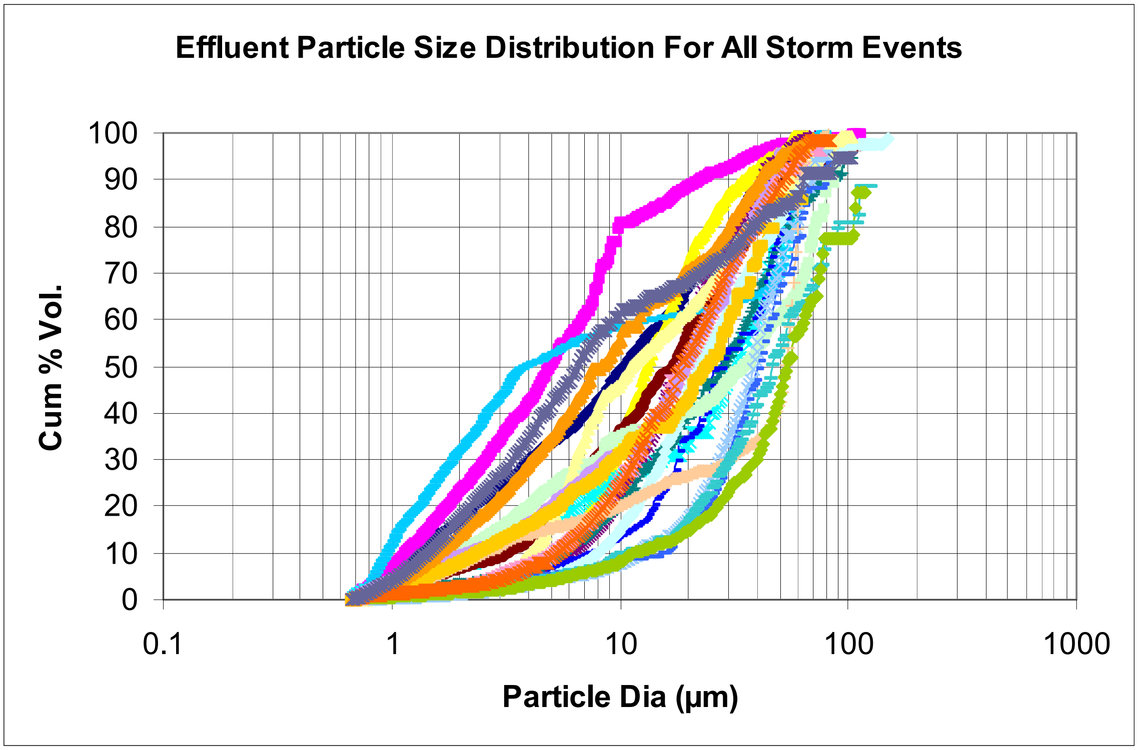

Figure 5-4: Effluent particle size distribution for all storm events.

As expected, the Up-Flo™ Filter is most effective in reducing pollutants mostly associated with particulate matter and less effective for dissolved constituents. Table 5-1 summarizes the overall performance of the Up-Flo™ Filter for the 24 sets of samples evaluated. This data summary does not include data where both influent and effluent were below the detection limits, such as happened for some dissolved heavy metals during some events.

Table 5-1: Summary of Up-Flo™ Filter actual storm event monitoring results

	Average influent concentration (all mg/L, except for bacteria that are #/100 mL, turbidity that is NTU, and metals that are µg/L) (and COV)	Average effluent concentration (all mg/L, except for bacteria that are #/100 mL, turbidity that is NTU, and metals that are µg/L) (and COV)	Calculated percentage removal based on average influent and average effluent concentrations (median of individual sample pair reductions)	Probability that influent ≠ effluent (nonparametric sign test) (significant reduction at 95% level?)
Turbidity (NTU)	43 (2.4)	15 (1.3)	65 (45)	>99% (significant reduction)
Suspended solids	64 (2.9)	19 (1.6)	70 (58)	>99% (significant reduction)
Total solids	137 (1.7)	90 (1.3)	34 (17)	>99% (significant reduction)
COD	111 (1.6)	81 (1.4)	27 (18)	>99% (significant reduction)
Phosphorus	0.94 (1.1)	0.77 (1.4)	18 (13)	98% (significant reduction)
Nitrates	0.7 (1.2)	0.7 (1.3)	0 (0)	93% (not significant reduction)
Ammonia	0.44 (1.5)	0.24 (1.30)	45 (24)	97% (significant reduction)
E. coli	4,750 (0.8)	3,290 (0.8)	31 (21)	>99% (significant reduction)
Total coliforms	12,400 (1.0)	6,560 (0.7)	47 (37)	>99% (significant reduction)
Total Zinc (µg/L)	169 (1.2)	130 (1.3)	23 (23)	>99% (significant reduction)
Dissolved Zinc (µg/L)	103 (0.5)	116 (1.3)	-13 (17)	3.7% (not significant reduction)
Total Copper (µg/L)	13 (1.5)	8.7 (1.2)	33 (26)	64.1% (not significant reduction)
Dissolved Copper (µg/L)	5.7 (0.6)	5.7 (1.0)	0 (35)	97.9% significant reduction)
Total Cadmium (µg/L)	1.7 (2.0)	2.6 (3.2)	-53 (-20)	0% (not significant reduction)
Dissolved Cadmium (µg/L)	7.6 (3.5)	2.2 (2.1)	71 (9)	0% (not significant reduction)
Total Lead (µg/L)	15.5 (1.9)	5.5 (1.9)	65 (50)	90.8% (significant reduction)
Dissolved Lead (µg/L)	11.3 (2.7)	2.8 (2.2)	75 (58)	97.8% (significant reduction)
<0.45 µm	0.087 (3.1)	0.69 (4.6)	-690 (60)	90.4% (not significant reduction)
0.45 to 3 µm	4.4 (1.7)	1.7 (1.6)	61 (65)	98.9% (significant reduction)
3 to 12 µm	13.4 (3.3)	3.9 (1.5)	71 (67)	90.7% (not significant reduction)
12 to 30 µm	28.7 (3.6)	6.1 (2.2)	79 (65)	>99% (significant reduction)
30 to 60 µm	12.0 (2.1)	4.5 (1.9)	63 (72)	>99% (significant reduction)
60 to 120 µm	3.1 (1.7)	1.5 (2.0)	52 (47)	97.4% (significant reduction)

Table 5-2 summarizes all the storm events that were sampled. Appendices B and C contain the results from the field monitoring for each constituent that was evaluated, including performance plots, scatterplots and regression analyses for each constituent. In most cases, significant regression relationships between influent and effluent concentrations were identified, showing strong correlations of performance with influent concentrations. The percentage reduction values shown in the tables in this section are overall averages, while the actual percentage reductions increase substantially as the influent concentrations increase.

Table 5-2: Summary of all the storm events

Storm Number	Date	Total Rain Depth (inches)	Beginning and Ending time of Rain	Rainfall Duration (hrs)	Average Rain Intensity (in/hr)	Peak 5-min Rain Intensity (in/hr)	Instantaneous Peak Runoff Rate (cfs)	Number of Sample Pairs Evaluated per Event
1	26-Mar-05	0.74	7.15pm – 11.25pm	4.17	0.18	1.08	0.27	1
2	1-Apr-05	0.11	3.35pm – 3.55pm	0.3	0.37	0.96	0.28	2
3	26-Apr-05	1.04	4am-6.30am and 9am-12.25pm	5.91	0.17	1.56	0.26	2
4	30-Apr-05	0.64	4.15am – 5.20am	1.08	0.59	3.72	0.31	2
5	5-Jul-05	0.2	2.45pm – 3.30pm	0.75	0.26	0.48	0.13	2
6	6-Jul-05	0.51	7.00am -2.45pm	7.75	0.06	0.24	0.12	5
7	29-Aug-05	3.2	12.35pm – 4.00am (29th aug - 30th aug)	15.42	0.2	3.6	1.01	6
8	16-Sep-05	0.12	1.45pm-2.45pm	1	0.12	0.24	0.17	2
9	25-Sep-05	1.47	5.15pm - 12.00am (25th Sep - 26th Sep)	6.75	0.218	3.96	1	1
10	6-Oct-05	0.11	8.15pm - 11.15pm	3	0.037	0.24	0.037	1
								Total Sample Pairs: 24

These data indicate that the performance of the Up-Flo™ Filter is dependent on influent concentrations. As an example, the following figures from Appendix C show the analyses for suspended solids. Figure 5-5 is a scatterplot of the observed influent concentrations vs. the effluent concentrations, while 5-6 is a line plot that connects paired influent and effluent concentrations. These plots show generally large reductions in TSS concentrations for most events.

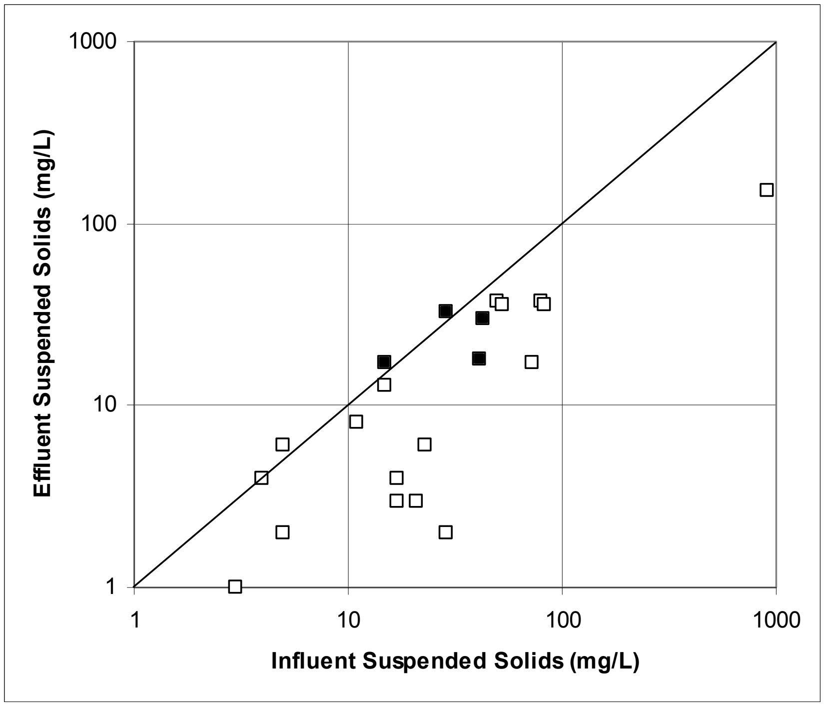

Figure 5-5: Scatterplot of observed influent and effluent suspended solids concentrations (filled symbols are events that had minor filter bypasses).

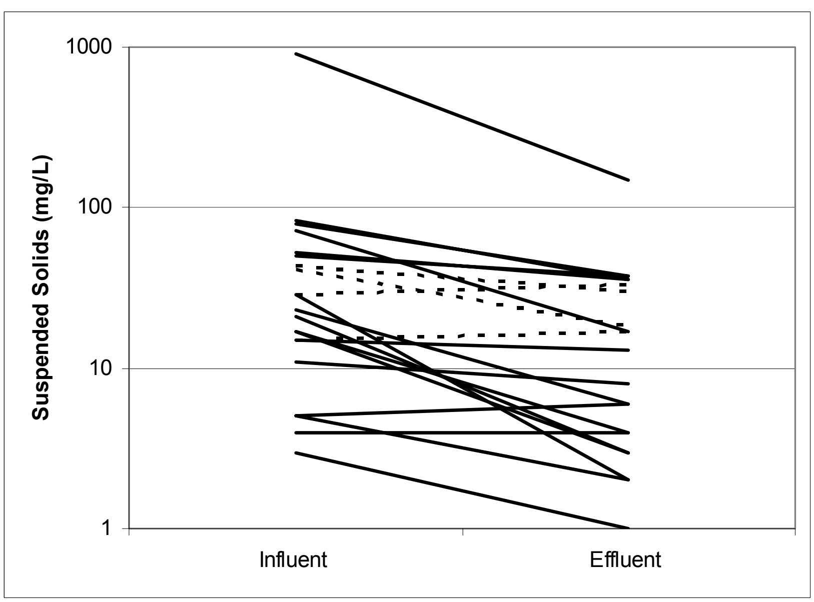

Figure 5-6: Paired influent and effluent suspended solids concentrations.

The nonparametric sign test was also used to calculate the probability that the influent equals the effluent concentrations. For the TSS data, $P < 0.01$, indicating with >99% confidence that the influent does not equal the effluent concentrations. Therefore, the test was statistically significant at least at the α 0.05 level.

These data were fitted to regression equations to predict the effluent concentrations from the influent conditions. In all cases, the data needed to be log-transformed in order to obtain proper residual behavior. For TSS, the following equation was found to be very significant, according to the ANOVA analyses:

Effluent Suspended Solids, log mg/L = 0.730 * (Influent Suspended Solids, log mg/L)

Regression Statistics on Observed Influent vs. Effluent Suspended Solids, log mg/L

Multiple R	0.94
R Square	0.89
Adjusted R Square	0.85
Standard Error	0.37
Observations	24

ANOVA

	df	SS	MS	F	Significance F
Regression	1	25.4	25.4	187	3.11E-12
Residual	23	3.12	0.136		
Total	24	28.55			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
X Variable 1*	0.730	0.053	13.7	1.56E-12	0.620	0.841

* the intercept term was determined to be not significant

As indicated on the ANOVA analyses above, the intercept term was not significant when included in the model, so that term was removed, and the statistical test conducted again. The overall significance of the model is very good (F<<0.001), and the adjusted R^2 term is 0.85. The P-value for the slope term of the equation is also highly significant (P<<0.001) and the 95% confidence limit of the calculated coefficient is relatively narrow (0.62 to 0.84). Figure 5-7 is a plot of the fitted equation along with the observed data, while Figure 5-8 contains the residual plots, all showing acceptable patterns.

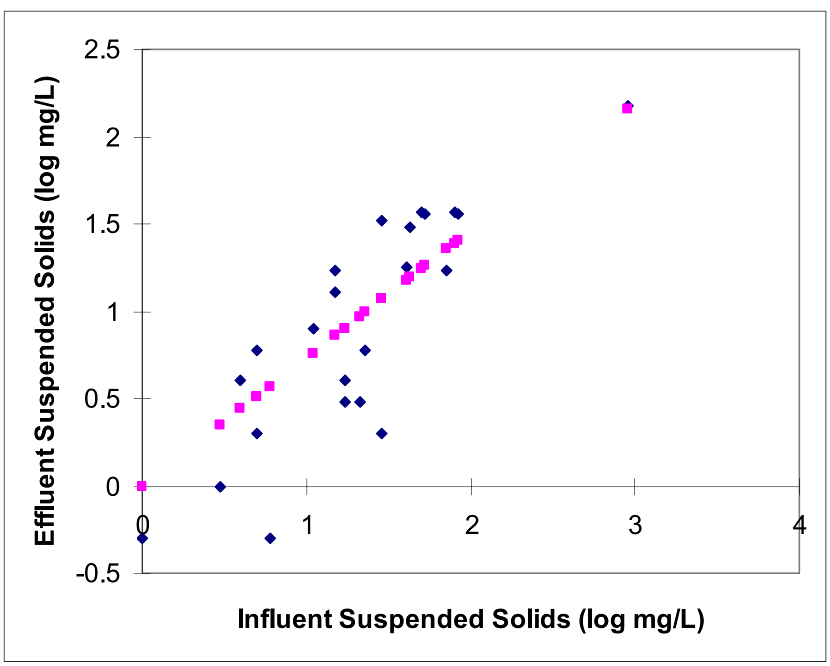

Figure 5-7: Fitted equation and data points for influent and effluent suspended solids.

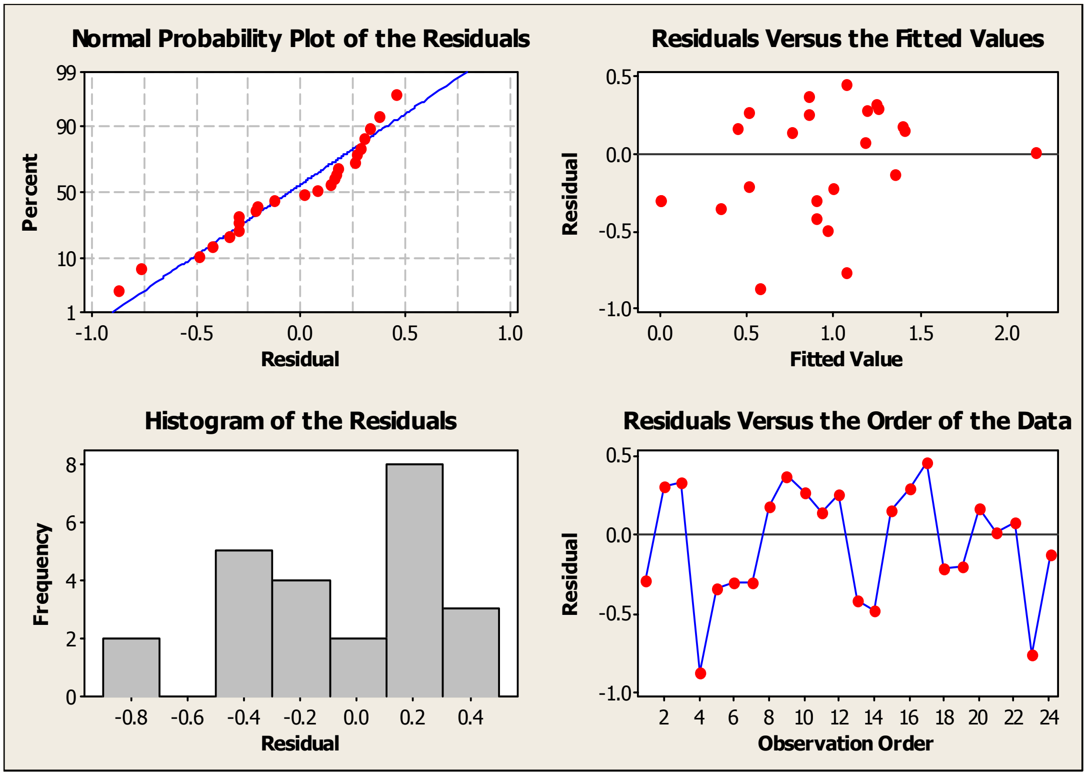

Figure 5-8: Residual analyses of fitted equation for suspended solids influent vs. effluent.

Confidence intervals of the influent vs. effluent plots are shown in Figure 5-9, while Figure 5-10 shows the confidence intervals for calculated percentage reduction values. As indicated in Figure 5-10, the TSS reductions would be >70% when influent concentrations exceeded about 80 mg/L, >80% when influent concentrations exceeded about 300 mg/L, and >90% when influent concentrations exceeded about 1000 mg/L.

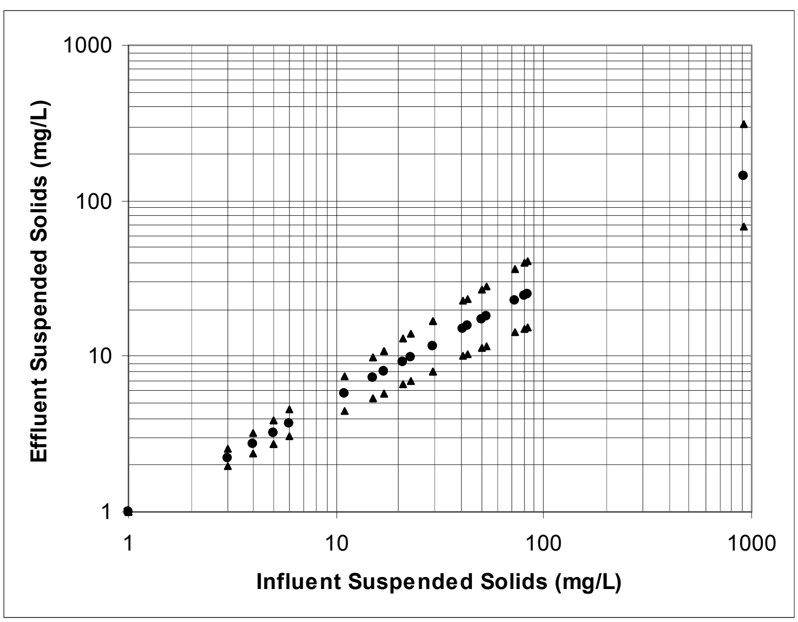

Figure 5-9: Predicted effluent concentrations for different influent concentrations, with 95% confidence limits.

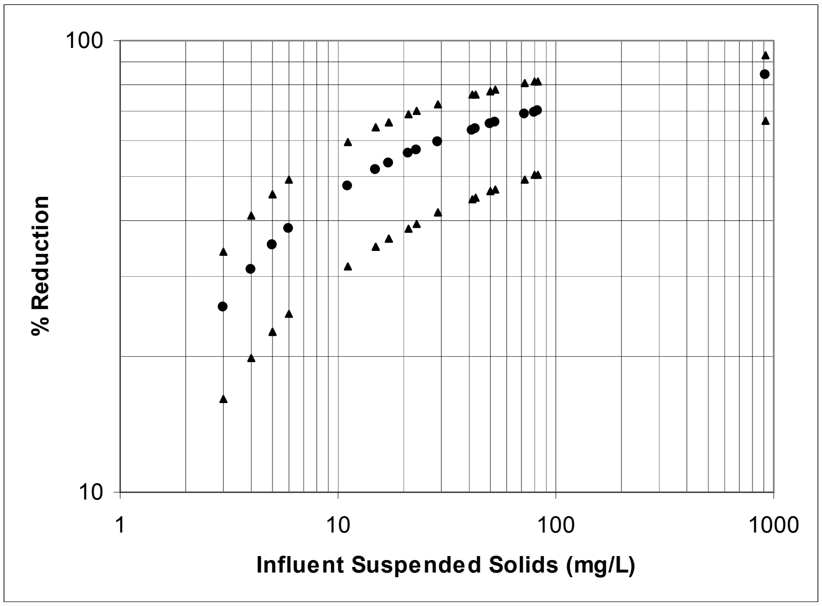

Figure 5-10: Percentage reductions as a function of influent concentrations, with 95% confidence limits.

5.2.2 Material in Up-Flo™ Filter Sump

At the end of the monitoring period, the Up-Flo™ Filter sump was cleaned out, the material collected, dried and weighed, sieved, and each particle size fraction analyzed. Appendix E contains the detailed data for these samples. Table 5-4 summarizes these data, by particle size grouping. For reference, Table 5-3 is a table showing sediment quality from older Bellevue, WA, catchbasin and inlet tests (Pitt and Bissonnette 1985). These values are comparable, with the expected differences for lead. Current lead sediment concentration values are about 1/10th of the older values.

Table 5-3: Chemical Quality of Bellevue, WA, Inlet Structure Sediment (mg constituent/kg total solids) (Pitt 1985)

Particle Size (µm)	COD	TKN	TP	Pb	Zn
<63	160,000	2,900	880	1,200	400
61-125	130,000	2,100	690	870	320
125-250	92,000	1,500	630	620	200
250-500	100,000	1,600	610	560	200
500-1,000	140,000	1,600	550	540	200
1,000-2,000	250,000	2,600	930	540	230
2,000-6,350	270,000	2,500	1,100	480	190
>6,350	240,000	2,100	760	290	150

Table 5-4. Observed Quantity and Quality of Sediment Collected from Up-Flo™ Filter Sump

Sediment Size Range (µm)	total amount in sump (kilograms)	% of total amount is sump in size range	COD (mg/kg)	P (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Cr (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
<75	1.1	2.0	233,000	3,580	117	15,600	6,050	190	21.2	80.4	1,340
75-150	1.6	2.9	129,000	1,620	177	25,300	4,960	99.8	17.4	70.3	958
150-250	3.6	6.6	35,500	511	158	22,900	3,010	48.2	8.0	34.9	501
250-425	11.5	21.5	60,100	315	134	18,600	2,790	33.6	6.7	28.4	539
425-850	17.1	31.9	45,000	496	146	19,700	2,290	22.1	3.7	23.7	270
850-2,000	10.5	19.6	29,200	854	312	44,700	4,050	27.8	6.9	25.1	414
2,000-4,750	4.8	8.9	143,000	1,400	452	65,000	4,430	54.9	10.5	27.8	450
>4,750	3.5	6.5	251,000	1,700	134	8,390	7,000	48.7	9.3	59.6	564
	53.6	100.0									

5.3 Overall Pollutant Removal by the Up-Flo™ Filter

Most of the sediment in the filter sump is greater than 150 µm in size, the approximate upper limit of the automatic sampler data shown above, and similar to the size fractions of sump material found by most researchers, as reported earlier in the literature review section. The finer material was captured within the media filter bags.

As noted previously, this prototype Up-Flo™ Filter was significantly under-sized for this installation. This occurred because of the difficulty in finding a suitable field monitoring location and the desire to make sure that high flows would be observed during the monitoring program. The site selected was unique in that it had a 5 ft deep outlet and was located at the upper area of a drainage system. Most of the inlets in Tuscaloosa and on the campus of the University of Alabama that were investigated were in-line manhole units with inlets and no sumps, having significant drainage entering the inlet in subsurface pipes from upland areas, and had shallow pipes. The selected site had no upland subsurface drainage components and had deeper pipes, making it the better location. The inlet box, however, was relatively small, but adequate for the available prototype Up-Flo™ Filter. The city was able to modify the inlet box to better accommodate the test unit. However, the surface area of the prototype's filtration media was limited to about 1.5 ft^2, with a corresponding rated peak filtration rate of about 25 gpm. This flow was expected to frequently be exceeded during the study period, as it was. As noted previously, the rain period certainly had several very large events, but the more typical mild spring and early summer events were lacking. The filter bags retained about 10 lbs of the fine material from the test period. This retained material was likely responsible for the slowly decreasing filter rate observed during the test period. The prototype Up-Flo™ Filter was about ¼ the size needed to treat about 90% of the expected runoff volume from the site, with about 10% bypassing the filter.

Tables 5-5 through 5-14 summarize the expected mass balance of particulate material removed by the Up-Flo™ Filter during the sampling period, considering both the measurements from the automatic samplers (for suspended material <150 µm in size) and the larger material retained in the sump, assuming all the runoff was treated by the filter, with no bypass, and all material greater than about 250 µm would be retained in the filter and sump. Figure 5-11 shows the measured particle size distributions for the influent and effluent water, considering both the water samples collected in the automatic samplers, plus the bed load material captured in the sump. The suspended solids removal rate is expected to be about 80%, while the removal rates for the other monitored constituents are expected to be about 72 to 84%, depending on their associations with the different particle sizes.

The filterable pollutant performance was summarized earlier. However, it is likely that those values were lower than would be expected for a properly-sized Up-Flo™ Filter that would treat more of the annual flows at a lower flow rate.

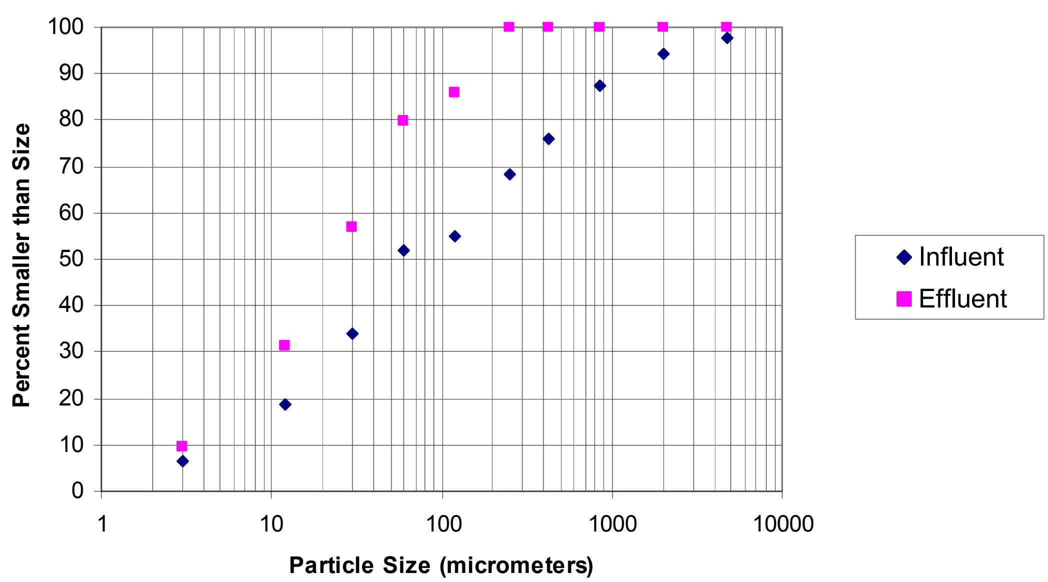

Figure 5-11: Particle size distributions for influent and effluent solids.

Table 5-5: Calculated Mass Balance of Particulate Solids for Monitoring Period

particle size range (µm)	SS influent mass (kg)	SS effluent mass (kg)	SS removed (kg)	% reduction
0.45-3	9.3	2.8	6.6	70
3-12	18.7	6.4	12.3	66
12-30	22.4	7.7	14.7	66
30-60	26.7	6.8	19.9	74
60-120	4.6	1.8	2.9	61
120-250	19.8	4.3	15.5	78
250-425	11.5	0.0	11.5	100
425-850	17.1	0.0	17.1	100
850-2,000	10.5	0.0	10.5	100
2,000-4,750	4.8	0.0	4.8	100
>4,750	3.5	0.0	3.5	100
sum	148.9	29.8	119.2	80

Table 5-6: Calculated Mass Balance of Particulate COD for Monitoring Period

particle size range (µm)	COD influent mass (grams)	COD effluent mass (grams)	COD removed (grams)	% reduction
0.45-3	2177	647	1530	70
3-12	4353	1493	2861	66
12-30	5224	1791	3433	66
30-60	6219	1592	4627	74
60-120	599	231	368	61
120-250	701	152	550	78
250-425	691	0	691	100
425-850	770	0	770	100
850-2,000	307	0	307	100
2,000-4,750	686	0	686	100
>4,750	879	0	879	100
sum	22635	5936	16699	74

Table 5-7: Calculated Mass Balance of Particulate Phosphorus for Monitoring Period

particle size range (µm)	P influent mass (grams)	P effluent mass (grams)	P removed (grams)	% reduction
0.45-3	33.4	9.9	23.5	70
3-12	66.9	22.9	44.0	66
12-30	80.3	27.5	52.7	66
30-60	95.6	24.5	71.1	74
60-120	7.5	2.9	4.6	61
120-250	10.1	2.2	7.9	78
250-425	3.6	0.0	3.6	100
425-850	8.5	0.0	8.5	100
850-2,000	9.0	0.0	9.0	100
2,000-4,750	6.7	0.0	6.7	100
>4,750	6.0	0.0	6.0	100
sum	328.0	90.4	237.6	72

Table 5-8: Calculated Mass Balance of Particulate Calcium for Monitoring Period

particle size range (µm)	Ca influent mass (grams)	Ca effluent mass (grams)	Ca removed (grams)	% reduction
0.45-3	1.1	0.3	0.8	70
3-12	2.2	0.7	1.4	66
12-30	2.6	0.9	1.7	66
30-60	3.1	0.8	2.3	74
60-120	0.8	0.3	0.5	61
120-250	3.1	0.7	2.4	78
250-425	1.5	0.0	1.5	100
425-850	2.5	0.0	2.5	100
850-2,000	3.3	0.0	3.3	100
2,000-4,750	2.2	0.0	2.2	100
>4,750	0.5	0.0	0.5	100
sum	22.9	3.8	19.2	84

Table 5-9: Calculated Mass Balance of Particulate Magnesium for Monitoring Period

particle size range (µm)	Mg influent mass (grams)	Mg effluent mass (grams)	Mg removed (grams)	% reduction
0.45-3	146	43	102	70
3-12	291	100	192	66
12-30	350	120	230	66
30-60	416	107	310	74
60-120	117	45	72	61
120-250	452	98	354	78
250-425	214	0	214	100
425-850	337	0	337	100
850-2,000	469	0	469	100
2,000-4,750	312	0	312	100
>4,750	29	0	29	100
sum	3137	515	2622	84

Table 5-10: Calculated Mass Balance of Particulate Iron for Monitoring Period

particle size range (µm)	Fe influent mass (grams)	Fe effluent mass (grams)	Fe removed (grams)	% reduction
0.45-3	57	17	40	70
3-12	113	39	74	66
12-30	136	47	89	66
30-60	161	41	120	74
60-120	23	9	14	61
120-250	59	13	47	78
250-425	32	0	32	100
425-850	39	0	39	100
850-2,000	43	0	43	100
2,000-4,750	21	0	21	100
>4,750	25	0	25	100
sum	709	166	544	77

Table 5-11: Calculated Mass Balance of Particulate Copper for Monitoring Period

particle size range (µm)	Cu influent mass (grams)	Cu effluent mass (grams)	Cu removed (grams)	% reduction
0.45-3	1.8	0.5	1.2	70
3-12	3.5	1.2	2.3	66
12-30	4.3	1.5	2.8	66
30-60	5.1	1.3	3.8	74
60-120	0.5	0.2	0.3	61
120-250	1.0	0.2	0.7	78
250-425	0.4	0.0	0.4	100
425-850	0.4	0.0	0.4	100
850-2,000	0.3	0.0	0.3	100
2,000-4,750	0.3	0.0	0.3	100
>4,750	0.2	0.0	0.2	100
sum	17.6	4.9	12.7	72

Table 5-12: Calculated Mass Balance of Particulate Chromium for Monitoring Period

particle size range (µm)	Cr influent mass (grams)	Cr effluent mass (grams)	Cr removed (grams)	% reduction
0.45-3	0.2	0.1	0.1	70
3-12	0.4	0.1	0.3	66
12-30	0.5	0.2	0.3	66
30-60	0.6	0.1	0.4	74
60-120	0.1	0.0	0.0	61
120-250	0.2	0.0	0.1	78
250-425	0.1	0.0	0.1	100
425-850	0.1	0.0	0.1	100
850-2,000	0.1	0.0	0.1	100
2,000-4,750	0.1	0.0	0.1	100
>4,750	0.0	0.0	0.0	100
sum	2.2	0.6	1.6	74

Table 5-13: Calculated Mass Balance of Particulate Lead for Monitoring Period

particle size range (µm)	Pb influent mass (grams)	Pb effluent mass (grams)	Pb removed (grams)	% reduction
0.45-3	0.8	0.2	0.5	70
3-12	1.5	0.5	1.0	66
12-30	1.8	0.6	1.2	66
30-60	2.1	0.5	1.6	74
60-120	0.3	0.1	0.2	61
120-250	0.7	0.1	0.5	78
250-425	0.3	0.0	0.3	100
425-850	0.4	0.0	0.4	100
850-2,000	0.3	0.0	0.3	100
2,000-4,750	0.1	0.0	0.1	100
>4,750	0.2	0.0	0.2	100
sum	8.6	2.2	6.4	74

Table 5-14. Calculated Mass Balance of Particulate Zinc for Monitoring Period

particle size range (µm)	**Zn influent mass (grams)**	**Zn effluent mass (grams)**	**Zn removed (grams)**	**% reduction**
0.45-3	12.5	3.7	8.8	70
3-12	25.0	8.6	16.5	66
12-30	30.0	10.3	19.7	66
30-60	35.8	9.2	26.6	74
60-120	4.4	1.7	2.7	61
120-250	9.9	2.1	7.8	78
250-425	6.2	0.0	6.2	100
425-850	4.6	0.0	4.6	100
850-2,000	4.3	0.0	4.3	100
2,000-4,750	2.2	0.0	2.2	100
>4,750	2.0	0.0	2.0	100
sum	137.2	35.8	101.4	74

5.4 Sizing the Up-Flo™ Filter for Net-Annual Pollutant Removal

The annual pollutant load removal of the Up-Flo™ Filter is directly dependent on the amount of the annual runoff that is treated by the unit. The above performance summaries assume that all of the runoff is treated. Over a long term, this objective is obviously not reasonable, as the largest peak flows are substantially greater than flows that occur most of the time. Therefore, a series of conservative preliminary calculations were made, using WinSLAMM, the Source Loading and Management Model, to determine the distribution of flows that could be expected for several sets of conditions. Figures 5-12 to 5-21 are net-annual sizing plots for one acre paved parking or storage areas for five locations in the US having very different rainfall conditions (Seattle, WA; Phoenix, AZ; Atlanta, GA; Milwaukee, WI; and Portland, ME). The first of each pair of plots shows the annual runoff distributions calculated using WinSLAMM for January through September of each of the years noted. The largest flows are likely under predicted, but the bulk of the probability distributions should be reasonable for these preliminary analyses. This 9 month period was used because of file size limitations in Excel. WinSLAMM is typically used for continuous simulations using several decades of rain data. These plots were made using calculated flows every 6 minutes, corresponding to the expected time of concentration limitations. The second plot of each pair shows the calculated percentage of the annual flows that would be treated at different treatment flow rates.

Table 5-15 summarizes these plots showing several treatment objectives. It is interesting to note that Seattle, typically known as a wet and rainy city, has the lowest flow rates for the probability points shown, and the smallest required treatment flow rates for the different treatment objectives. In contrast, Phoenix, a desert city, is shown to have some of the highest flow rates and largest treatment flow rates needed. The total rainfall in Phoenix is small, but when it does rain, the rain intensities and associated flow rates are large. In this sampling of cities, the needed treatment flow rates for the same treatment objectives are seen to range by a factor of about three or four: it would require four Up-Flo™ Filter modules per acre of paved drainage area to treat about 90% of the annual runoff in Atlanta (similar to what was found for the Tuscaloosa test site during the monitoring period), while only one or two modules would be needed for the same area and treatment of 90% of annual runoff for Seattle.

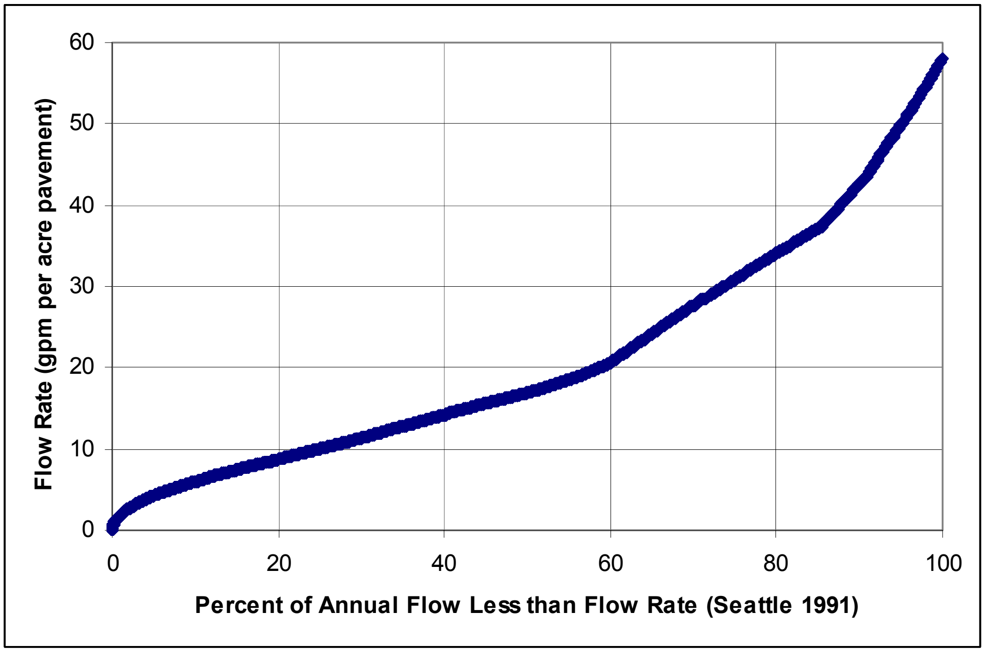

Figure 5-12: Treatment flow rates needed for Seattle, WA.

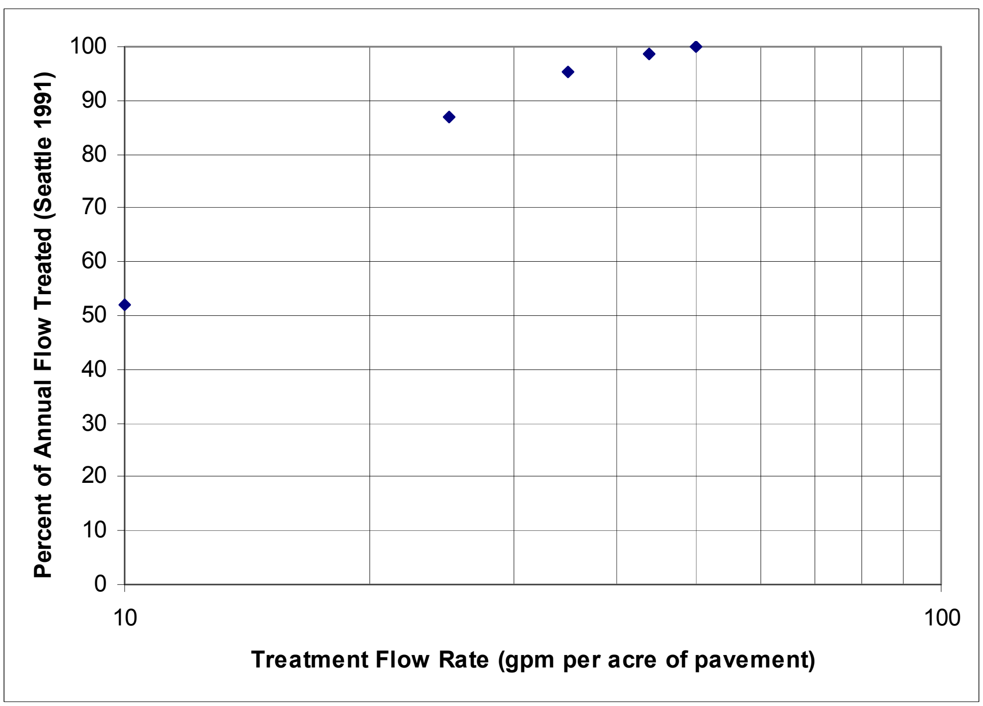

Figure 5-13: Treatment flow rates needed for Seattle, WA.

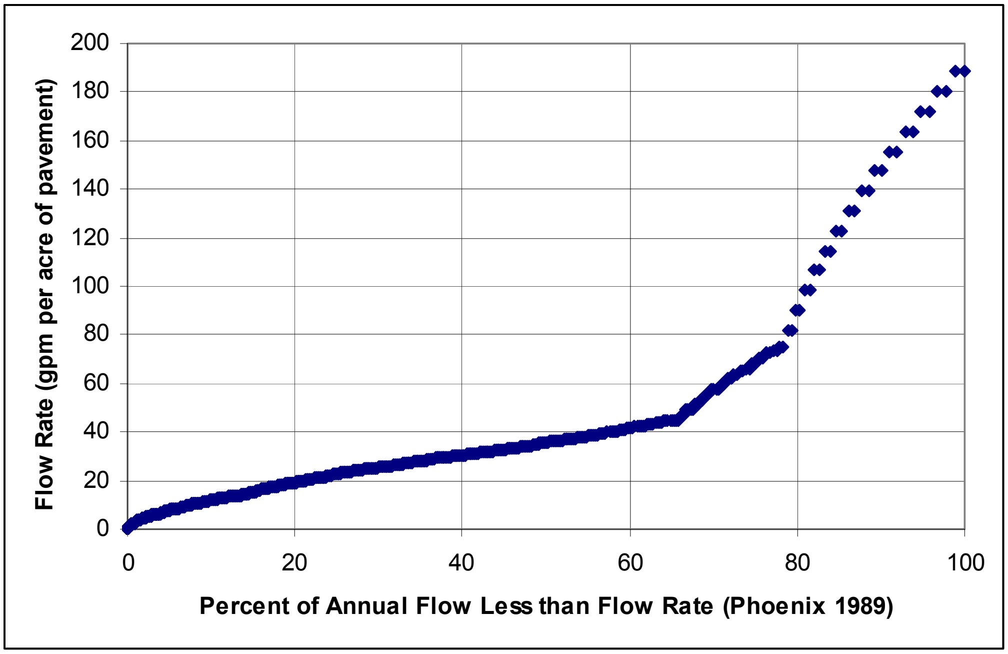

Figure 5-14: Treatment flow rates needed for Phoenix, AZ.

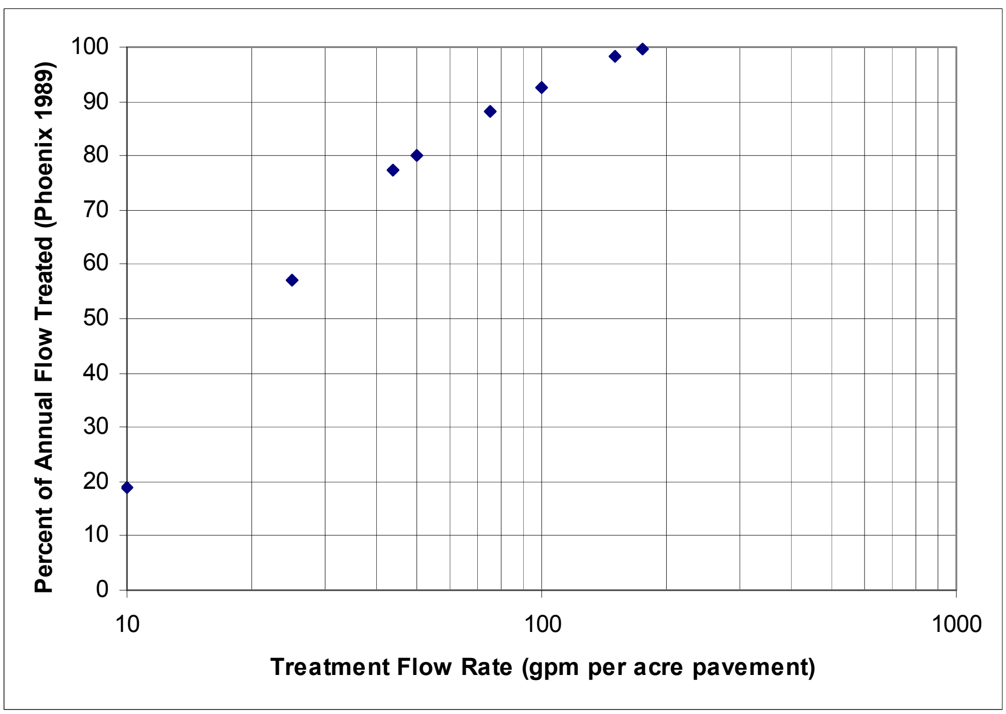

Figure 5-15: Treatment flow rates needed for Phoenix, AZ.

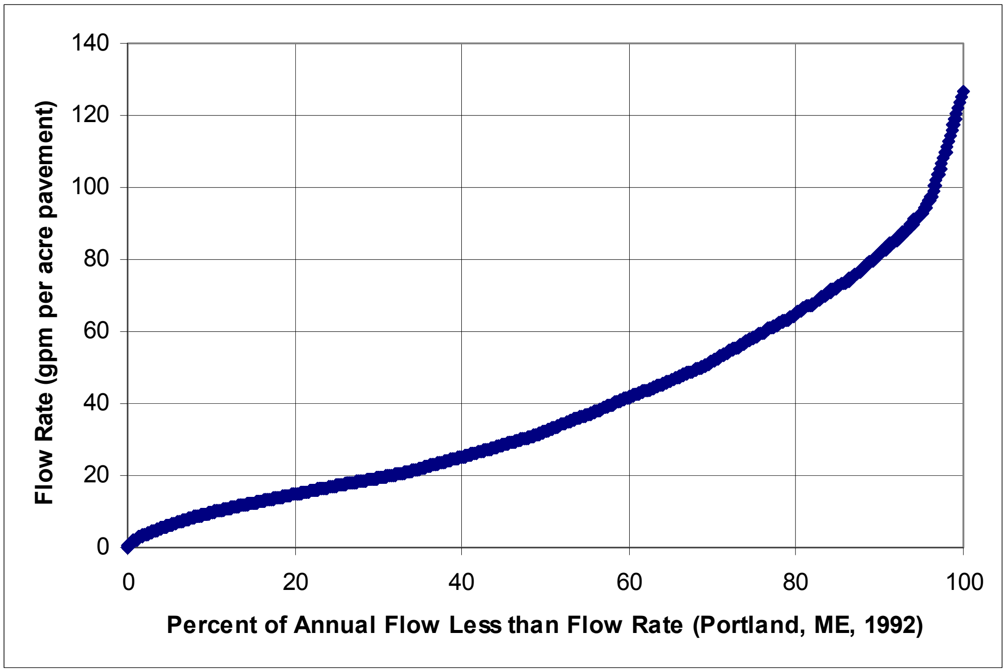

Figure 5-16: Treatment flow rates needed for Portland, ME.

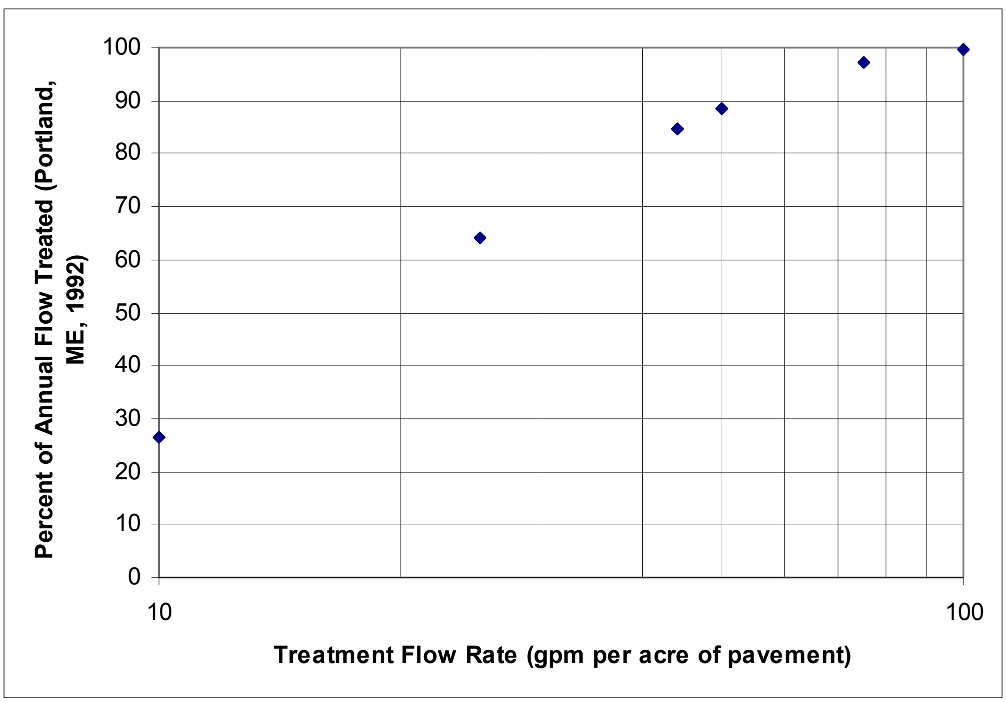

Figure 5-17: Treatment flow rates needed for Portland, ME.

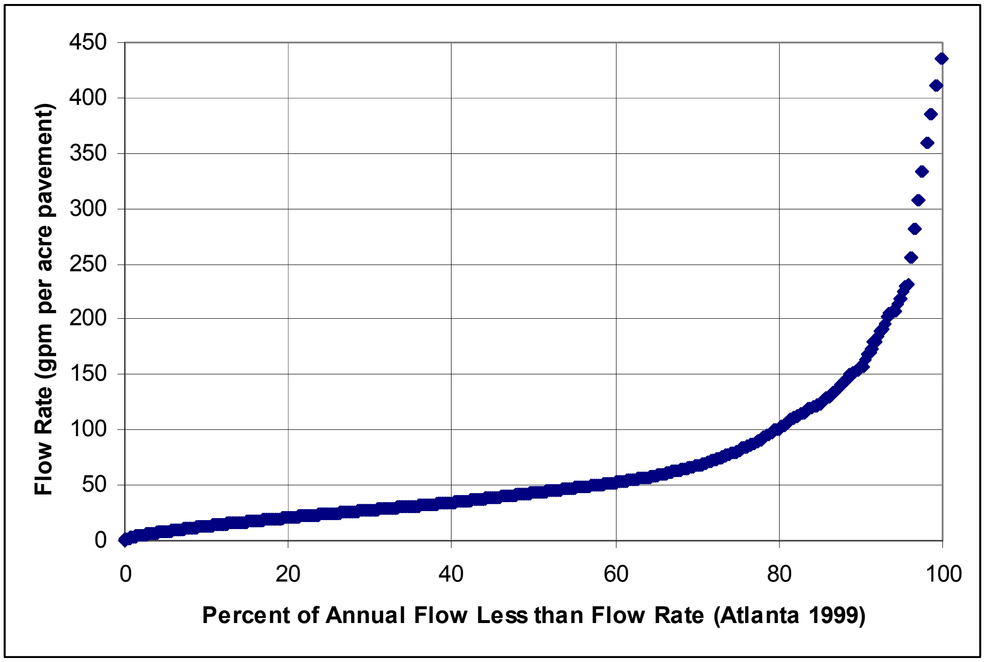

Figure 5-18: Treatment flow rates needed for Atlanta, GA.

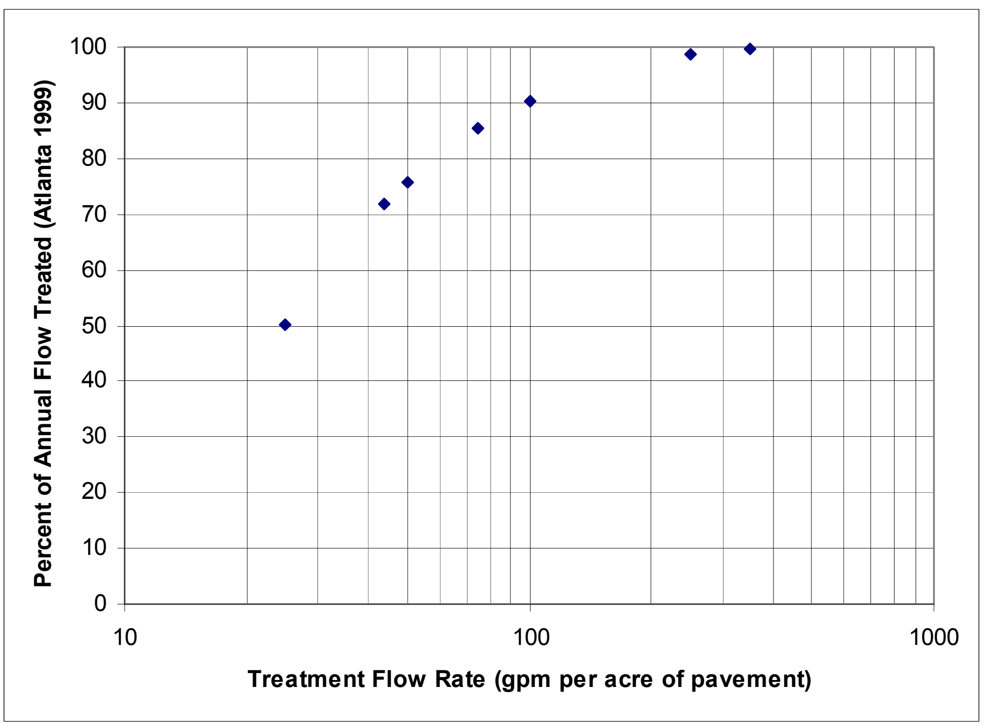

Figure 5-19: Treatment flow rates needed for Atlanta, GA.

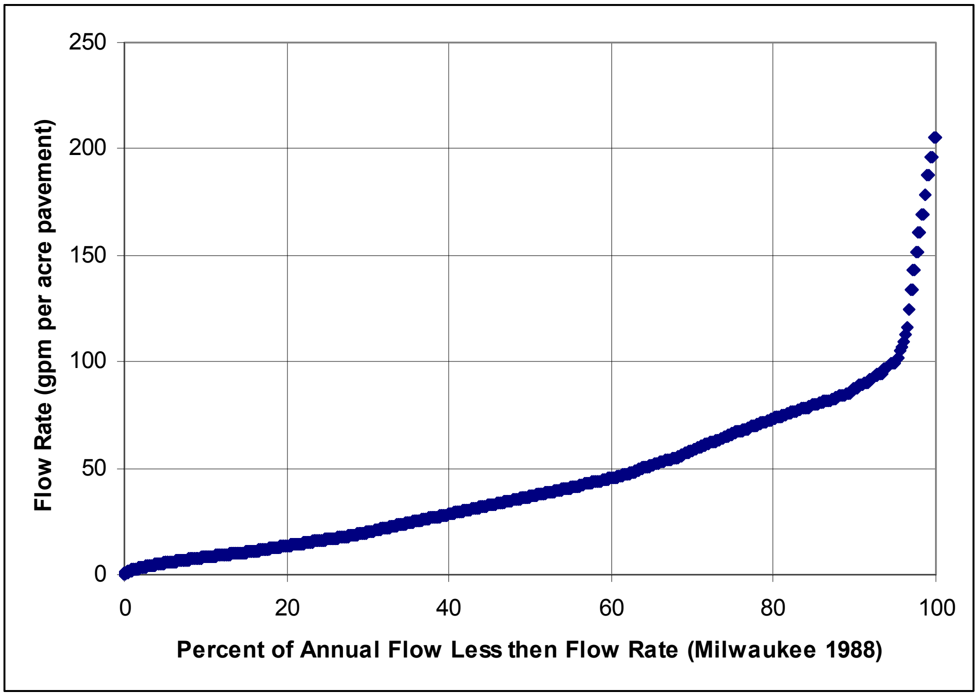

Figure 5-20: Treatment flow rates needed for Milwaukee, WI.

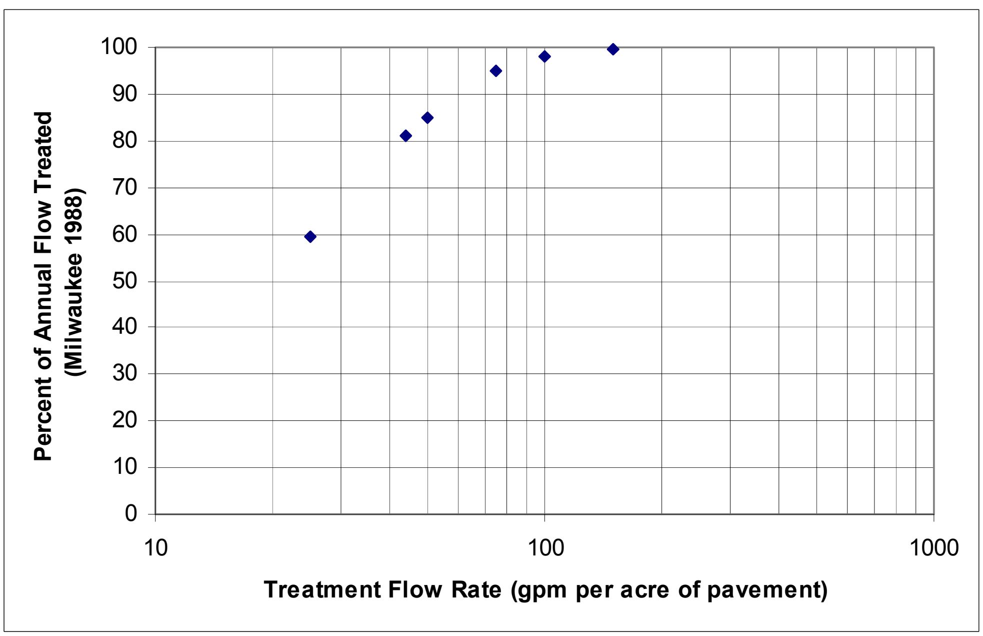

Figure 5-21: Treatment flow rates needed for Milwaukee, WI.

Table 5-15: Example Runoff Rates and Treatment Rates Needed for Different Treatment Objectives

Location	Annual Flow Rate Distributaries (gpm/acre pavement)			Flow Rate Needed for Different Levels of Annual Flow Treatment (gpm/acre pavement)		
	50th Percentile	70th Percentile	90th Percentile	50%	70%	90%
Seattle, WA	16	28	44	10	18	30
Portland, ME	31	52	80	18	30	53
Milwaukee, WI	35	60	83	20	35	65
Phoenix, AZ	38	60	150	20	35	90
Atlanta, GA	45	65	160	25	40	100

6.0 CONCLUSIONS

This report summarizes in-field performance data of the prototype Up-Flo™ Filter tested under controlled runoff conditions and during actual rain events. Conclusions drawn from the field data are presented in the following paragraphs.

The Up-Flo™ Filter is shown to be a filtration device with a relatively high treatment rate per unit surface area. Flows in excess of 20 gpm/ft^2 occur for an operational driving head of about 20 inches.

Sediment removal tests were conducted under controlled runoff conditions at varying flow rates and influent sediment concentrations. The percentage reductions for suspended solids for the mixed media tests and high influent concentrations (485 to 492 mg/L) were 84 to 94%, with effluent concentrations ranging from 31 to 79 mg/L for flows ranging from 15 to 30 gpm. During the low concentration tests (54 to 76 mg/L), the reductions ranged from 68 to 86%, with effluent concentrations ranging from 11 to 19 mg/L. The flow rates are shown to be an important factor for particulate solids capture. Particle size distribution analysis effluent samples show that the effluent particle size distributions of various controlled testing trials are similar irrespective of flow rate and influent concentration showing the filter to be effective at controlling influent solids and their associated pollutants.

Thirty-one separate rains occurred during the 10 month monitoring period from February 2 to November 21, 2005. During the monitoring period, several severe thunderstorms having peak rain intensities (5-min) of up to 4 inches per hour. Several hurricane-category events fell within the monitoring period, including Hurricane Katrina. On August 29, 2005, Hurricane Katrina delivered about 3 inches of rain over a 15 hour period, having peak rain intensities as high as 1 in/hr in the Tuscaloosa area.

During the 10-month monitoring period, the treatment flow rates of the Up-Flo™ Filter prototype were observed to decrease with time. Based on earlier lab scale work, the Up-Flo™ Filter prototype was expected to have a filtration rate of about 25 gpm. However, much higher filtration rates were seen in the field. Over the entire duration of the 10-month monitoring period, the filtration rate never decreased to a treatment rate as low as 25 gpm. It is estimated that the filtration rate of the Up-Flo™ Filter prototype would decrease to as low as 25 gpm after about 30 inches of rainfall (in an area having 0.9 acre of impervious surfaces), or after about 45,000 ft^3 of runoff.

The Up-Flo™ Filter is shown to be most effective in reducing the pollutants that are highly associated with particulate matter, and less so for removing dissolved constituents as would be expected. The data indicated that the percentage of pollutants removed by the Up-Flo™ Filter is dependent on influent concentrations with on average TSS reductions >70% when influent concentrations were in the 80 mg/L range, >80% when influent concentrations were about 300 mg/L, and >90% when influent concentrations exceeded about 1000 mg/L.

Table 6-1 summarizes the expected mass balance of particulate material removed by the Up-Flo™ Filter during the sampling period, considering both the measurements from the automatic samplers (for suspended material <150 µm in size) and the larger material retained in the sump, assuming all the runoff was treated by the Up-Flo™ Filter and no flows were bypassed. The suspended solids removal rate is expected to be about 80%, while the removal rates for the other monitored constituents are expected to be about 72 to 84%, depending on their associations with the different particle sizes.

Table 6-1: Calculated mass balance of particulate solids for monitoring period

Particle size range (µm)	SS influent mass (kg)	SS effluent mass (kg)	SS removed (kg)	% reduction
0.45-3	9.3	2.8	6.6	70
3-12	18.7	6.4	12.3	66
12-30	22.4	7.7	14.7	66
30-60	26.7	6.8	19.9	74
60-120	4.6	1.8	2.9	61
120-250	19.8	4.3	15.5	78
250-425	11.5	0.0	11.5	100
425-850	17.1	0.0	17.1	100
850-2,000	10.5	0.0	10.5	100
2,000-4,750	4.8	0.0	4.8	100
>4,750	3.5	0.0	3.5	100
sum	148.9	29.8	119.2	80

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Appendix A: Actual Storm Events Flows and Hydrographs

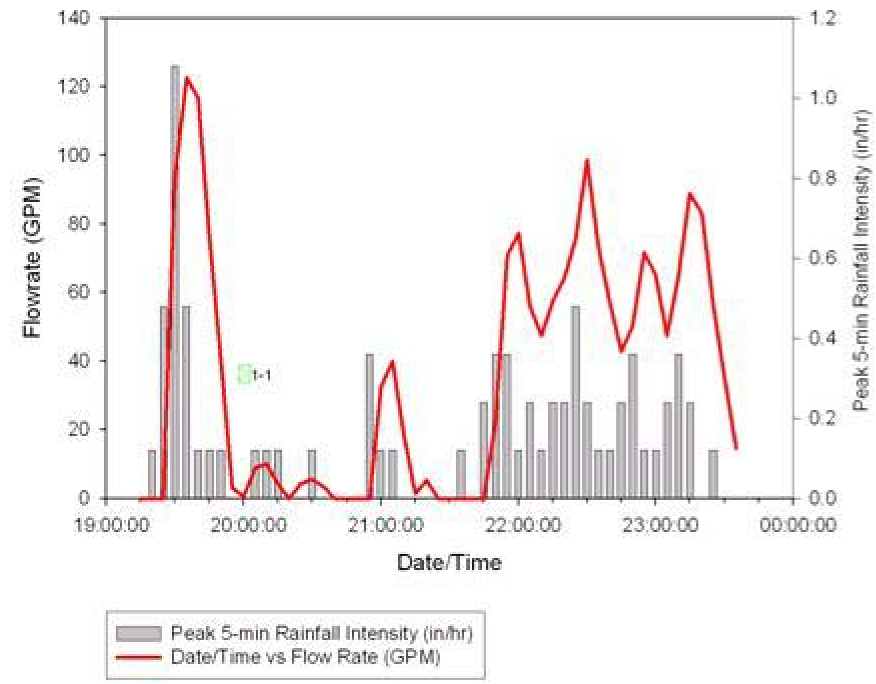


Figure A-1: Flow and hydrograph for March 26, 2005 event

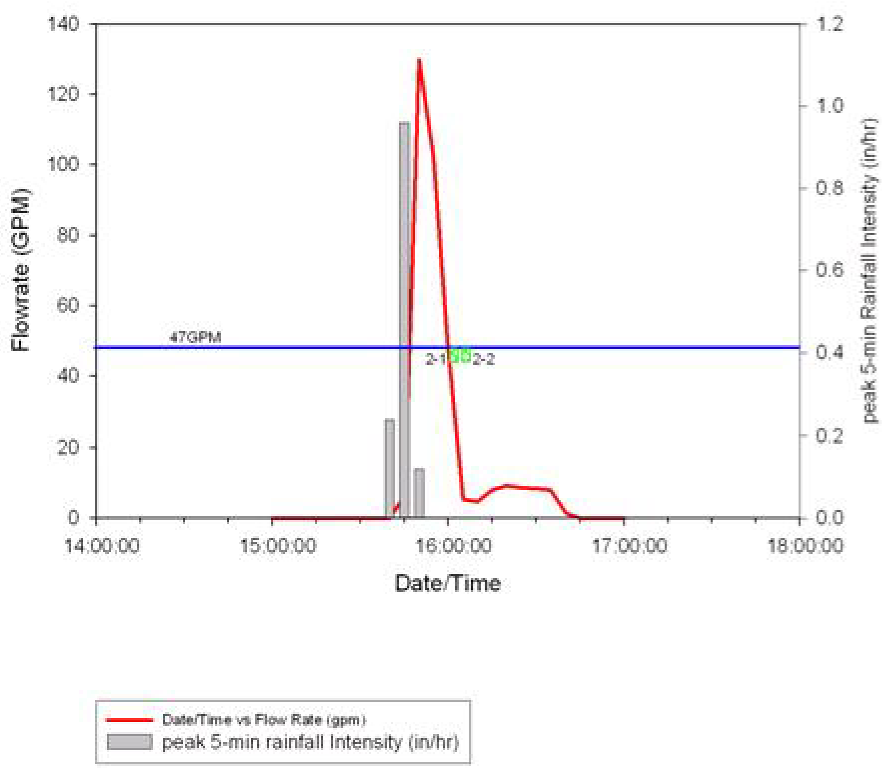


Figure A-2: Flow and hydrograph for April 01, 2005 event

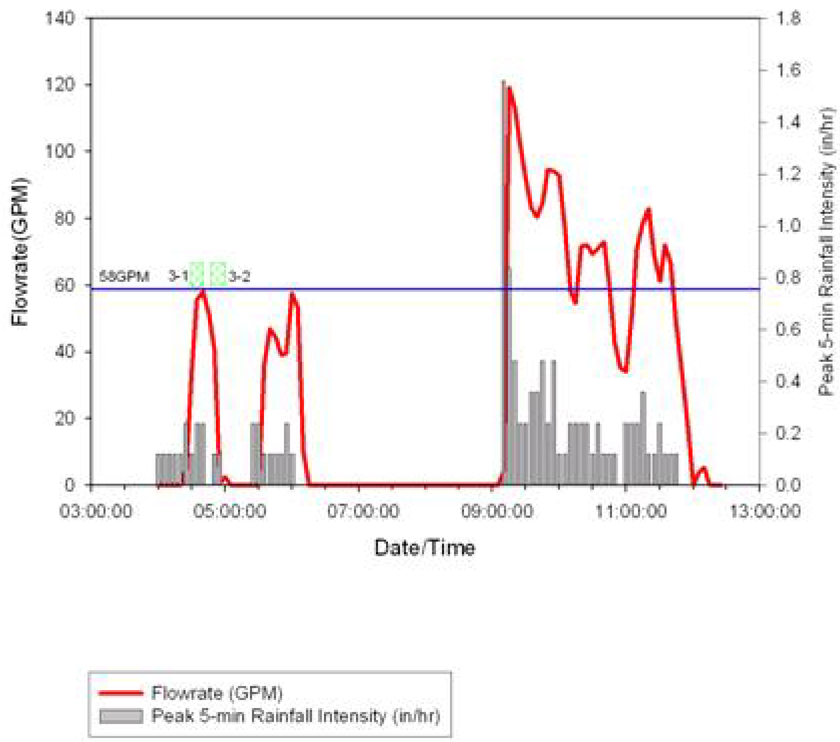


Figure A-3: Flow and hydrograph for April 26, 2005 event

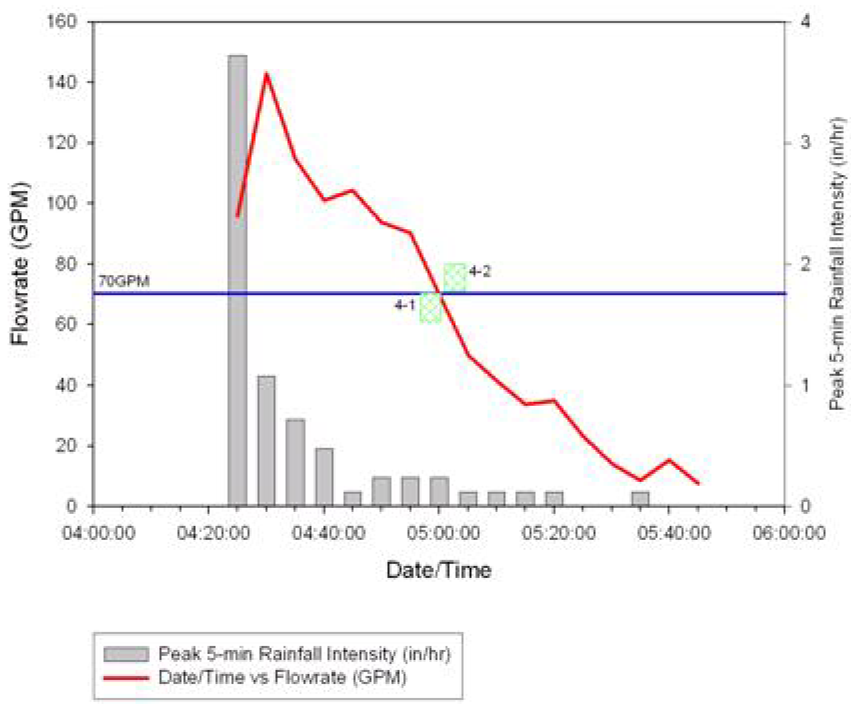


Figure A-4: Flow and hydrograph for April 30, 2005 event

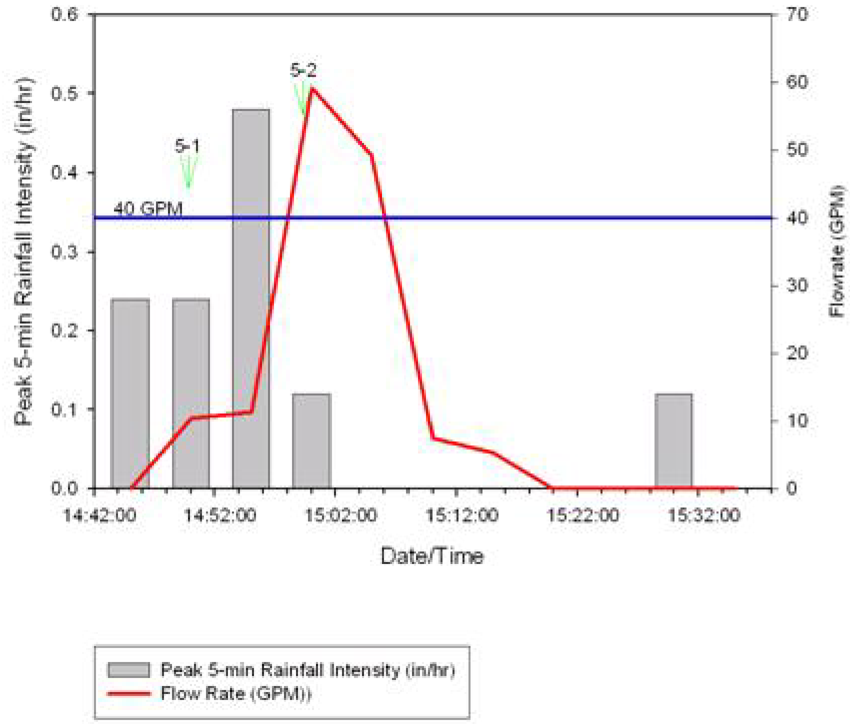


Figure A-5: Flow and hydrograph for July 05, 2005 event

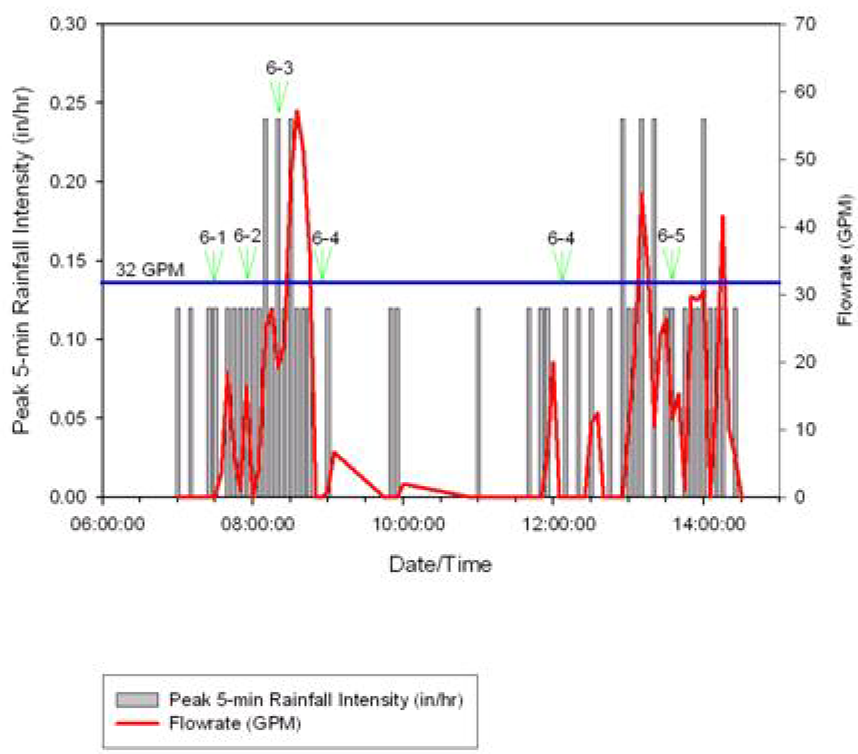


Figure A-6: Flow and hydrograph for July 06, 2005 event

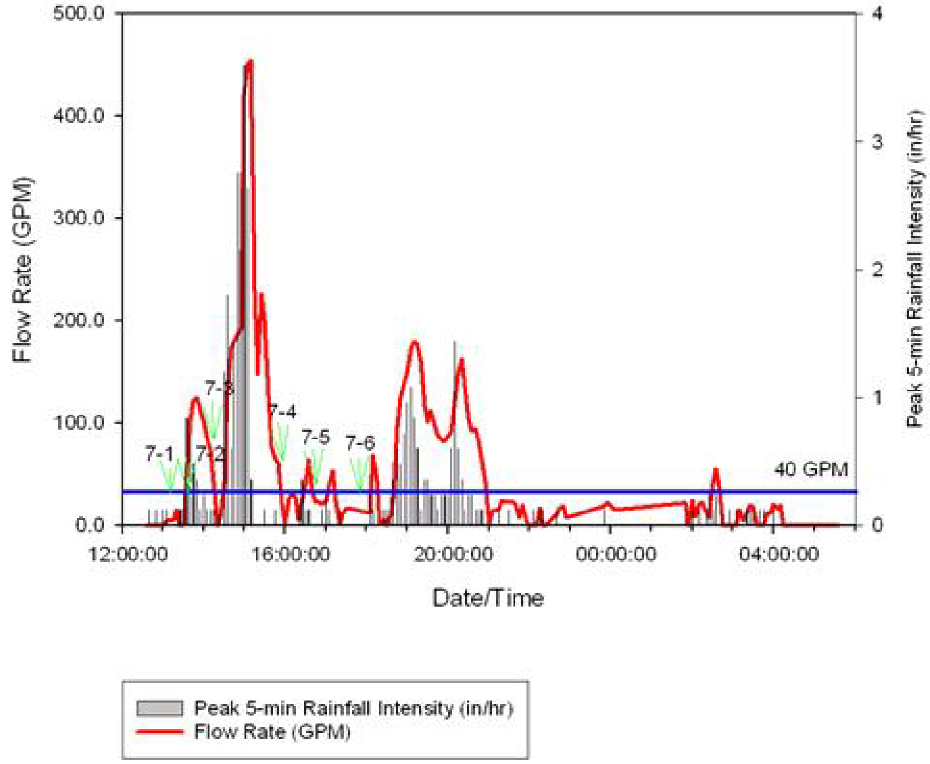


Figure A-7: Flow and hydrograph for August 29, 2005 event

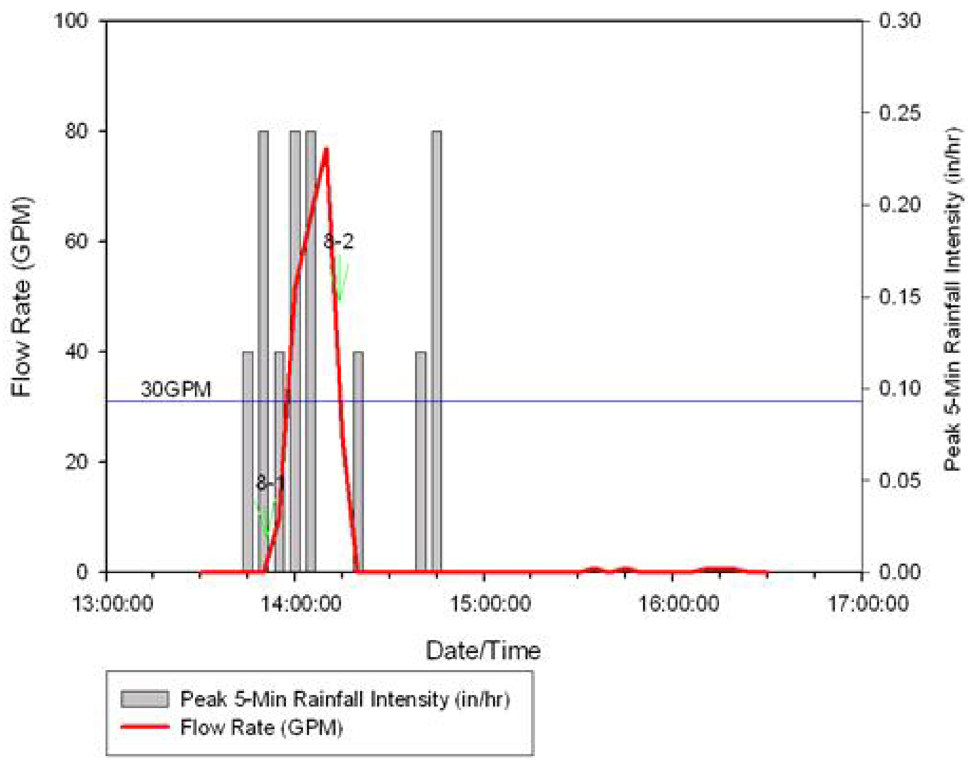


Figure A-8: Flow and hydrograph for September 16, 2005 event

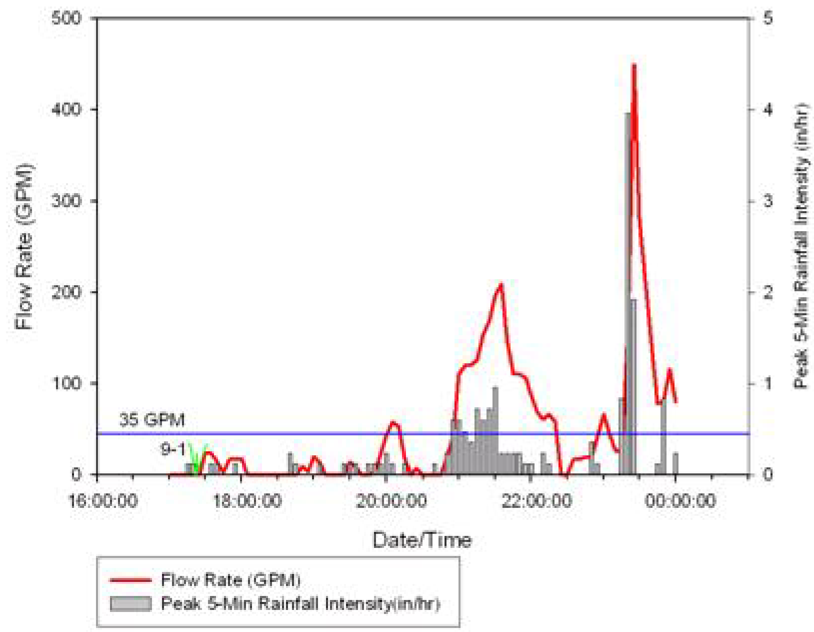


Figure A-9: Flow and hydrograph for September 25, 2005 event

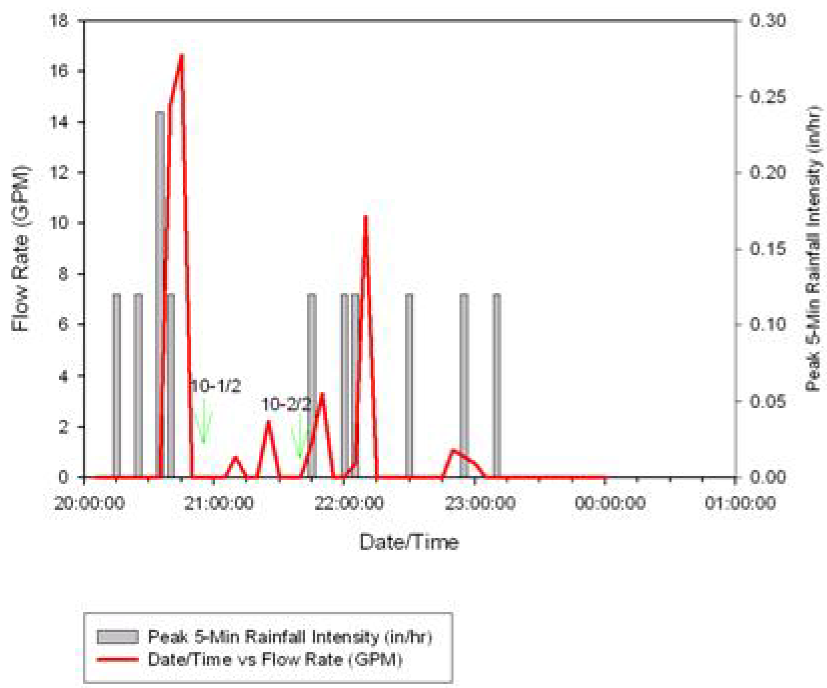


Figure A-10: Flow and hydrograph for October 06, 2005 event

Date	Total Rain Depth Tipping Bucket (Inches)	Total Rain Depth Cumulative Rain Gauge (Inches)	% Difference
26-Mar-05	0.74	0.75	1.33
1-Apr-05	0.11	0.12	8.33
26-Apr-05	1.04	1.1	5.45
30-Apr-05	0.64	0.7	8.57
5-Jul-05	0.20	0.25	20.00
6-Jul-05	0.51	0.6	15.00
29-Aug-05	3.20	3.45	7.25
16-Sep-05	0.12	0.12	0.00
25-Sep-05	1.47	1.5	2.00
6-Oct-05	0.11	0.11	0.00

Appendix B: Actual Storm Events Particle Size Range Performance, Scatter, Box, and Probability Plots for Particle Sizes

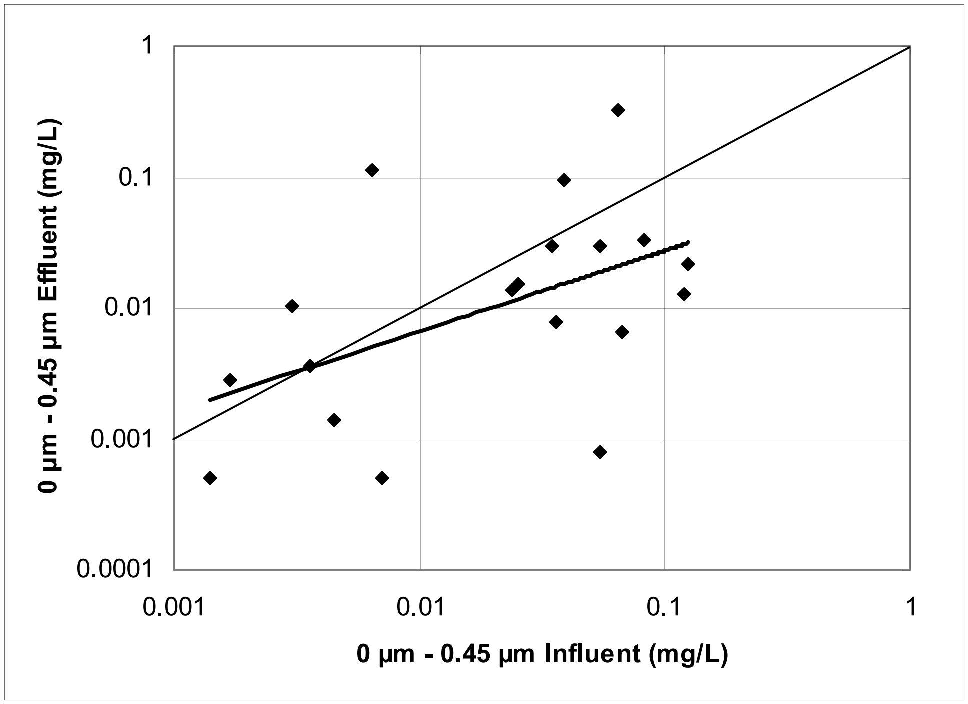
0 to 0.45 µm Particle Size

Comparison of 0 to 0.45 µm particles for storm events

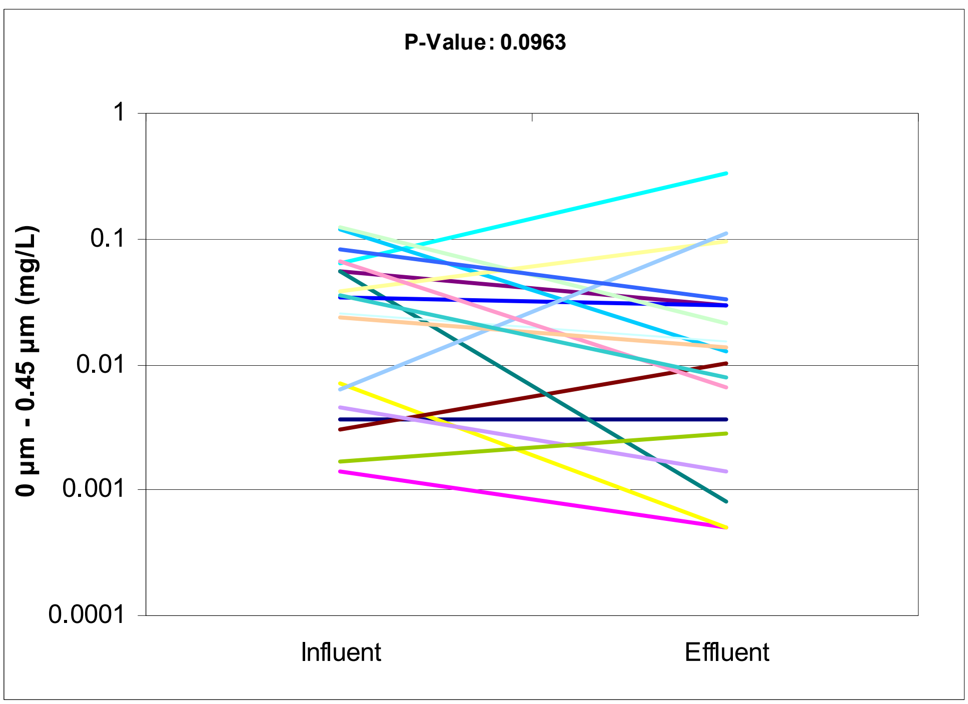
Observed 0 to 0.45 µm Particle Size Concentrations

Sample Number	Influent (mg/L)	Effluent (mg/L)	% reduc
1-1	0	0	n/a
2-1	0	15.67	n/a
2-2	0	0	na/
3-1	0.0072	0	100
3-2	0.0036	0.0036	0
4-1	0.0014	0	100
4-2	0.0071	0	100
5-1	0.064	0.33	-416
5-2	0.055	0.03	45
6-1	0.003	0.0102	-240
6-2	0.055	0.0008	99
6-3	0.0345	0.0299	13
6-4	0.1207	0.0129	89
6-5	0.0252	0.015	40
7-1	0.1245	0.0216	83
7-2	0.0387	0.096	-148
7-3	0.00638	0.1122	-1659
7-4	0.0667	0.0066	90
7-5	0.0045	0.0014	69
7-6	0.024	0.0136	43
8-1	0.0821	0.033	60
8-2	0.036	0.0079	78
9-1	0.0017	0.0028	-65
10-1	1.325	0.2057	84
min	0.000	0.000	-1659
max	1.325	15.670	100
average	0.087	0.692	-68
median	0.025	0.012	60
st dev	0.266	3.191	387
COV	3.1	4.6	-6

Probability that influent = effluent (nonparametric sign test): 0.0963 (90.4% confident that influent ≠ effluent), therefore not statistically significant at least at the α 0.05 level.



Scatterplot of observed influent and effluent 0 to 0.45 µm particle size concentrations.



Paired influent and effluent 0 to 0.45 µm particle size concentrations.

Fitted Equation:

Effluent Turbidity, (0 to 0.45 µm particle size log mg/L) = 1.10 * (0 to 0.45 µm particle size log mg/L)

Regression Statistics

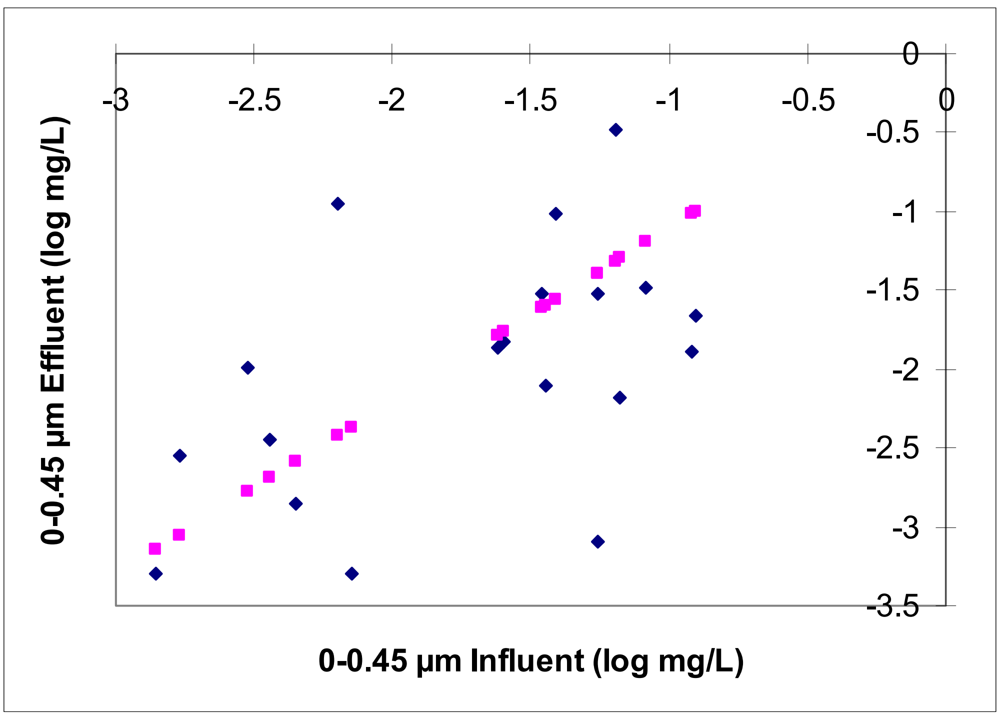
Multiple R	0.939
R Square	0.882
Adjusted R Square	0.826
Standard Error	0.758
Observations	19

ANOVA

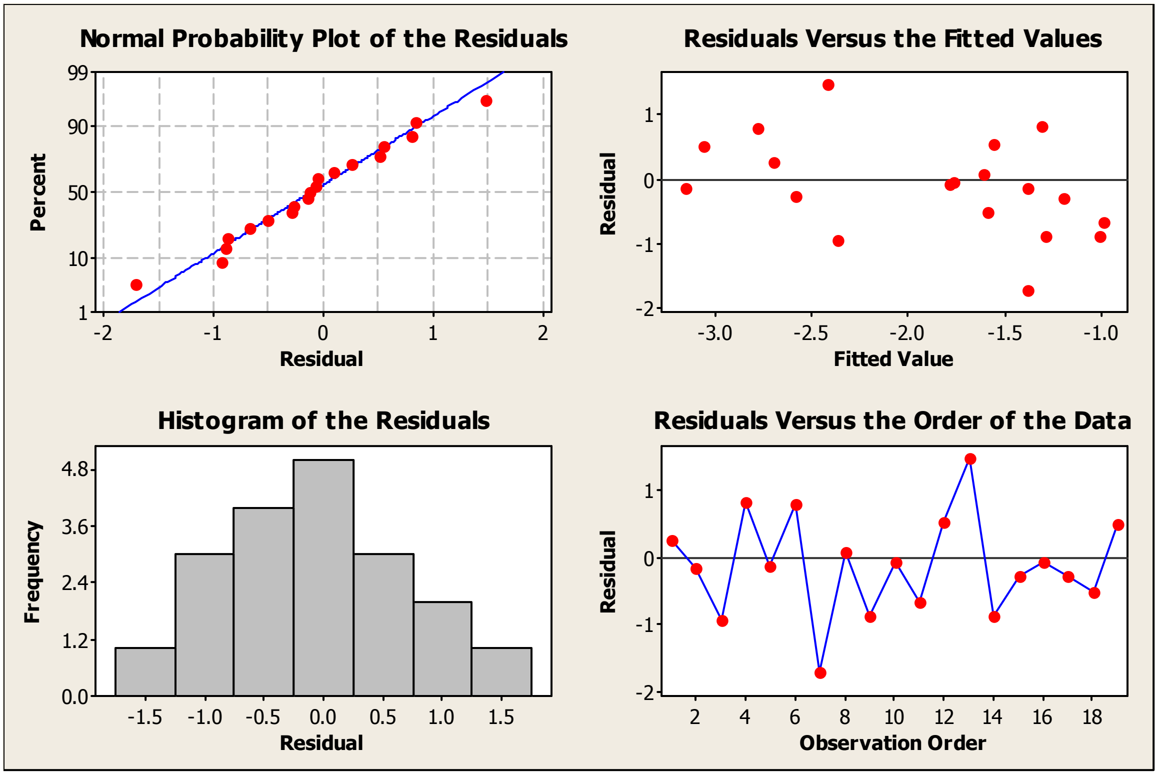
	df	SS	MS	F	Significance F
Regression	1	77.0	77.0	134	1.74E-09
Residual	18	10.38	0.575		
Total	19	87.3			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
0-0.45 µm Log Influent*	1.10	0.0953	11.6	9.00E-10	0.902	1.30

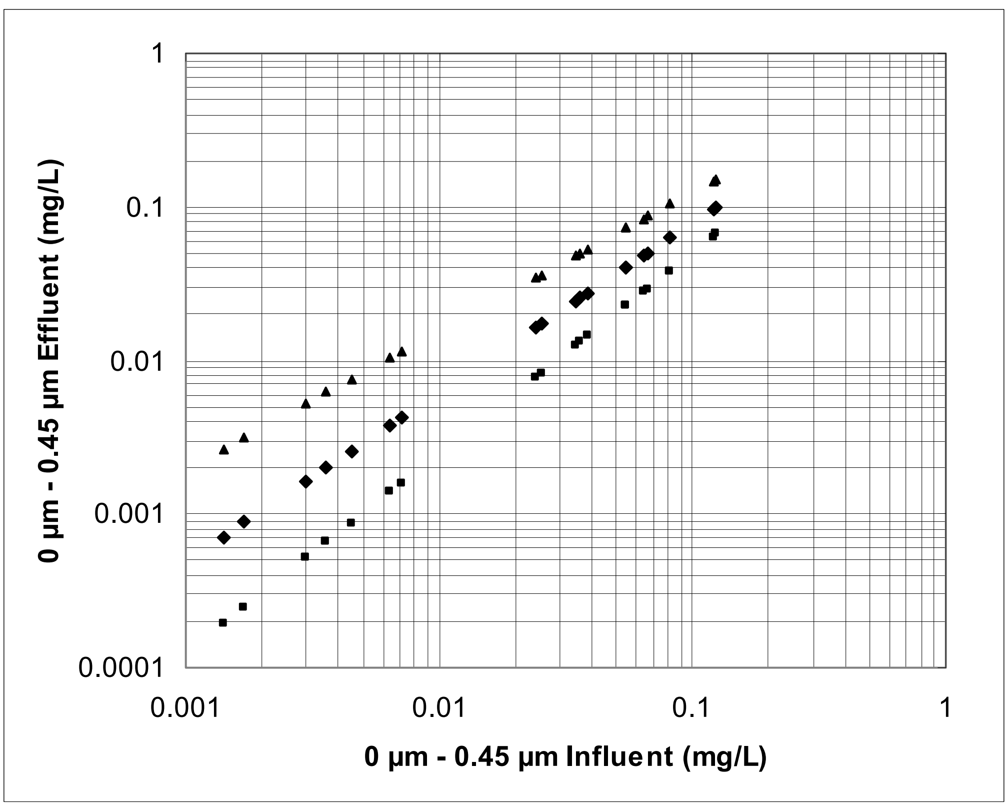
* the intercept term was determined to be not significant



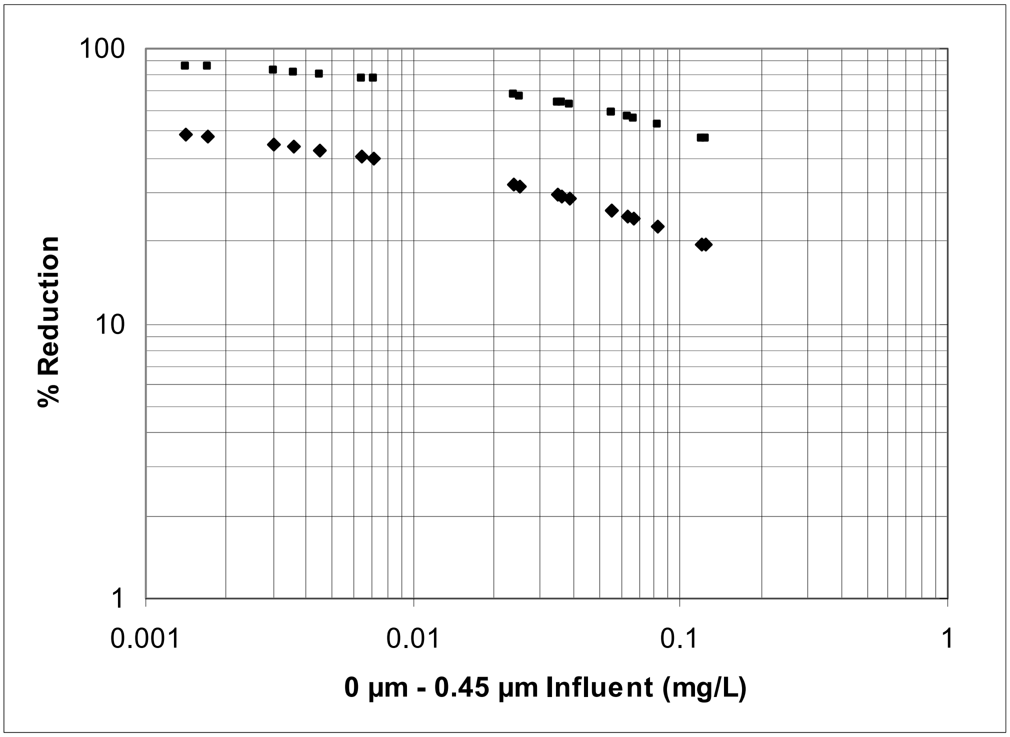
Fitted equation and data points for influent and effluent 0 to 0.45 µm particle size.



Residual analyses of fitted equation for 0 to 0.45 μm particle size influent vs. effluent.



Predicted effluent concentrations for different influent concentrations, with 95% confidence limits.



Percentage reductions as a function of influent concentrations, with 95% confidence limits.

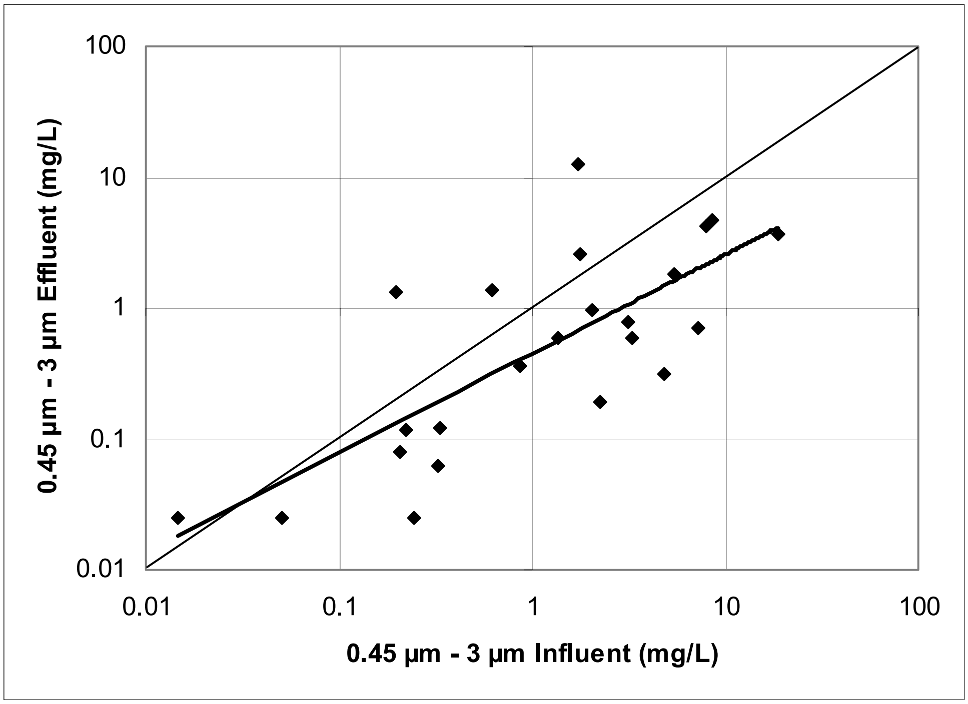
0.45 to 3 µm Particle Size

Comparison of 0.45 to 3 µm particles for storm events

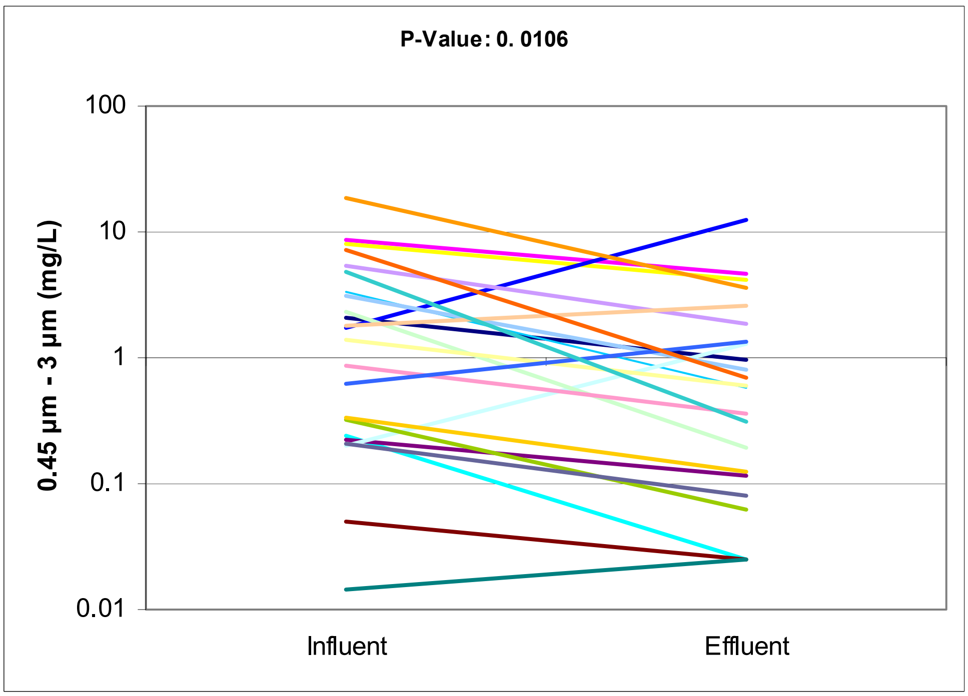
Observed 0.45 to 3 µm Particle Size Concentrations

Sample Number	Influent (mg/L)	Effluent (mg/L)	% reduc
1-1	2.0451	0.9596	53
2-1	8.6655	4.7268	45
2-2	7.95	4.2217	47
3-1	0.2448	0	100
3-2	0.22401	0.1153	49
4-1	0.0501	0	100
4-2	0.0145	0	100
5-1	1.712	12.3728	-623
5-2	3.2805	0.5814	82
6-1	0.197	1.3092	-565
6-2	2.2759	0.1904	92
6-3	1.365	0.5993	56
6-4	3.1331	0.792	75
6-5	0.8652	0.3618	58
7-1	5.4448	1.836	66
7-2	1.788	2.62	-47
7-3	0.62	1.36	-119
7-4	4.8783	0.3114	94
7-5	0.3255	0.0632	81
7-6	0.3368	0.1232	63
8-1	18.8169	3.612	81
8-2	7.2988	0.6994	90
9-1	0.209	0.08	62
10-1	34.42	3.8114	89
min	0.015	0.000	-623
max	34.420	12.373	100
average	4.423	1.698	5
median	1.750	0.649	65
st dev	7.672	2.707	191
COV	1.7	1.6	35

Probability that influent = effluent (nonparametric sign test): 0.0106 (98.9% confident that influent ≠ effluent), therefore statistically significant at least at the α 0.05 level.



Scatterplot of observed influent and effluent 0.45 to 3 µm particle size concentrations.



Paired influent and effluent 0.45 to 3 µm particle size concentrations.

Fitted Equation:

Effluent Turbidity, (0.45 to 3 µm particle size log mg/L) = -0.347 + 0.757 * (0.45 to 3 µm particle size log mg/L)

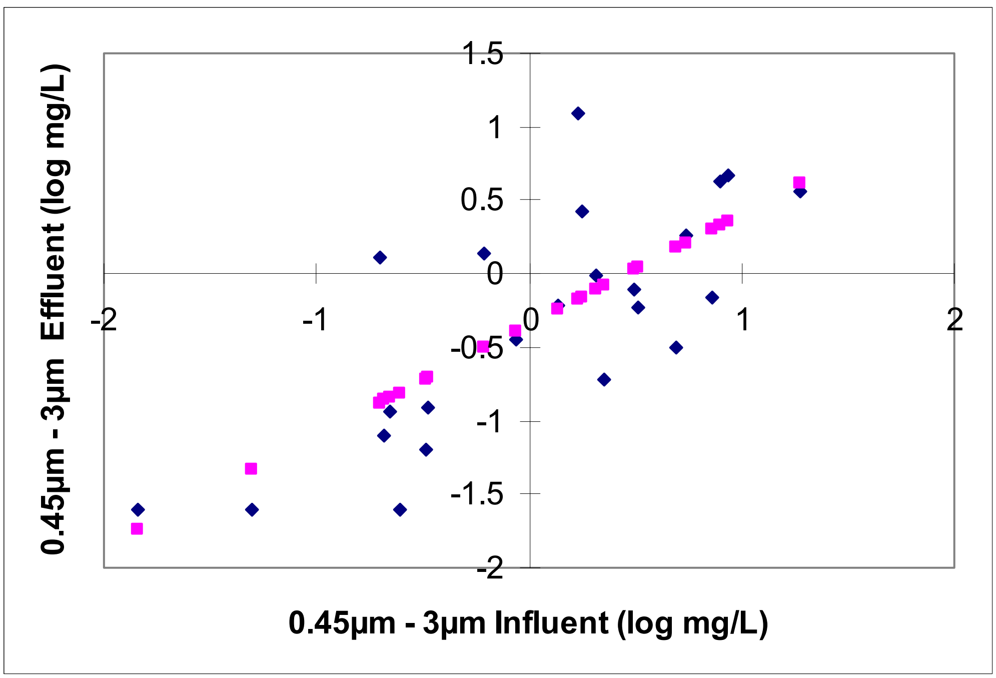
Regression Statistics

Multiple R	0.754
R Square	0.568
Adjusted R Square	0.547
Standard Error	0.524
Observations	23

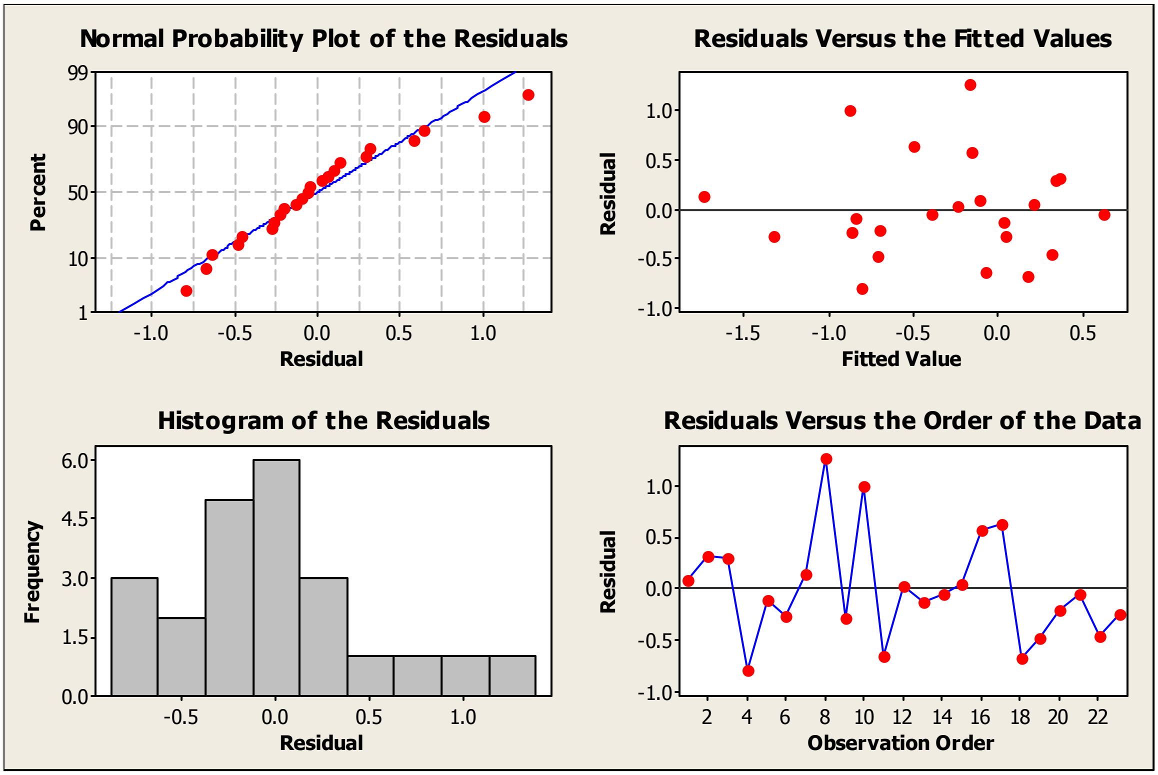
ANOVA

	df	SS	MS	F	Significance F
Regression	1	7.59	7.59	27.6	3.30E-05
Residual	21	5.77	0.274		
Total	22	13.4			

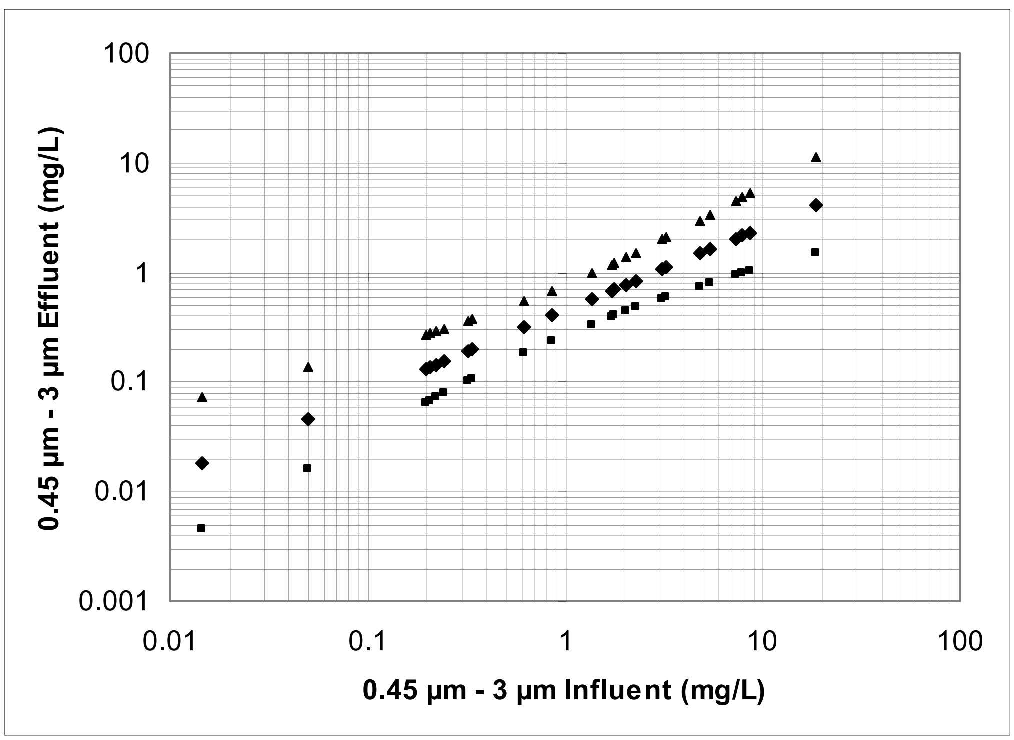
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	-0.347	0.109	-3.17	0.00458	-0.575	-0.120
0.45µm - 3µm Log Influent	0.757	0.144	5.25	3.30E-05	0.457	1.06



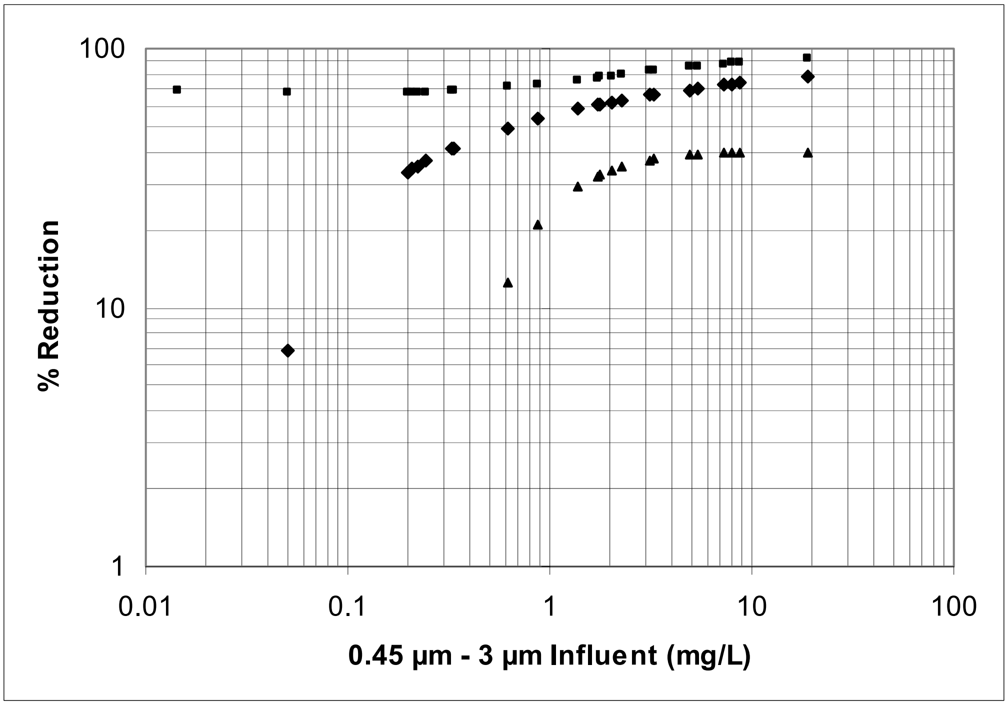
Fitted equation and data points for influent and effluent 0.45 to 3 µm particle size.



Residual analyses of fitted equation for 0.45 to 3 µm particle size influent vs. effluent.



Predicted effluent concentrations for different influent concentrations, with 95% confidence limits.



Percentage reductions as a function of influent concentrations, with 95% confidence limits.

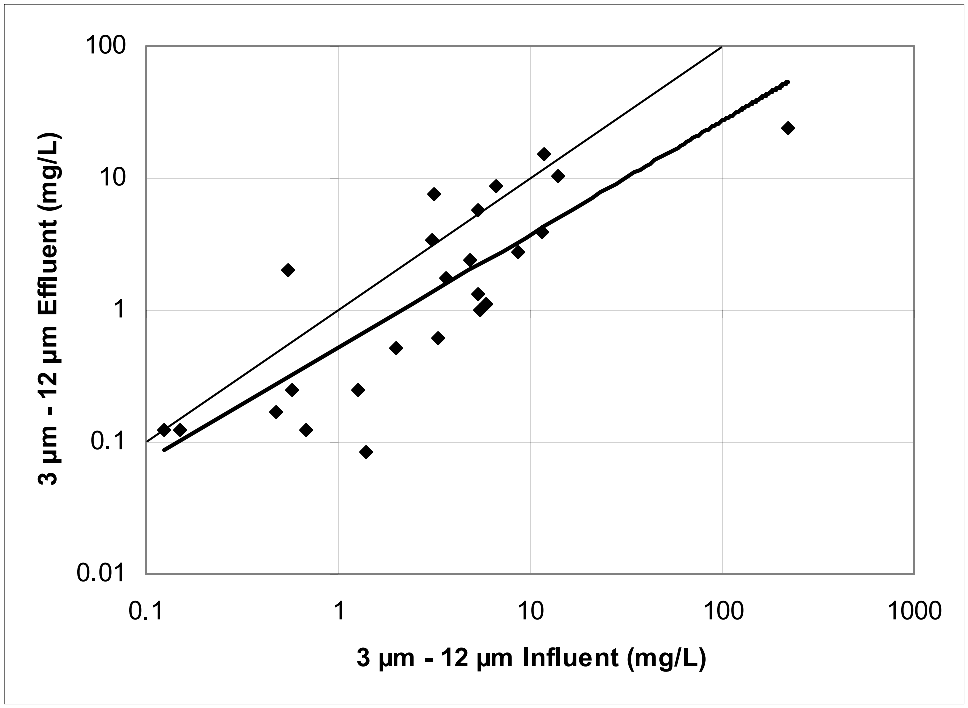
3 to 12 µm Particle Size

Comparison of 3 to 12 µm particles for storm events

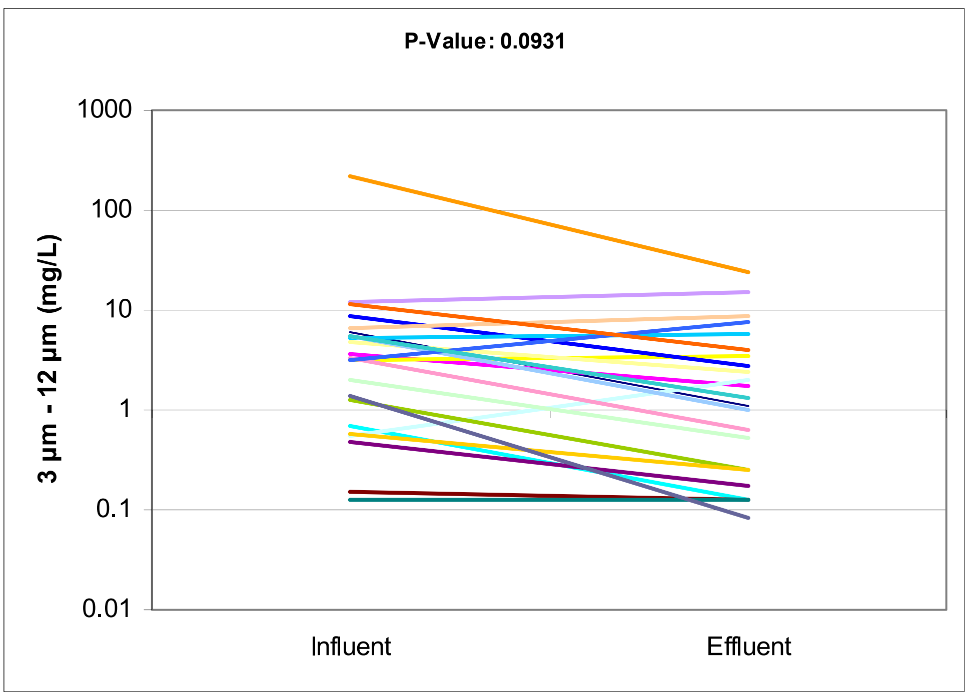
Observed 3 to 12 µm Particle Size Concentrations

Sample Number	Influent (mg/L)	Effluent (mg/L)	% reduc
1-1	5.96	1.12	81
2-1	3.62	1.74	52
2-2	3.105	3.45	-11
3-1	0.68	0	100
3-2	0.48	0.17	65
4-1	0.15	0	100
4-2	0.124	0	100
5-1	8.58	2.78	68
5-2	5.32	5.74	-8
6-1	0.551	2.03	-268
6-2	2.02	0.519	74
6-3	4.866	2.36	52
6-4	5.505	1	82
6-5	3.28	0.617	81
7-1	11.93	15.43	-29
7-2	6.65	8.67	-30
7-3	3.15	7.61	-142
7-4	5.41	1.33	75
7-5	1.27	0.25	80
7-6	0.58	0.25	57
8-1	221.44	23.71	89
8-2	11.67	3.93	66
9-1	1.39	0.085	94
10-1	13.92	10.25	26
min	0.124	0.000	-268
max	221.440	23.710	100
average	13.402	3.877	36
median	3.450	1.535	67
st dev	44.485	5.761	86
COV	3.3	1.5	2

Probability that influent = effluent (nonparametric sign test): 0.0931 (90.7% confident that influent ≠ effluent), therefore not statistically significant at least at the α 0.05 level.



Scatterplot of observed influent and effluent 3 to 12 µm particle size concentrations.



Paired influent and effluent 3 µm to 12 µm particle size concentrations.

Fitted Equation:

Effluent Turbidity, (3 to 12 µm particle size log mg/L) = -0.322 + 0.923 * (3 to 12 µm particle size log mg/L)

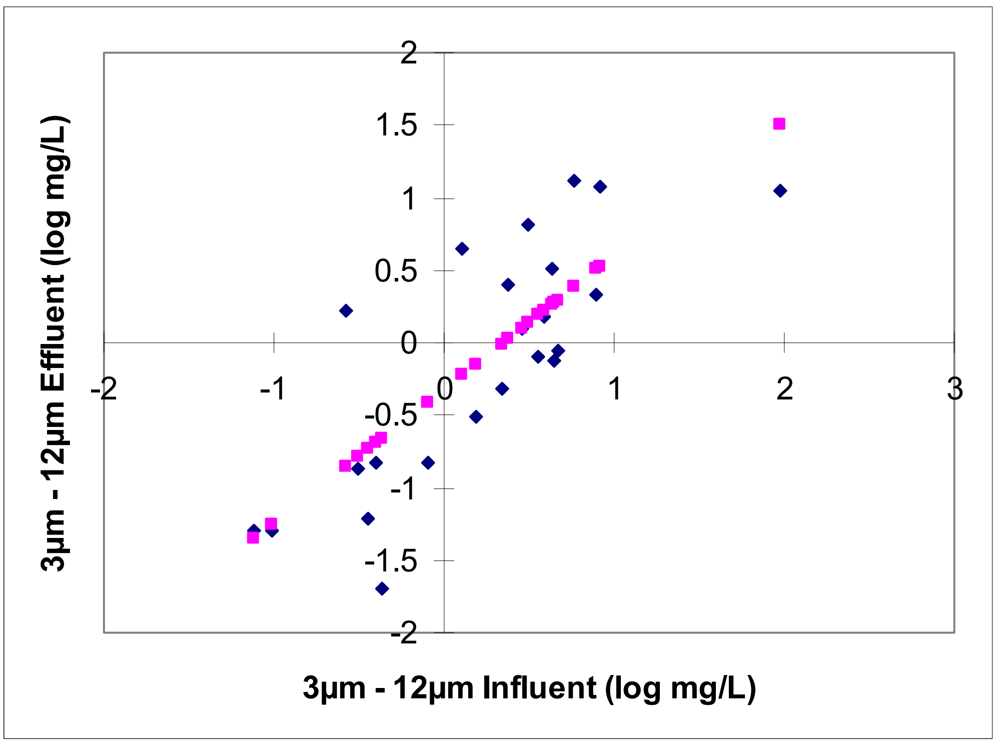
Regression Statistics

Multiple R	0.787
R Square	0.619
Adjusted R Square	0.601
Standard Error	0.525
Observations	23

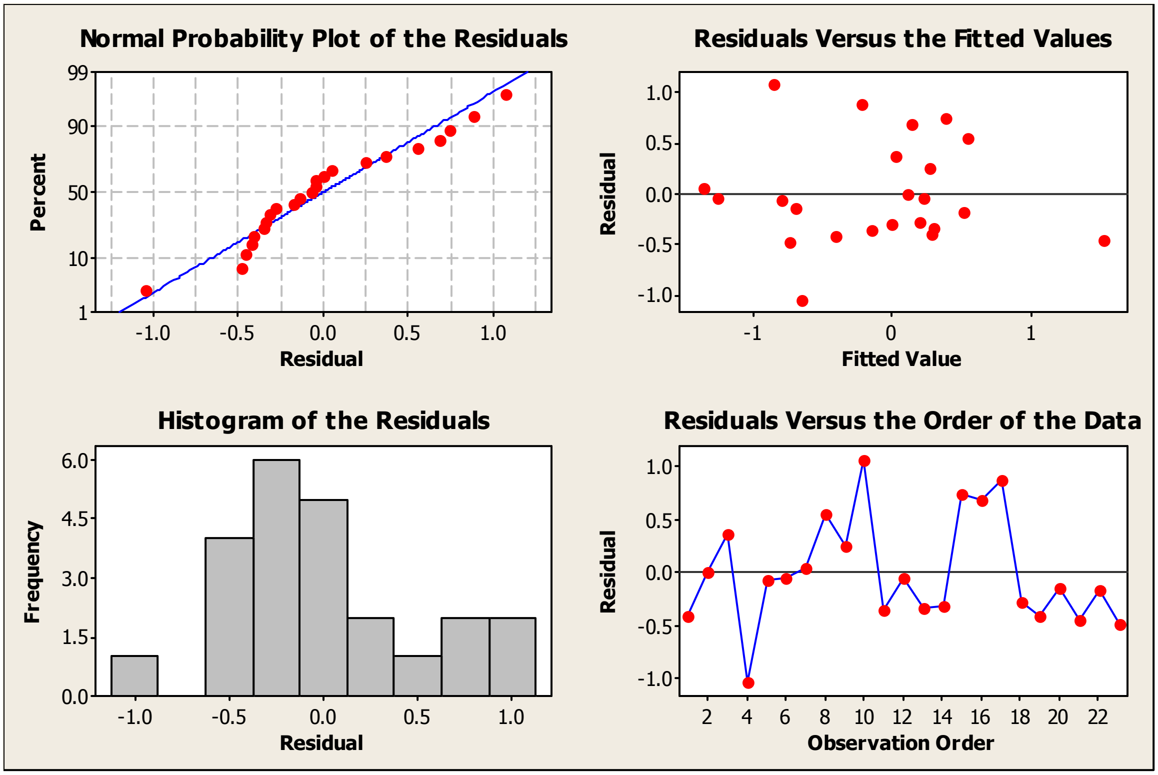
ANOVA

	df	SS	MS	F	Significance F
Regression	1	9.41	9.41	34.2	8.391E-06
Residual	21	5.78	0.275		
Total	22	15.2			

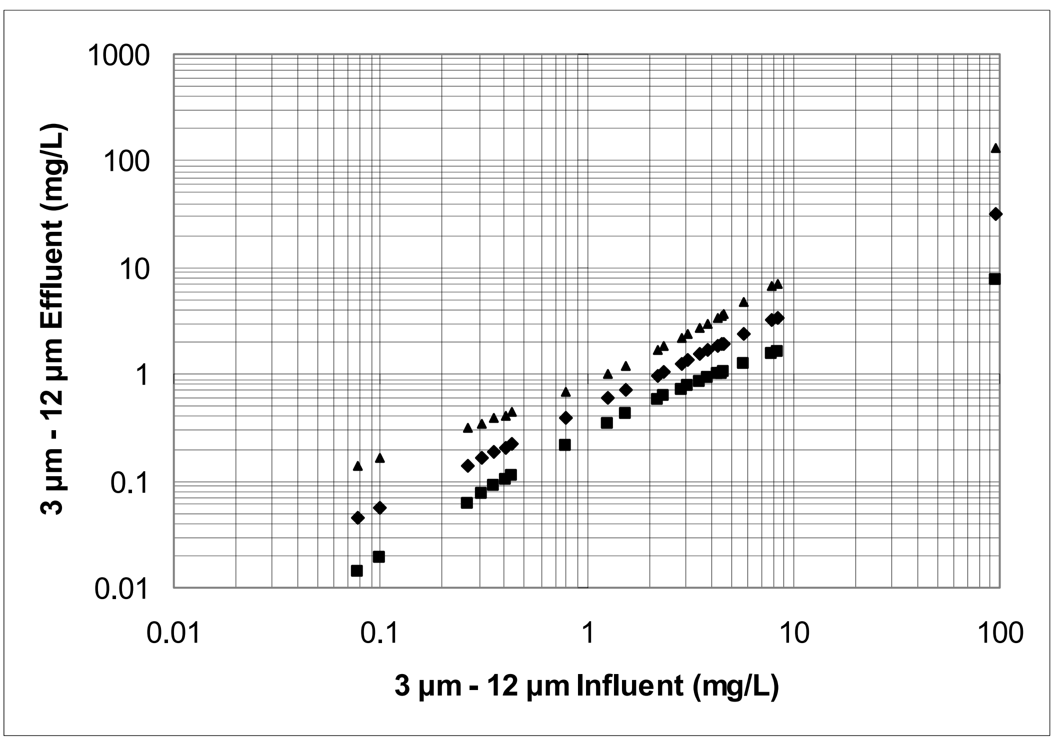
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	-0.322	0.115	-2.80	0.0108	-0.560	-0.0823
3µm - 12µm Log Influent	0.923	0.158	5.85	8.39E-06	0.595	1.25



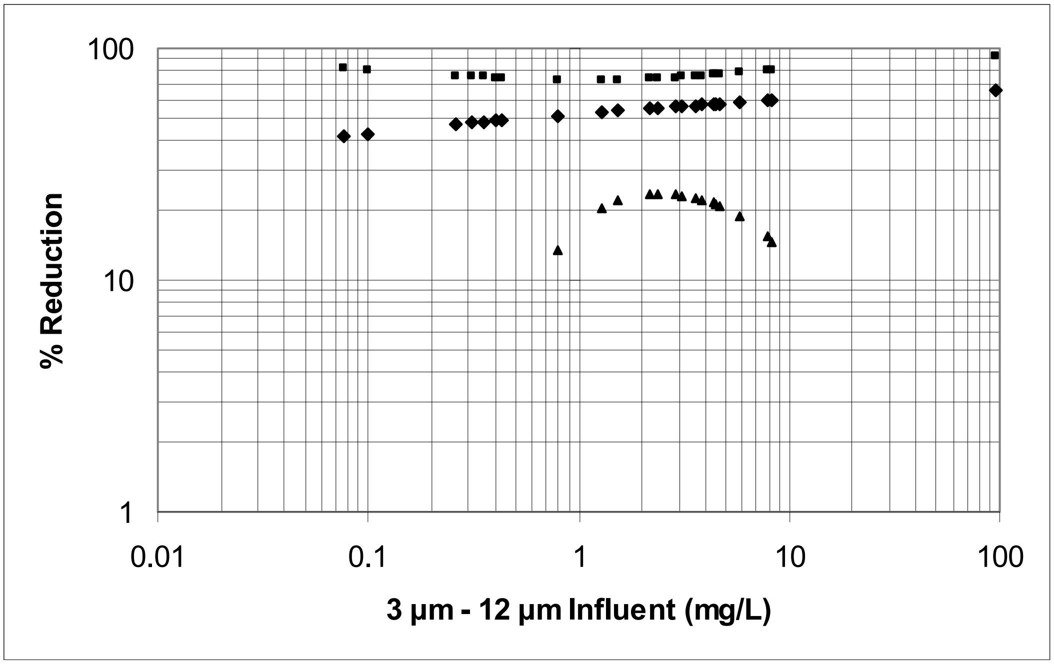
Fitted equation and data points for influent and effluent 3 to 12 µm particle size.



Residual analyses of fitted equation for 3 to 12 µm particle size influent vs. effluent.



Predicted effluent concentrations for different influent concentrations, with 95% confidence limits.



Percentage reductions as a function of influent concentrations, with 95% confidence limits.

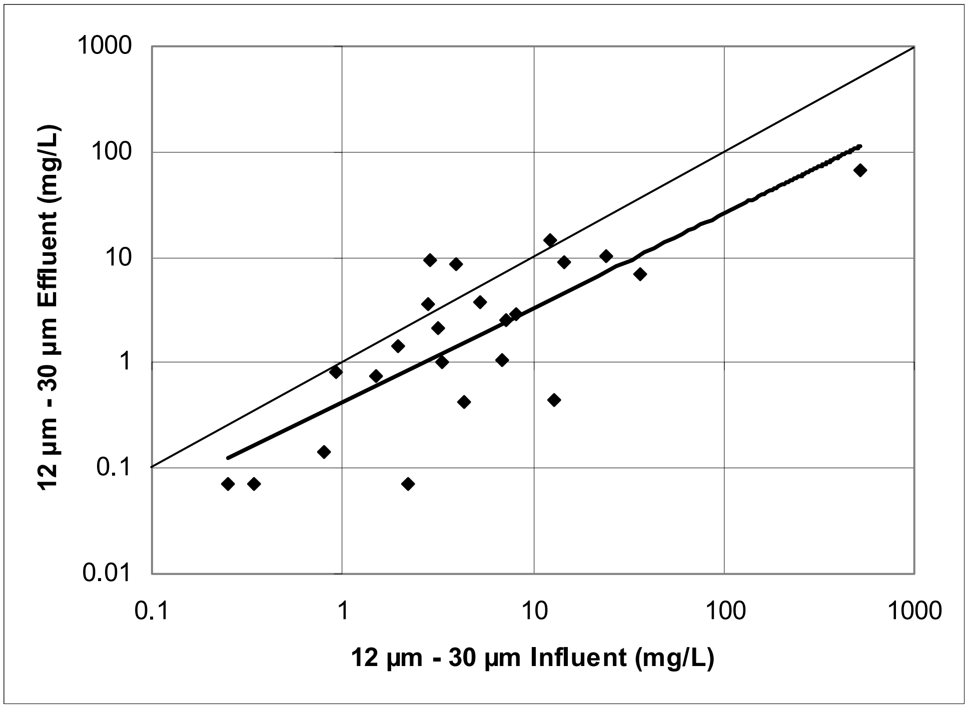
12 to 30 µm Particle Size

Comparison of 12 to 30 µm particles for storm events

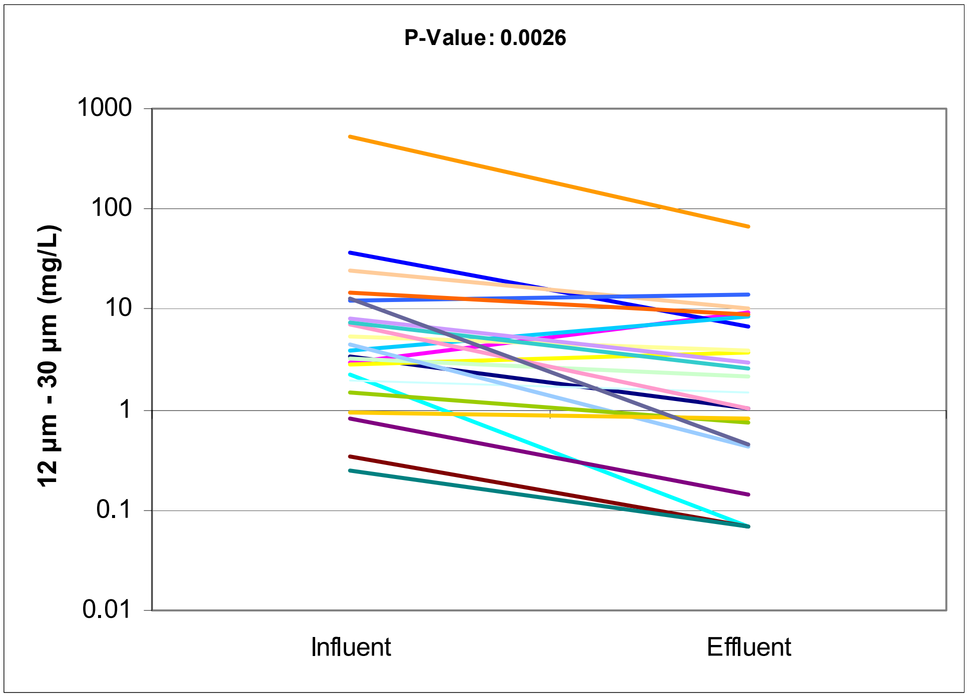
Observed 12 to 30 µm Particle Size Concentrations

Sample Number	Influent (mg/L)	Effluent (mg/L)	% reduc
1-1	3.36	1.04	69
2-1	2.91	9.23	-217
2-2	2.8	3.63	-30
3-1	2.23	0	100
3-2	0.8	0.14	83
4-1	0.344	0	100
4-2	0.252	0	100
5-1	36.86	6.83	81
5-2	3.97	8.45	-113
6-1	1.961	1.45	26
6-2	3.193	2.135	33
6-3	5.3025	3.804	28
6-4	4.39	0.423	90
6-5	6.95	1.045	85
7-1	8.17	2.92	64
7-2	24.37	10.11	59
7-3	12.26	14.33	-17
7-4	7.25	2.54	65
7-5	1.49	0.753	49
7-6	0.92	0.82	11
8-1	515.53	66.82	87
8-2	14.61	9.04	38
9-1	13.02	0.453	97
10-1	15.732	1.266	92
min	0.252	0.000	-217
max	515.530	66.820	100
average	28.695	6.135	41
median	4.180	1.793	65
st dev	104.054	13.528	75
COV	3.6	2.2	2

Probability that influent = effluent (nonparametric sign test): 0.0026 (99.7% confident that influent ≠ effluent), therefore statistically significant at least at the α 0.05 level.



Scatterplot of observed influent and effluent 12 to 30 µm particle size concentrations.



Paired influent and effluent 12 µm to 30 µm particle size concentrations.

Fitted Equation:

Effluent Turbidity, (12 to 30 µm particle size log mg/L) = -0.319 + 0.796 * (12 to 30 µm particle size log mg/L)

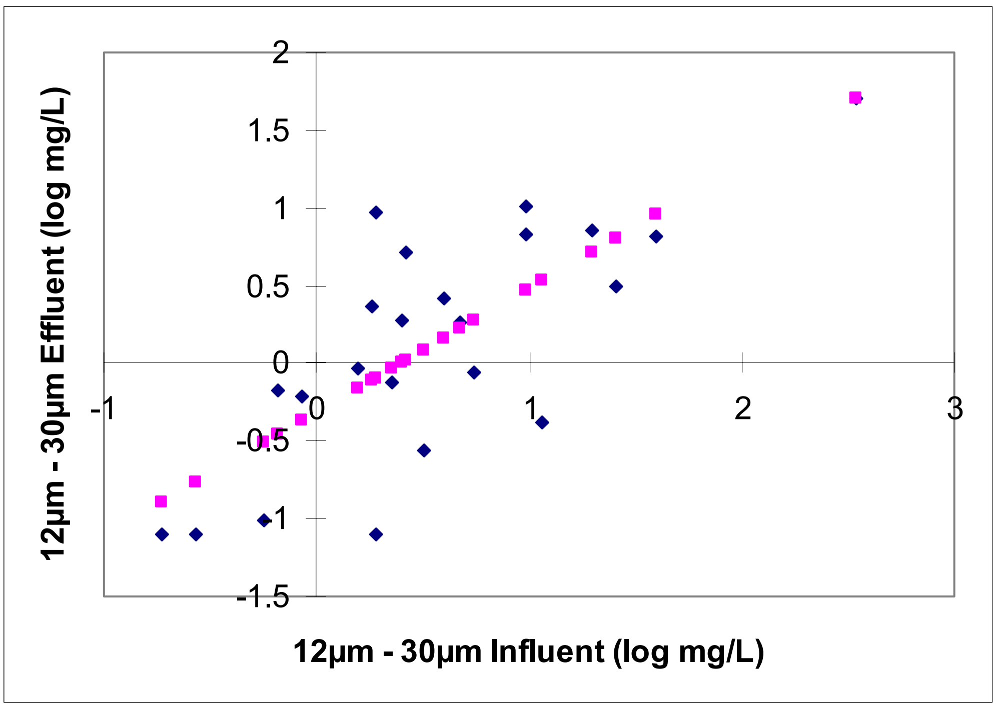
Regression Statistics

Multiple R	0.763
R Square	0.582
Adjusted R Square	0.562
Standard Error	0.508
Observations	23

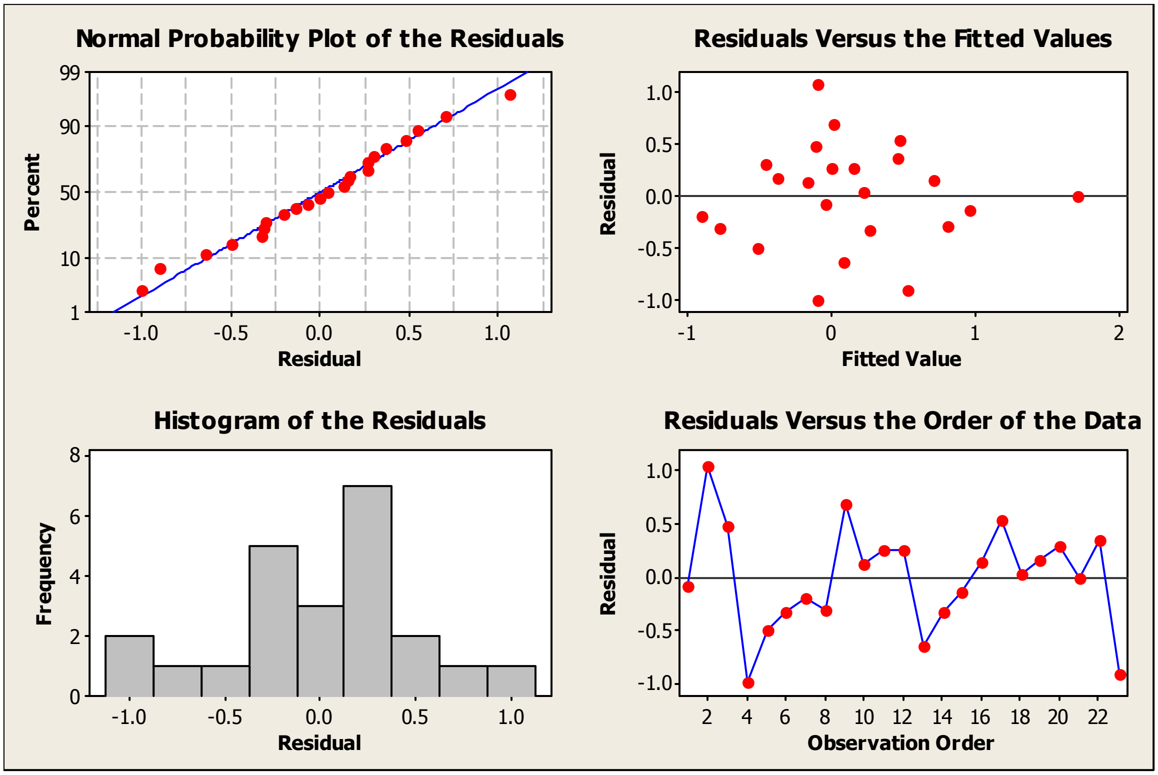
ANOVA

	df	SS	MS	F	Significance F
Regression	1	7.55	7.55	29.2	2.33E-05
Residual	21	5.43	0.258		
Total	22	13.0			

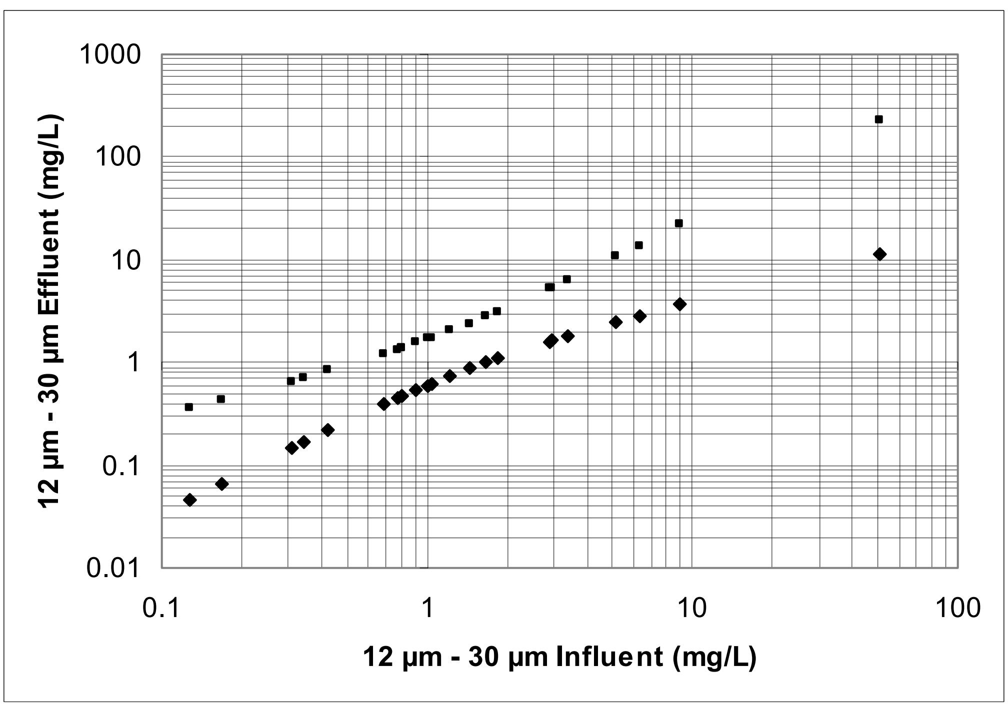
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	-0.319	0.134	-2.38	0.0270	-0.598	-0.0399
12µm - 30µm Log Influent	0.796	0.147	5.406	2.33E-05	0.490	1.10



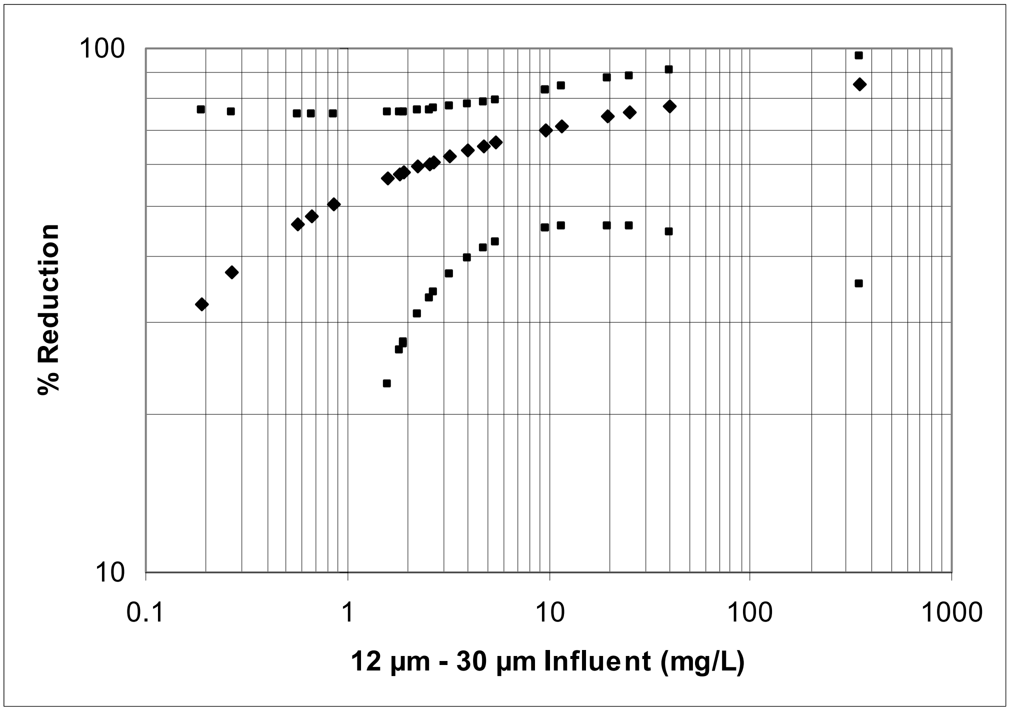
Fitted equation and data points for influent and effluent 12 to 30 µm particle size.



Residual analyses of fitted equation for 12 to 30 µm particle size influent vs. effluent.



Predicted effluent concentrations for different influent concentrations, with 95% confidence limits.



Percentage reductions as a function of influent concentrations, with 95% confidence limits.

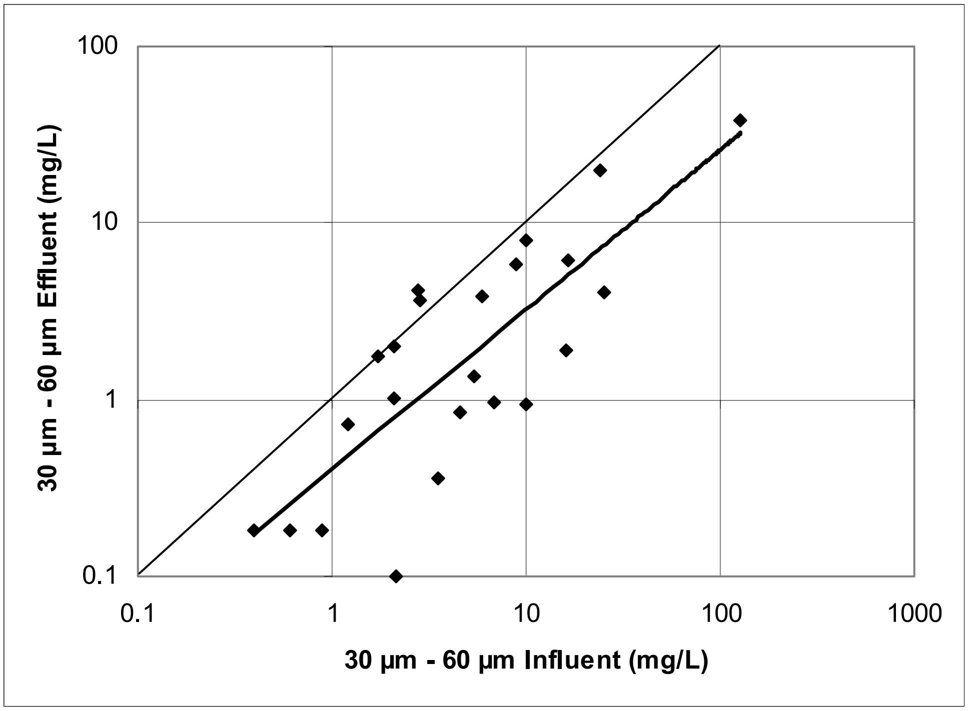
30 to 60 µm Particle Size

Comparison of 30 to 60 µm particles for storm events

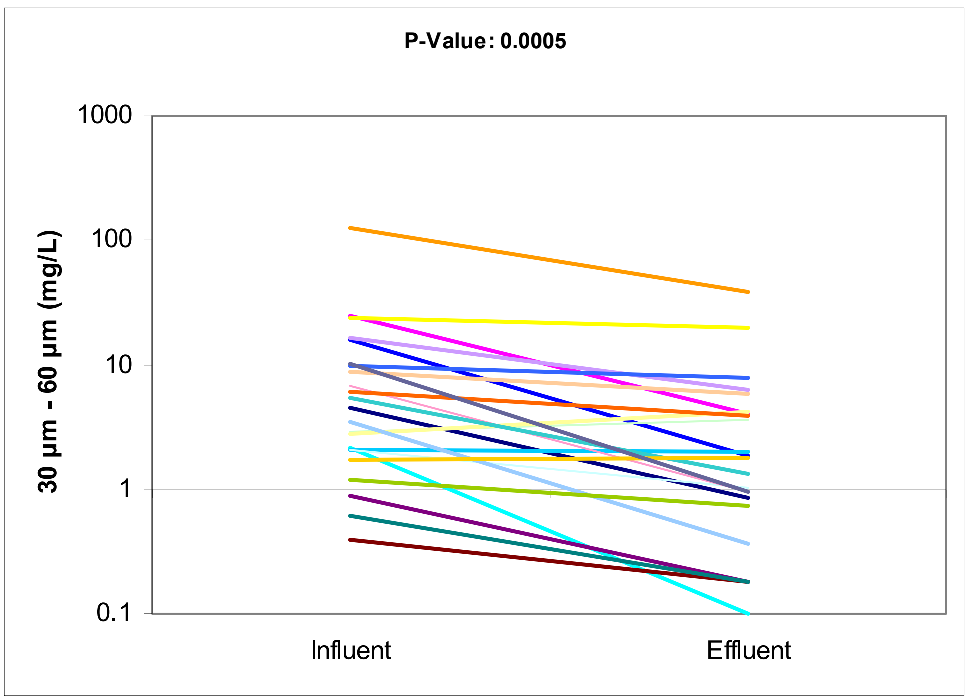
Observed 30 to 60 µm Particle Size Concentrations

Sample Number	Influent (mg/L)	Effluent (mg/L)	% reduc
1-1	4.5883	0.848	82
2-1	25.0902	4.086	84
2-2	24.1	19.758	18
3-1	2.1594	0	100
3-2	0.879	0.1841	79
4-1	0.394	0	100
4-2	0.6026	0	100
5-1	16.16	1.8796	88
5-2	2.1075	2.0196	4
6-1	2.0645	1.0194	51
6-2	2.8721	3.6696	-28
6-3	2.7885	4.1717	-50
6-4	3.4952	0.3618	90
6-5	6.8712	0.9606	86
7-1	16.3095	6.2028	62
7-2	8.7935	5.889	33
7-3	9.9934	7.9233	21
7-4	5.3866	1.3428	75
7-5	1.205	0.7338	39
7-6	1.7272	1.7772	-3
8-1	128.0939	38.13	70
8-2	6.0024	3.8394	36
9-1	10.092	0.9374	91
10-1	5.3928	1.4297	73
min	0.394	0.000	-50
max	128.094	38.130	100
average	11.965	4.465	54
median	4.987	1.603	72
st dev	25.706	8.296	42
COV	2.1	1.9	1

Probability that influent = effluent (nonparametric sign test): 0.0005 (99.95% confident that influent ≠ effluent), therefore statistically significant at least at the α 0.05 level.



Scatterplot of observed influent and effluent 30 to 60 µm particle size concentrations.



Paired influent and effluent 30 to 60 µm particle size concentrations.

Fitted Equation:

Effluent Turbidity, (30 to 60 µm particle size log mg/L) = -0.396 + 0.905 * (30 to 60 µm particle size log mg/L)

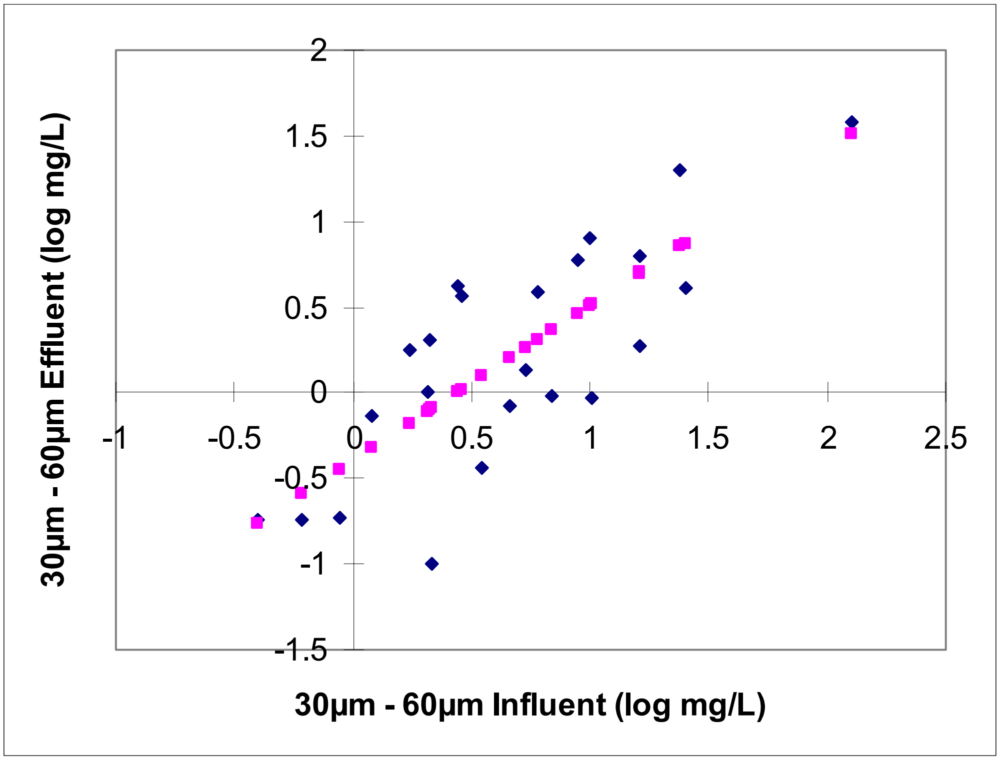
Regression Statistics

Multiple R	0.794
R Square	0.631
Adjusted R Square	0.613
Standard Error	0.414
Observations	23

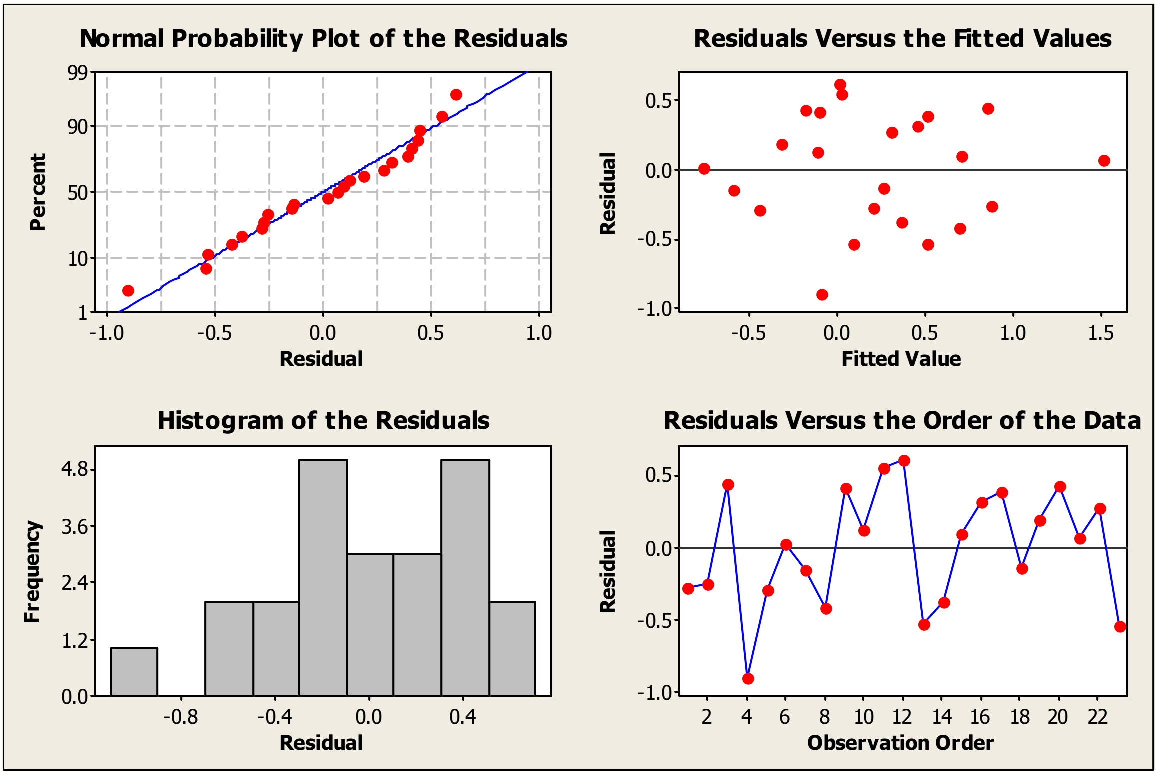
ANOVA

	df	SS	MS	F	Significance F
Regression	1	6.15	6.15	35.9	6.06E-06
Residual	21	3.60	0.172		
Total	22	9.75			

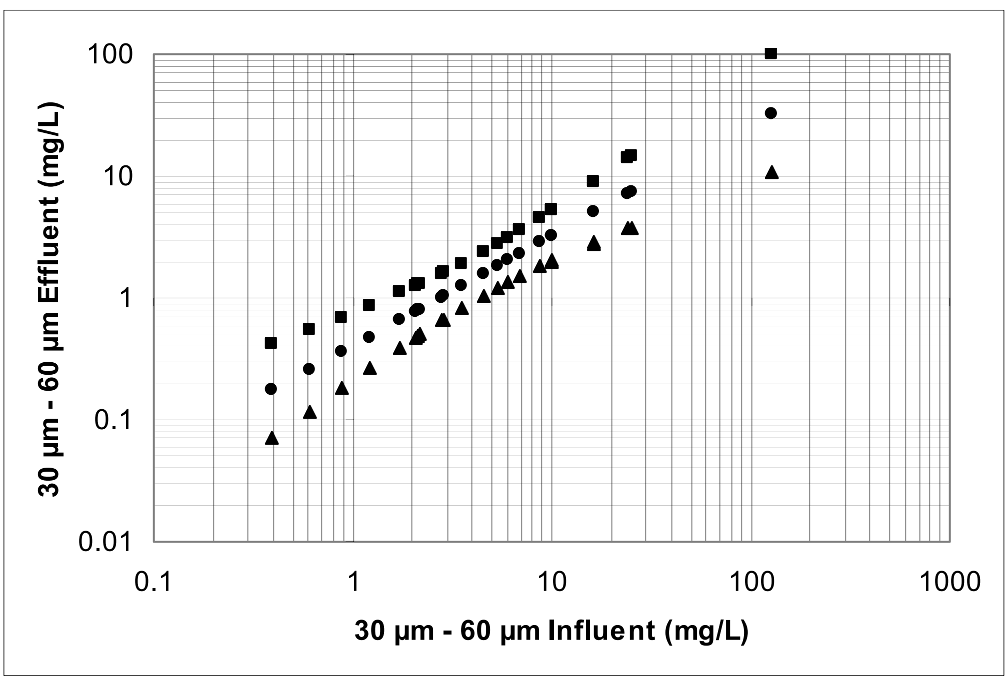
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	-0.396	0.134	-2.98	0.00707	-0.672	-0.120
30µm - 60µm Log Influent	0.905	0.151	5.99	6.06	0.591	1.22



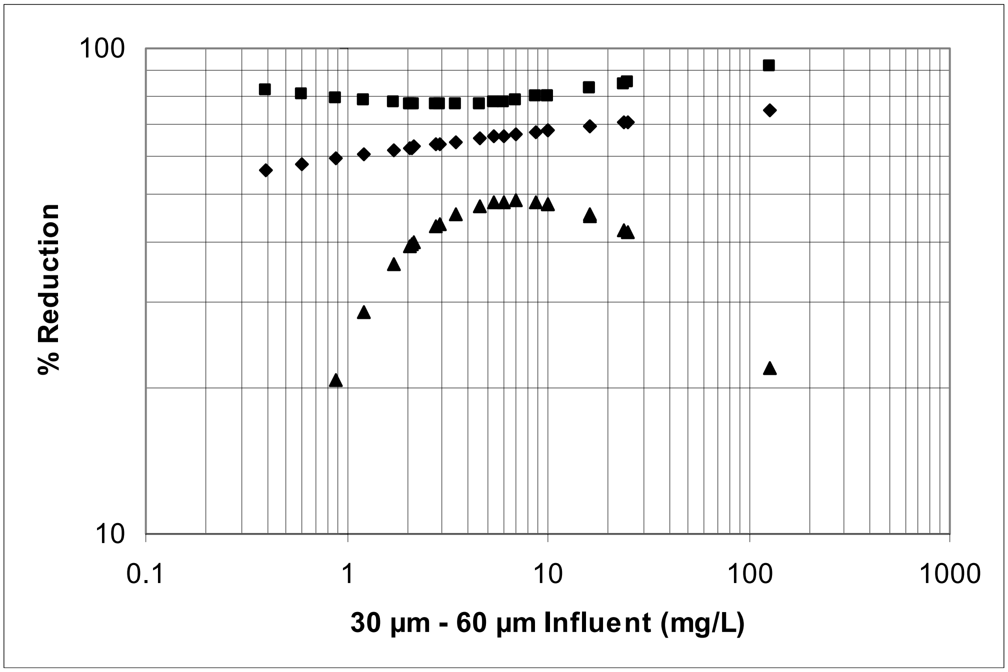
Fitted equation and data points for influent and effluent 30 to 60 µm particle size.



Residual analyses of fitted equation for 30 to 60 µm particle size influent vs. effluent.



Predicted effluent concentrations for different influent concentrations, with 95% confidence limits.



Percentage reductions as a function of influent concentrations, with 95% confidence limits.

60 to 120 µm Particle Size

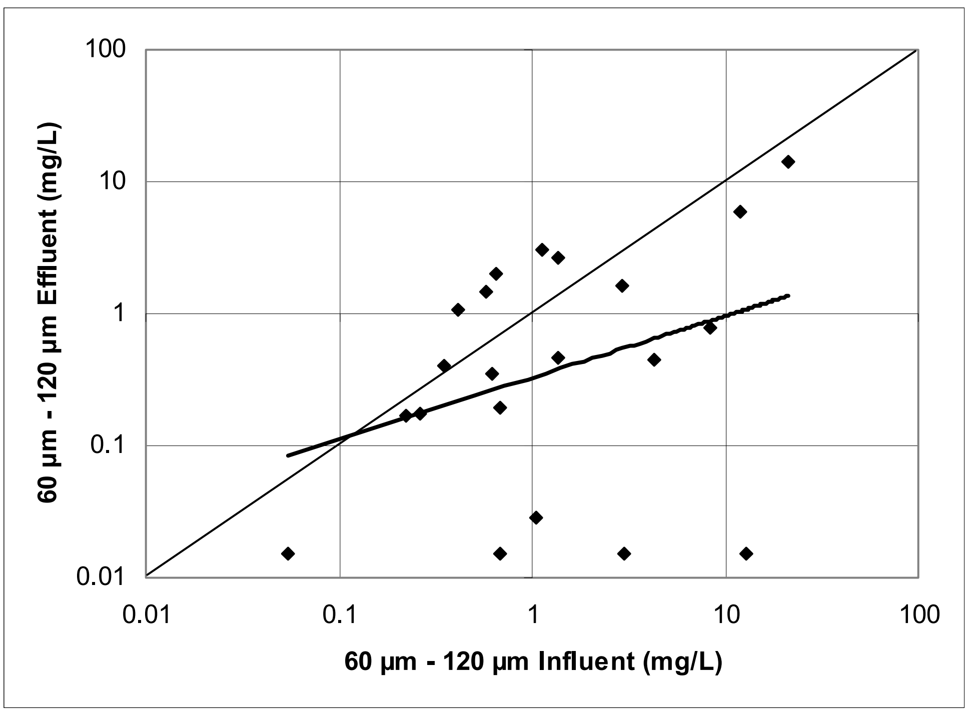
Table 6.26: Comparison of 60 to 120 µm particles for storm events

Observed 60 to 120 µm Particle Size Concentrations

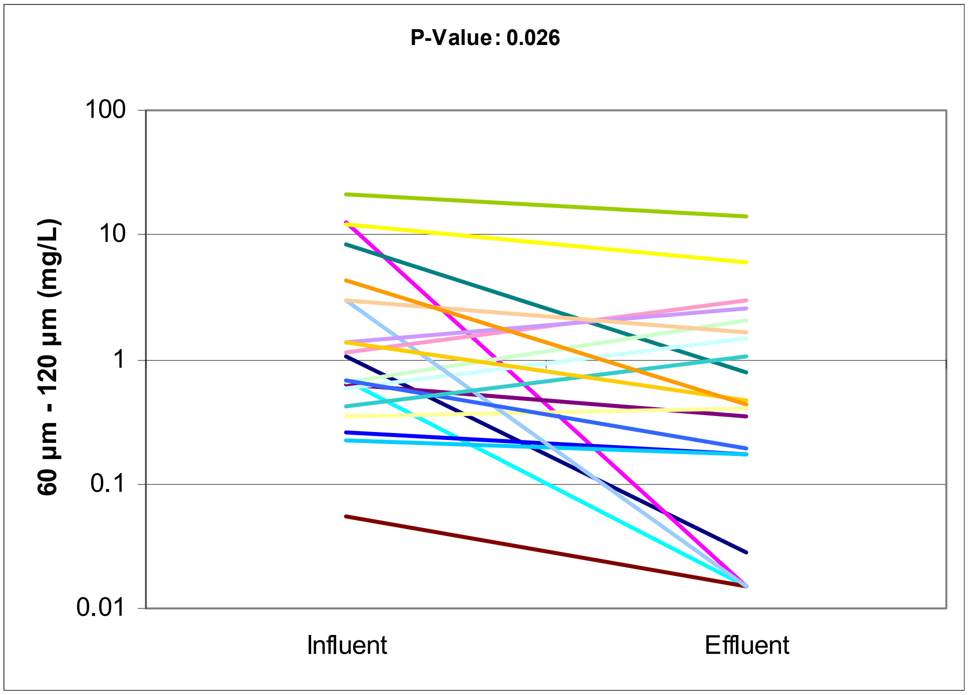
Sample Number	Influent (mg/L)	Effluent (mg/L)	% reduc
1-1	1.0523	0.028	97
2-1	12.7041	0	100
2-2	12.055	5.9422	51
3-1	0.6768	0	100
3-2	0.6195	0.3467	44
4-1	0.0543	0	100
4-2	0	0	n/a
5-1	8.288	0.7955	90
5-2	0.261	0.1734	34
6-1	0.2235	0.1698	24
6-2	0.5753	1.4848	-158
6-3	0.6435	2.0319	-216
6-4	0.3519	0.4038	-15
6-5	2.9988	0	100
7-1	1.1205	3.0312	-171
7-2	1.3631	2.613	-92
7-3	2.9609	1.65	44
7-4	0	0.4596	n/a
7-5	0.69	0.1936	72

7-6	0.4116	1.0548	-156
8-1	21.2729	14.115	34
8-2	1.3735	0.4716	66
9-1	4.2775	0.441	90
10-1	1.2024	0.0272	98
min	0.000	0.000	-216
max	21.273	14.115	100
average	3.132	1.476	15
median	0.871	0.422	47
st dev	5.269	3.022	103
COV	1.7	2.0	7

Probability that influent = effluent (nonparametric sign test): 0.026 (97.4% confident that influent ≠ effluent), therefore statistically significant at least at the α 0.05 level.



Scatterplot of observed influent and effluent 60 to 120 µm particle size concentrations.



Paired influent and effluent 60 to 120 µm particle size concentrations.

Fitted Equation:

Effluent Turbidity, (60 to 120 µm particle size log mg/L) = -0.483 + 0.466 * (60 to 120 µm particle size log mg/L)

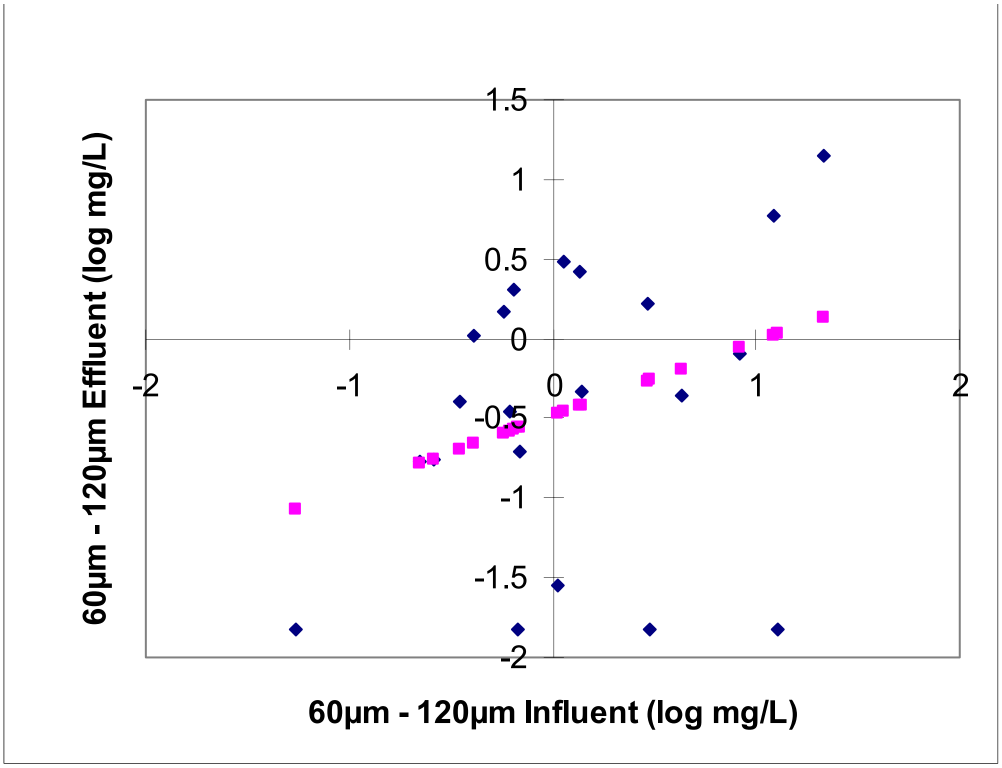
Regression Statistics

Multiple R	0.336
R Square	0.113
Adjusted R Square	0.0665
Standard Error	0.877
Observations	21

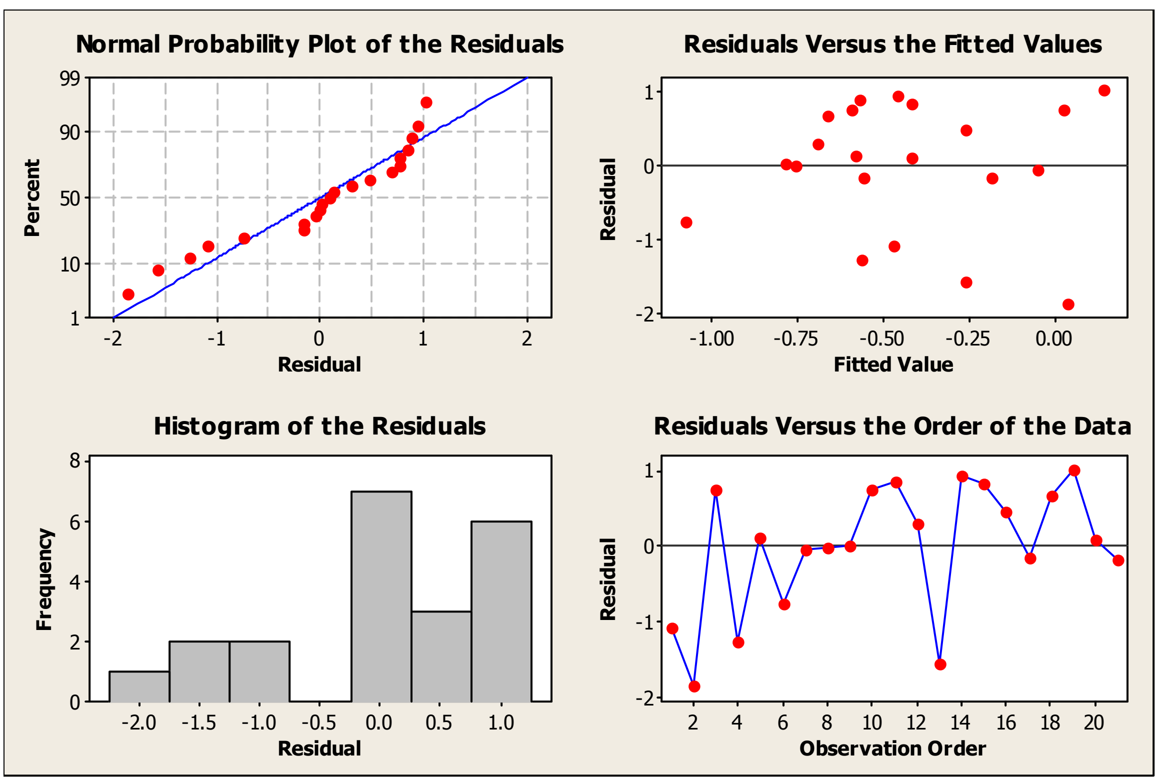
ANOVA

	df	SS	MS	F	Significance F
Regression	1	1.87	1.87	2.42	0.136
Residual	19	14.6	0.770		
Total	20	16.5			

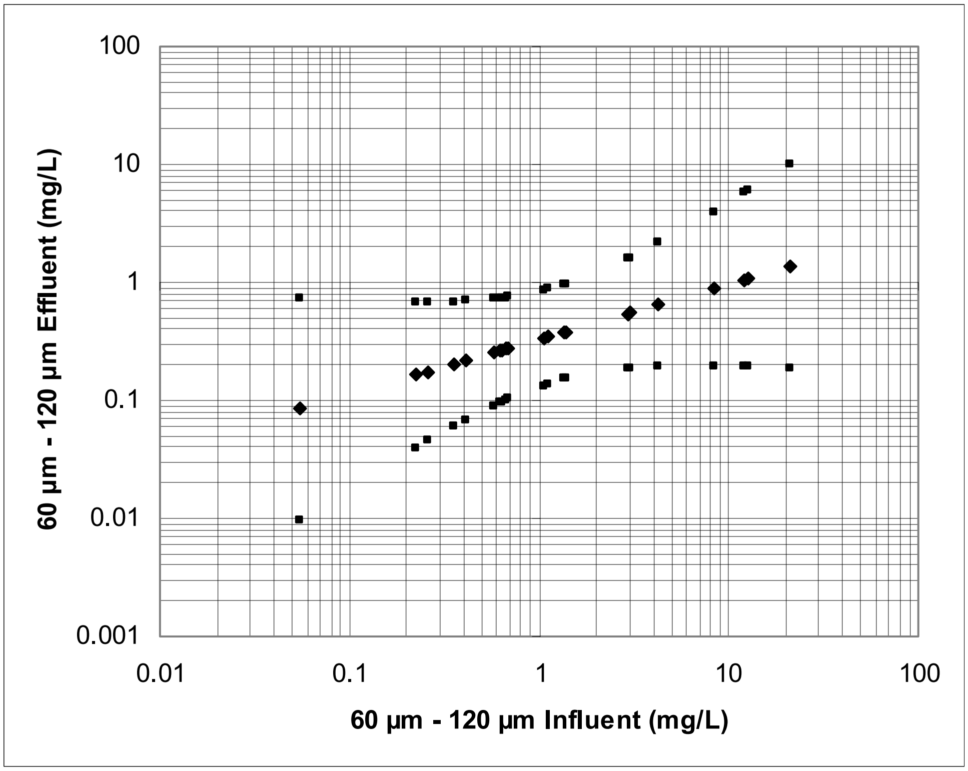
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	-0.483	0.194	-2.49	0.022	-0.888	-0.0775
60µm - 120µm Log Influent	0.466	0.299	1.562	0.136	-0.160	1.09



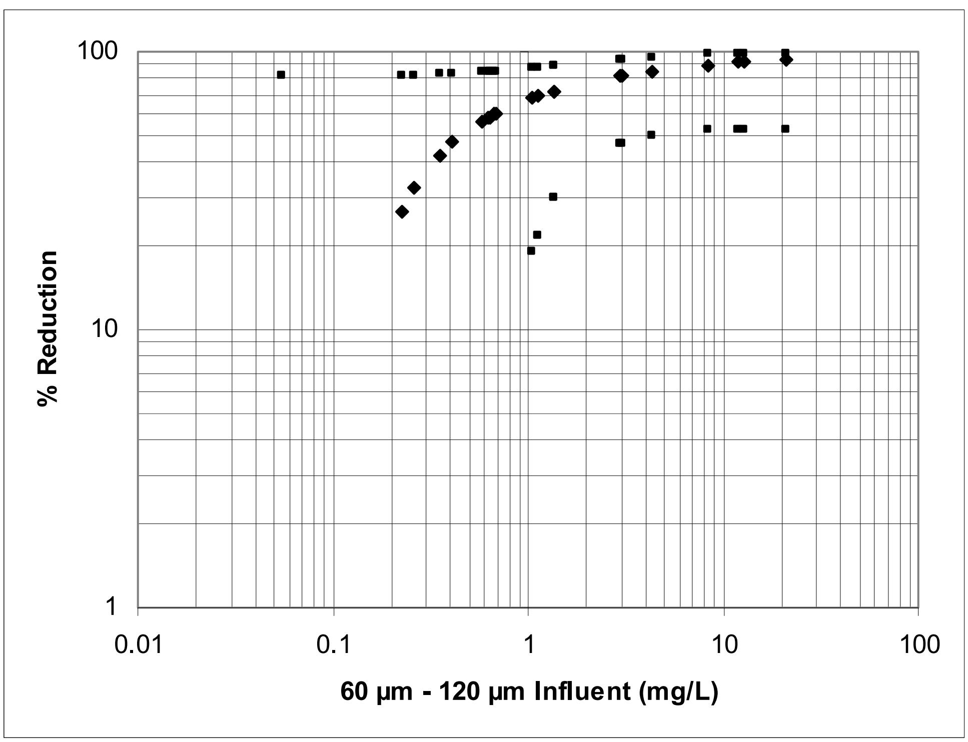
Fitted equation and data points for influent and effluent 60 to 120 µm particle size.



Residual analyses of fitted equation for 60 to 120 µm particle size influent vs. effluent.



Predicted effluent concentrations for different influent concentrations, with 95% confidence limits.



Percentage reductions as a function of influent concentrations, with 95% confidence limits.

Appendix C: Actual Storm Events Pollutant Removal Performance, Box, Scatter, and Probability Plots

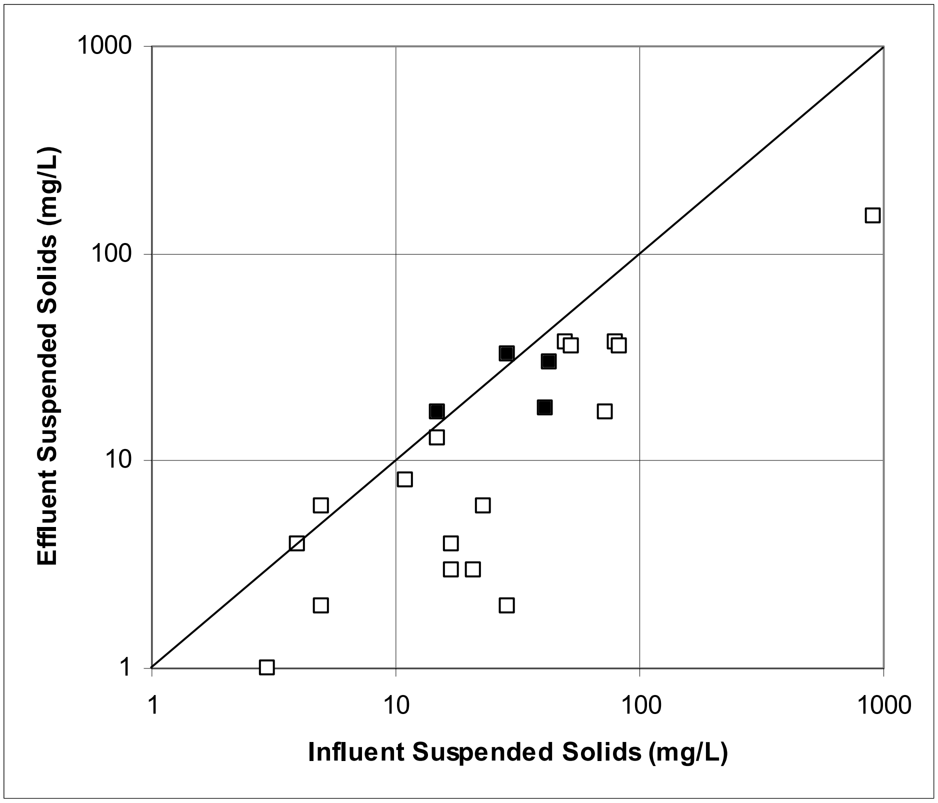
Suspended Solids

Suspended Solids Summary for storm events

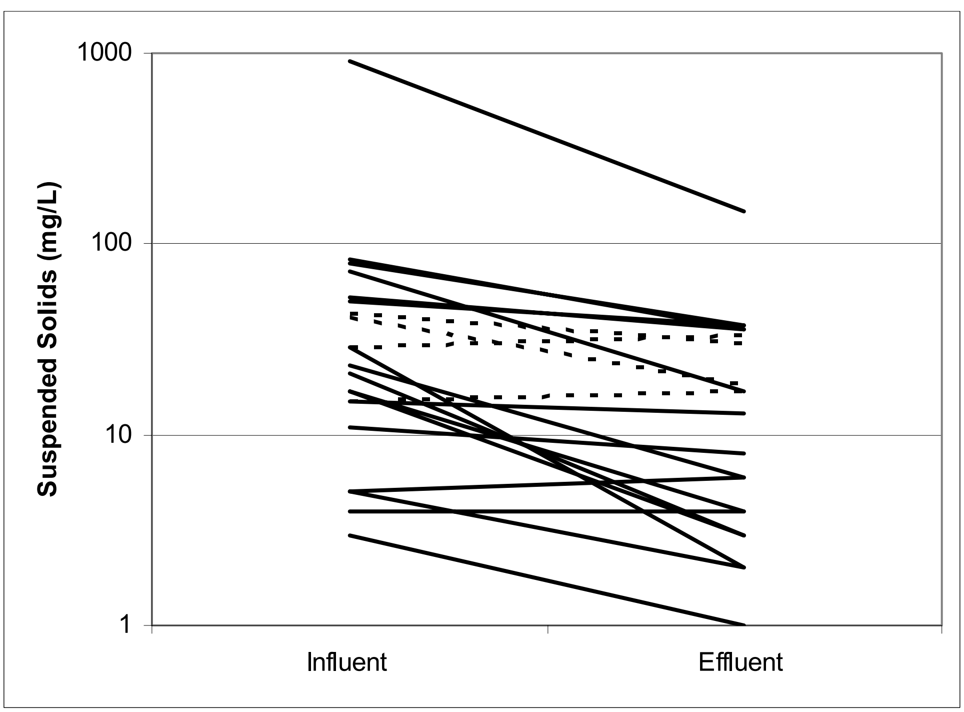
Observed Suspended Solids Concentrations

Sample Number	Influent (mg/L)	Effluent (mg/L)	% reduc
1-1	17	4	76
2-1	53	36	32
2-2	50	37	26
3-1	6	0	100
3-2	3	1	67
4-1	1	0	100
4-2	1	0	100
5-1	80	37	54
5-2	15	17	-13
6-1	5	6	-20
6-2	11	8	27
6-3	15	13	13
6-4	17	3	82
6-5	21	3	86
7-1	83	36	57
7-2	43	30	30
7-3	29	33	-14
7-4	23	6	74
7-5	5	2	60
7-6	4	4	0
8-1	913	150	84
8-2	41	18	56
9-1	29	2	93
10-1	72	17	76
min	1.000	0.000	-20
max	913.000	150.000	100
average	64.042	19.292	52
median	19.000	7.000	58
st dev	182.538	31.035	38
COV	2.9	1.6	1

Probability that influent = effluent (nonparametric sign test): 0.00 (>99% confident that influent ≠ effluent), therefore statistically significant at least at the α 0.05 level.



Scatterplot of observed influent and effluent suspended solids concentrations (filled symbols are events that had minor filter bypasses).



Paired influent and effluent suspended solids concentrations.

Fitted Equation:

Effluent Suspended Solids, log mg/L = 0.730 * (Influent Suspended Solids, log mg/L)

Regression Statistics on Observed Influent vs. Effluent Suspended Solids, log mg/L

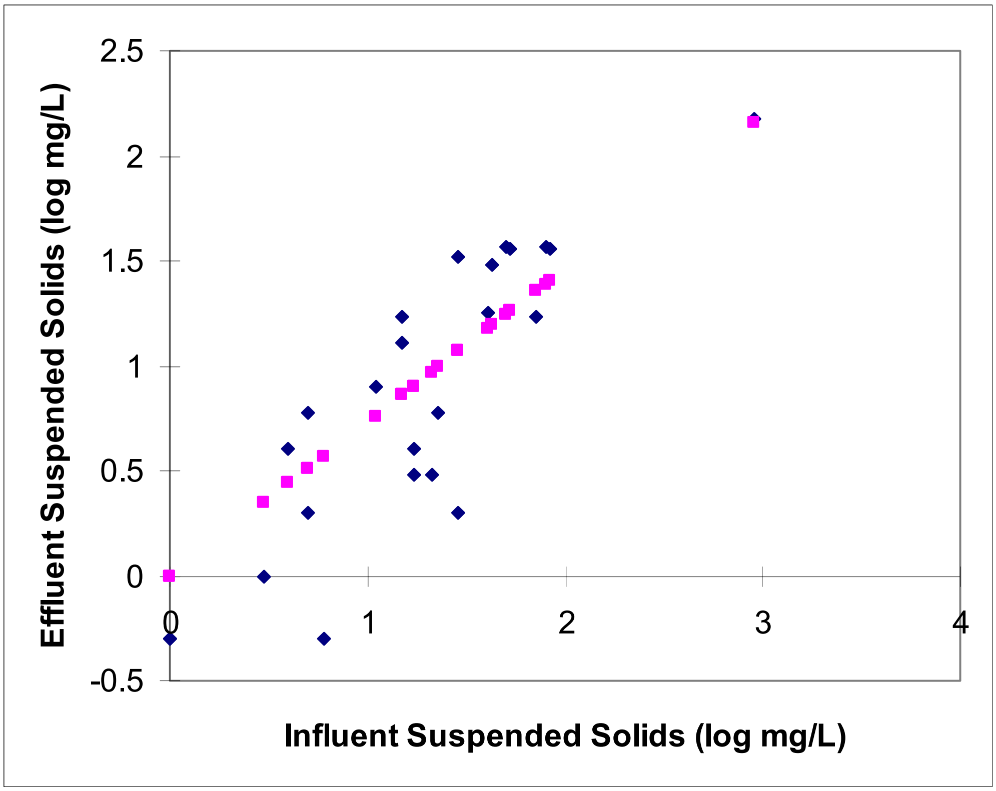
Multiple R	0.94
R Square	0.89
Adjusted R Square	0.85
Standard Error	0.37
Observations	24

ANOVA

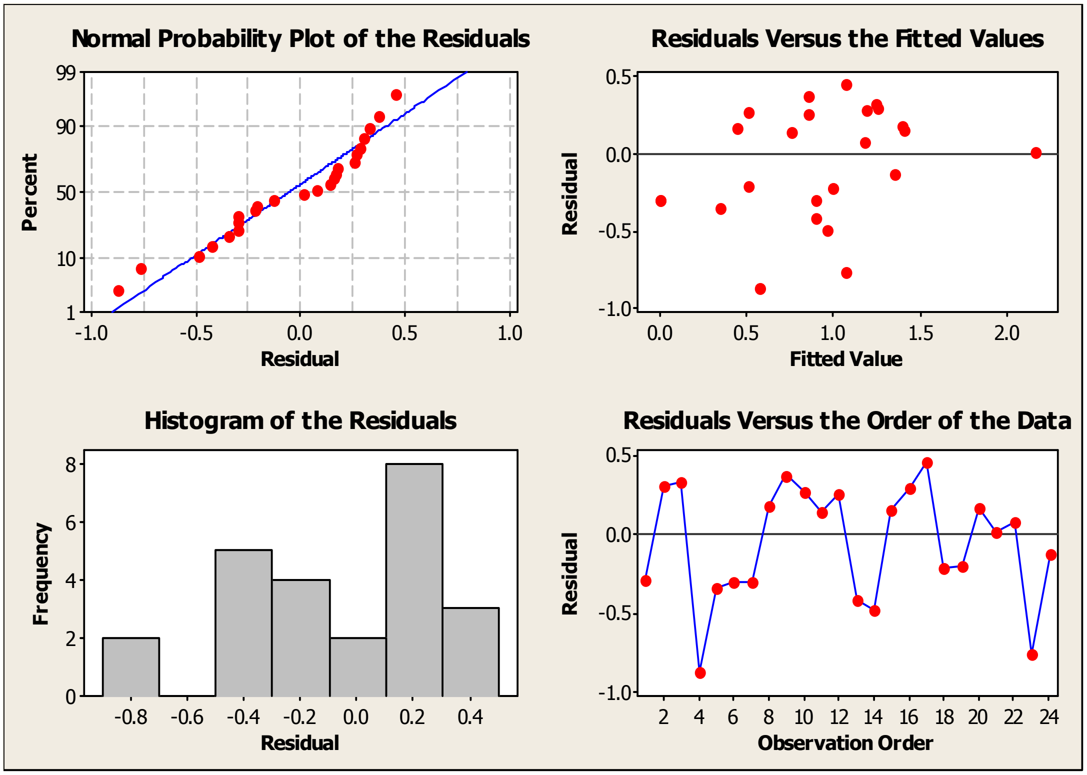
	df	SS	MS	F	Significance F
Regression	1	25.4	25.4	187	3.11E-12
Residual	23	3.12	0.136		
Total	24	28.55			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
X Variable 1*	0.730	0.053	13.7	1.56E-12	0.620	0.841

* the intercept term was determined to be not significant

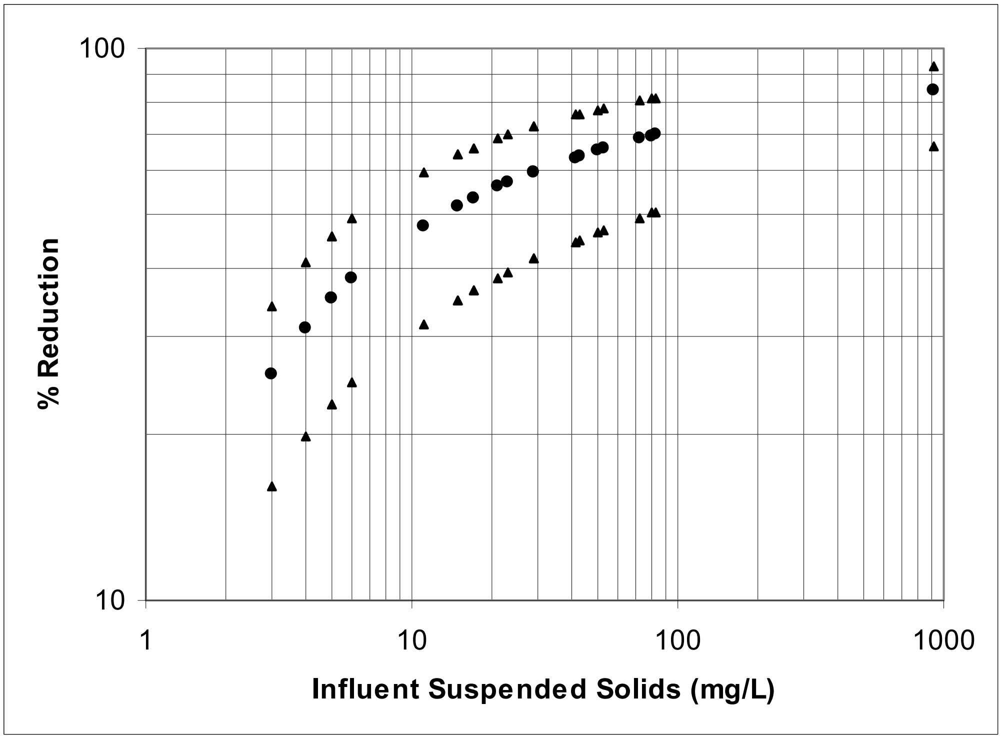


Fitted equation and data points for influent and effluent suspended solids.



Residual analyses of fitted equation for suspended solids influent vs. effluent.

Predicted effluent concentrations for different influent concentrations, with 95% confidence limits.



Percentage reductions as a function of influent concentrations, with 95% confidence limits.

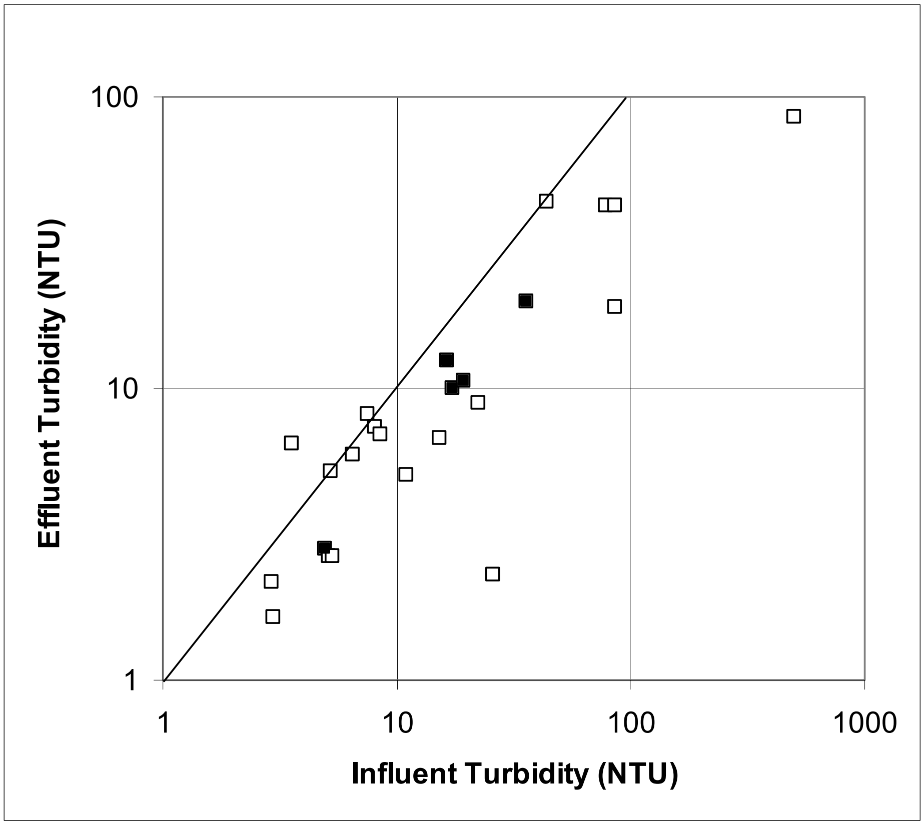
Turbidity

Turbidity Summary for all storm events

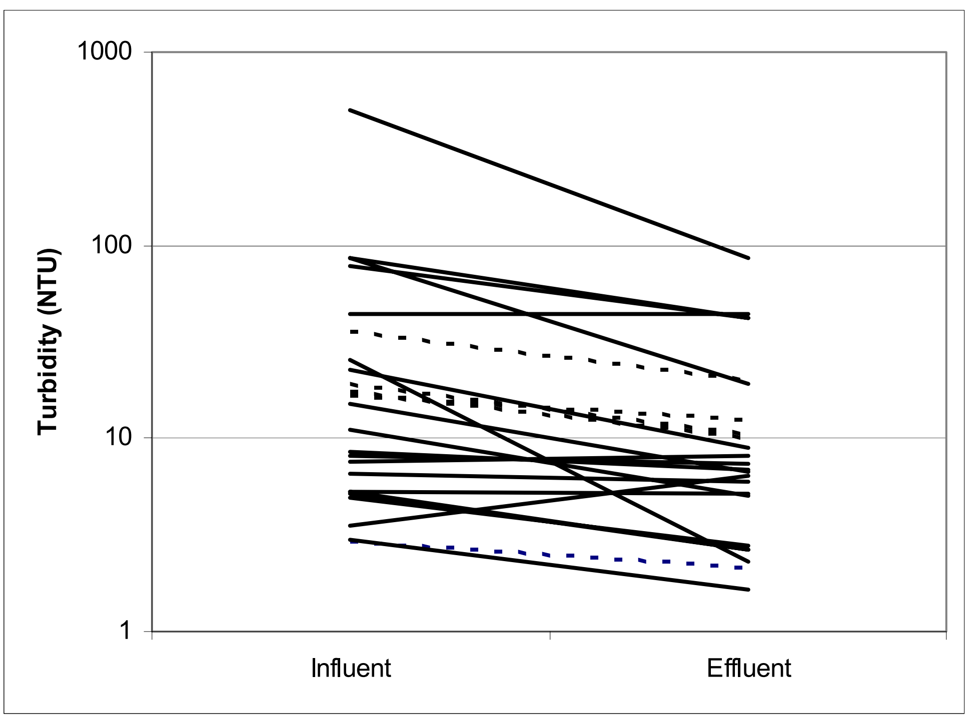
Observed Turbidity Concentrations

Sample Number	Influent (mg/L)	Effluent (mg/L)	% reduc
1-1	15.2	6.76	56
2-1	85.6	42.4	50
2-2	78.6	42.3	46
3-1	8.53	6.95	19
3-2	2.97	1.64	45
4-1	4.93	2.8	43
4-2	2.93	2.16	26
5-1	22.5	8.94	60
5-2	17.5	9.98	43
6-1	8.08	7.33	9
6-2	6.51	5.92	9
6-3	5.35	2.65	50
6-4	7.51	8.15	-9
6-5	3.54	6.45	-82
7-1	44.2	43.7	1
7-2	19.3	10.6	45
7-3	16.5	12.5	24
7-4	5.27	5.21	1
7-5	11.1	5.02	55
7-6	5.15	2.67	48
8-1	502	85.8	83
8-2	35.8	19.9	44
9-1	25.7	2.28	91
10-1	85.7	19	78
min	2.930	1.640	-82
max	502.000	85.800	91
average	42.520	15.046	35
median	13.150	7.140	45
st dev	101.198	19.790	36
COV	2.4	1.3	1

Probability that influent = effluent (nonparametric sign test): 0.00 (>99% confident that influent ≠ effluent), therefore statistically significant at least at the α 0.05 level.



Scatterplot of observed influent and effluent turbidity concentrations (filled symbols are events that had minor filter bypasses).



Paired influent and effluent Turbidity concentrations.

Fitted Equation:

Effluent Turbidity, log NTU = 0.772 * (Influent Turbidity, log NTU)

Regression Statistics on Observed Influent vs. Effluent Turbidity, log NTU

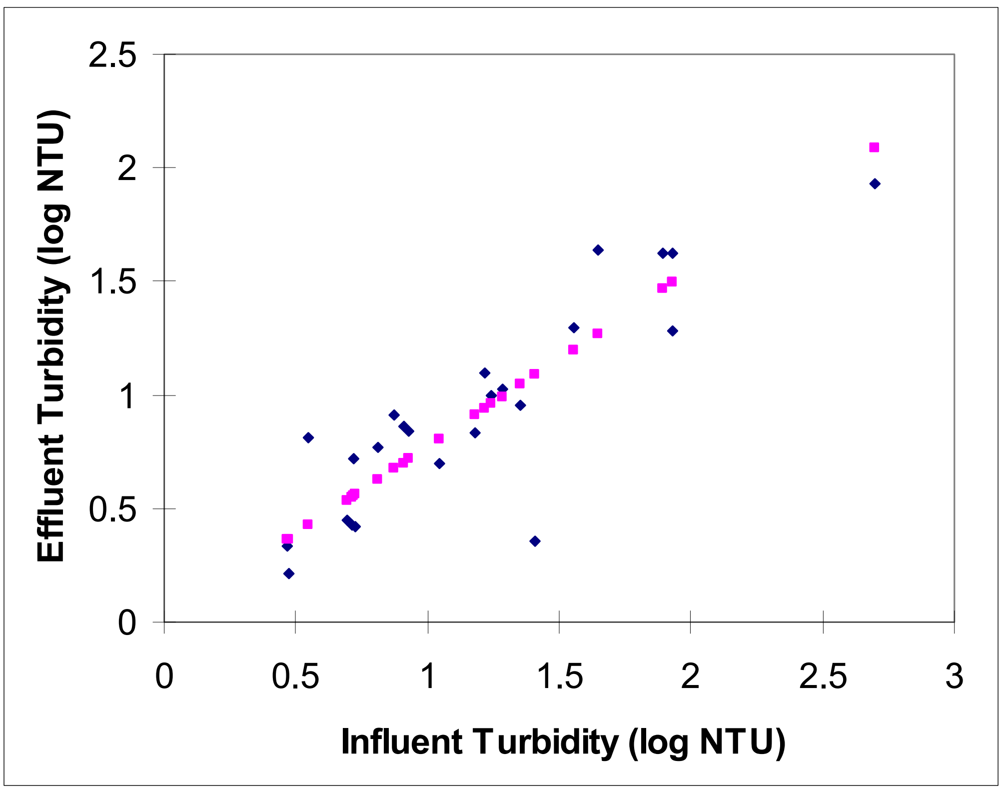
Multiple R	0.98
R Square	0.95
Adjusted R Square	0.91
Standard Error	0.23
Observations	24

ANOVA

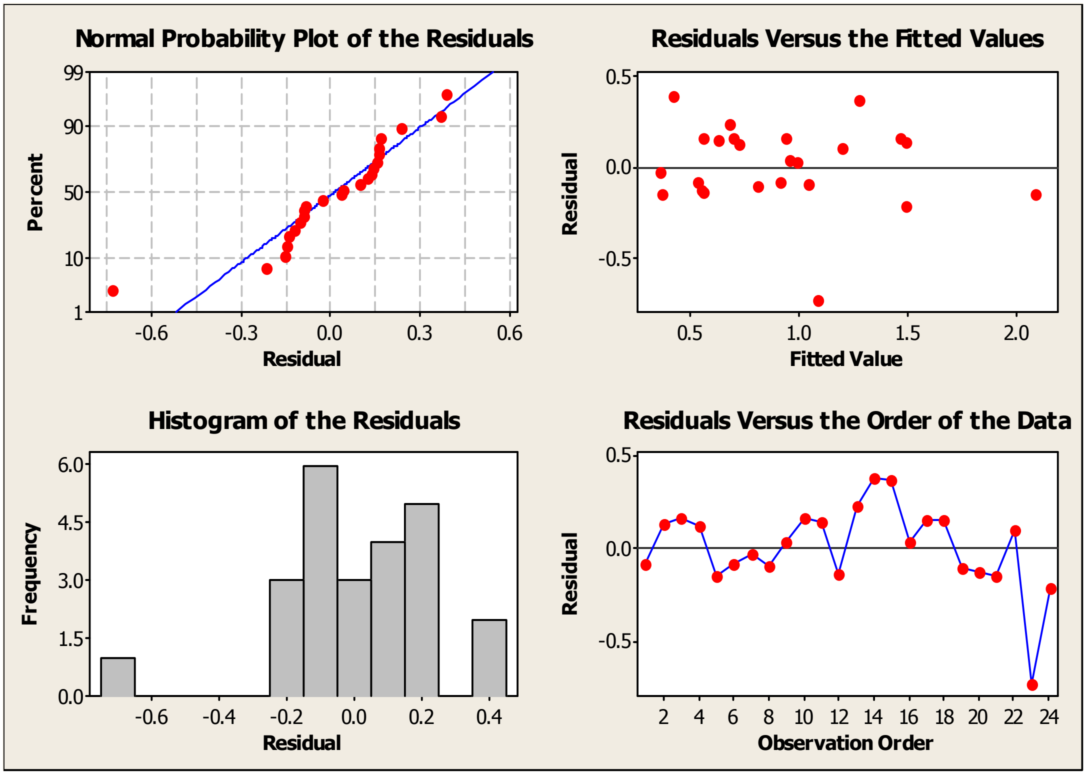
	df	SS	MS	F	Significance F
Regression	1	24.1	24.1	459	3.14E-16
Residual	23	1.21	0.0524		
Total	24	25.3			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Influent Turbidity*	0.772	0.0360	21.4	1.070E-16	0.698	0.847

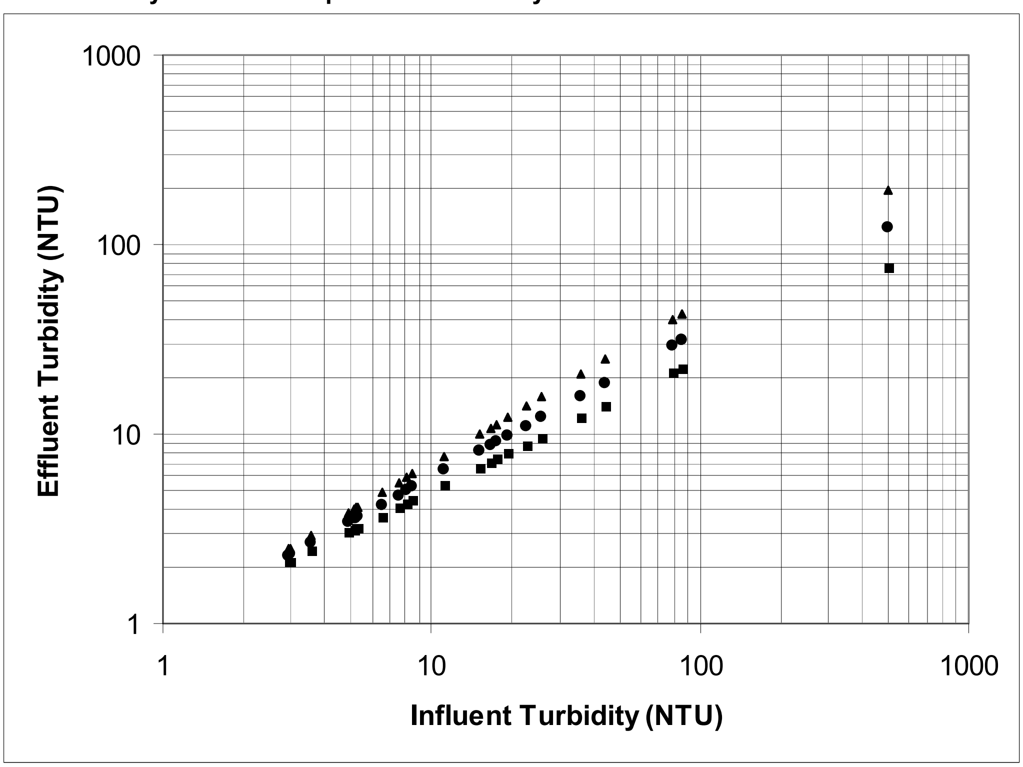
* the intercept term was determined to be not significant



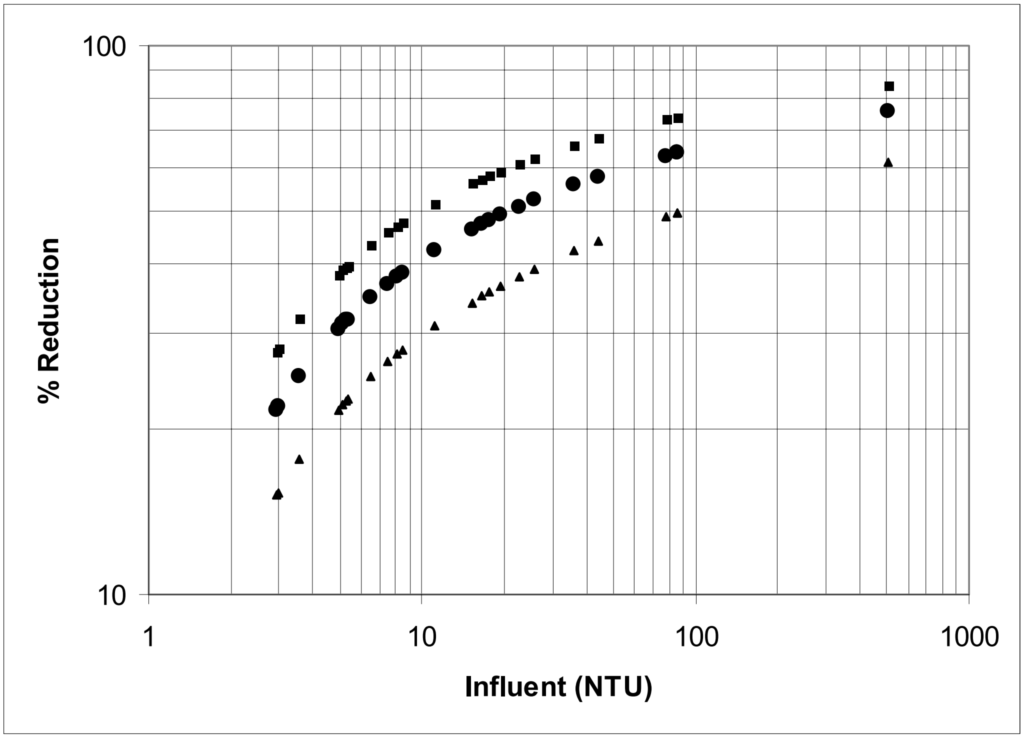
Fitted equation and data points for influent and effluent turbidity.



Residual analyses of fitted equation for turbidity influent vs. effluent.



Predicted effluent concentrations for different influent concentrations, with 95% confidence limits.



Percentage reductions as a function of influent concentrations, with 95% confidence limits.

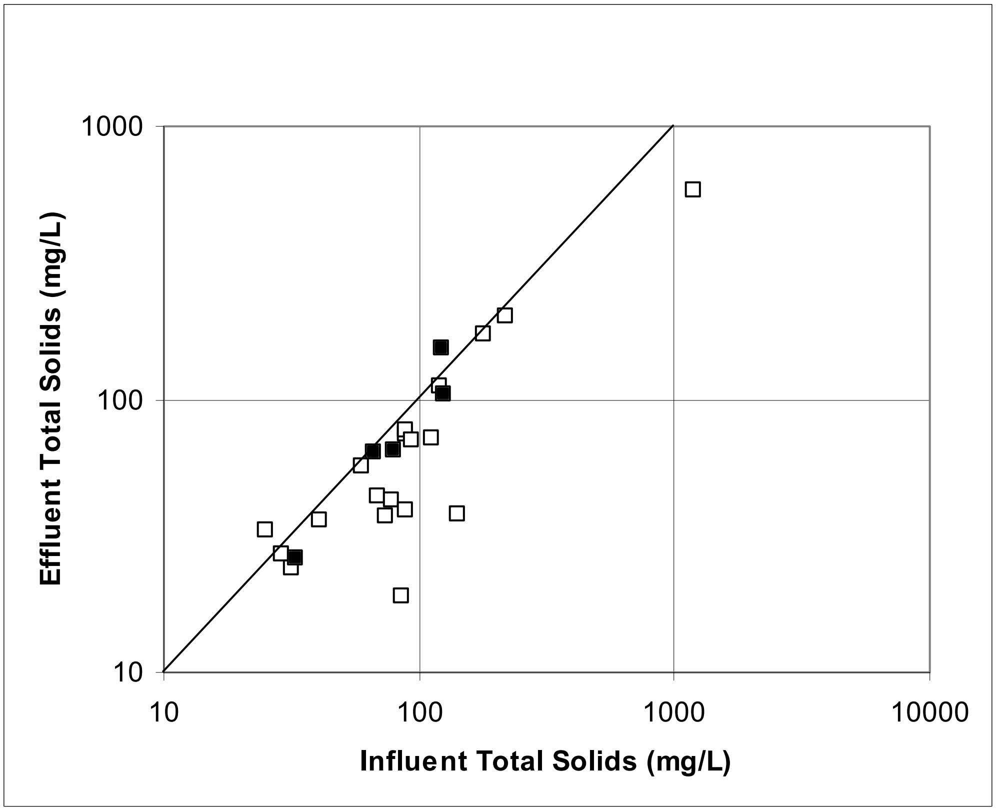
Total Solids

Total Solids summary for storm events

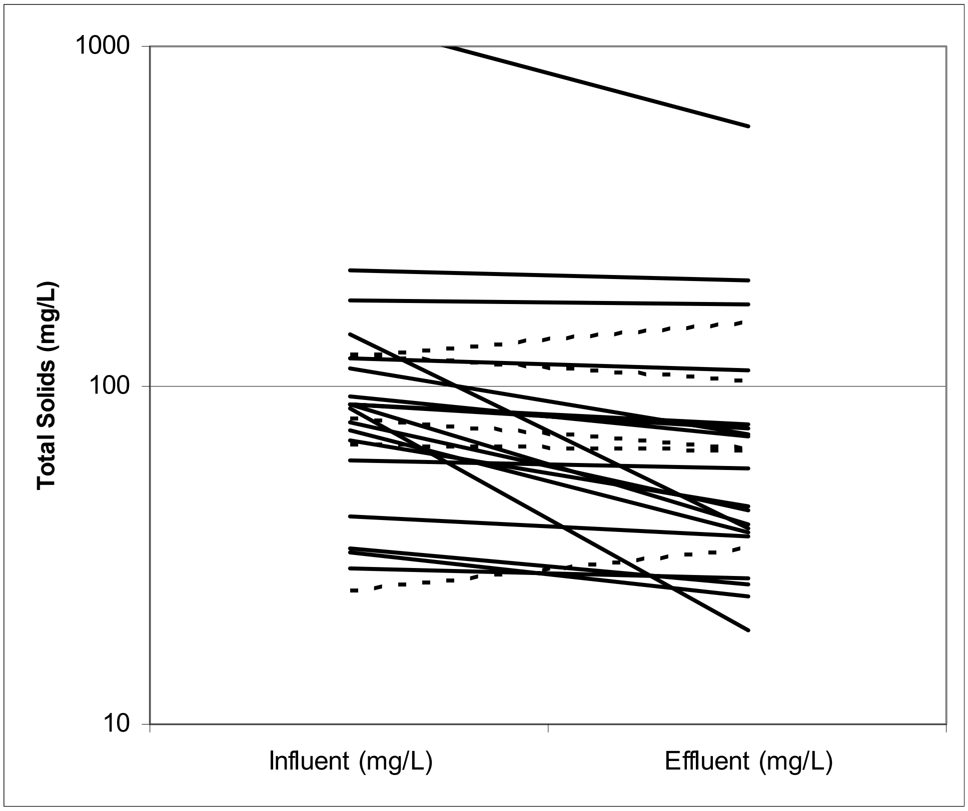
Observed Total Solids Concentrations

Sample Number	Influent (mg/L)	Effluent (mg/L)	% reduc
1-1	69	44	36
2-1	88	75	15
2-2	93	71	24
3-1	41	36	12
3-2	142	38	73
4-1	33	26	21
4-2	25	33	-32
5-1	217	203	6
5-2	124	104	16
6-1	120	111	8
6-2	88	77	13
6-3	60	57	5
6-4	78	43	45
6-5	88	39	56
7-1	178	173	3
7-2	80	65	19
7-3	67	64	4
7-4	29	27	7
7-5	74	37	50
7-6	32	24	25
8-1	1192	580	51
8-2	122	153	-25
9-1	112	72	36
10-1	86	19	78
min	25.000	19.000	-32
max	1192.000	580.000	78
average	134.917	90.458	23
median	87.000	60.500	17
st dev	229.886	114.947	27
COV	1.7	1.3	1

Probability that influent = effluent (nonparametric sign test): 0.00 (>99% confident that influent ≠ effluent), therefore statistically significant at least at the α 0.05 level.



Scatterplot of observed influent and effluent total solids concentrations (filled symbols are events that had minor filter bypasses).



Paired influent and effluent total solids concentrations.

Fitted Equation:

Effluent Total Solids, log mg/L = 0.928 * (Influent Total Solids, log mg/L)

Regression Statistics on Observed Influent vs. Effluent Total Solids, log mg/L

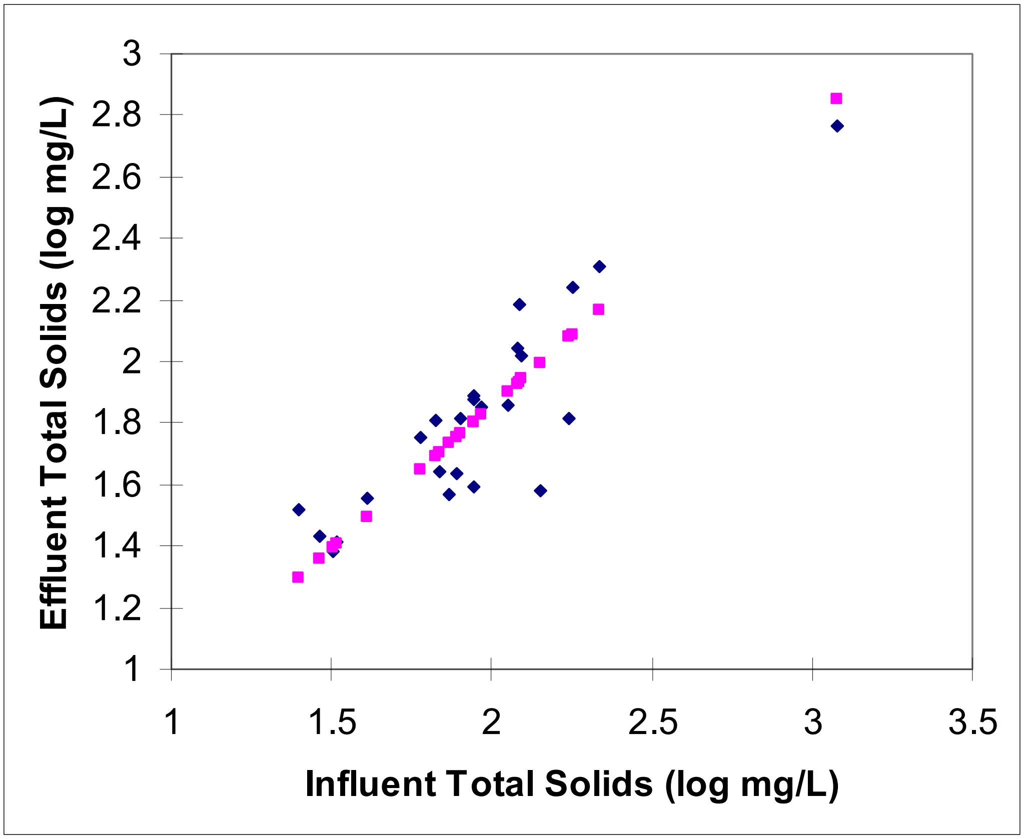
Multiple R	0.99
R Square	0.99
Adjusted R Square	0.95
Standard Error	0.16
Observations	24

ANOVA

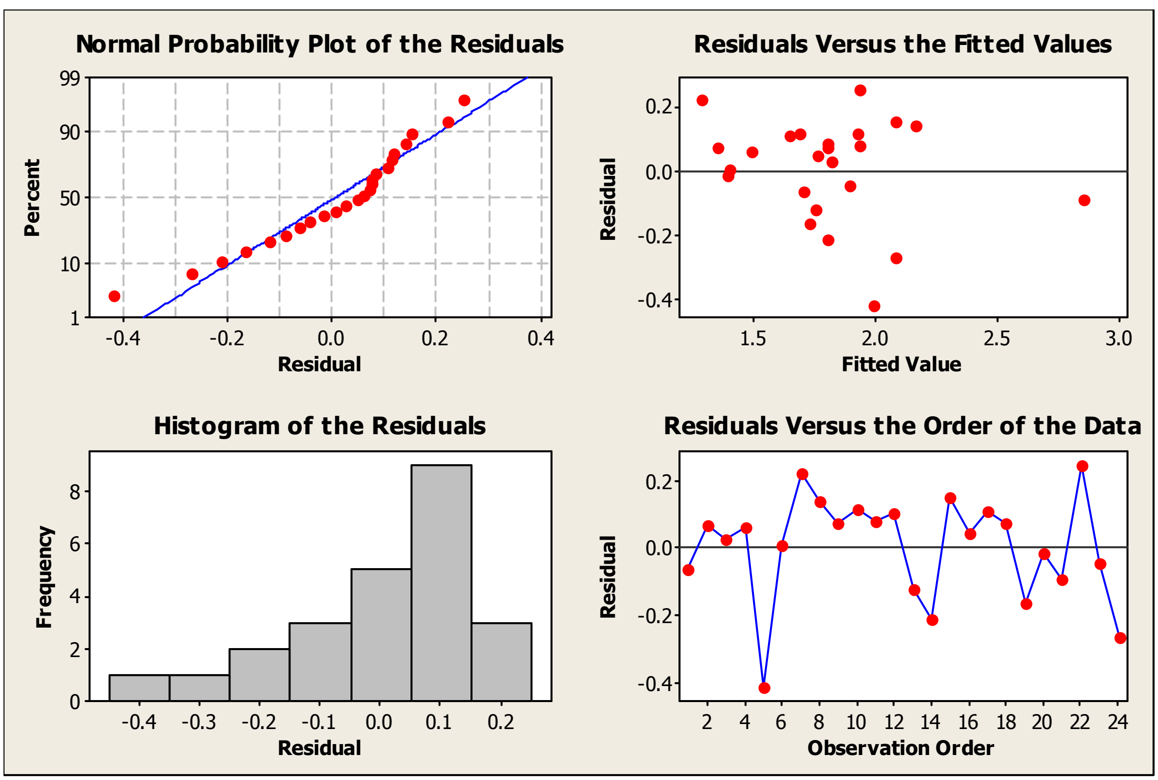
	df	SS	MS	F	Significance F
Regression	1	80.8	80.8	3274	1.98E-25
Residual	23	0.568	0.0247		
Total	24	81.4			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Influent total solids	0.928	0.0162	57.2	2.63E-26	0.894	0.961

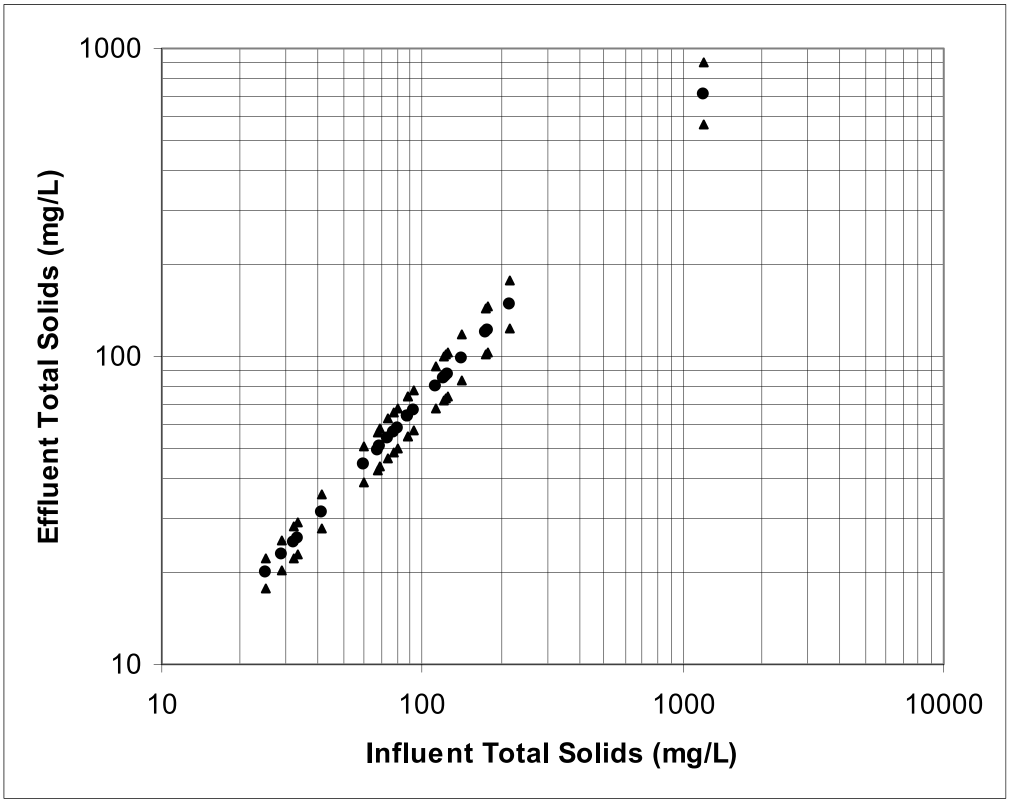
* the intercept term was determined to be not significant



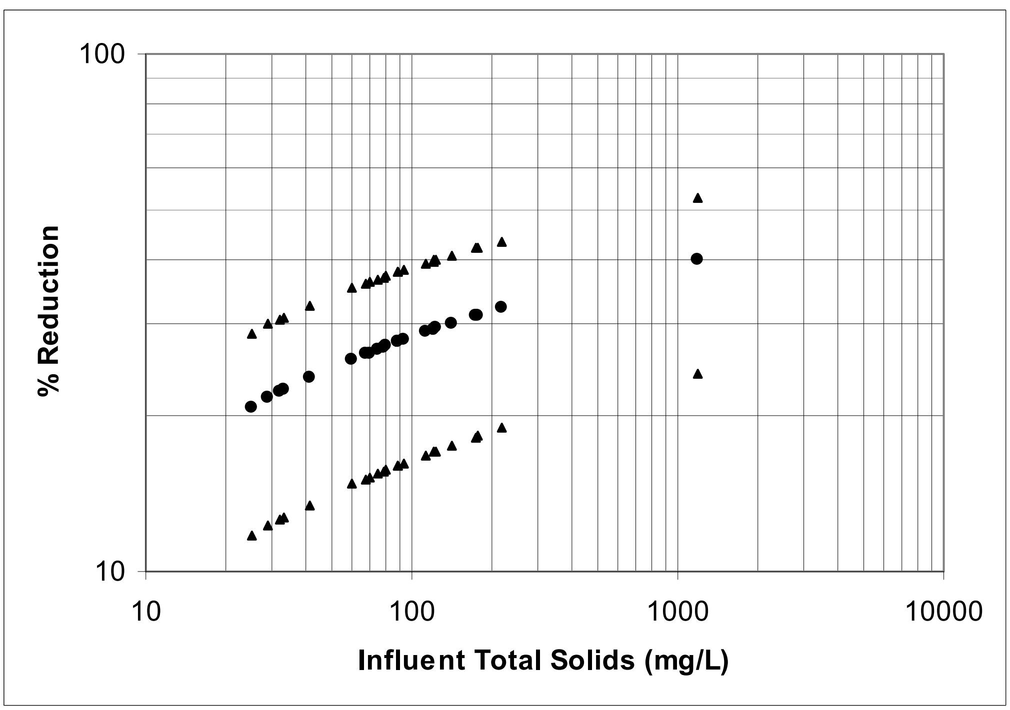
Fitted equation and data points for influent and effluent total solids.



Residual analyses of fitted equation for total solids influent vs. effluent.



Predicted effluent concentrations for different influent concentrations, with 95% confidence limits.



Percentage reductions as a function of influent concentrations, with 95% confidence limits.

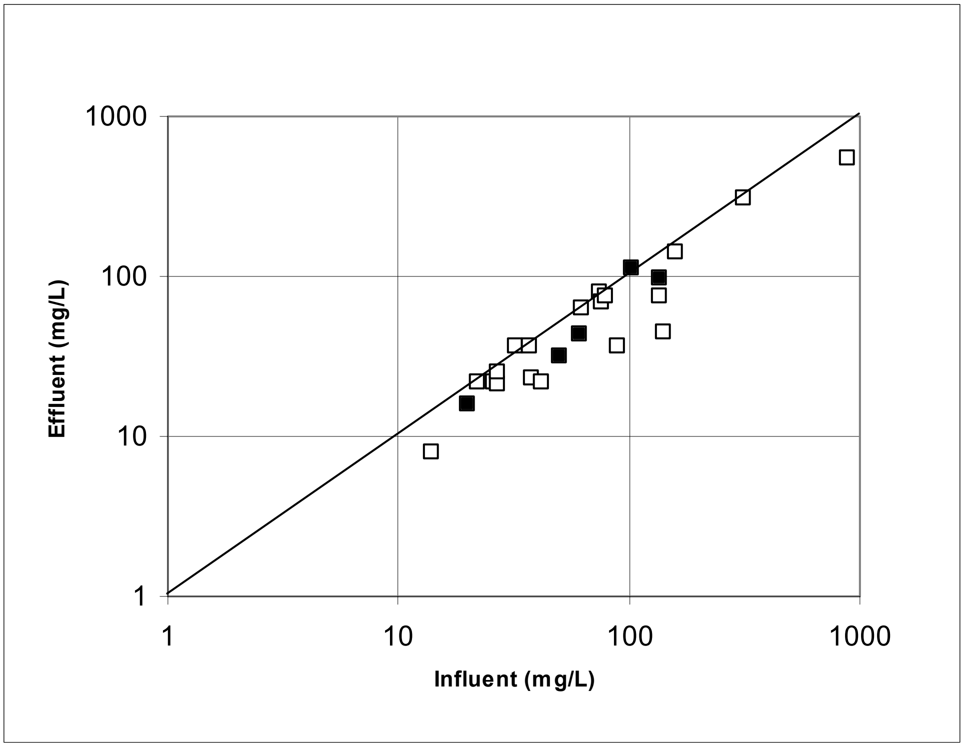
COD

COD summary for storm events

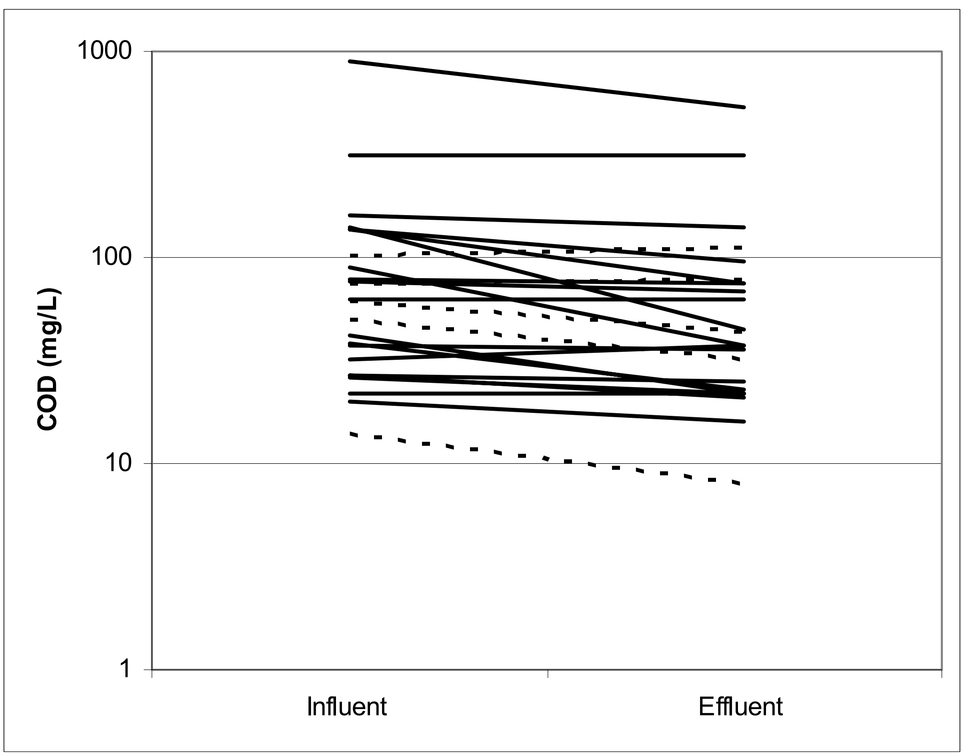
Observed COD Concentrations

Sample Number	Influent (mg/L)	Effluent (mg/L)	% reduc
1-1	89	37	58
2-1	141	45	68
2-2	137	75	45
3-1	38	23	39
3-2	42	22	48
4-1	20	16	20
4-2	14	8	43
5-1	159	141	11
5-2	75	79	-5
6-1	79	75	5
6-2	62	63	-2
6-3	37	36	3
6-4	27	21	22
6-5	26	22	15
7-1	137	96	30
7-2	61	44	28
7-3	50	32	36
7-4	22	22	0
7-5	32	37	-16
7-6	27	25	7
8-1	891	540	39
8-2	103	112	-9
9-1	76	68	11
10-1	312	310	1
min	14.000	8.000	-16
max	891.000	540.000	68
average	110.708	81.208	21
median	61.500	40.500	18
st dev	178.743	116.009	23
COV	1.6	1.4	1

Probability that influent = effluent (nonparametric sign test): 0.00 (>99% confident that influent ≠ effluent), therefore statistically significant at least at the α 0.05 level.



Scatterplot of observed influent and effluent COD concentrations (filled symbols are events that had minor filter bypasses).



Paired influent and effluent COD concentrations.

Fitted Equation:

Effluent COD, log mg/L = 0.933 * (Influent COD, log mg/L)

Regression Statistics

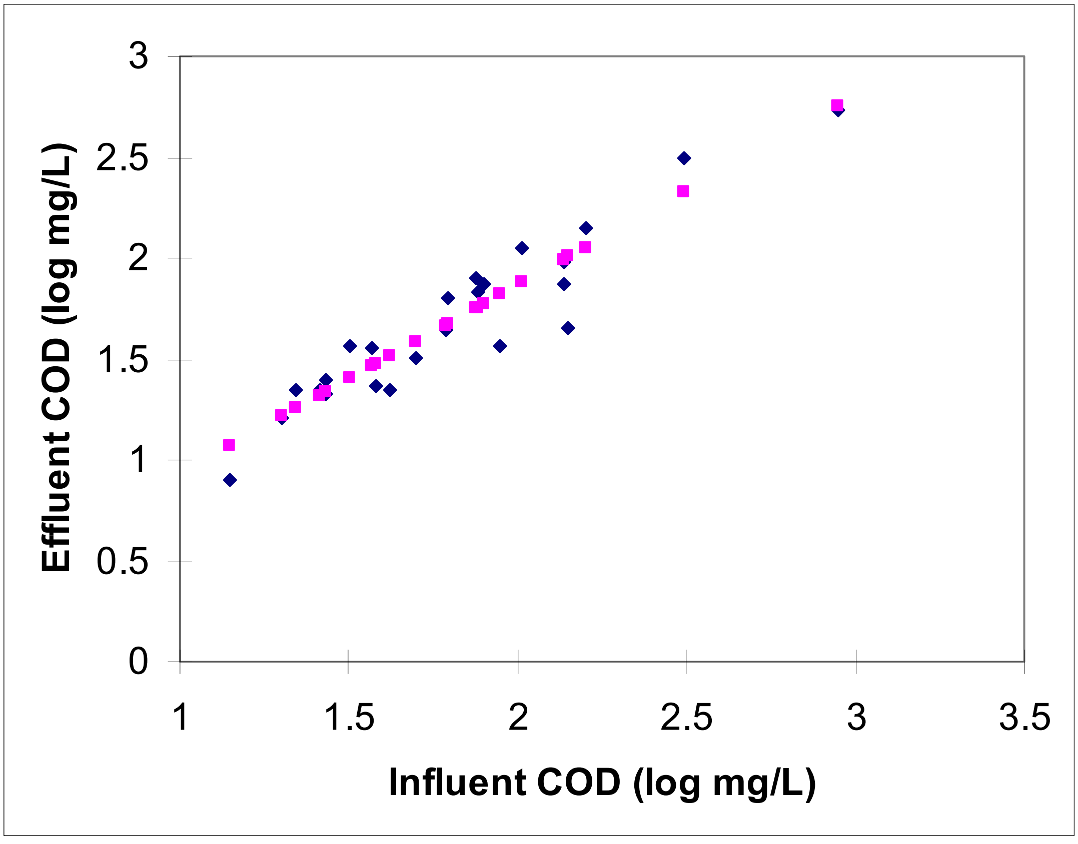
Multiple R	0.997
R Square	0.994
Adjusted R Square	0.950
Standard Error	0.139
Observations	24

ANOVA

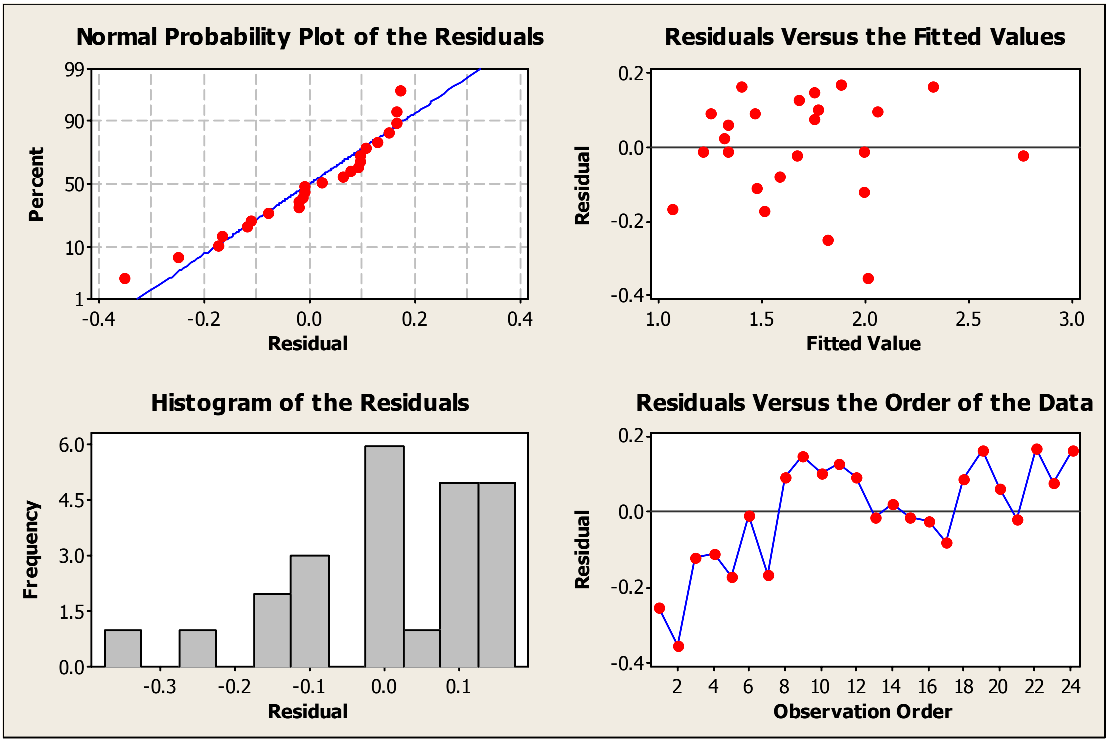
	df	SS	MS	F	Significance F
Regression	1	71.5	71.5	3679	5.52E-26
Residual	23	0.447	0.0194		
Total	24	71.9			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Influent COD*	0.933	0.0154	60.7	6.91E-27	0.901	0.965

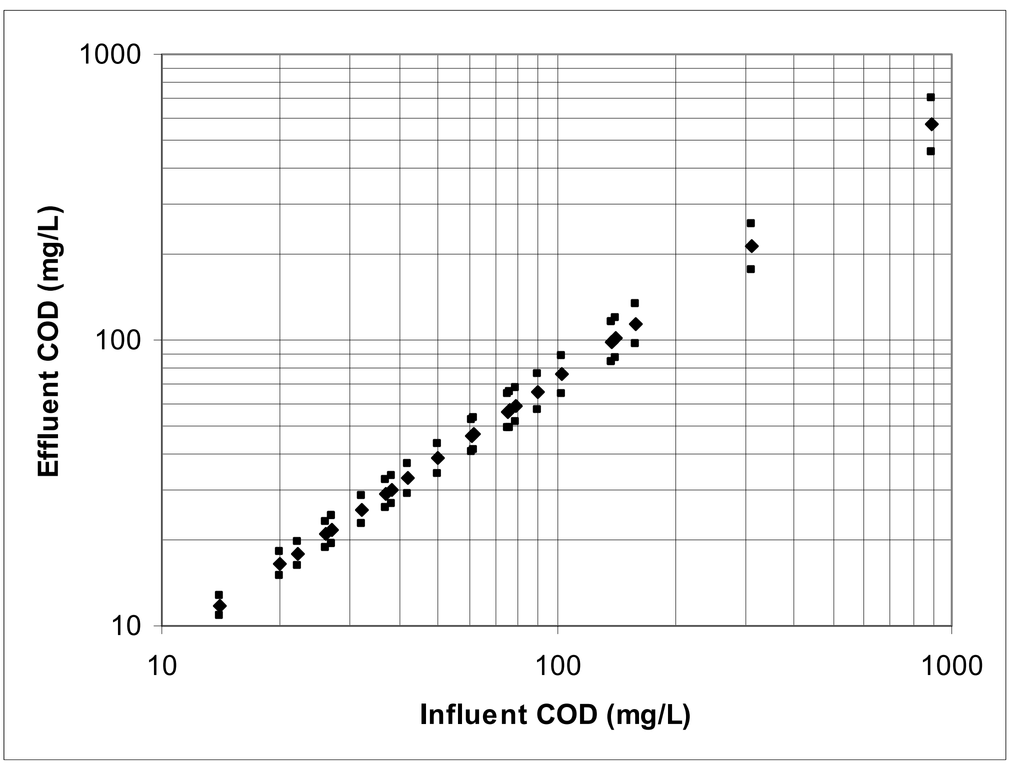
* the intercept term was determined to be not significant



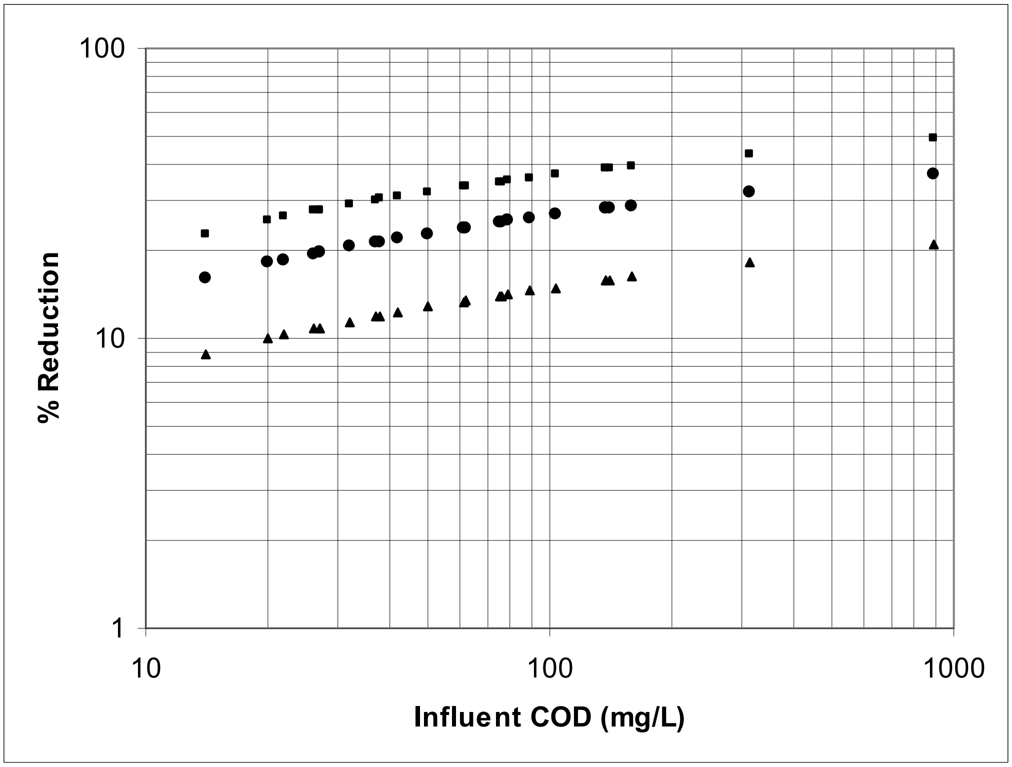
Fitted equation and data points for influent and effluent COD.



Residual analyses of fitted equation for COD influent vs. effluent.



Predicted effluent concentrations for different influent concentrations, with 95% confidence limits.



Percentage reductions as a function of influent concentrations, with 95% confidence limits.

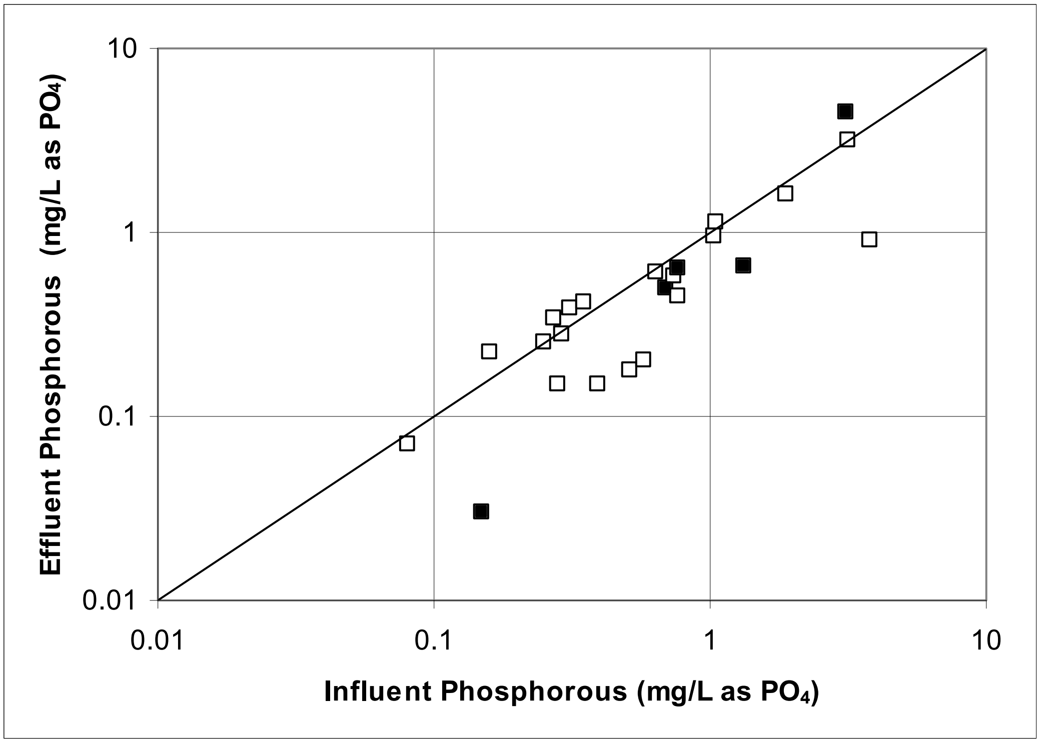
Phosphorus

Phosphorus summary for storm events

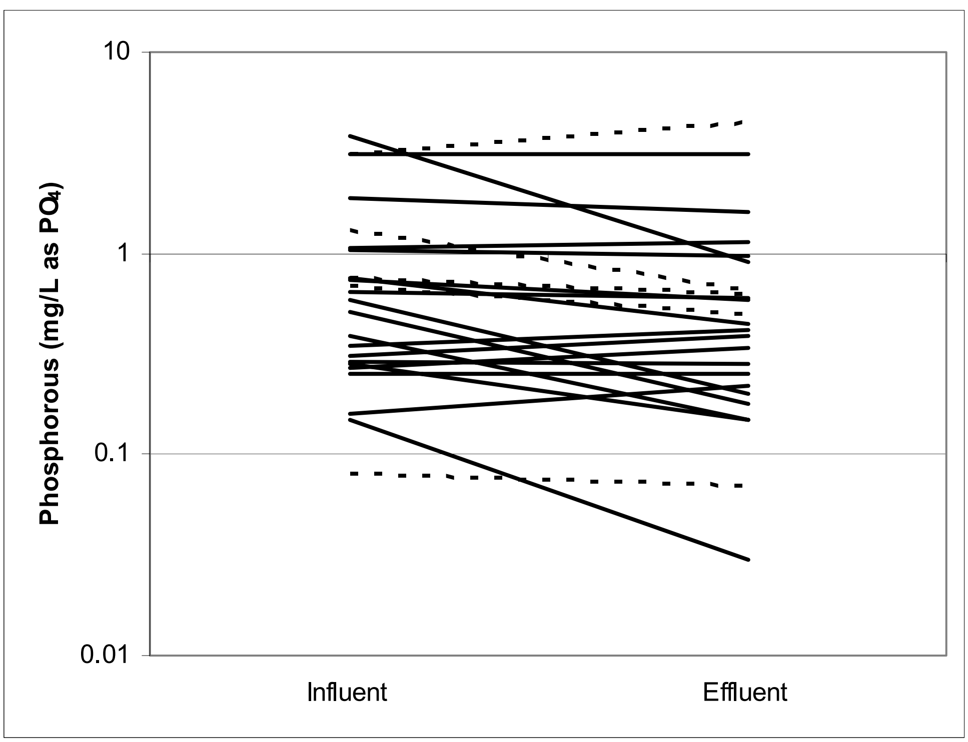
Observed Phosphorus Concentrations

Sample Number	Influent (mg/L)	Effluent (mg/L)	% reduc
1-1	0.35	0.42	-20
2-1	0.64	0.6	6
2-2	0.25	0.25	0
3-1	0.58	0.2	66
3-2	0.15	0.03	80
4-1	0.08	0.07	13
4-2	1.06	1.14	-8
5-1	0.76	0.63	17
5-2	0.31	0.39	-26
6-1	0.27	0.34	-26
6-2	0.28	0.15	46
6-3	0.39	0.15	62
6-4	0.16	0.22	-38
6-5	1.88	1.62	14
7-1	0.69	0.5	28
7-2	1.32	0.66	50
7-3	0.29	0.28	3
7-4	0.76	0.45	41
7-5	0.51	0.18	65
7-6	3.14	3.14	0
8-1	0.74	0.58	22
8-2	3.12	4.54	-46
9-1	1.04	0.96	8
10-1	3.81	0.9	76
min	0.080	0.030	-46
max	3.810	4.540	80
average	0.941	0.767	18
median	0.610	0.435	13
st dev	1.027	1.038	36
COV	1.1	1.4	2

Probability that influent = effluent (nonparametric sign test): 0.02 (98% confident that influent ≠ effluent), therefore statistically significant at least at the α 0.05 level.



Scatterplot of observed influent and effluent phosphorus concentrations (filled symbols are events that had minor filter bypasses).



Paired influent and effluent phosphorus concentrations.

Fitted Equation:

Effluent phosphorus, log mg/L = -0.145 + 0.979 * (Influent phosphorus, log mg/L)

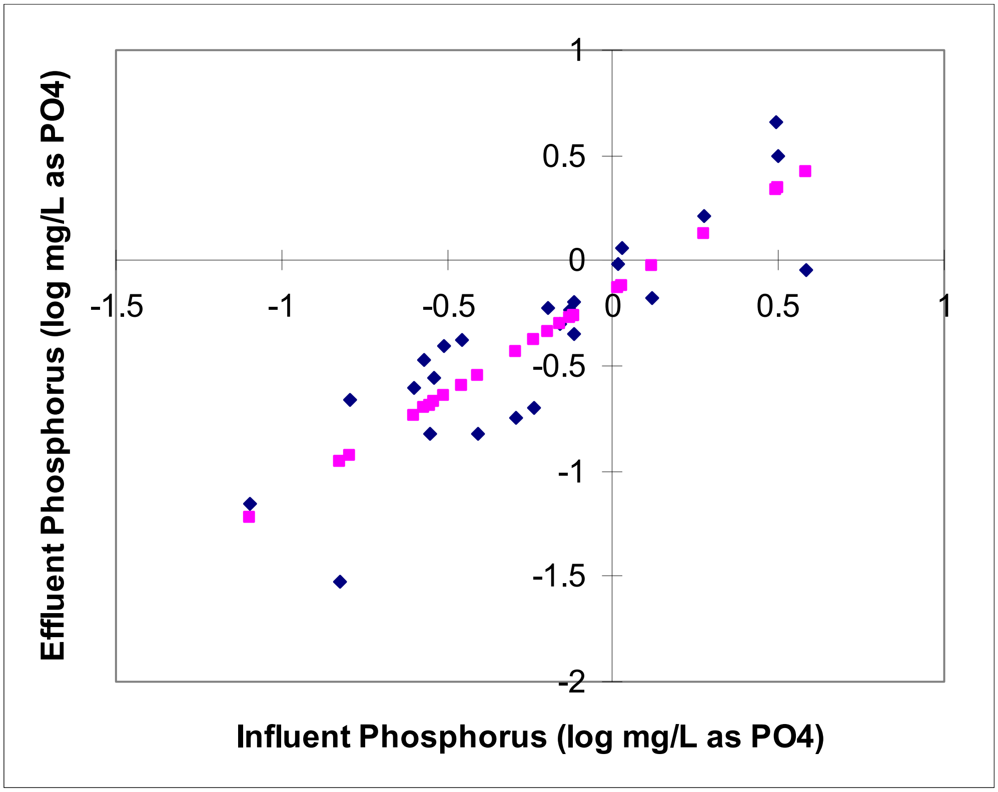
Regression Statistics

Multiple R	0.869
R Square	0.756
Adjusted R Square	0.744
Standard Error	0.246
Observations	24

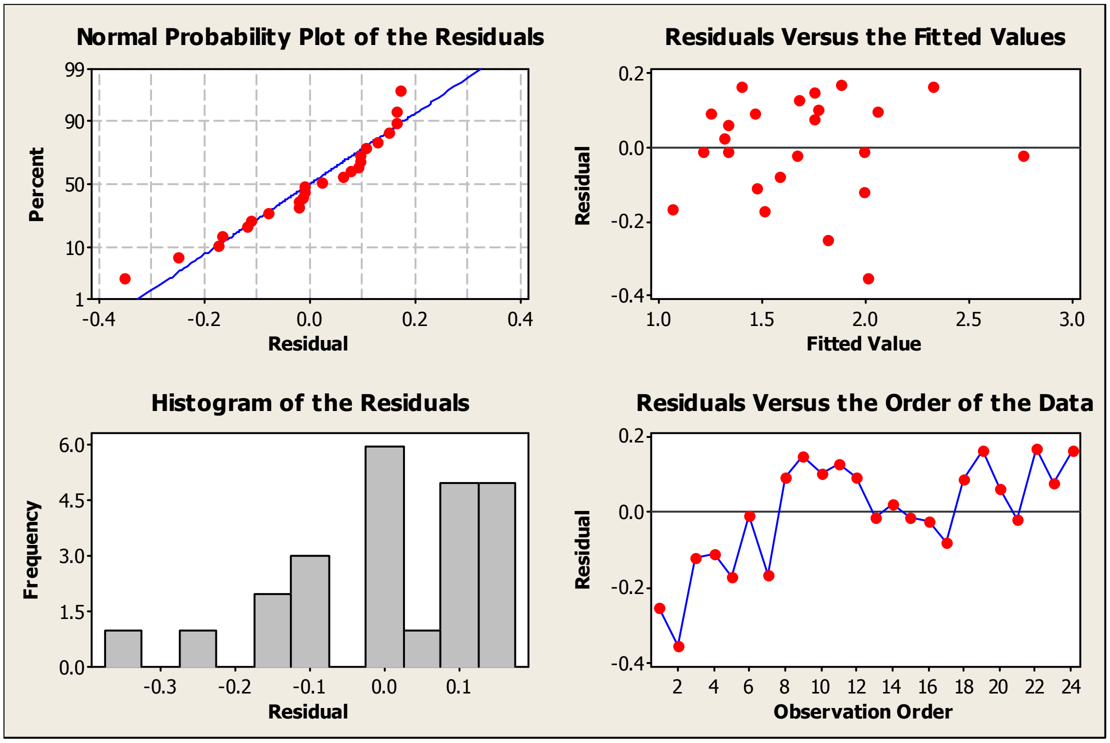
ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	4.12	4.12	68.0	3.56E-08
Residual	22	1.33	0.0606		
Total	23	5.45			

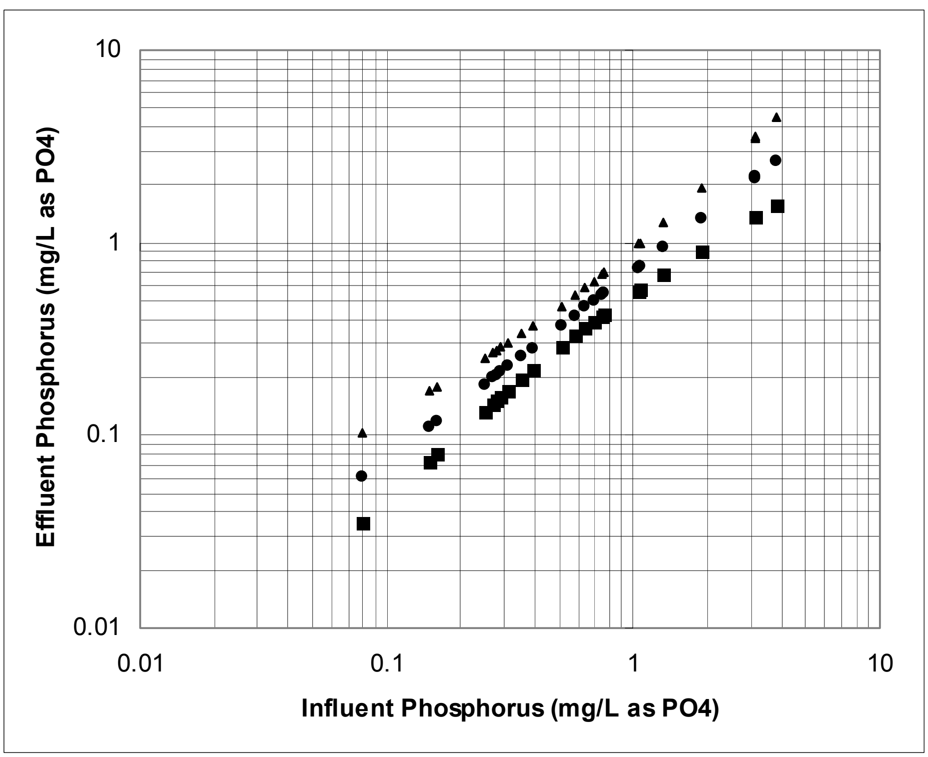
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-0.145	0.05746	-2.53	0.0189	-0.264	-0.02644
Influent Phosphates	0.9792	0.119	8.25	3.56E-08	0.733	1.23



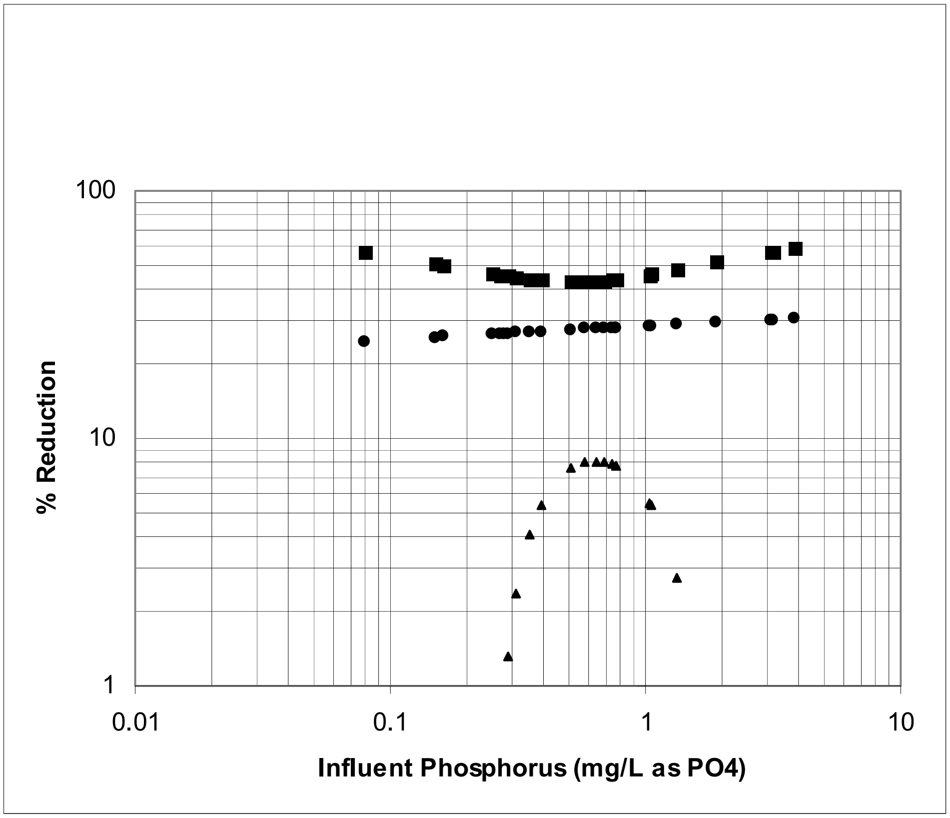
Fitted equation and data points for influent and effluent phosphorus.



Residual analyses of fitted equation for phosphorus influent vs. effluent.



Predicted effluent concentrations for different influent concentrations, with 95% confidence limits.



Percentage reductions as a function of influent concentrations, with 95% confidence limits.

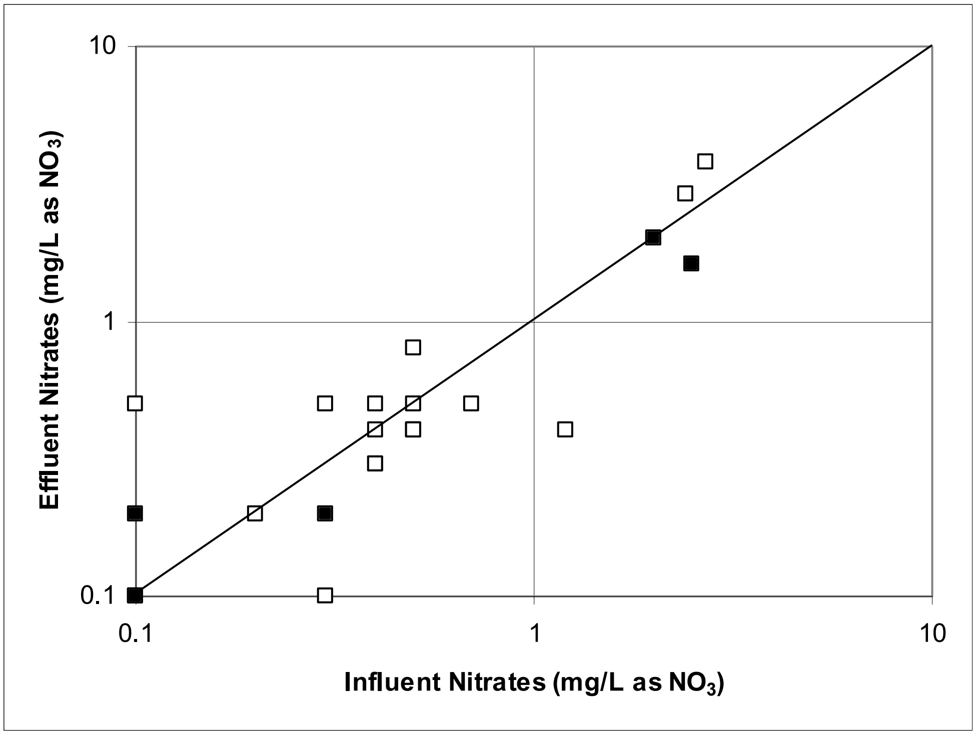
Nitrates

Nitrates summary for storm events

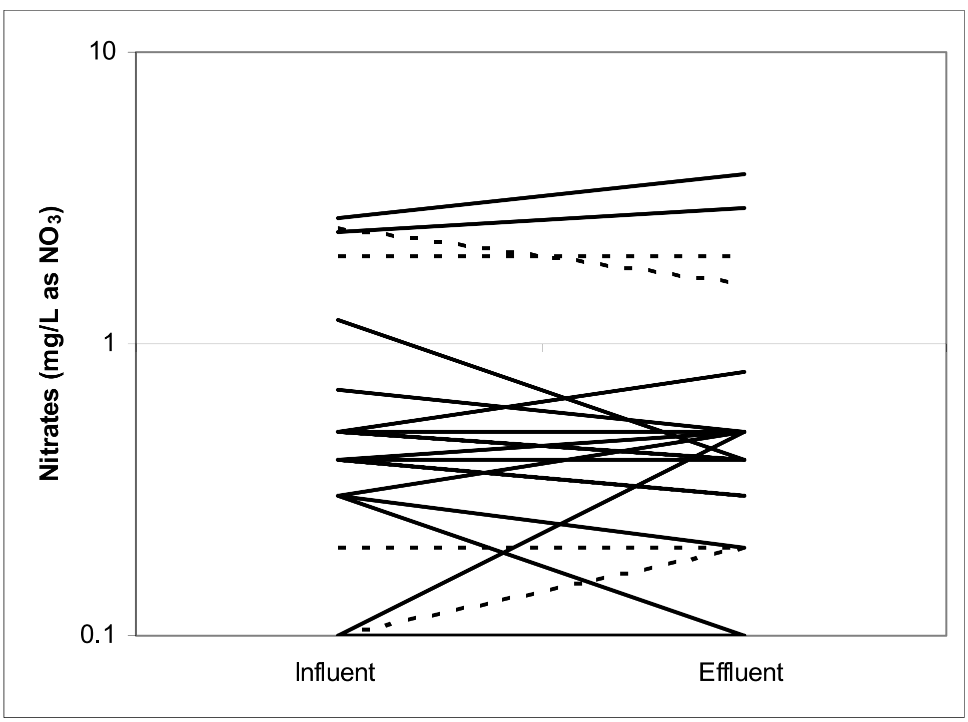
Observed Nitrates Concentrations

Sample Number	Influent (mg/L)	Effluent (mg/L)	% reduc
1-1	0.5	0.5	0
2-1	0.4	0.4	0
2-2	0.5	0.4	20
3-1	0.3	0.5	-67
3-2	0.4	0.5	-25
4-1	0.3	0.2	33
4-2	0.2	0.2	0
5-1	2.7	3.8	-41
5-2	2.5	1.6	36
6-1	0.5	0.8	-60
6-2	0.4	0.3	25
6-3	0.3	0.1	67
6-4	0.1	0.1	0
6-5	0.1	0.1	0
7-1	0.5	0.4	20
7-2	0.1	0.1	0
7-3	0.1	0.2	-100
7-4	0	0	n/a
7-5	0.1	0.5	-400
7-6	0.4	0.3	25
8-1	2.4	2.9	-21
8-2	2	2	0
9-1	0.7	0.5	29
10-1	1.2	0.4	67
min	0.000	0.000	-400
max	2.700	3.800	67
average	0.696	0.700	-17
median	0.400	0.400	0
st dev	0.824	0.945	93
COV	1.2	1.3	-5

Probability that influent = effluent (nonparametric sign test): 0.07 (93% confident that influent ≠ effluent), therefore not statistically significant at least at the α 0.05 level.



Scatterplot of observed influent and effluent nitrates concentrations (filled symbols are events that had minor filter bypasses).



Paired influent and effluent nitrates concentrations.

Fitted Equation:

Effluent nitrates, log mg/L = 0.910 * (Influent nitrates, log mg/L)

Regression Statistics

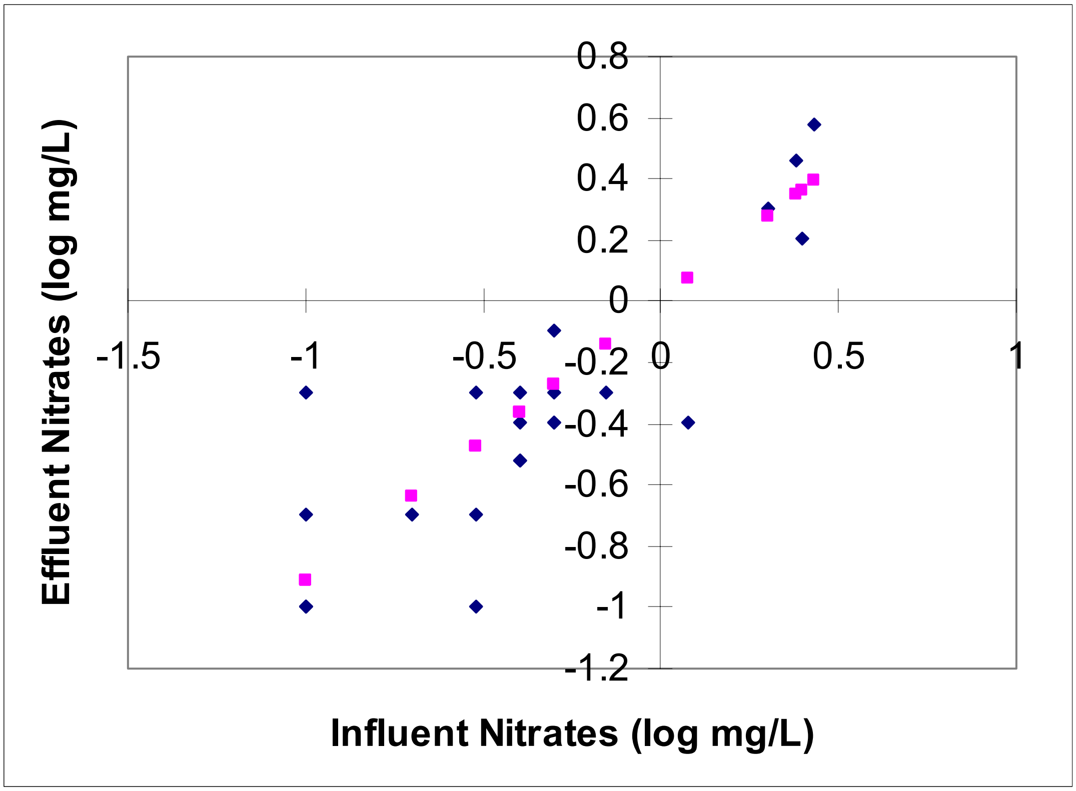
Multiple R	0.917
R Square	0.841
Adjusted R Square	0.795
Standard Error	0.237
Observations	23

ANOVA

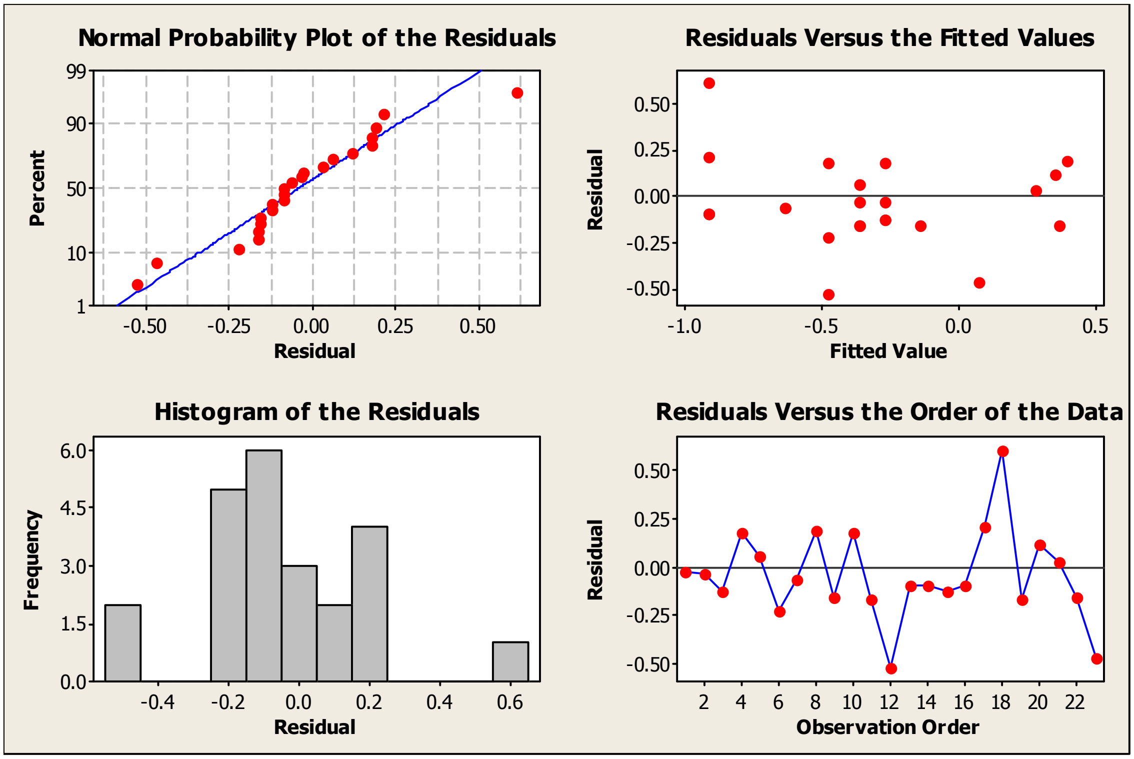
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	6.55	6.55	116	5.07E-10
Residual	22	1.24	0.0563		
Total	23	7.79			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Influent Nitrates*	0.910	0.0844	10.8	3.005E-10	0.735	1.085

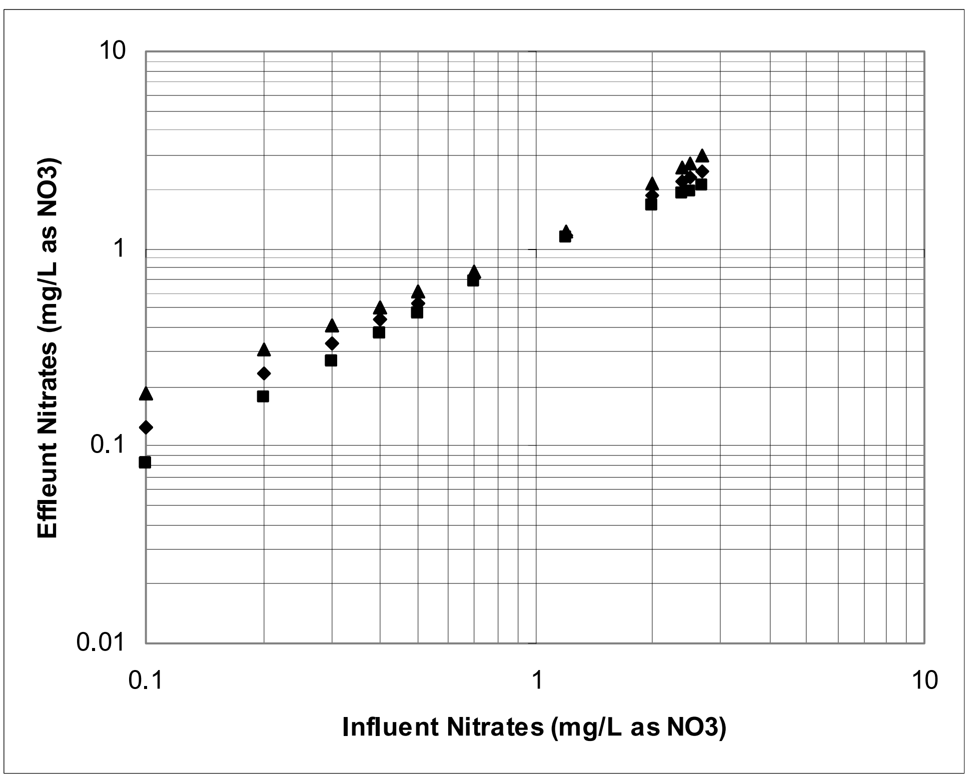
* the intercept term was determined to be not significant



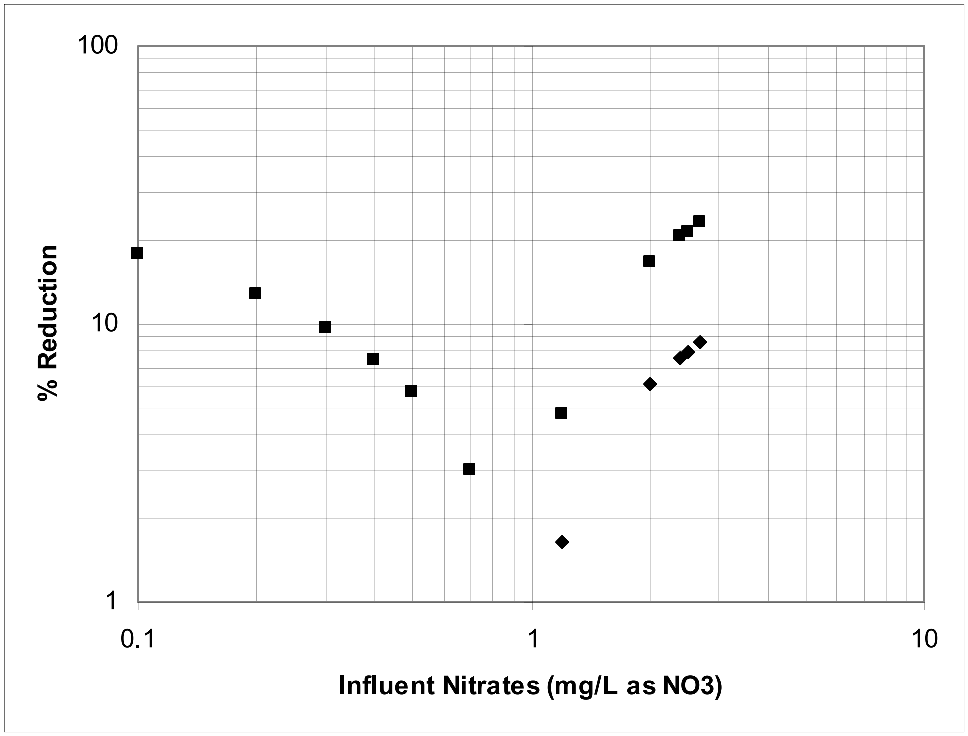
Fitted equation and data points for influent and effluent nitrates.



Residual analyses of fitted equation for nitrates influent vs. effluent.



Predicted effluent concentrations for different influent concentrations, with 95% confidence limits.



Percentage reductions as a function of influent concentrations, with 95% confidence limits.

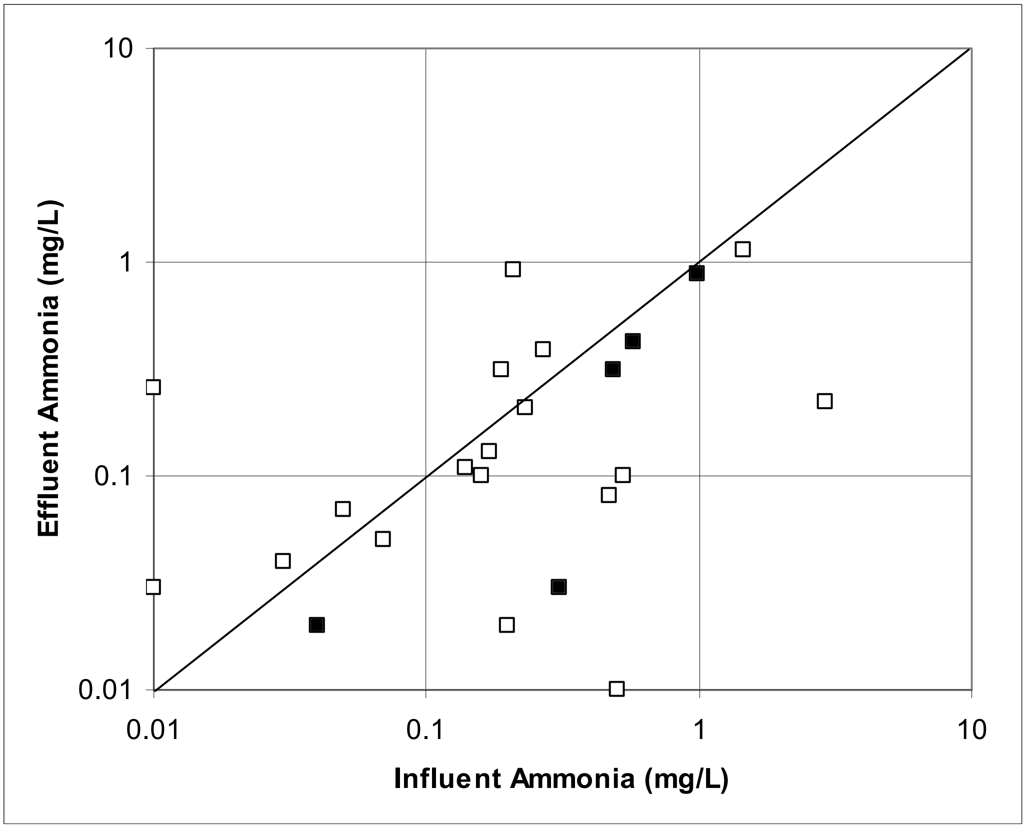
Ammonia

Ammonia summary for storm events

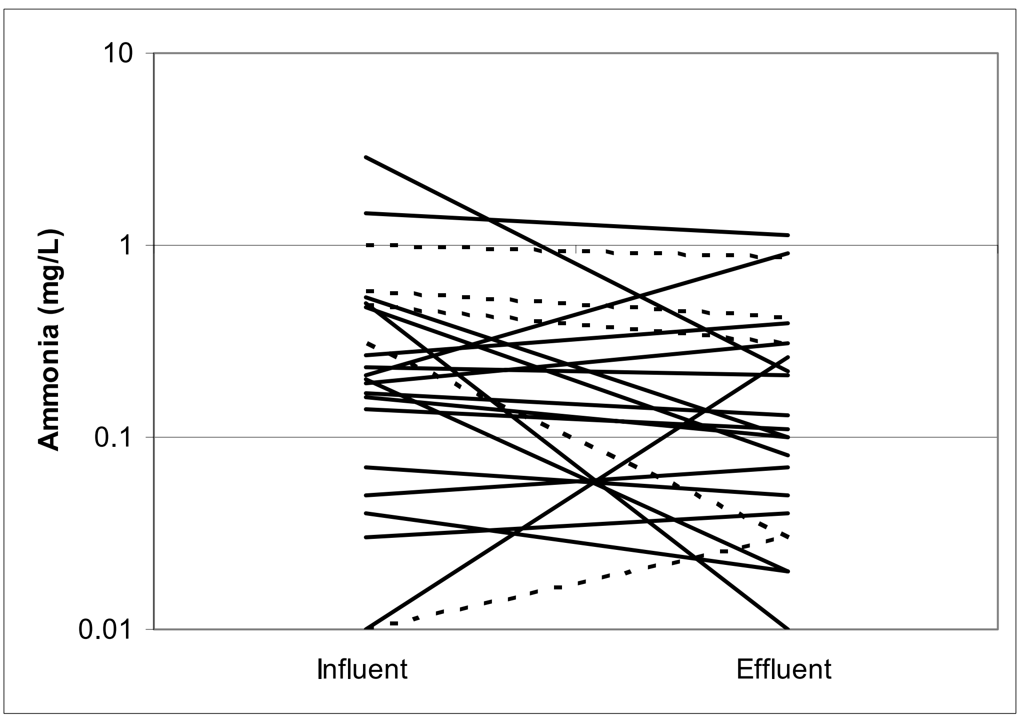
Observed Ammonia Concentrations

Sample Number	Influent (mg/L)	Effluent (mg/L)	% reduc
1-1	0.21	0.91	-333
2-1	0.23	0.21	9
2-2	0.27	0.39	-44
3-1	0.16	0.1	38
3-2	0.5	0.01	98
4-1	0.04	0.02	50
4-2	0.01	0.03	-200
5-1	0.19	0.31	-63
5-2	0.31	0.03	90
6-1	0.17	0.13	24
6-2	0.14	0.11	21
6-3	0.07	0.05	29
6-4	0.05	0.07	-40
6-5	0.03	0.04	-33
7-1	1.47	1.14	22
7-2	0.58	0.42	28
7-3	0.49	0.31	37
7-4	0.47	0.08	83
7-5	0.53	0.1	81
7-6	0	0.02	n/a
8-1	2.9	0.22	92
8-2	0.99	0.87	12
9-1	0.2	0.02	90
10-1	0.01	0.26	-2500
min	0.000	0.010	-2500
max	2.900	1.140	98
average	0.418	0.244	-105
median	0.205	0.105	24
st dev	0.630	0.310	531
COV	1.5	1.3	-5

Probability that influent = effluent (nonparametric sign test): 0.03 (97% confident that influent ≠ effluent), therefore statistically significant at least at the α 0.05 level.



Scatterplot of observed influent and effluent ammonia concentrations (filled symbols are events that had minor filter bypasses).



Paired influent and effluent ammonia concentrations.

Fitted Equation:

Effluent ammonia, log mg/L = -0.647 + 0.373 * (Influent ammonia, log mg/L)

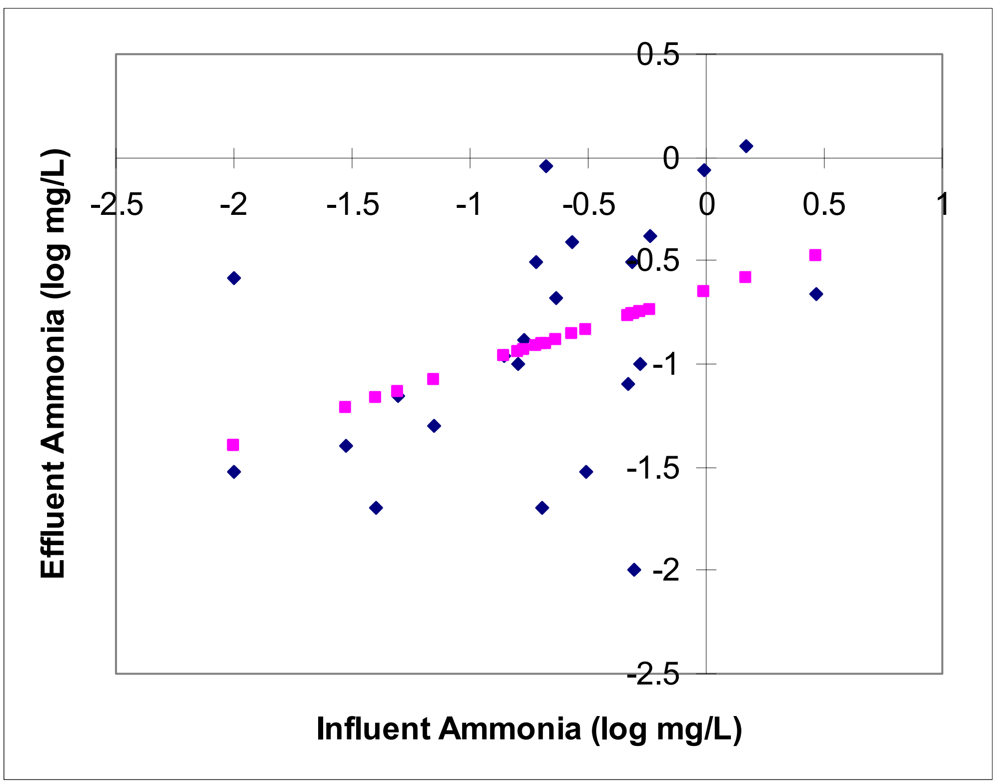
Regression Statistics

Multiple R	0.409
R Square	0.167
Adjusted R Square	0.128
Standard Error	0.534
Observations	23

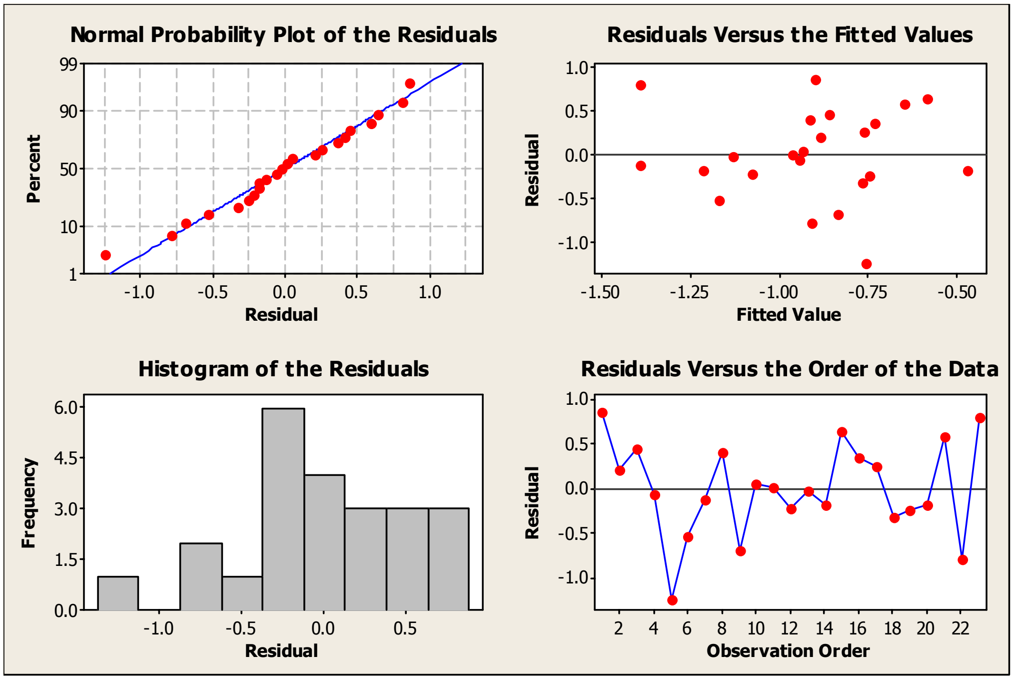
ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.202	1.20	4.22	0.0526
Residual	21	5.98	0.285		
Total	22	7.18			

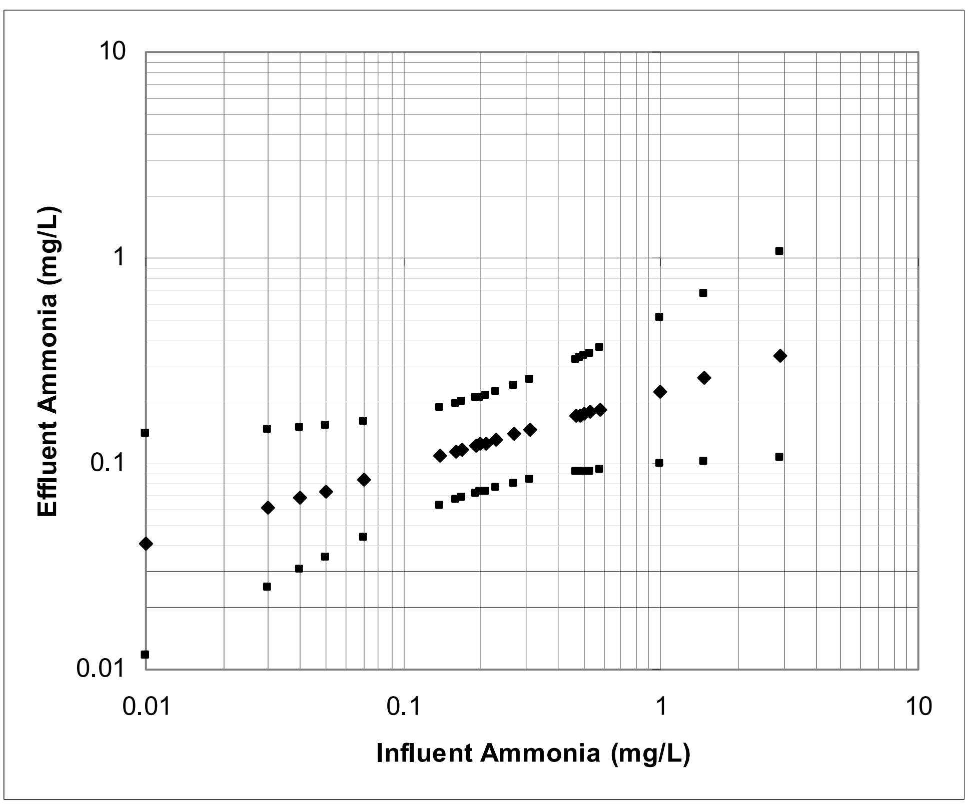
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-0.647	0.171	-3.78	0.00109	-1.00	-0.291
Influent Ammonia	0.373	0.182	2.05	0.0526	-0.00456	0.751



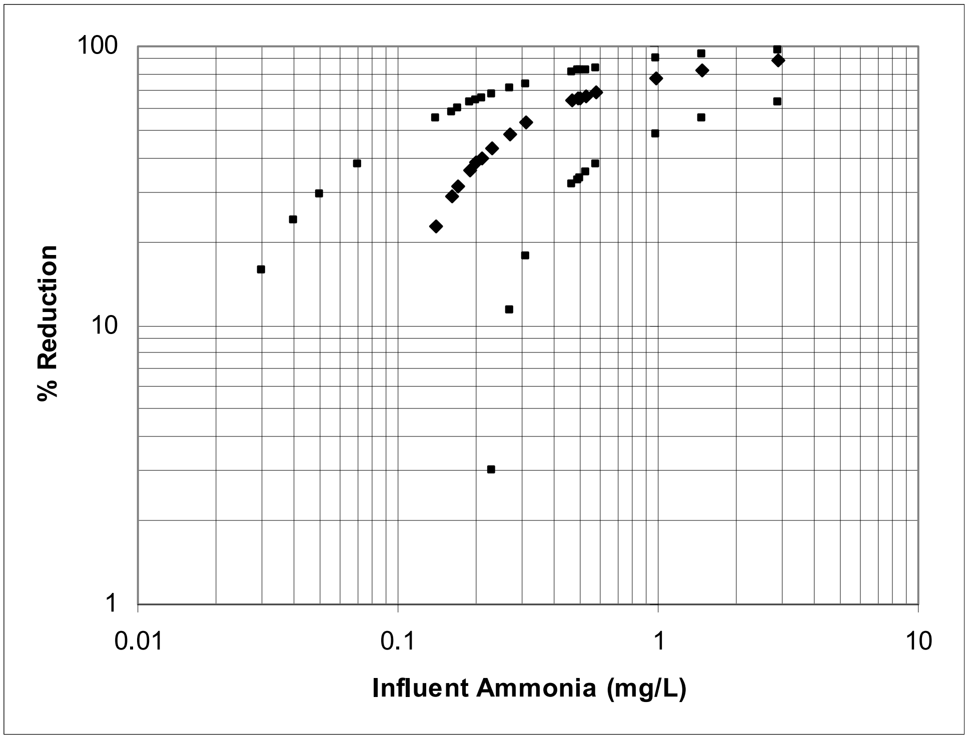
Fitted equation and data points for influent and effluent ammonia.



Residual analyses of fitted equation for ammonia influent vs. effluent.



Predicted effluent concentrations for different influent concentrations, with 95% confidence limits.



Percentage reductions as a function of influent concentrations, with 95% confidence limits.

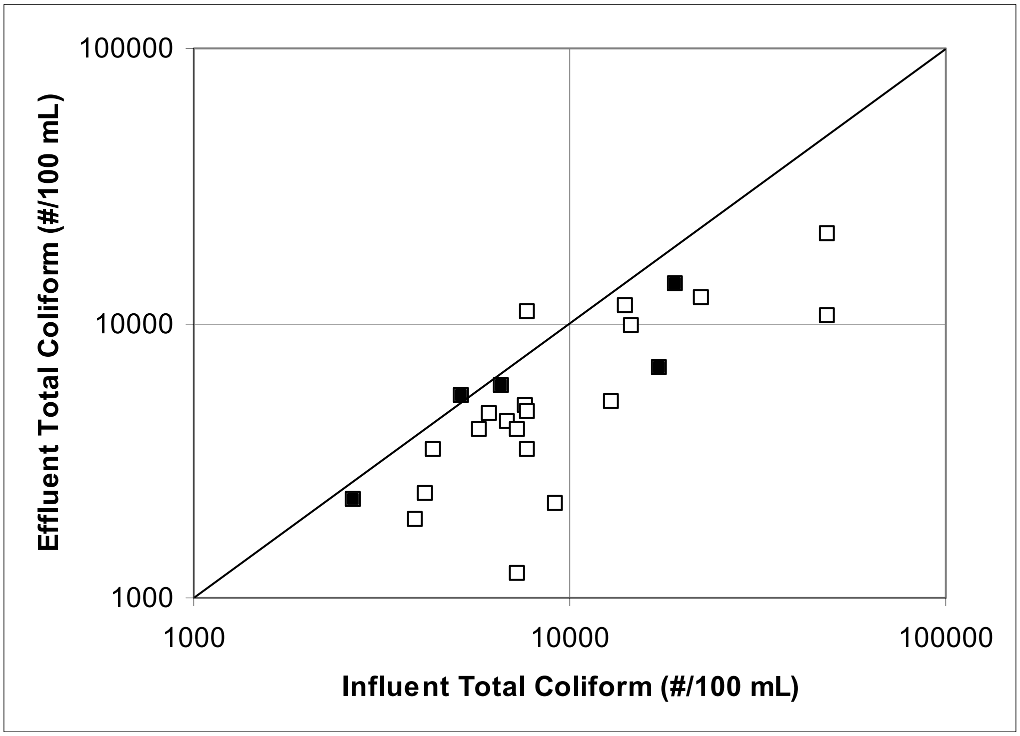
Total Coliforms

Comparison of Total Coliform for storm events

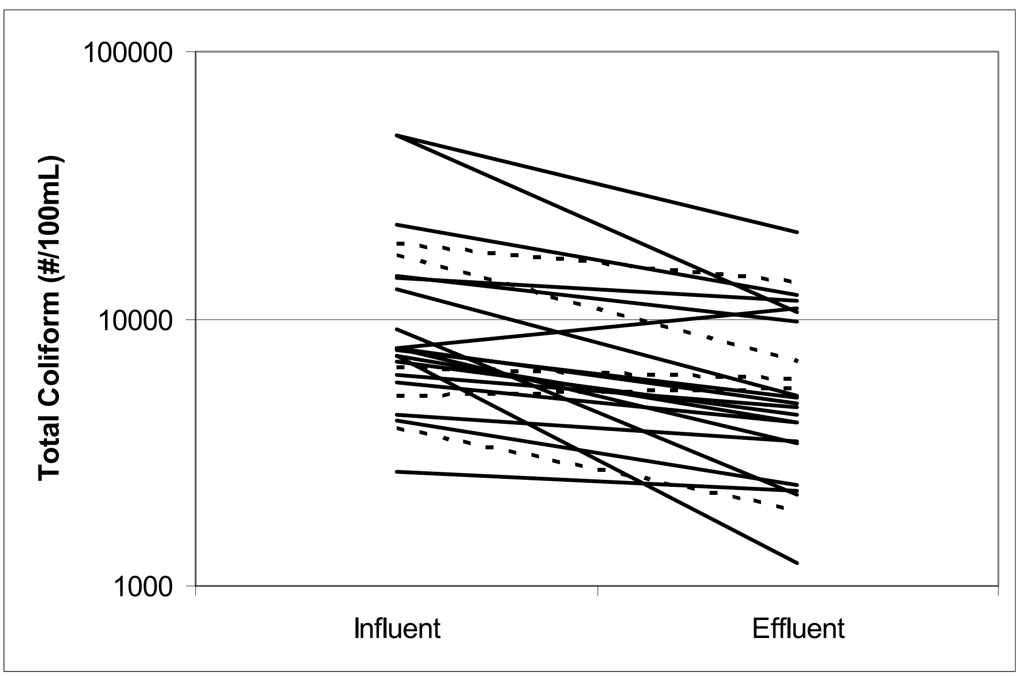
Observed Total Coliforms Counts

Sample Number	Influent (#/100 mL)	Effluent (#/100 mL)	% reduc
1-1	48384	20924.8	57
2-1	7754	10950	-41
2-2	22397	12262	45
3-1	7701	4786	38
3-2	9208	2209	76
4-1	2656	2277	14
4-2	3877	1937	50
5-1	14540	9768	33
5-2	6628	5944	10
6-1	4352	3448	21
6-2	6131	4701	23
6-3	5794	4106	29
6-4	4160	2382	43
6-5	6867	4386	36
7-1	7270	1220	83
7-2	14136	11620	18
7-3	17328.7	6910	60
7-4	5172	5468	-6
7-5	12996.5	5172	60
7-6	7270	4106	44
8-1	48394	10670	78
8-2	19212	13820	28
9-1	7622	5026	34
10-1	7770	3440	56
min	2656.000	1220.000	-41
max	48394.000	20924.800	83
average	12400.842	6563.867	37
median	7661.500	4906.000	37
st dev	12192.521	4741.179	28
COV	1.0	0.7	1

Probability that influent = effluent (nonparametric sign test): 0.00 (>99% confident that influent ≠ effluent), therefore statistically significant at least at the α 0.05 level.



Scatterplot of observed influent and effluent total coliforms concentrations (filled symbols are events that had minor filter bypasses).



Paired influent and effluent total coliforms concentrations.

Fitted Equation:

Effluent total coliforms, log #/100 mL = 0.937 * (Influent total coliforms, log #/100 mL)

Regression Statistics

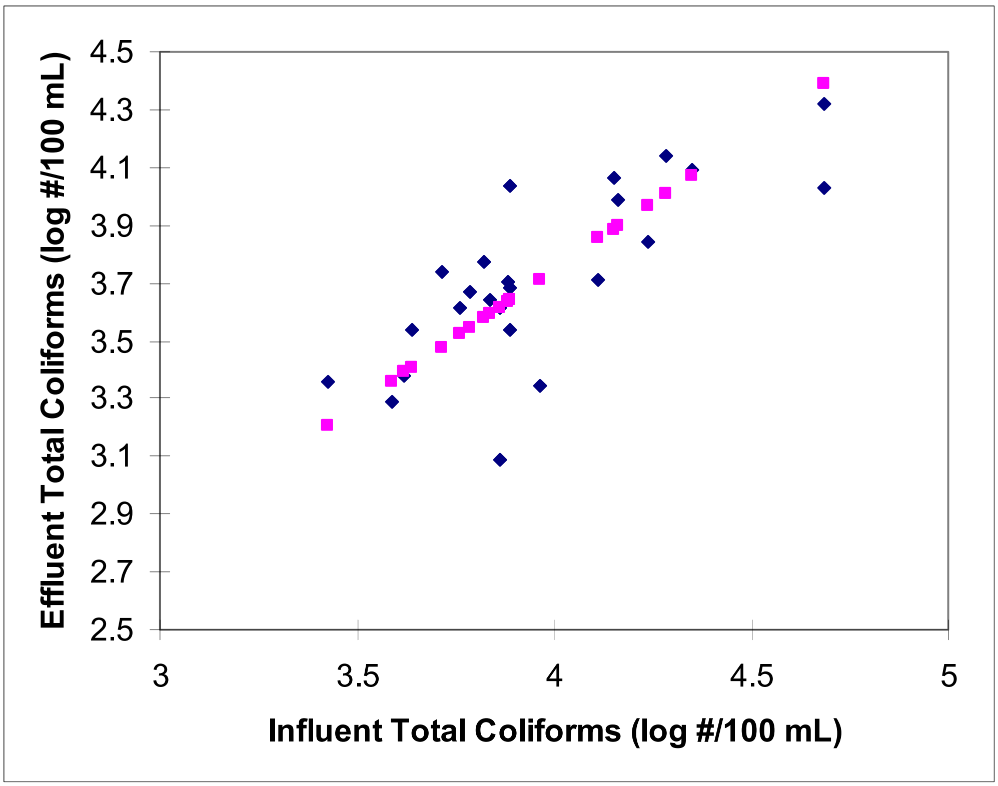
Multiple R	0.999
R Square	0.997
Adjusted R Square	0.953
Standard Error	0.208
Observations	24

ANOVA

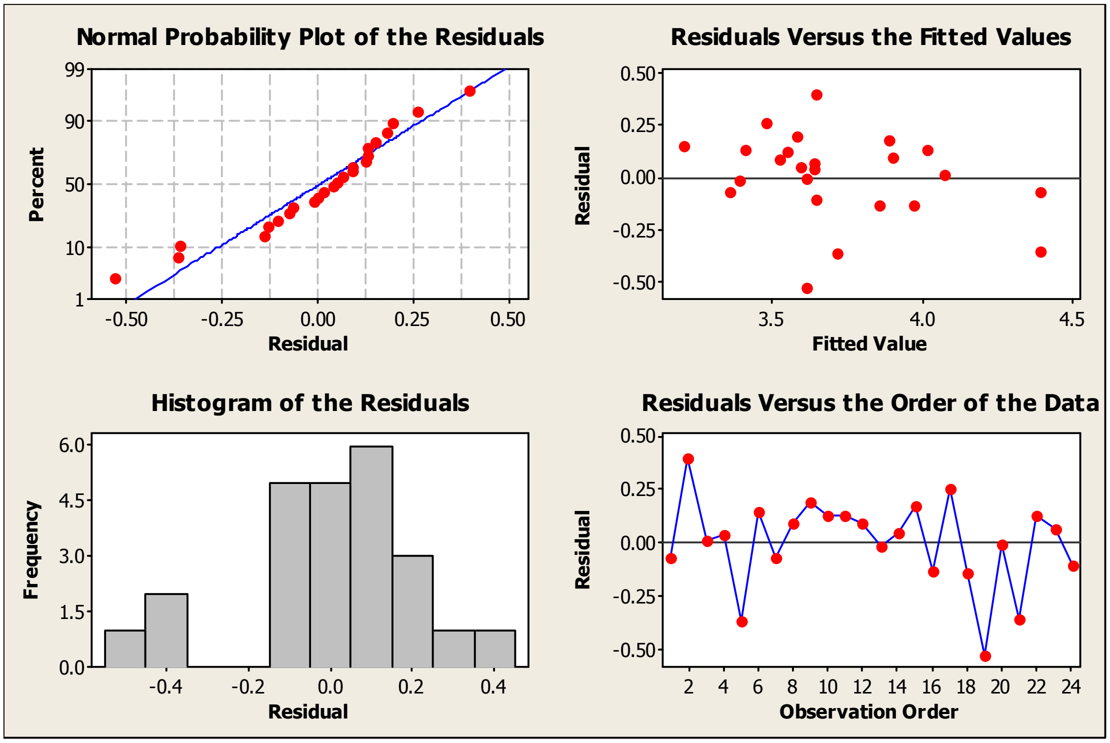
	df	SS	MS	F	Significance F
Regression	1	333	333	7688	1.72E-29
Residual	23	0.995	0.0433		
Total	24	334			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Influent Total Coliform*	0.937	0.0107	87.7	1.450E-30	0.914	0.965

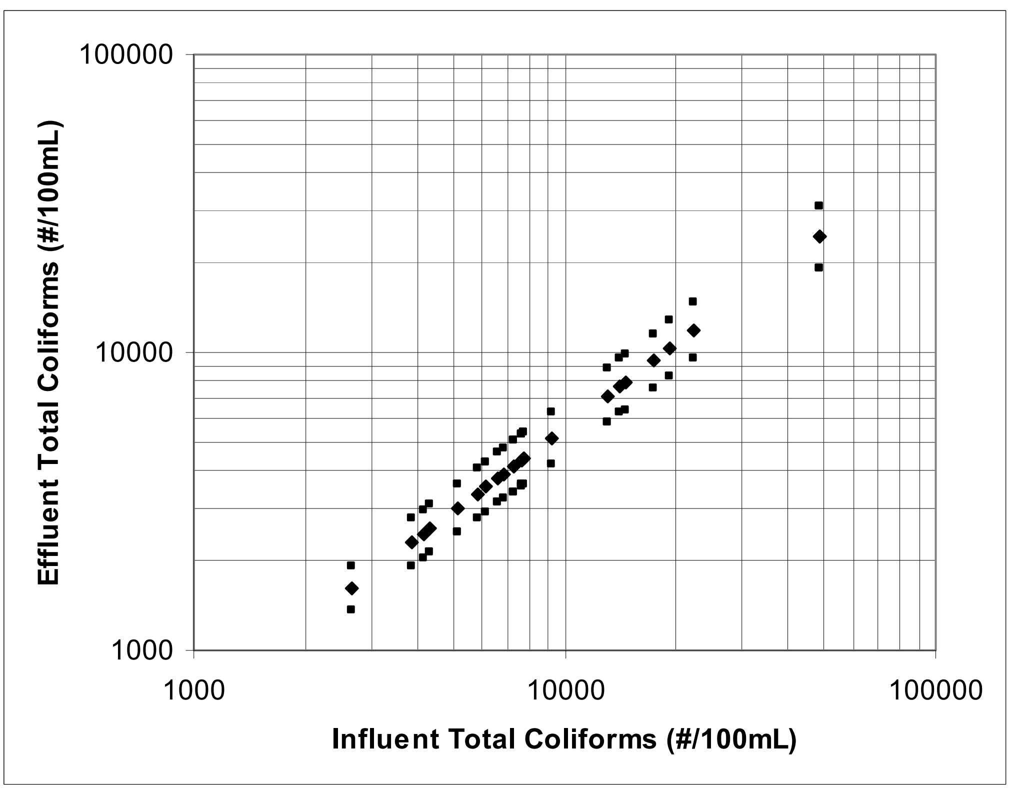
* the intercept term was determined to be not significant



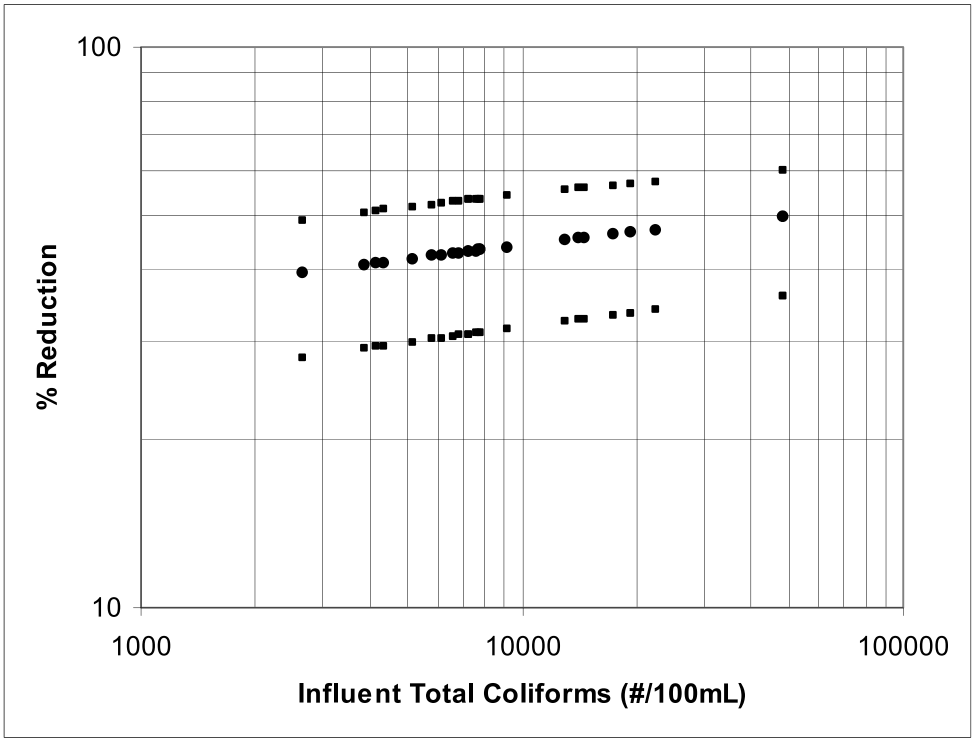
Fitted equation and data points for influent and effluent total coliforms.



Residual analyses of fitted equation for total coliforms influent vs. effluent.



Predicted effluent concentrations for different influent concentrations, with 95% confidence limits.



Percentage reductions as a function of influent concentrations, with 95% confidence limits.

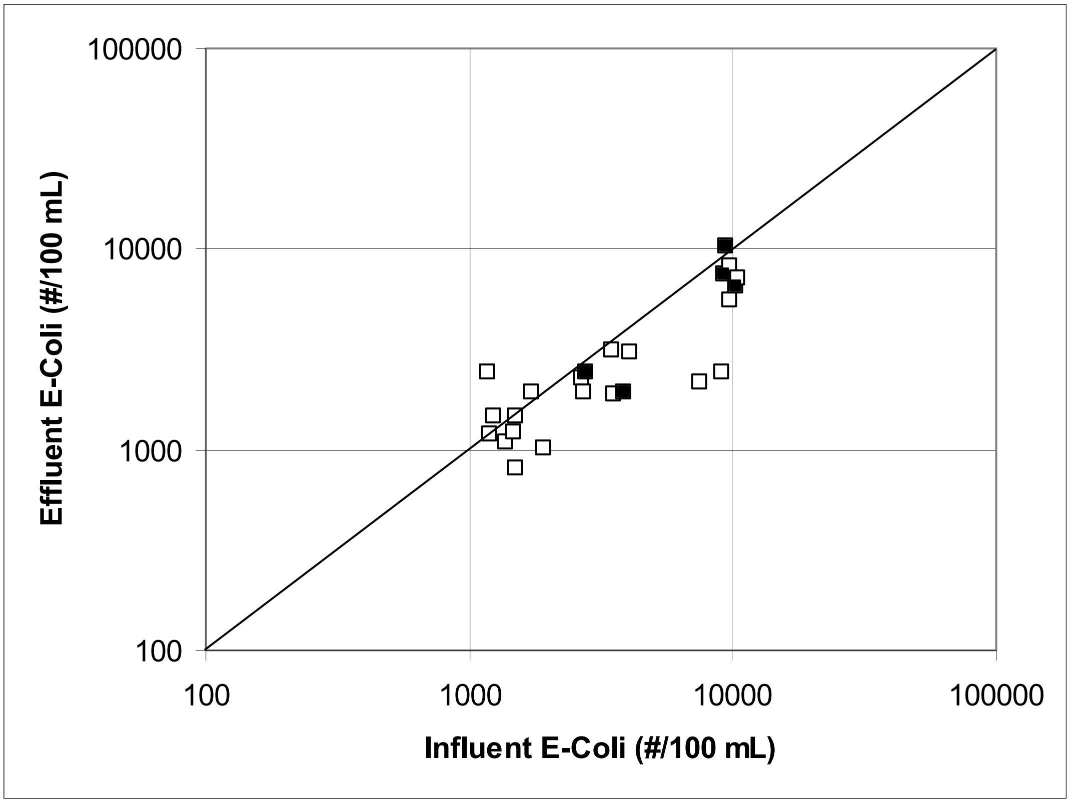
E. Coli.

Comparison of E. coli for storm events

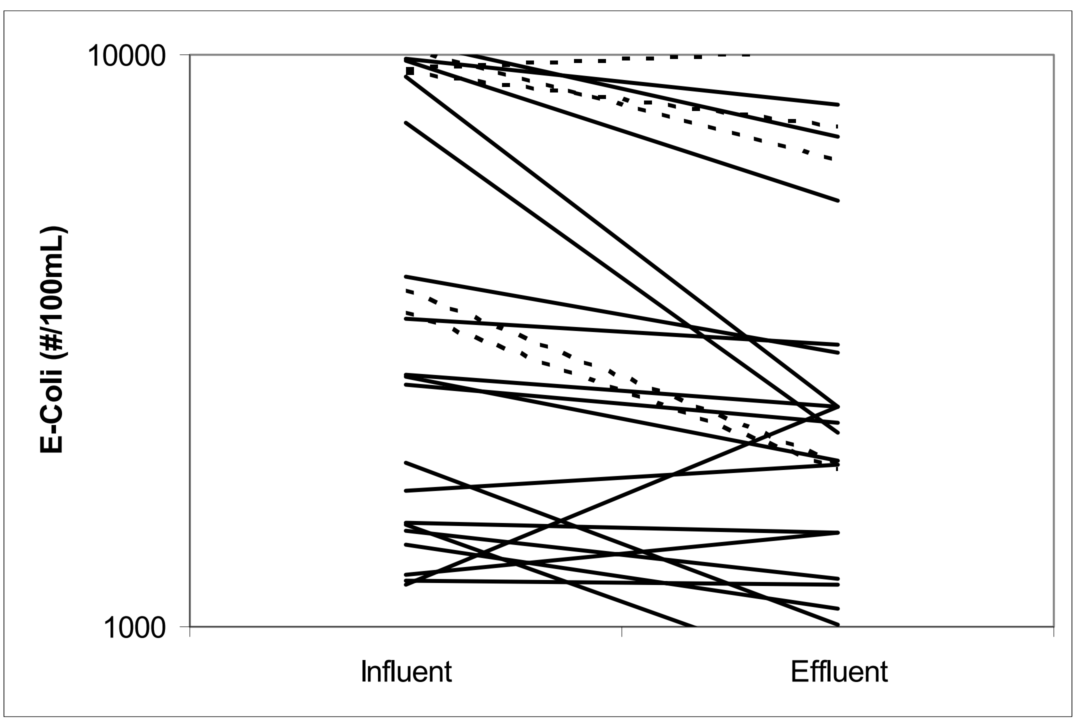
Observed E. coli Counts

Sample Number	Influent (#/100 mL)	Effluent (#/100 mL)	% reduc
1-1	1466	1218	17
2-1	1202	1182	2
2-2	1390	1076	23
3-1	2656	2277	14
3-2	1508	808	46
4-1	3877	1937	50
4-2	2750	2430	12
5-1	3540	1890	47
5-2	3458	3122	10
6-1	1236	1457	-18
6-2	1187	2419	-104
6-3	1935	1011	48
6-4	1725	1918	-11
6-5	1515	1455	4
7-1	10560	7180	32
7-2	9300	7460	20
7-3	10240	6540	36
7-4	9740	5560	43
7-5	7580	2180	71
7-6	9140	2420	74
8-1	9814	8166	17
8-2	9442	10198	-8
9-1	4084	3024	26
10-1	2745	1952	29
min	1187.000	808.000	-104
max	10560.000	10198.000	74
average	4670.417	3286.667	20
median	3104.000	2228.500	21
st dev	3604.267	2666.438	35
COV	0.8	0.8	2

Probability that influent = effluent (nonparametric sign test): 0.00 (>99% confident that influent ≠ effluent), therefore statistically significant at least at the α 0.05 level.



Scatterplot of observed influent and effluent E. Coli. concentrations (filled symbols are events that had minor filter bypasses).



Paired influent and effluent E. Coli. concentrations.

Fitted Equation:

Effluent E. coli., log #/100 mL = 0.745 + 0.751 * (Influent E. coli., log #/100 mL)

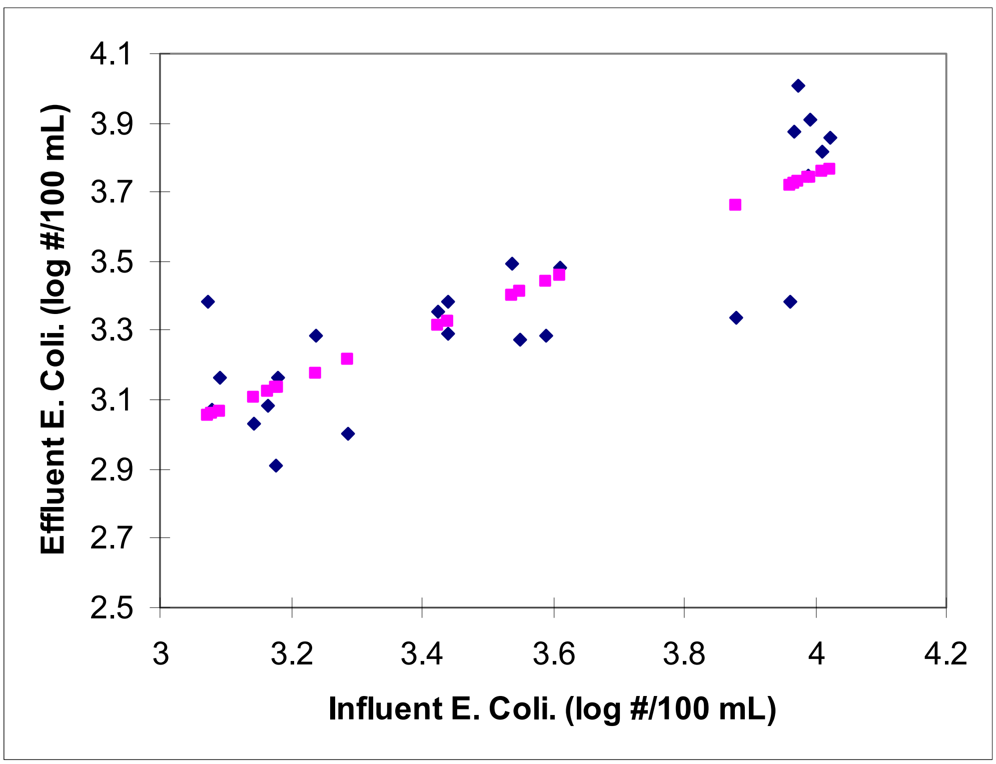
Regression Statistics

Multiple R	0.848
R Square	0.719
Adjusted R Square	0.706
Standard Error	0.171
Observations	24

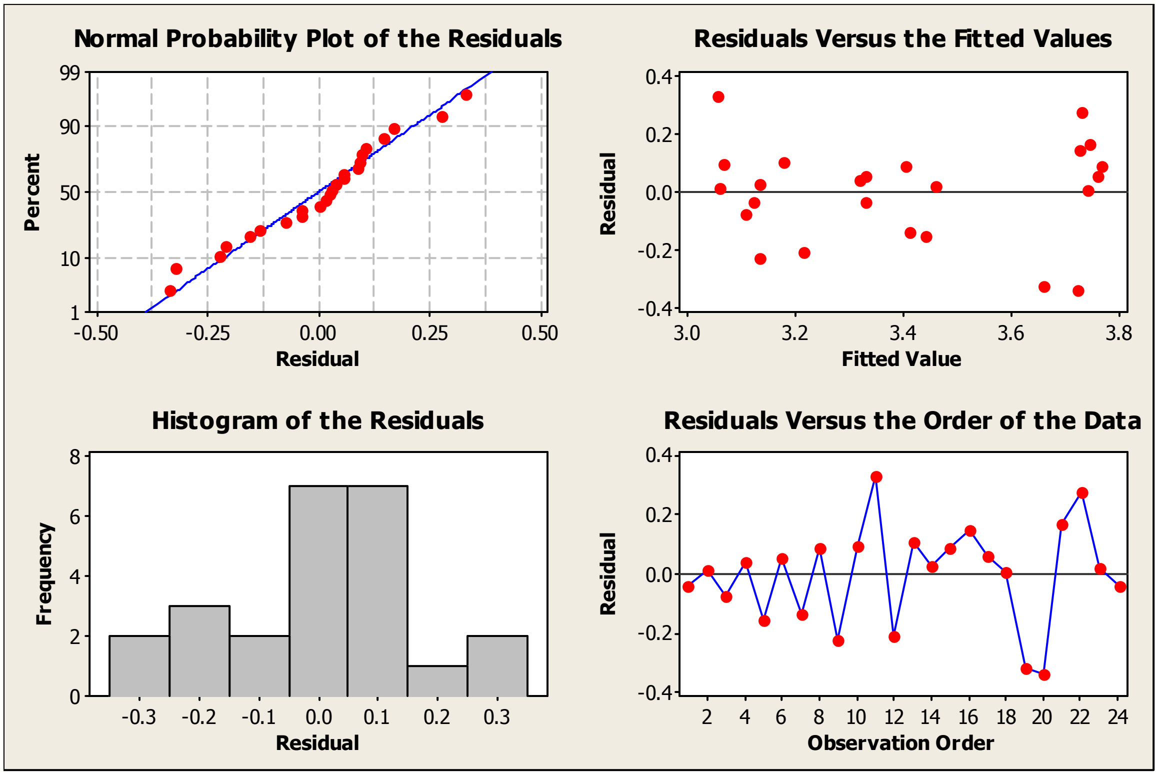
ANOVA

	df	SS	MS	F	Significance F
Regression	1	1.64	1.64	56.2	1.70E-07
Residual	22	0.642	0.0292		
Total	23	2.28			

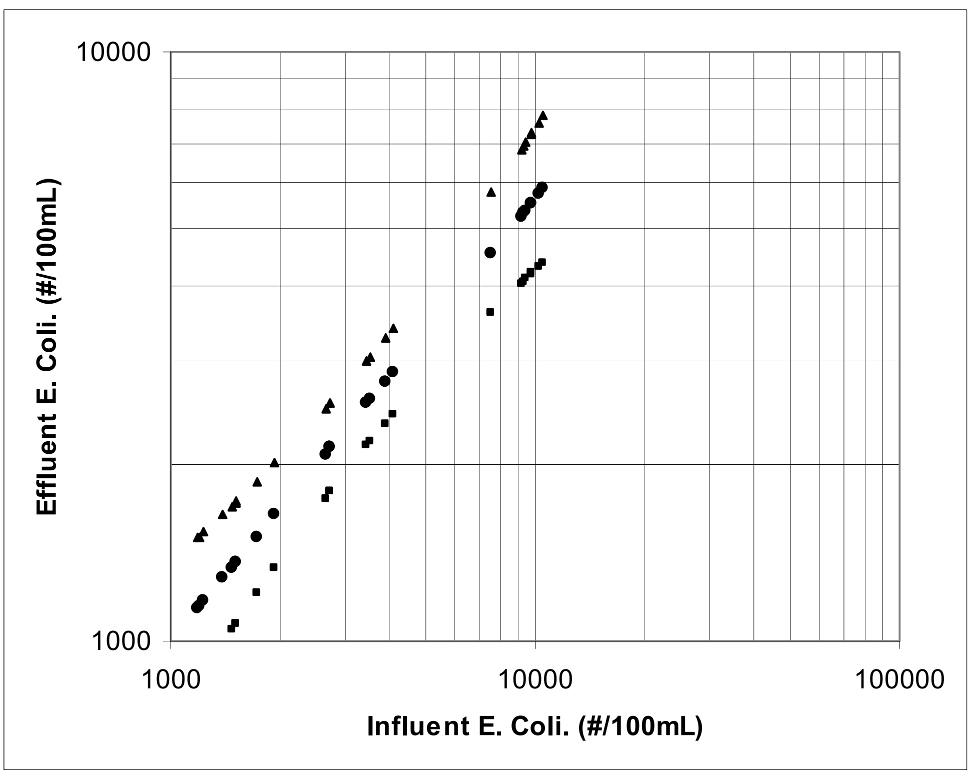
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0.745	0.356	2.09	0.0480	0.00718	1.48
Influent E-Coli	0.751	0.100	7.50	1.70E-07	0.543	0.959



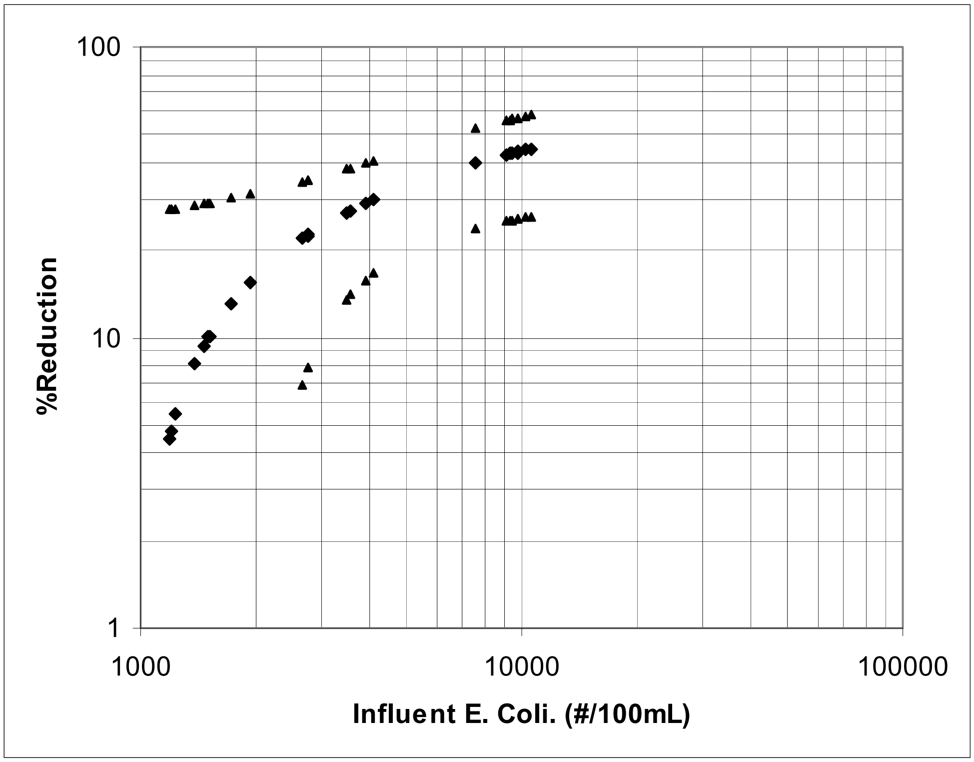
Fitted equation and data points for influent and effluent E. Coli.



Residual analyses of fitted equation for E. coli. influent vs. effluent.



Predicted effluent concentrations for different influent concentrations, with 95% confidence limits.



Percentage reductions as a function of influent concentrations, with 95% confidence limits.

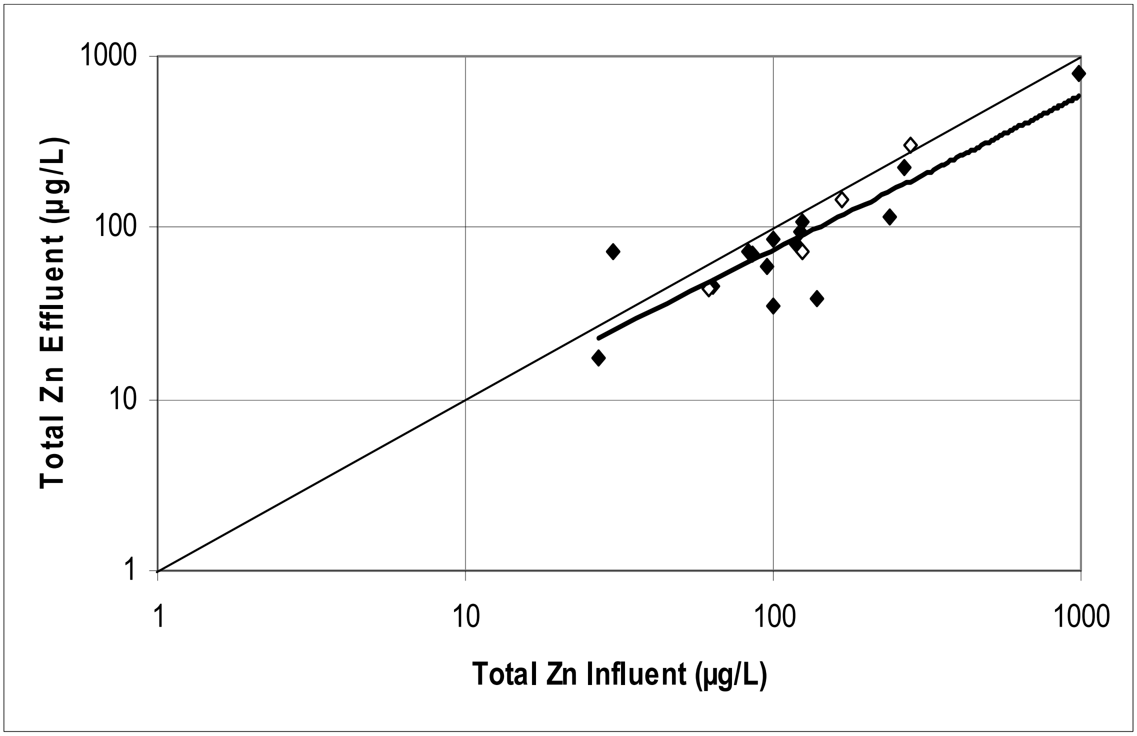
Total Zinc

Comparison of Total Zinc for storm events

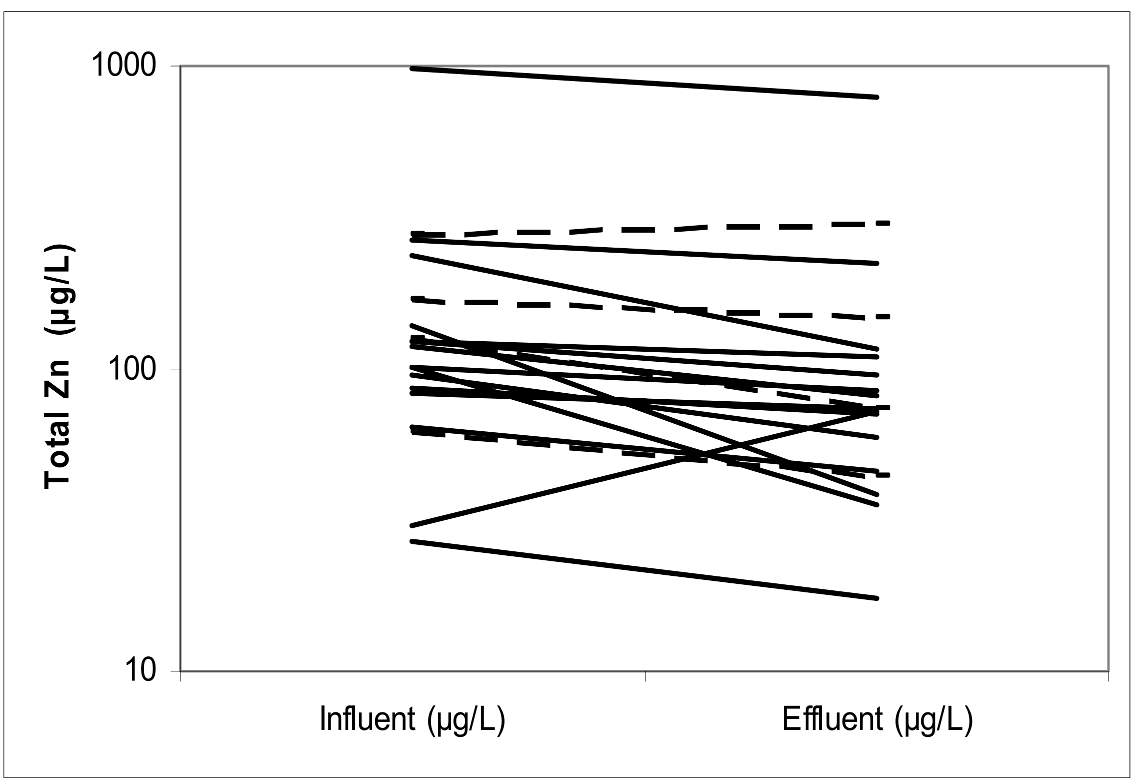
Observed Total Zinc Concentrations

Sample Number	Influent (ug/L)	Effluent (ug/L)	% reduc
1-1	118	81	31
2-1	123	95	23
5-1	267	221	17
5-2	168	147	13
6-1	101	85	16
6-2	86	70	19
6-3	83	73	12
6-4	95	60	37
6-5	100	35	65
7-1	124	109	12
7-2	125	73	42
7-3	62	44	29
7-4	27	17	37
7-5	30	72	-140
7-6	64	46	28
8-1	990	785	21
8-2	277	298	-8
9-1	139	38	73
10-1	237	115	51
min	27.000	17.000	-140
max	990.000	785.000	73
average	169.263	129.684	20
median	118.000	73.000	23
st dev	210.900	172.435	43
COV	1.2	1.3	2

Probability that influent = effluent (nonparametric sign test): 0.0007 (>99% confident that influent ≠ effluent), therefore statistically significant at least at the α 0.05 level.



Scatterplot of observed influent and effluent total Zn concentrations (unfilled symbols are events that had minor filter bypasses.



Paired influent and effluent total Zn concentrations (Sign test Significant P-value = 0.0007).

Fitted Equation:

Effluent Total Zn, log µg/L = 0.933 * (Influent Total Zn, log µg/L)

Regression Statistics on Observed Influent vs. Effluent Total Zn, log µg/L

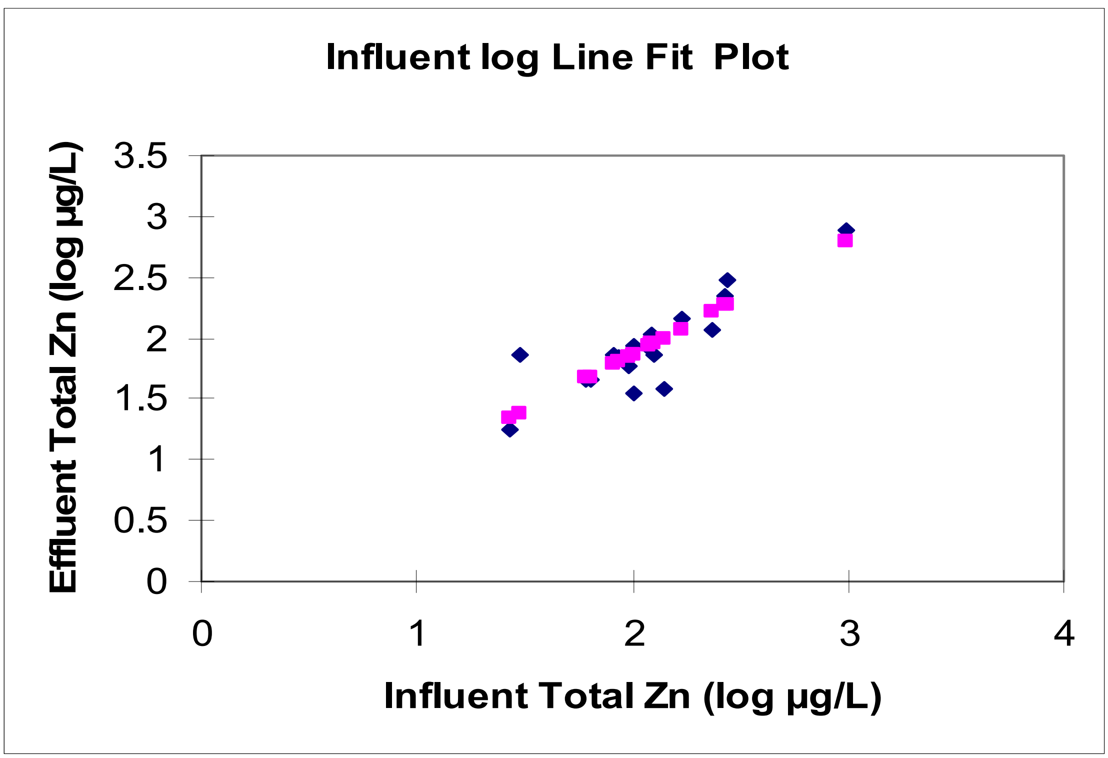
Multiple R	0.860
R Square	0.740
Adjusted R Square	0.684
Standard Error	0.187
Observations	19

ANOVA

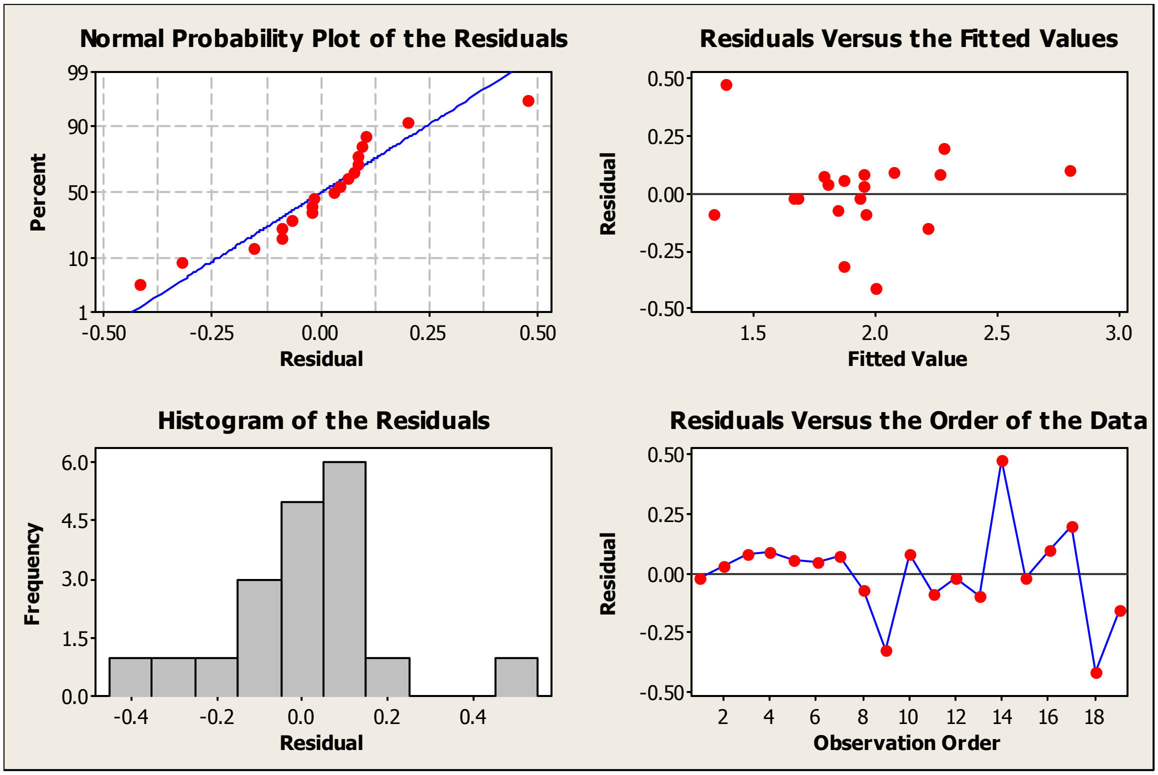
	df	SS	MS	F	Significance F
Regression	1	1.80	1.80	51.2	1.61E-06
Residual	18	0.632	0.0351		
Total	19	2.43			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Influent Total Zn	0.933	0.0205	45.5	4.93E-20	0.889	0.976

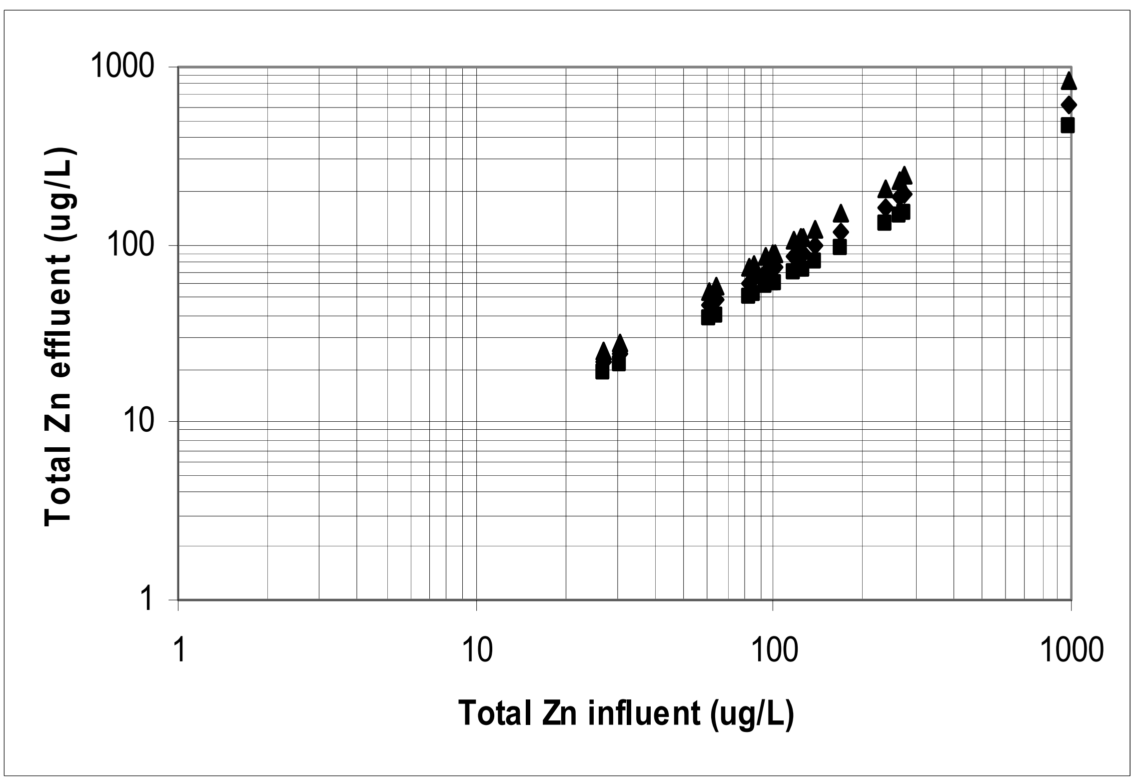
* the intercept term was determined to be not significant



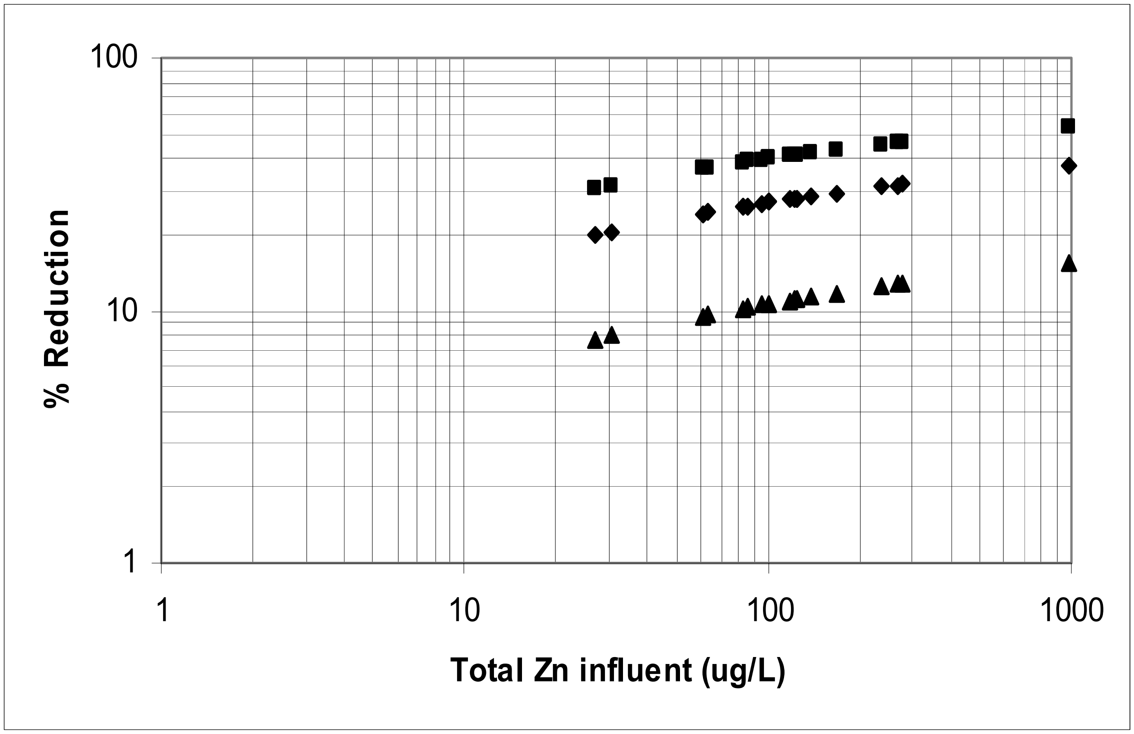
Fitted equation and data points for influent and effluent Total Zn.



Residual analyses of fitted equation for Total Zn influent vs. effluent.



Predicted effluent concentrations for different influent concentrations, with 95% confidence limits.



Percentage reductions as a function of influent concentrations, with 95% confidence limits.

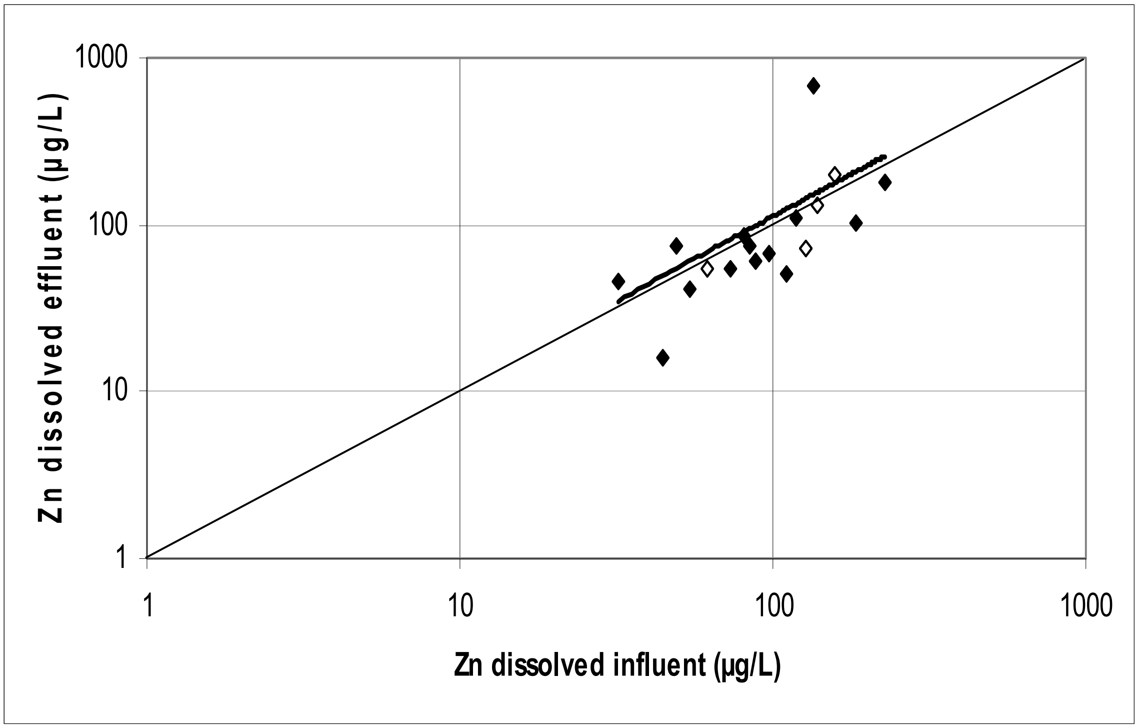
Dissolved Zinc

Comparison of dissolved zinc for storm events

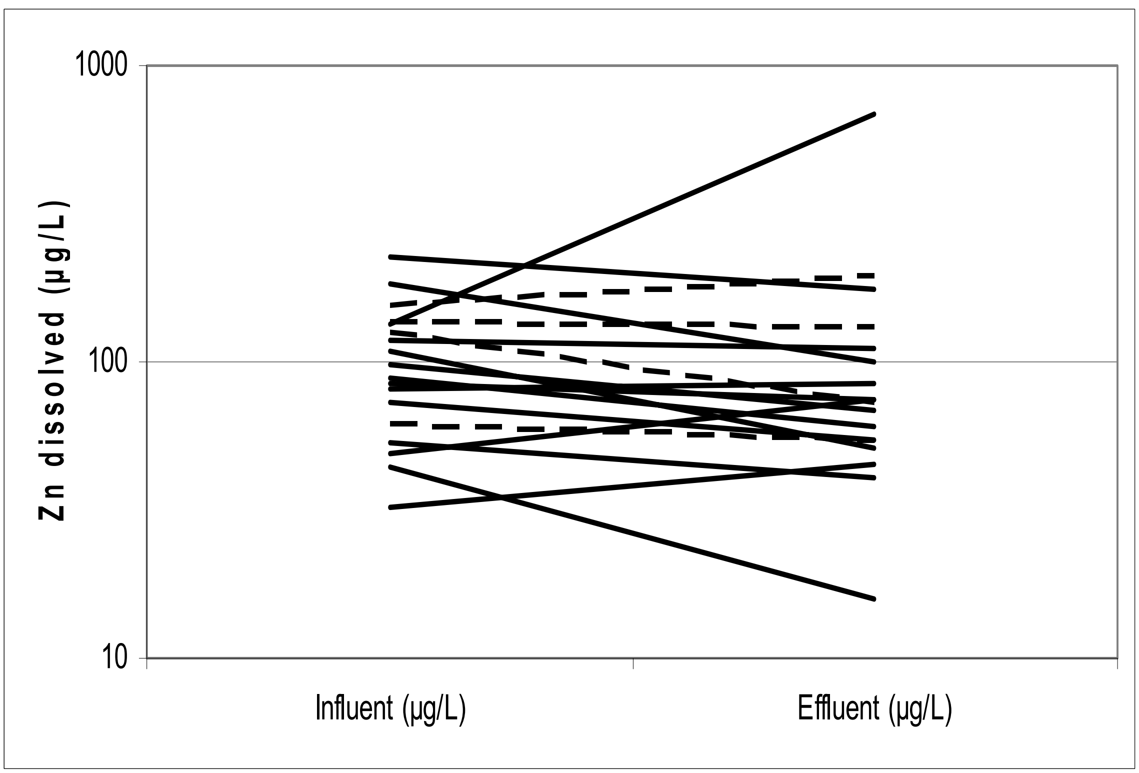
Observed Dissolved Zinc Concentrations

Sample Number	Influent (ug/L)	Effluent (ug/L)	% reduc
1-1	84.8	73.9	13
5-1	227.4	177.8	22
5-2	137.9	132	4
6-1	97.3	68.3	30
6-2	109.8	50.9	54
6-3	80.3	84.6	-5
6-4	87.5	60.6	31
6-5	73	54.8	25
7-1	118.2	110.8	6
7-2	127	72.8	43
7-3	61.8	54.3	12
7-4	53.9	40.7	24
7-5	49.4	74.8	-51
7-6	44.2	15.8	64
8-1	135.4	679.6	-402
8-2	156.5	196.57	-26
9-1	32	45.1	-41
10-1	183.7	100.7	45
min	32.000	15.800	-402
max	227.400	679.600	64
average	103.339	116.337	-8
median	92.400	73.350	17
st dev	51.716	148.059	103
COV	0.5	1.3	-12

Probability that influent = effluent (nonparametric sign test): 0.963 (4.7% confident that influent ≠ effluent), therefore not statistically significant at least at the α 0.05 level.



Scatterplot of observed influent and effluent dissolved Zn concentrations.



Paired influent and effluent dissolved Zn concentrations (Sign test Significant P-value = 0.96).

Fitted Equation:

Effluent Dissolved Zn, log µg/L = 0.9734 * (Influent Dissolved Zn, log µg/L)

Regression Statistics on Observed Influent vs. Effluent Dissolved Zn, log µg/L

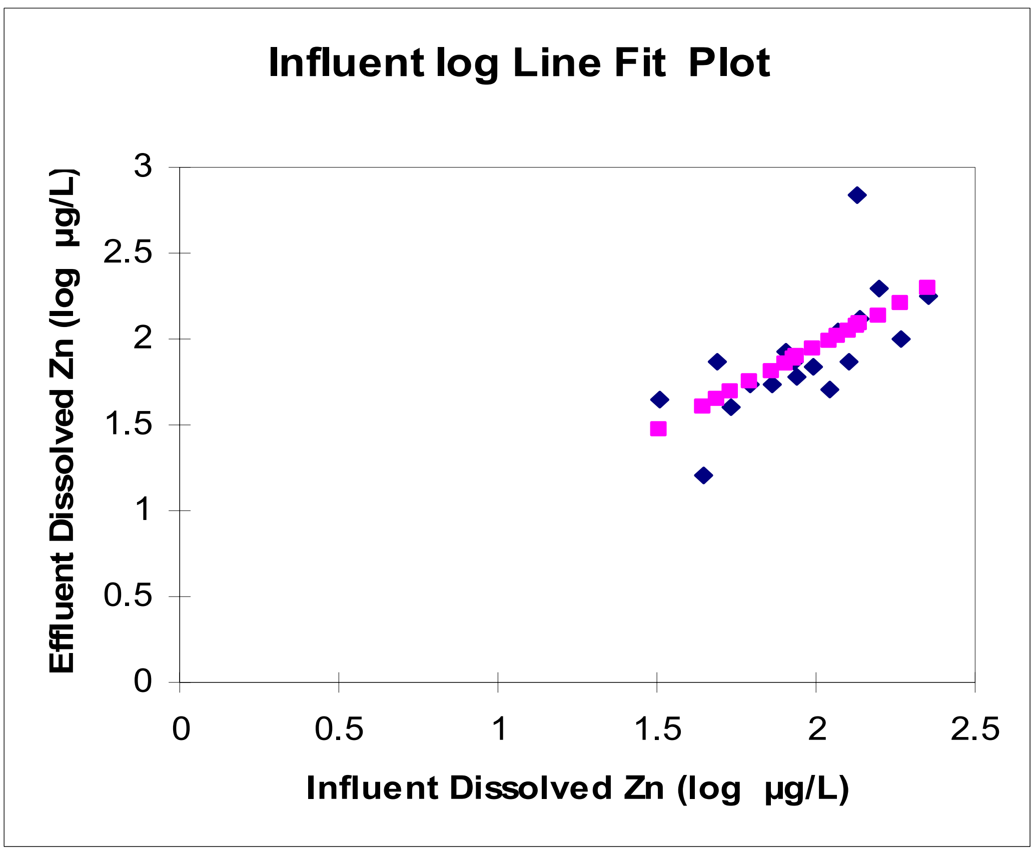
Multiple R	0.687
R Square	0.472
Adjusted R Square	0.413
Standard Error	0.248
Observations	18

ANOVA

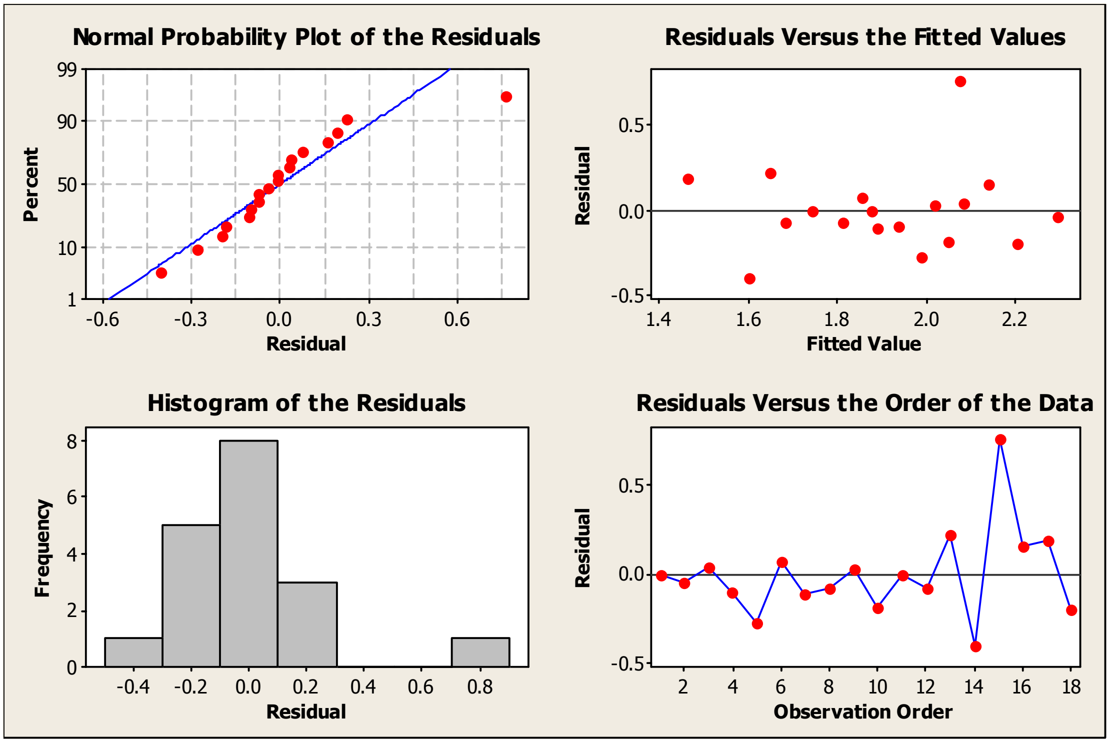
	df	SS	MS	F	Significance F
Regression	1	0.931	0.931	15.2	0.00129
Residual	17	1.04	0.061		
Total	18	1.97			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Influent Dissolved Zn	0.973	0.030	32.9	7.77E-17	0.911	1.04

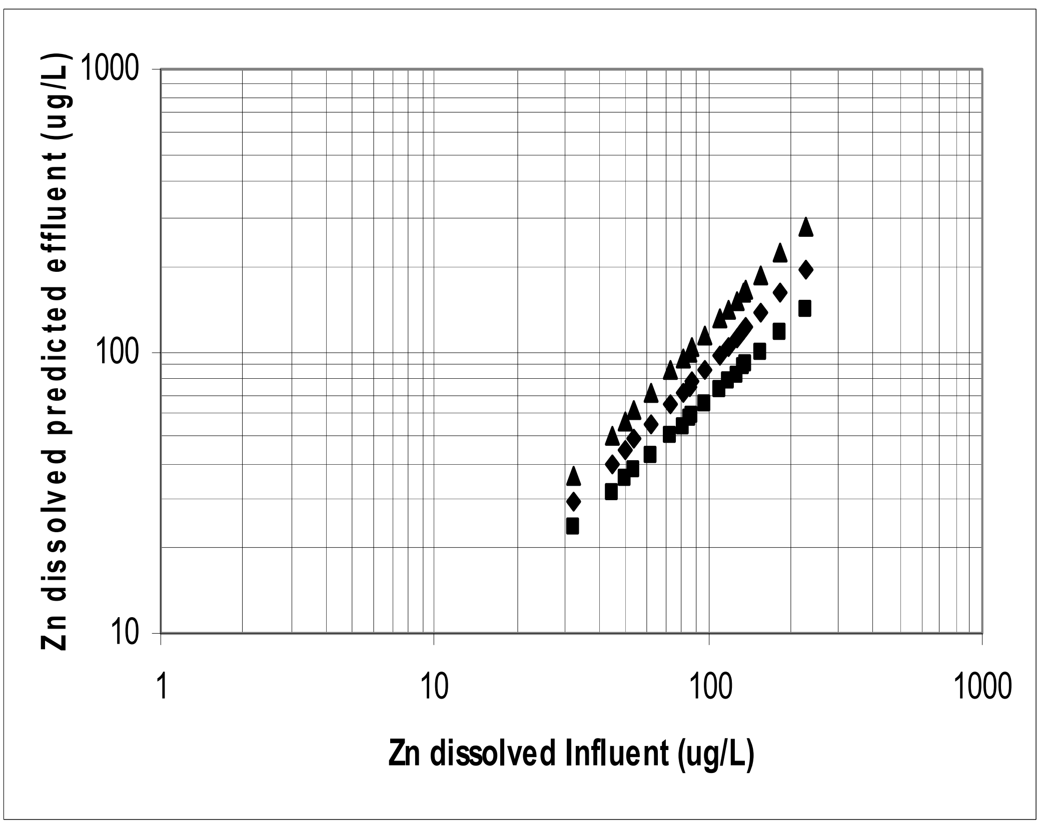
* the intercept term was determined to be not significant



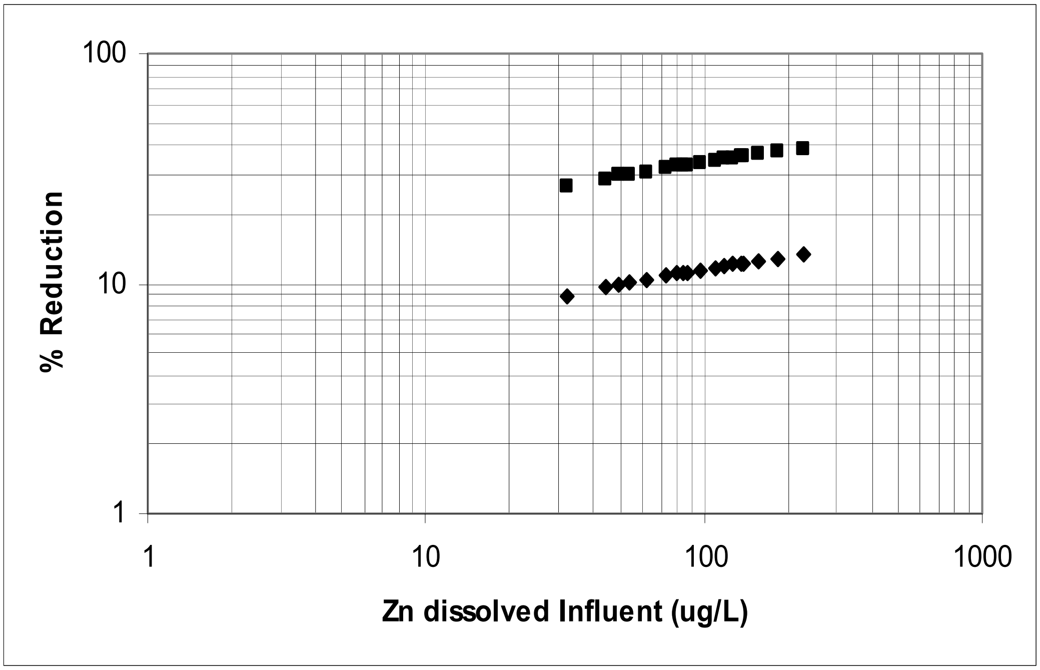
Fitted equation and data points for influent and effluent Dissolved Zn.



Residual analyses of fitted equation for Dissolved Zn influent vs. effluent.



Predicted effluent concentrations for different influent concentrations, with 95% confidence limits.



Percentage reductions as a function of influent concentrations, with 95% confidence limits.

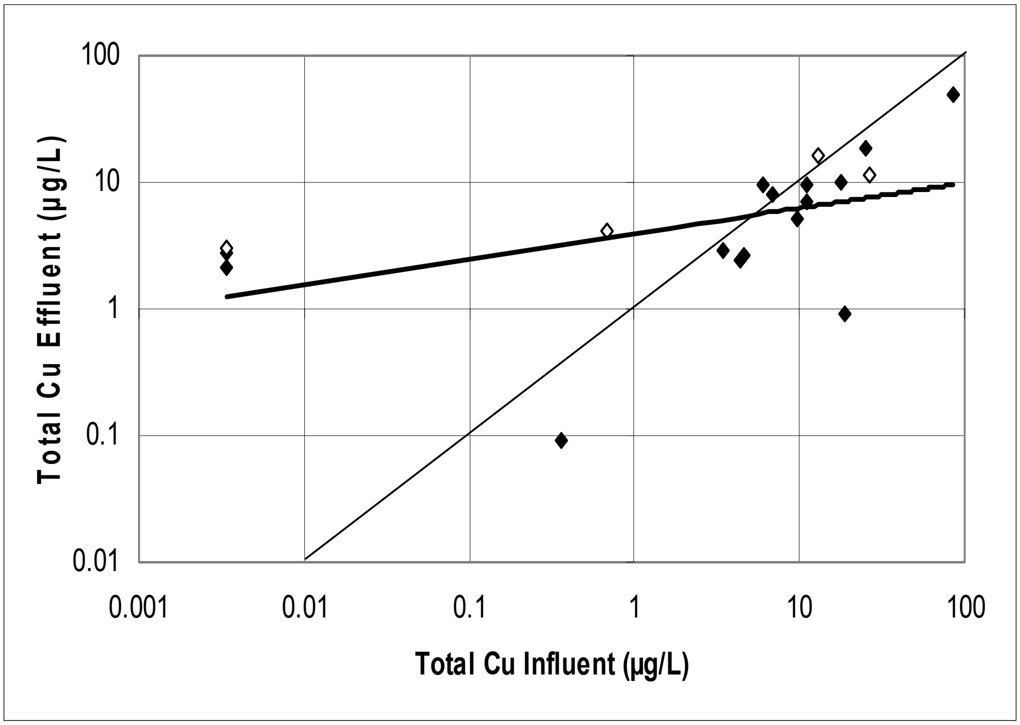
Total Copper

Comparison of Total Copper for storm events

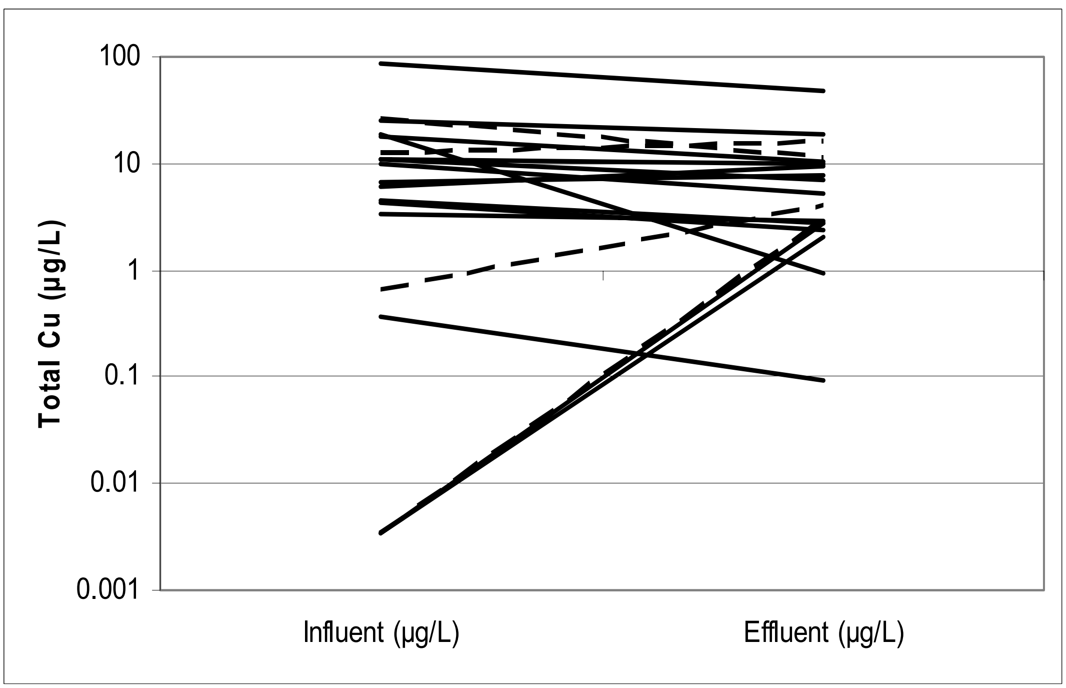
Observed Total Copper Concentrations

Sample Number	Influent (ug/L)	Effluent (ug/L)	% reduc
1-1	4.6	2.7	41
2-1	9.7	5.2	46
5-1	25.5	18.9	26
5-2	13	16.5	-27
6-1	18	10.2	43
6-2	6.8	7.9	-16
6-3	3.4	2.9	15
6-4	4.4	2.4	45
6-5	19	0.9	95
7-1	6	9.4	-57
7-2	0.7	4	-471
7-3	0.003	3.1	-103233
7-4	0.003	2.1	-69900
7-5	0.003	2.7	-89900
7-6	0.4	0.1	75
8-1	85.8	48.2	44
8-2	26.3	11.5	56
9-1	11.2	7	38
10-1	11	9.7	12
min	0.003	0.100	-103233
max	85.800	48.200	95
average	12.937	8.705	-13846
median	6.800	5.200	26
st dev	19.512	10.877	33319
COV	1.5	1.2	-2

Probability that influent = effluent (nonparametric sign test): 0.3593 (64.1% confident that influent ≠ effluent), therefore not statistically significant at least at the α 0.05 level.



Scatterplot of observed influent and effluent total Cu concentrations.



Paired influent and effluent total Cu concentrations (Sign test Significant P-value = 0.36).

Fitted Equation:

Effluent Total Cu, log µg/L = 0.598 + 0.1991 * (Influent Total Cu, log µg/L)

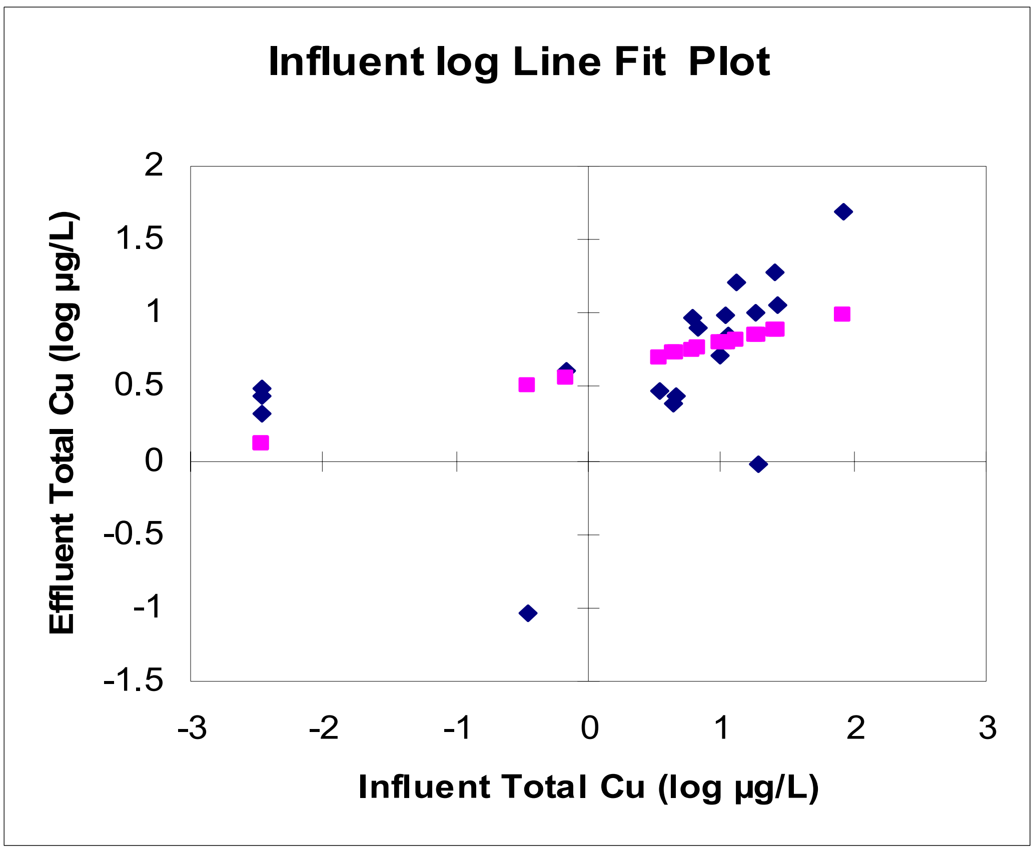
Regression Statistics on Observed Influent vs. Effluent Total Cu, log µg/L

Multiple R	0.470
R Square	0.221
Adjusted R Square	0.175
Standard Error	0.527
Observations	19

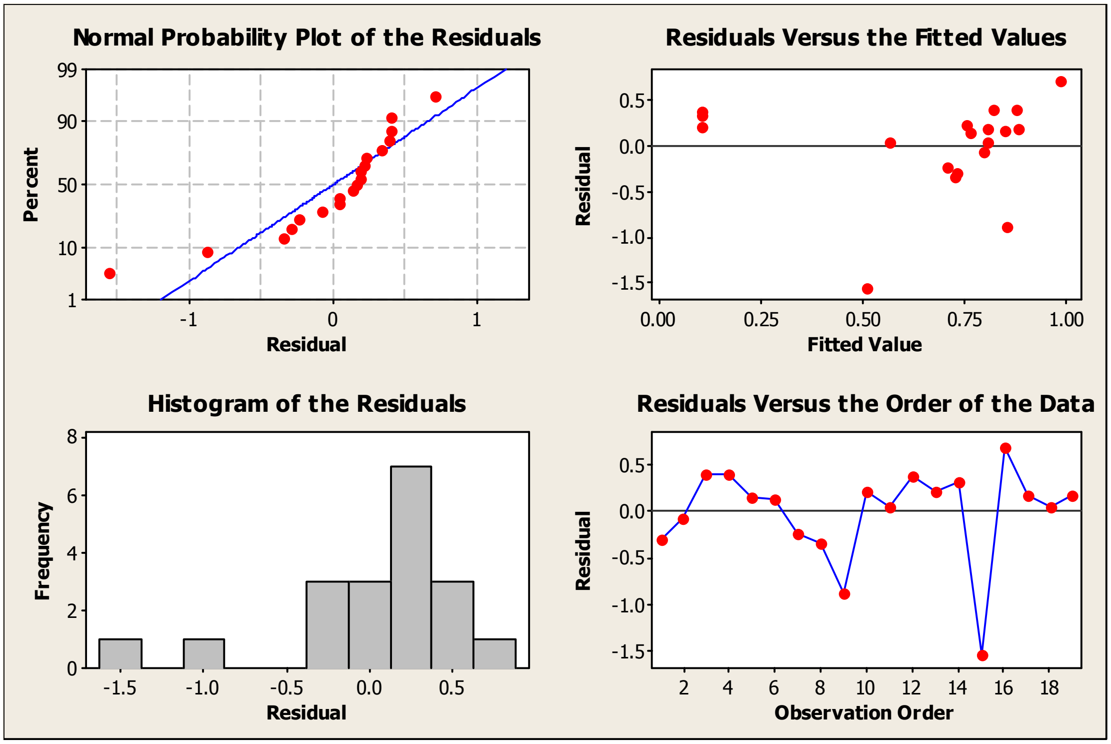
ANOVA

	df	SS	MS	F	Significance F
Regression	1	1.34	1.34	4.82	0.0424
Residual	17	4.72	0.278		
Total	18	6.06			

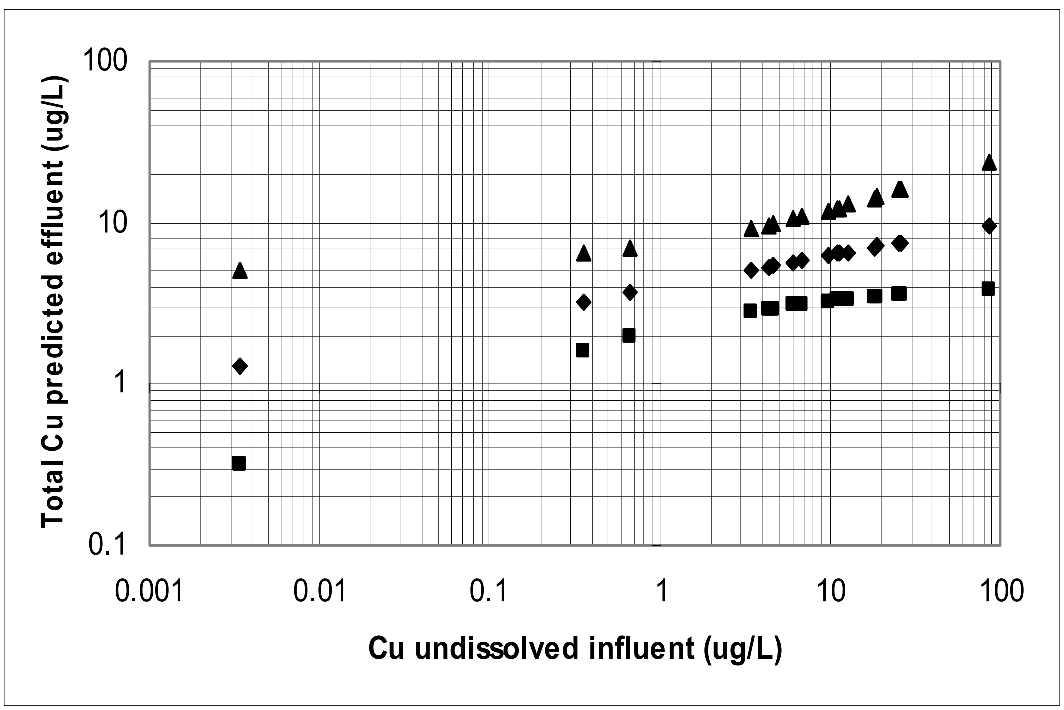
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0.597	0.125	4.76	0.000180	0.333	0.862
Influent Total Cu	0.199	0.0907	2.20	0.0423	0.00773	0.391



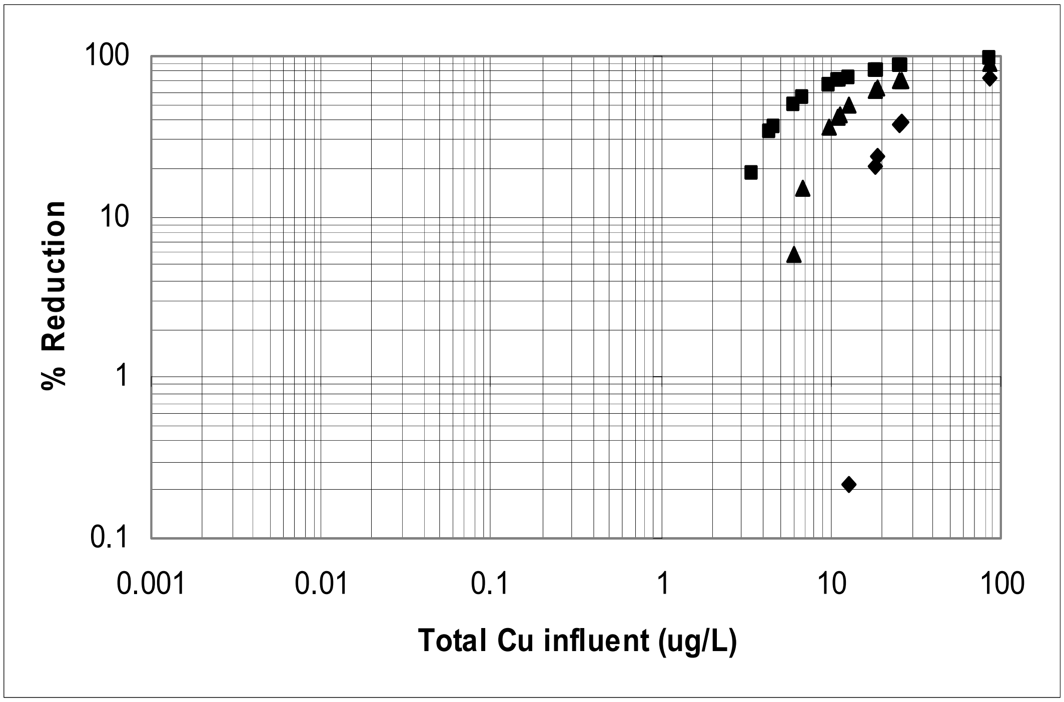
Fitted equation and data points for influent and effluent Total Cu.



Residual analyses of fitted equation for Total Cu influent vs. effluent.



Predicted effluent concentrations for different influent concentrations, with 95% confidence limits.



Percentage reductions as a function of influent concentrations, with 95% confidence limits.

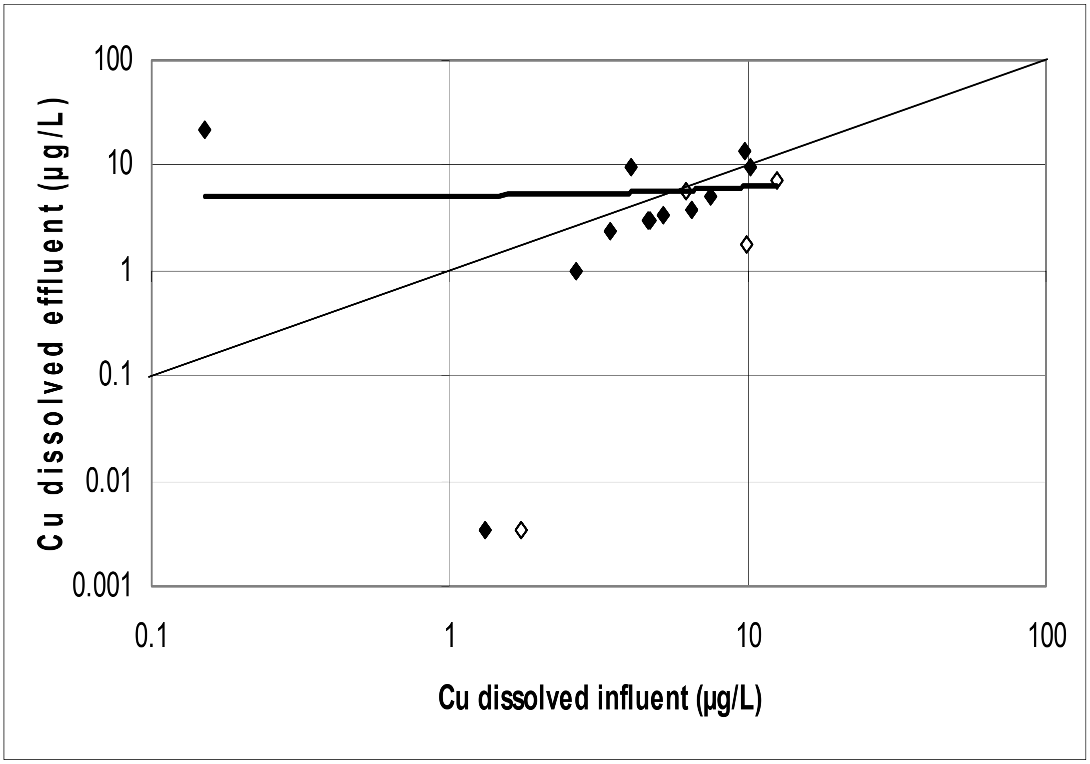
Dissolved Copper

Comparison of dissolved copper for storm events

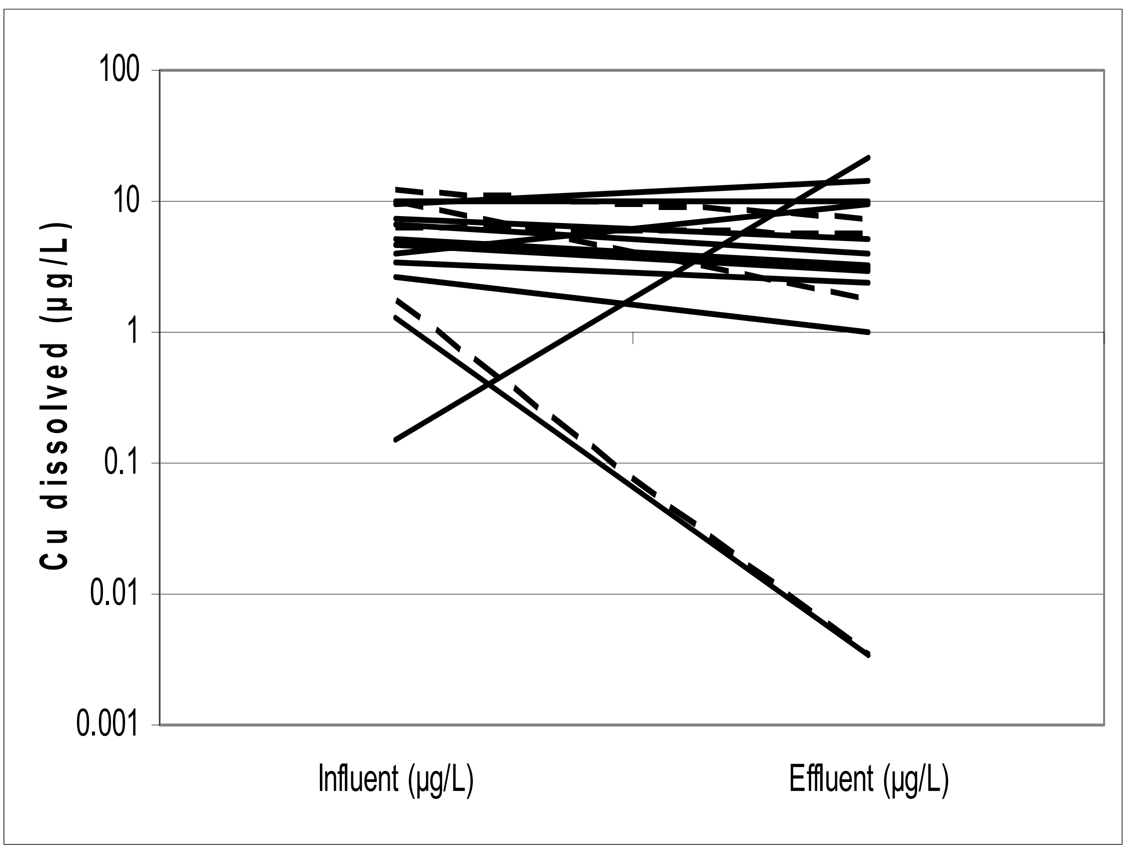
Observed Dissolved Copper Concentrations

Sample Number	Influent (ug/L)	Effluent (ug/L)	% reduc
1-1	3.43	2.35	31
5-1	9.73	14.07	-45
5-2	12.5	7.27	42
6-1	10.18	9.83	3
6-2	6.49	3.9	40
6-3	5.2	3.32	36
6-4	4.72	3	36
6-5	2.67	0.98	63
7-1	4.08	9.44	-131
7-2	9.85	1.77	82
7-3	1.73	0.0034	100
7-6	1.32	0.0034	100
8-1	0.15	22.07	-14613
8-2	6.24	5.76	8
9-1	4.63	3.02	35
10-1	7.55	5.2	31
min	0.150	0.003	-14613
max	12.500	22.070	100
average	5.654	5.749	-886
median	4.960	3.610	35
st dev	3.551	5.825	3661
COV	0.6	1.0	-4

Probability that influent = effluent (nonparametric sign test): 0.0213 (97.9% confident that influent ≠ effluent), therefore statistically significant at least at the α 0.05 level.



Scatterplot of observed influent and effluent dissolved Cu concentrations.



Paired influent and effluent dissolved Cu concentrations (Sign test significant P-value = 0.02).

The ANOVA evaluations of the alternative regression equations for dissolved copper did not show any significant equations or equation coefficients.

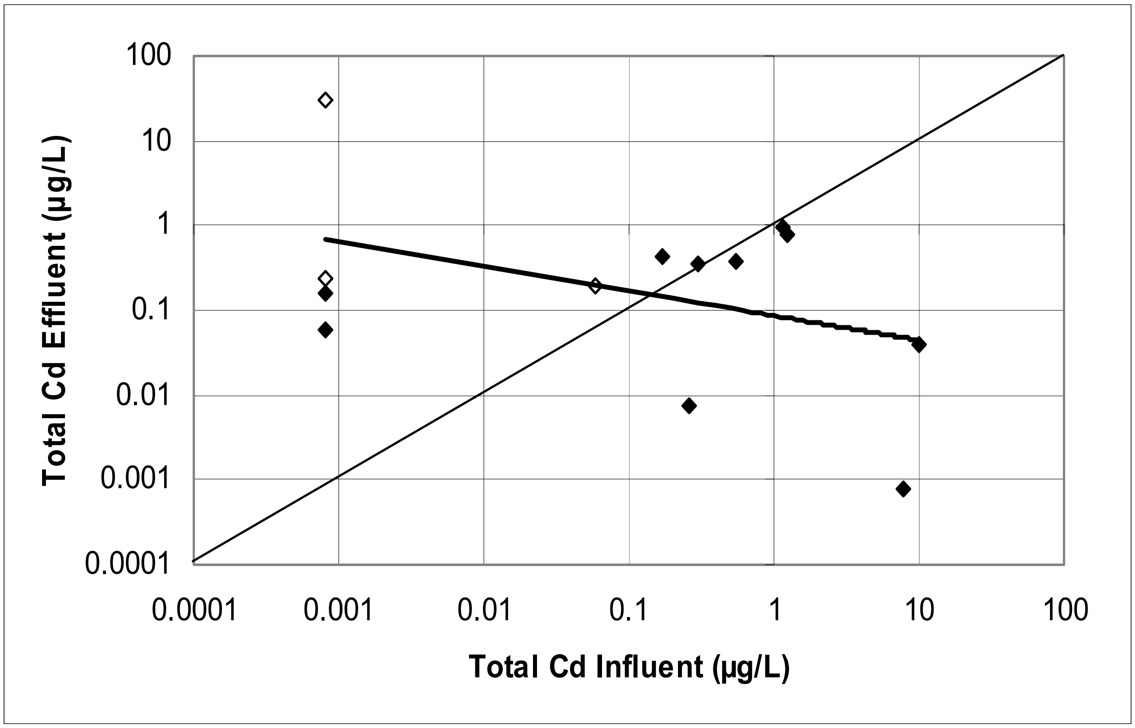
Total Cadmium

Comparison of Total Cadmium for storm events

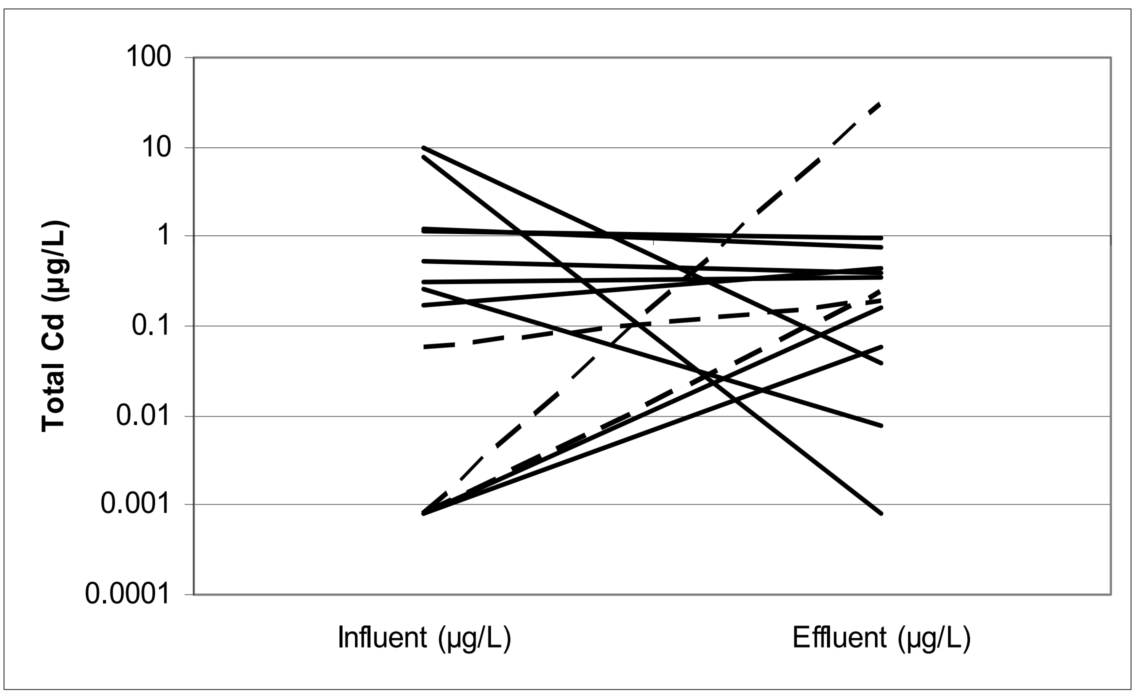
Observed Total Cadmium Concentrations

Sample Number	Influent (ug/L)	Effluent (ug/L)	% reduc
1-1	1.23	0.76	38
2-1	0.54	0.39	28
5-1	10	0.039	100
5-2	0.0008	29.92	-3739900
6-5	7.82	0.0008	100
7-1	0.0008	0.156	-19400
7-2	0.0008	0.24	-29900
7-5	0.0008	0.058	-7150
7-6	0.17	0.44	-159
8-1	1.15	0.95	17
8-2	0.058	0.2	-245
9-1	0.26	0.008	97
10-1	0.3	0.36	-20
min	0.001	0.001	-3739900
max	10.000	29.920	100
average	1.656	2.579	-292030
median	0.260	0.240	-20
st dev	3.276	8.220	1035998
COV	2.0	3.2	-4

Probability that influent = effluent (nonparametric sign test): 1 (0% confident that influent ≠ effluent), therefore not statistically significant at least at the α 0.05 level.



Scatterplot of observed influent and effluent total Cd concentrations.



Paired influent and effluent total Cd concentrations (Sign test significant P-value = 1.0).

The ANOVA evaluations of the alternative regression equations for total cadmium did not show any significant equations or equation coefficients.

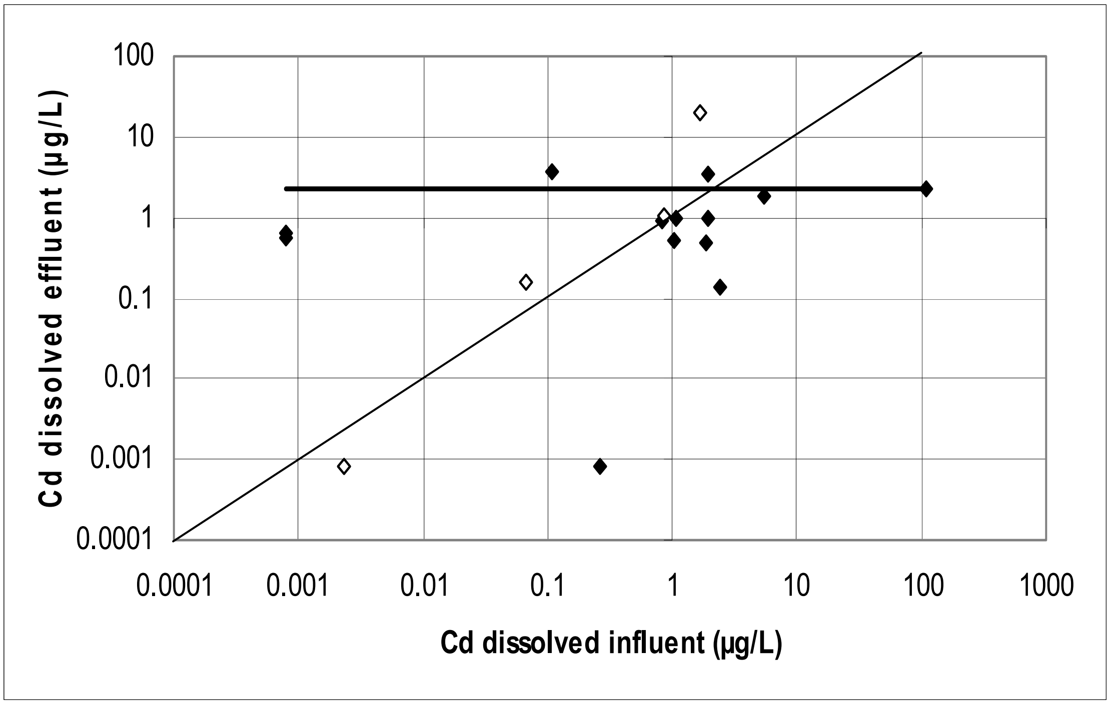
Dissolved Cadmium

Comparison of dissolved cadmium for storm events

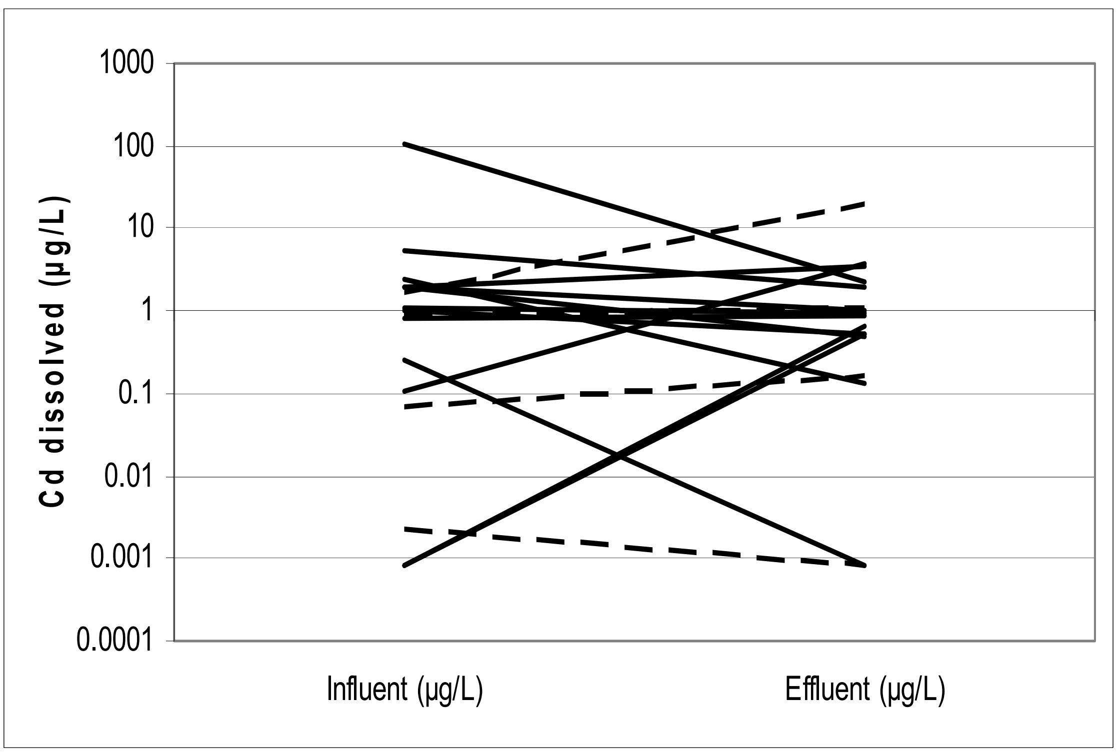
Observed Dissolved Cadmium Concentrations

Sample Number	Influent (ug/L)	Effluent (ug/L)	% reduc
1-1	1.06	0.96	9
5-1	1.88	0.49	74
5-2	0.0023	0.0008	65
6-2	0.26	0.0008	100
6-3	0.0008	0.54	-67400
6-4	1.03	0.53	49
6-5	0.0008	0.65	-81150
7-1	109.1	2.23	98
7-2	0.86	1.06	-23
7-3	1.64	20.32	-1139
7-4	5.52	1.88	66
7-5	0.11	3.83	-3382
7-6	1.9	0.99	48
8-1	0.82	0.88	-7
8-2	0.067	0.16	-139
9-1	1.93	3.4	-76
10-1	2.46	0.13	95
min	0.001	0.001	-81150
max	109.100	20.320	100
average	7.567	2.238	-8983
median	1.030	0.880	9
st dev	26.200	4.793	24710
COV	3.5	2.1	-3

Probability that influent = effluent (nonparametric sign test): 1 (0% confident that influent ≠ effluent), therefore not statistically significant at least at the α 0.05 level.



Scatterplot of observed influent and effluent dissolved Cd concentrations.



Paired influent and effluent dissolved Cd concentrations (Sign test significant P-value = 1.0).

The ANOVA evaluations of the alternative regression equations for dissolved cadmium did not show any significant equations or equation coefficients.

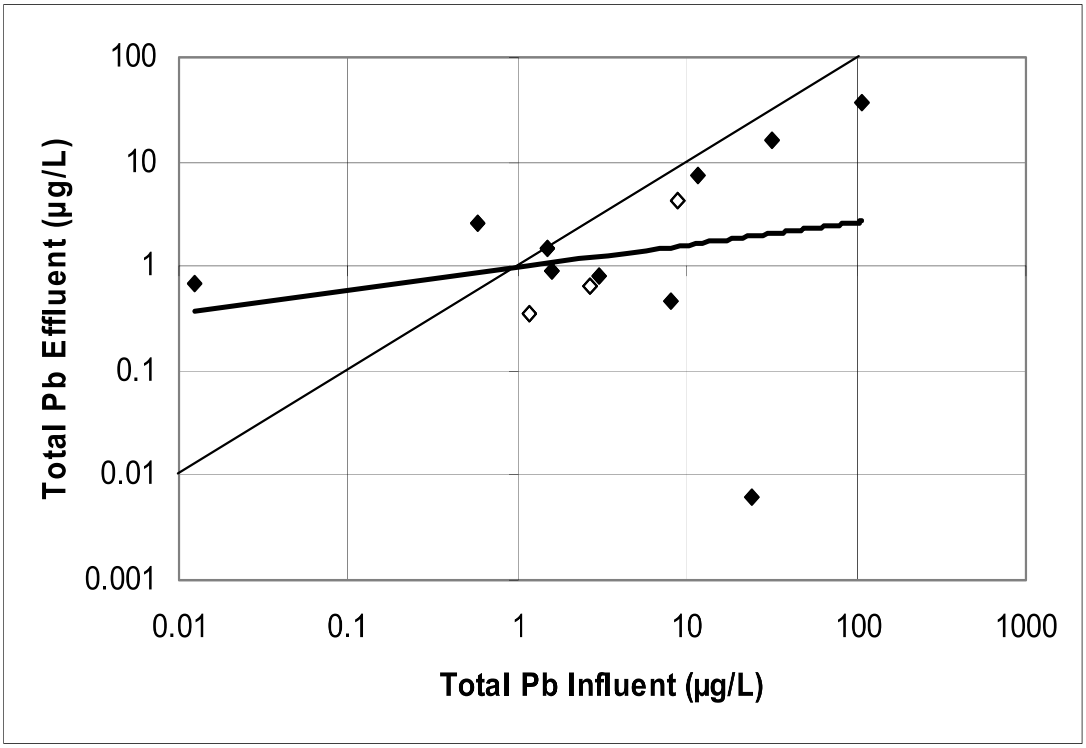
Total Lead

Comparison of total lead for storm events

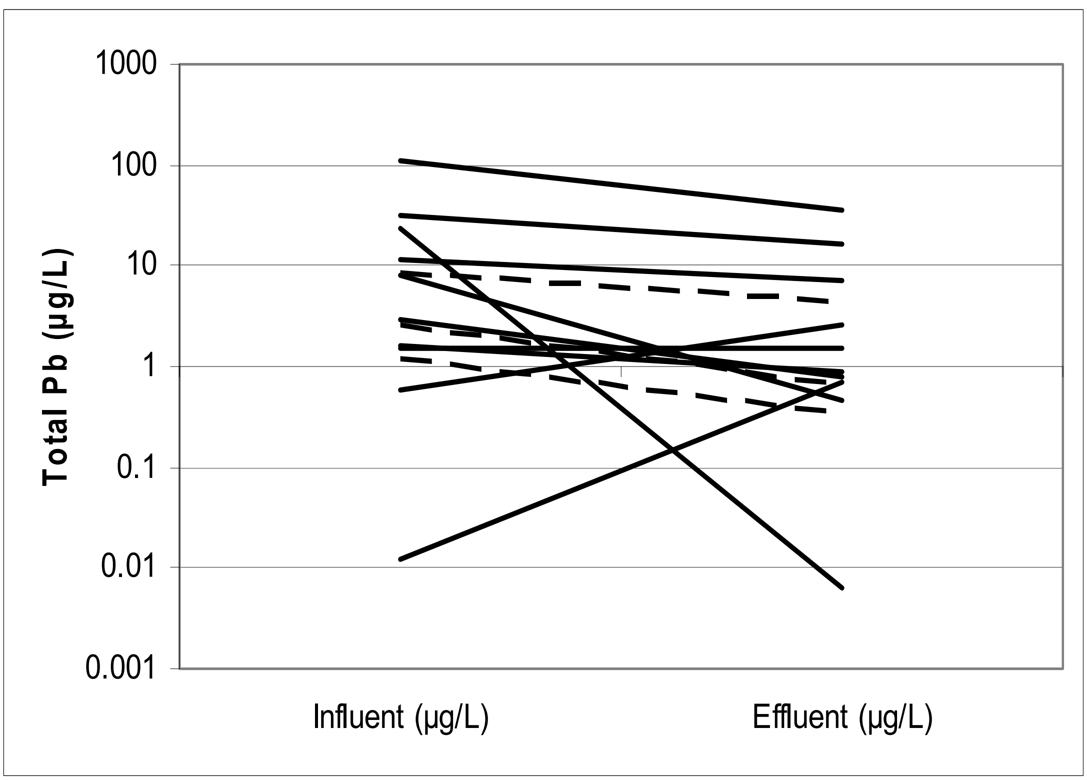
Observed Total Lead Concentrations

Sample Number	Influent (ug/L)	Effluent (ug/L)	% reduc
1-1	31.68	16.17	49
2-1	11.44	7.26	37
5-1	24.16	0.0062	100
7-1	1.5	1.51	-1
7-2	2.64	0.65	75
7-3	1.19	0.345	71
7-4	0.58	2.6	-348
7-5	0.012	0.68	-5567
7-6	1.6	0.91	43
8-1	107.4	36.29	66
8-2	8.67	4.35	50
9-1	7.9	0.47	94
10-1	3	0.8	73
min	0.012	0.006	-5567
max	107.400	36.290	100
average	15.521	5.542	-404
median	3.000	0.910	50
st dev	29.271	10.257	1555
COV	1.9	1.9	-4

Probability that influent = effluent (nonparametric sign test): 0.0923 (90.8% confident that influent ≠ effluent), therefore not statistically significant at least at the α 0.05 level.



Scatterplot of observed influent and effluent total Pb concentrations.



Paired influent and effluent total Pb concentrations (Sign test significant P-value = 0.09).

The ANOVA evaluations of the alternative regression equations for total lead did not show any significant equations or equation coefficients.

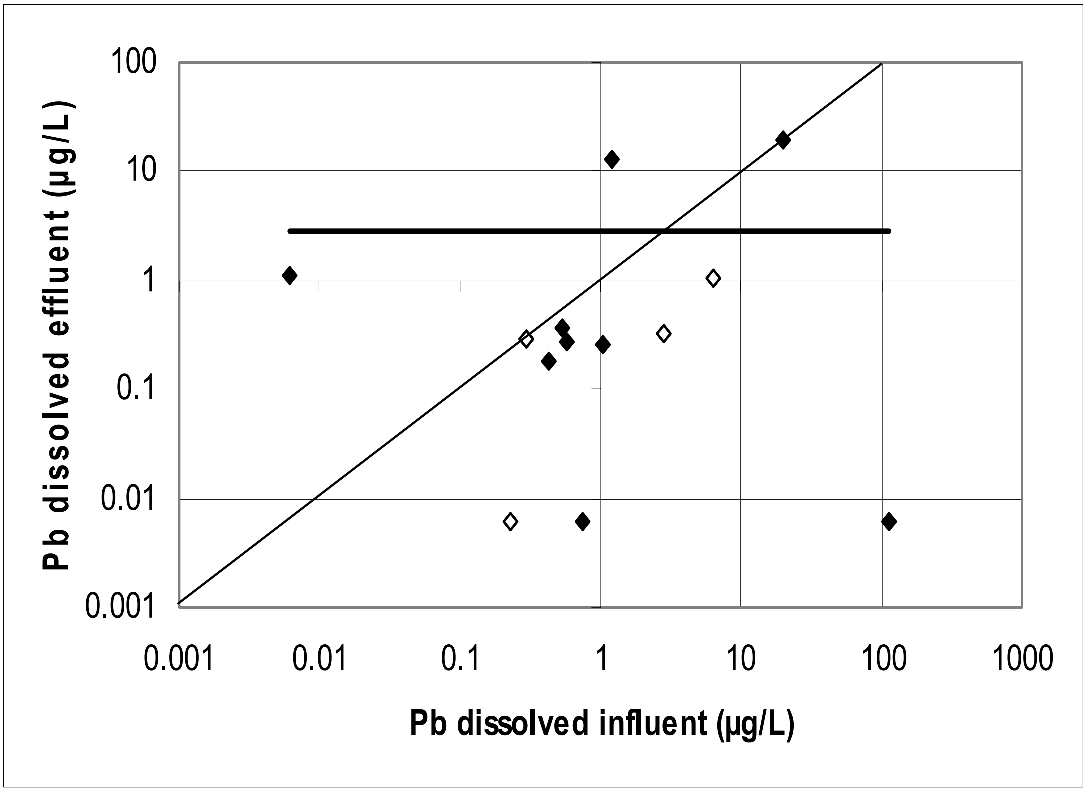
Dissolved Lead

Comparison of dissolved lead for storm events

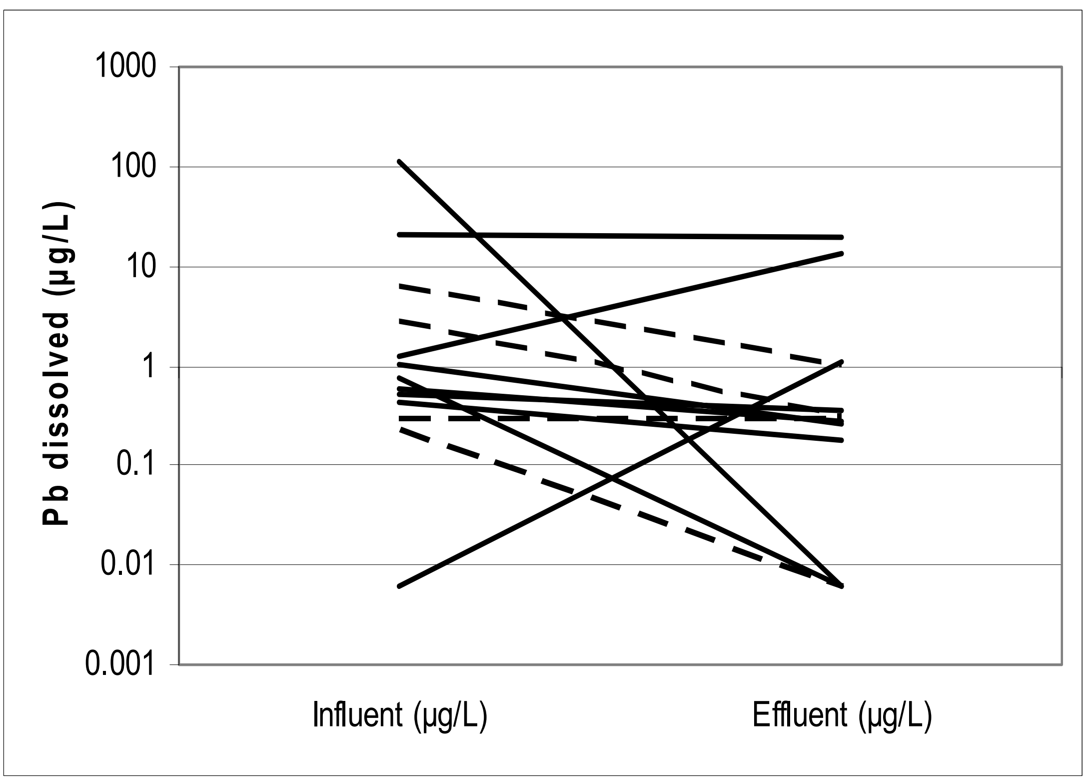
Observed Dissolved Lead Concentrations

Sample Number	Influent (ug/L)	Effluent (ug/L)	% reduc
1-1	20.3	19.5	4
5-1	112	0.0062	100
5-2	0.23	0.0062	97
7-1	0.0062	1.13	-18126
7-2	0.3	0.3	0
7-3	2.83	0.32	89
7-4	0.43	0.18	58
7-5	0.53	0.36	32
7-6	1.06	0.26	75
8-1	1.22	13.2	-982
8-2	6.23	1.05	83
9-1	0.74	0.0062	99
10-1	0.58	0.28	52
min	0.006	0.006	-18126
max	112.000	19.500	100
average	11.266	2.815	-1417
median	0.740	0.300	58
st dev	30.764	6.153	5029
COV	2.7	2.2	-4

Probability that influent = effluent (nonparametric sign test): 0.0225 (97.8% confident that influent ≠ effluent), therefore statistically significant at least at the α 0.05 level.



Scatterplot of observed influent and effluent dissolved Pb concentrations.



Paired influent and effluent dissolved Pb concentrations (Sign test P-value = 0.023).

The ANOVA evaluations of the alternative regression equations for dissolved lead did not show any significant equations or equation coefficients.

Appendix D: Sonde Data

The data on sondes is not available of the 4 storms April 26, 05; August 29, 05; September 16, 05; September 25, 05.

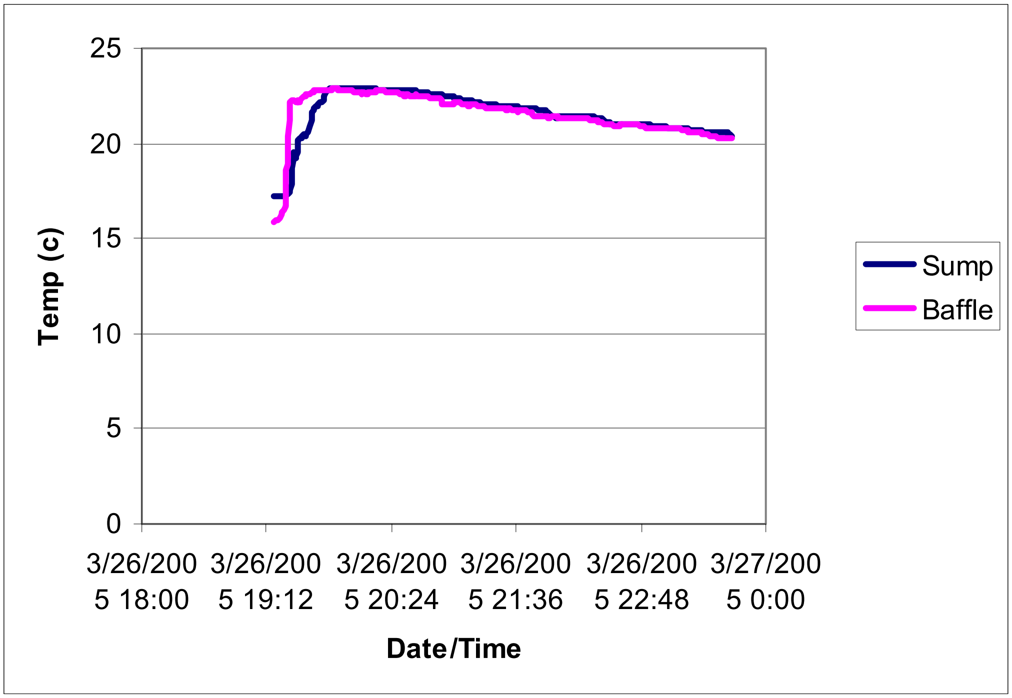


Figure D-1: Comparison of Temperature for Storm Event on March 26, 05

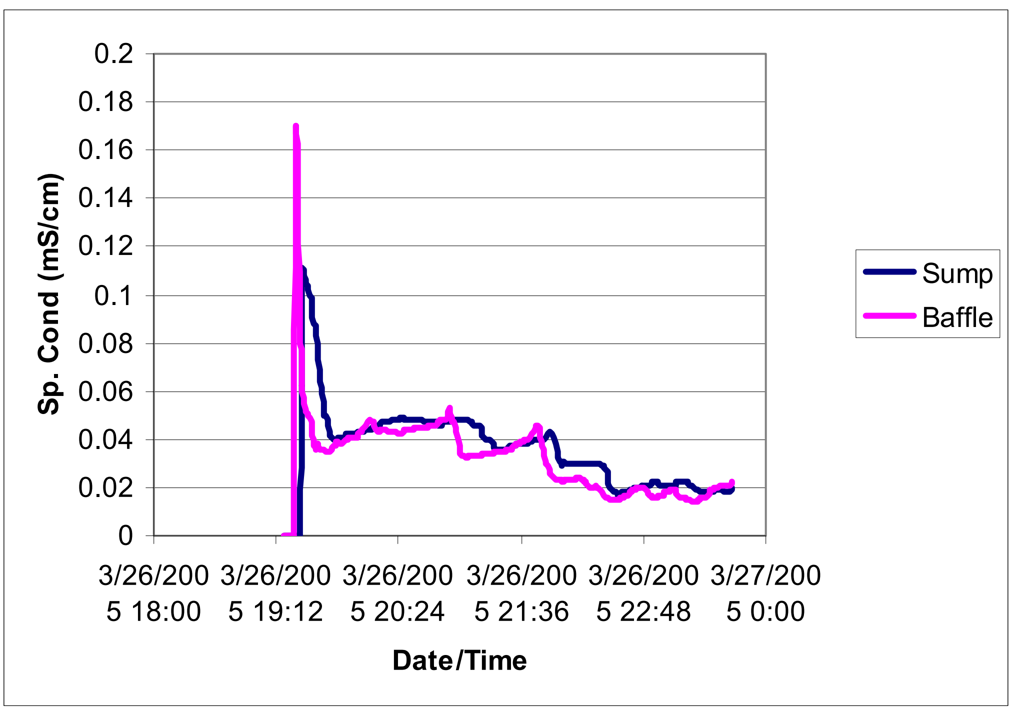


Figure D-2: Comparison of Specific Conductivity for Storm Event on March 26, 05

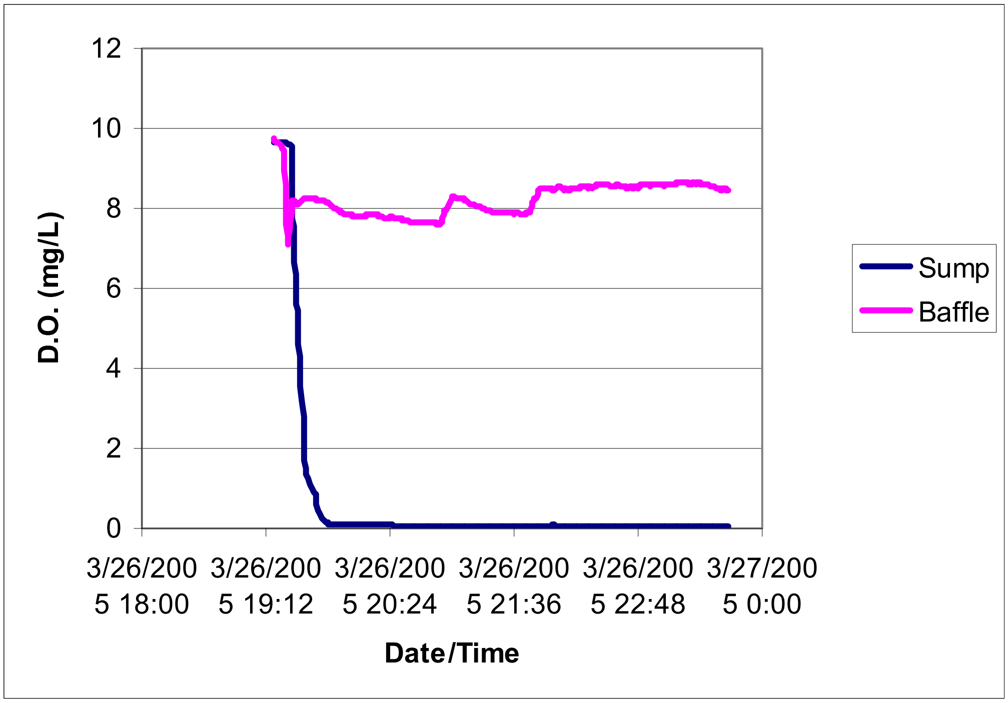


Figure D-3: Comparison of Dissolved Oxygen for Storm Event on March 26, 05

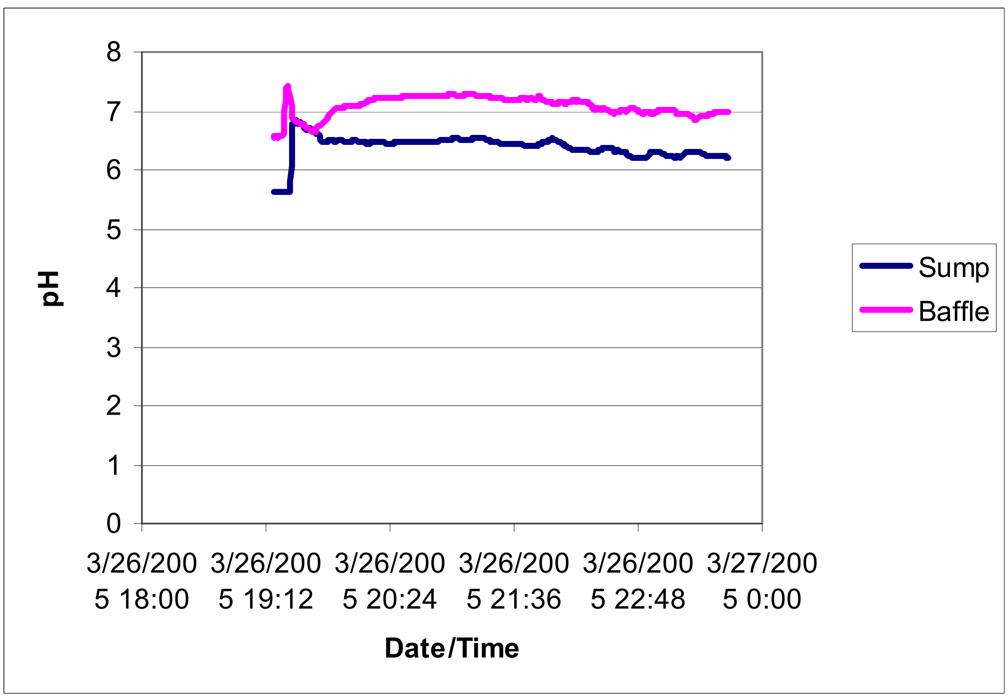


Figure D-4: Comparison of pH for Storm Event on March 26, 05

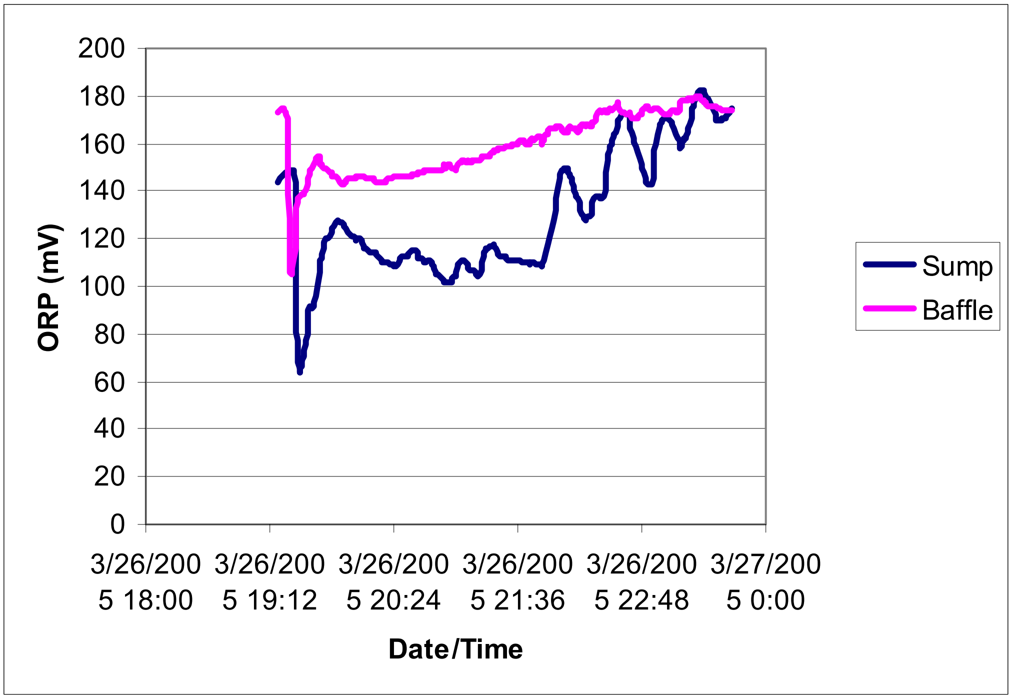


Figure D-5: Comparison of ORP for Storm Event on March 26, 05

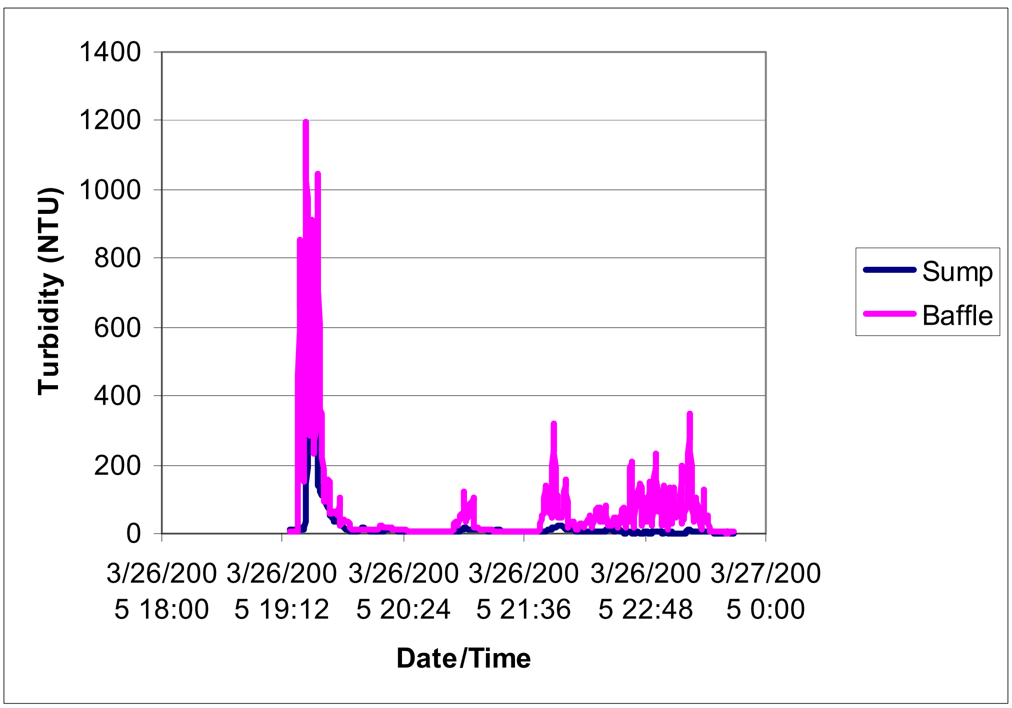


Figure D-6: Comparison of Turbidity for Storm Event on March 26, 05

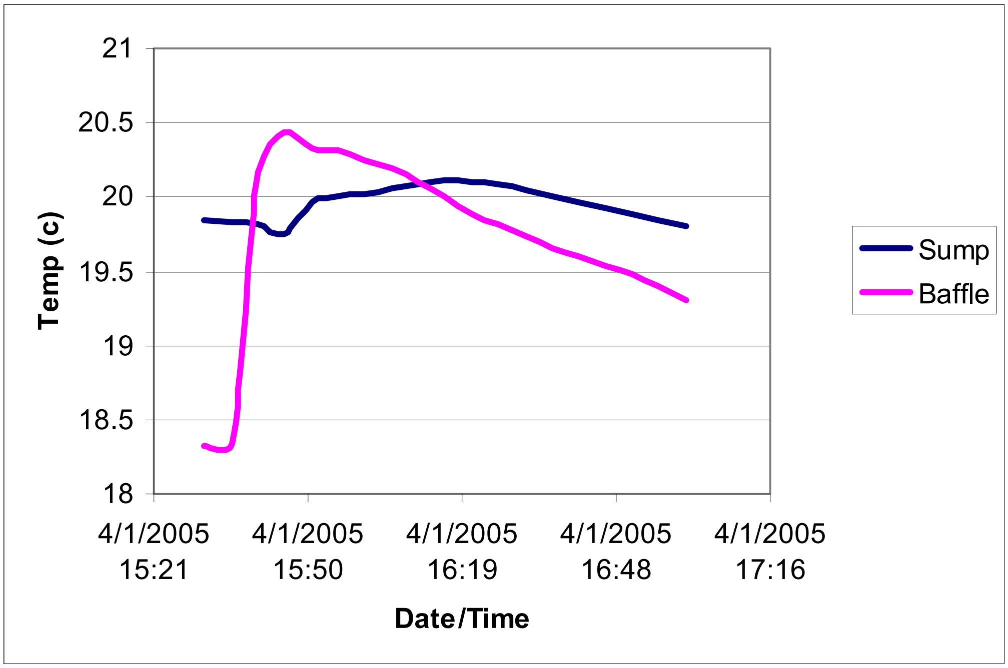


Figure D-7: Comparison of Temperature for Storm Event on April 01, 05

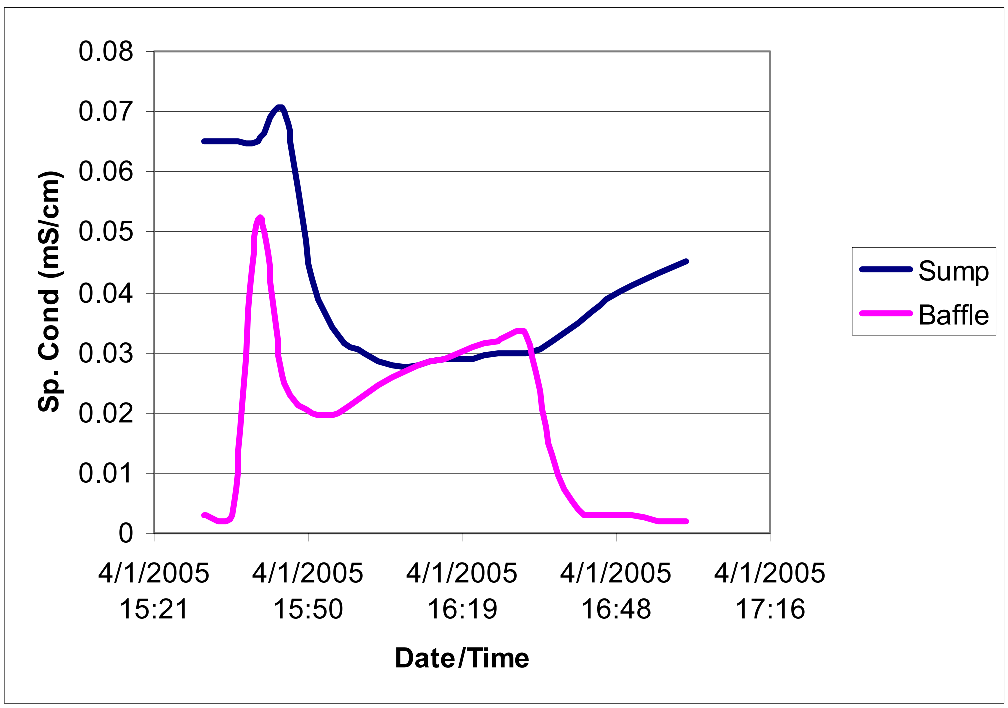


Figure D-8: Comparison of Specific Conductivity for Storm Event on April 01, 05

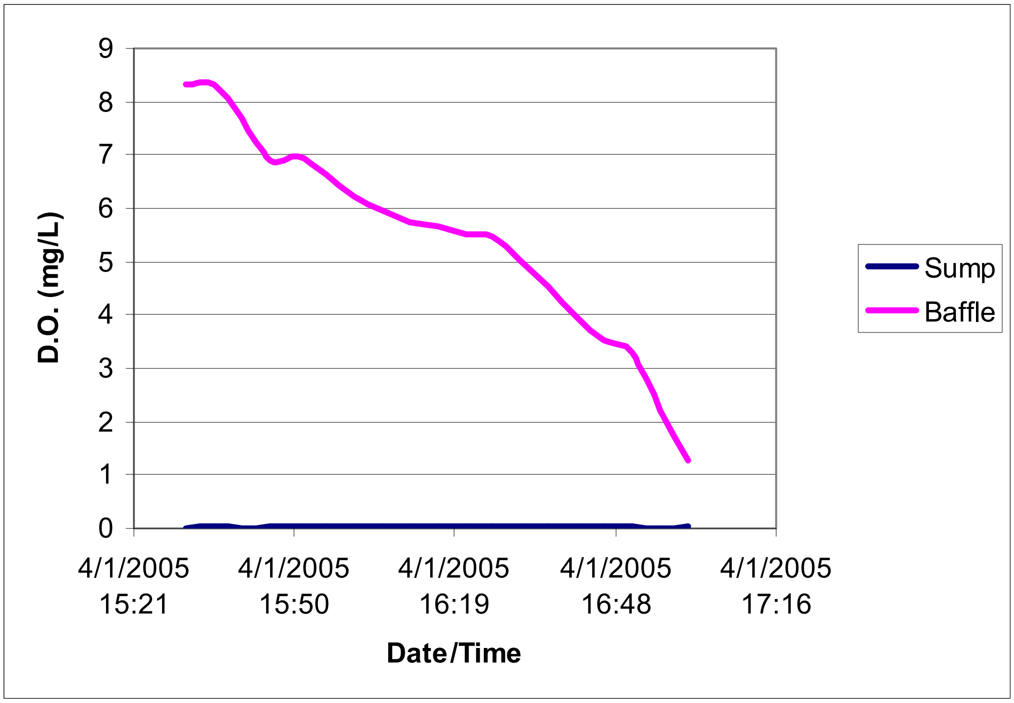


Figure D-9: Comparison of Dissolved Oxygen for Storm Event on April 01, 05

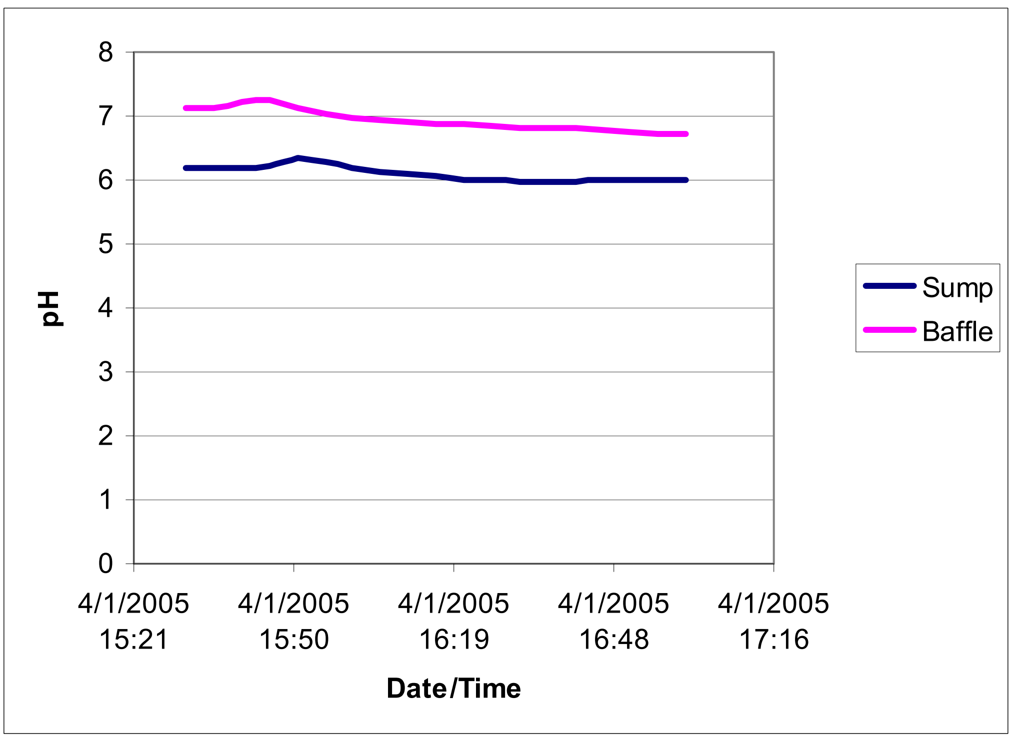


Figure D-10: Comparison of pH for Storm Event on April 01, 05

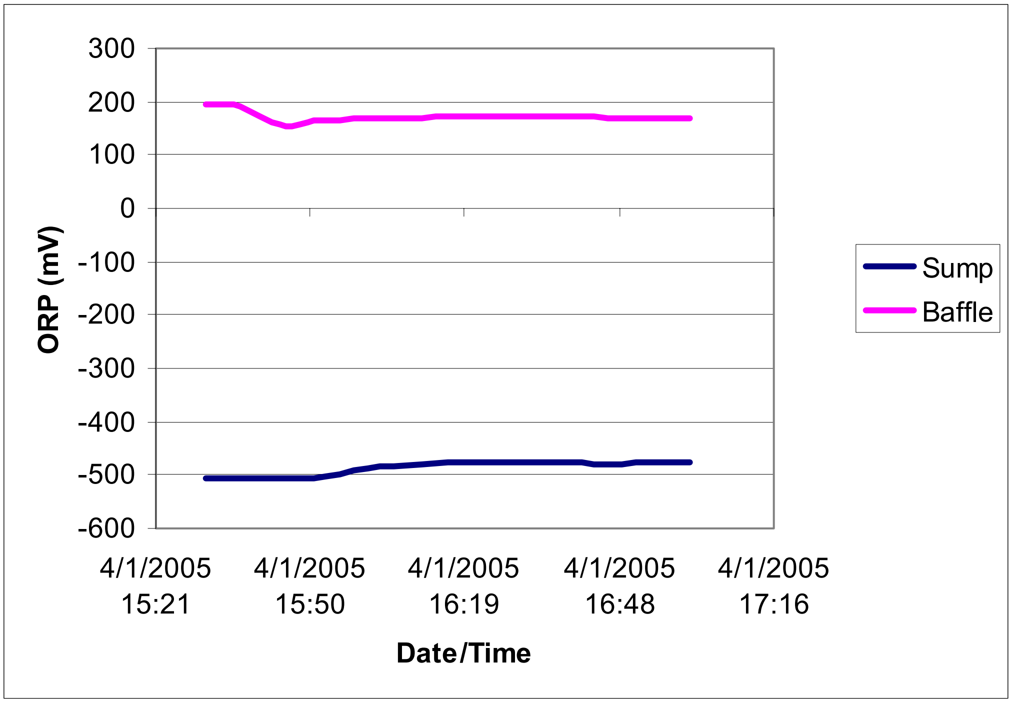
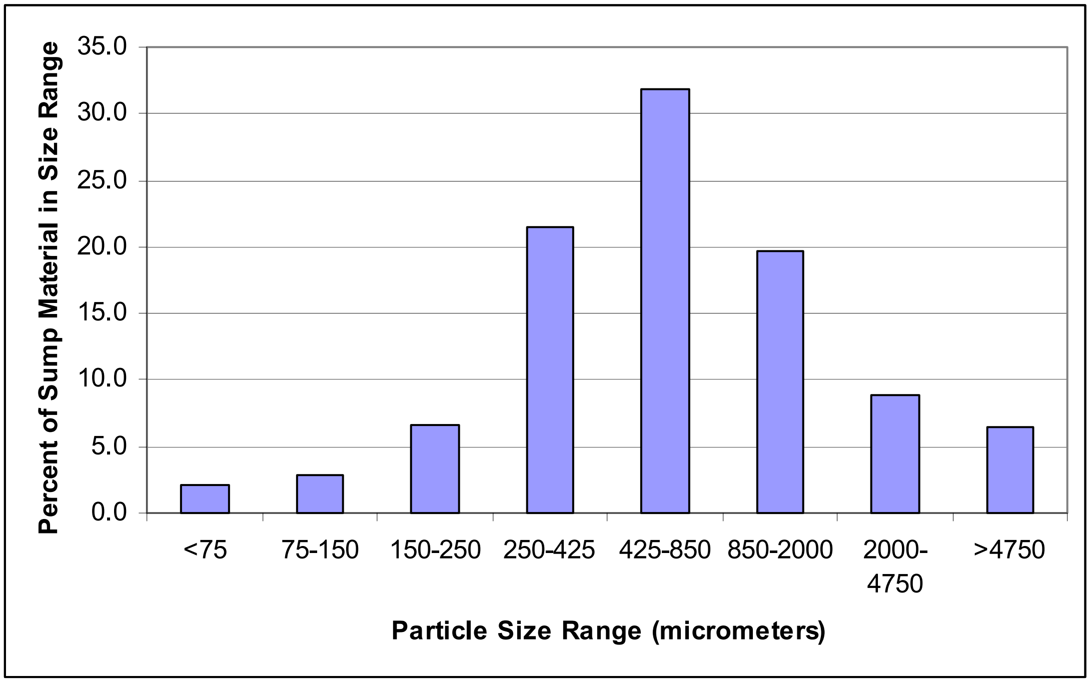
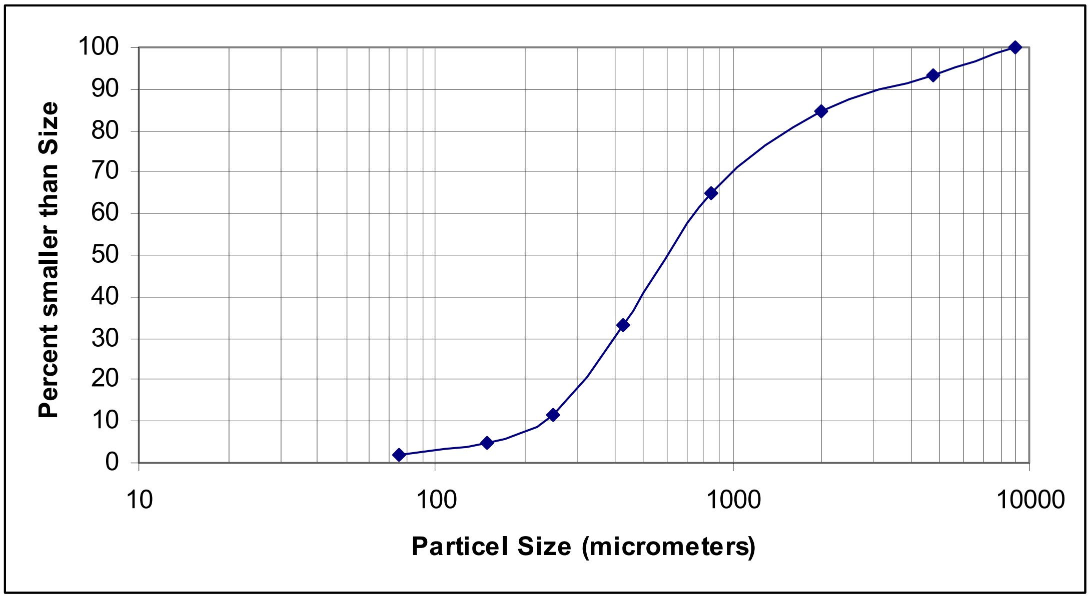


Figure D-11: Comparison of ORP for Storm Event on April 01, 05

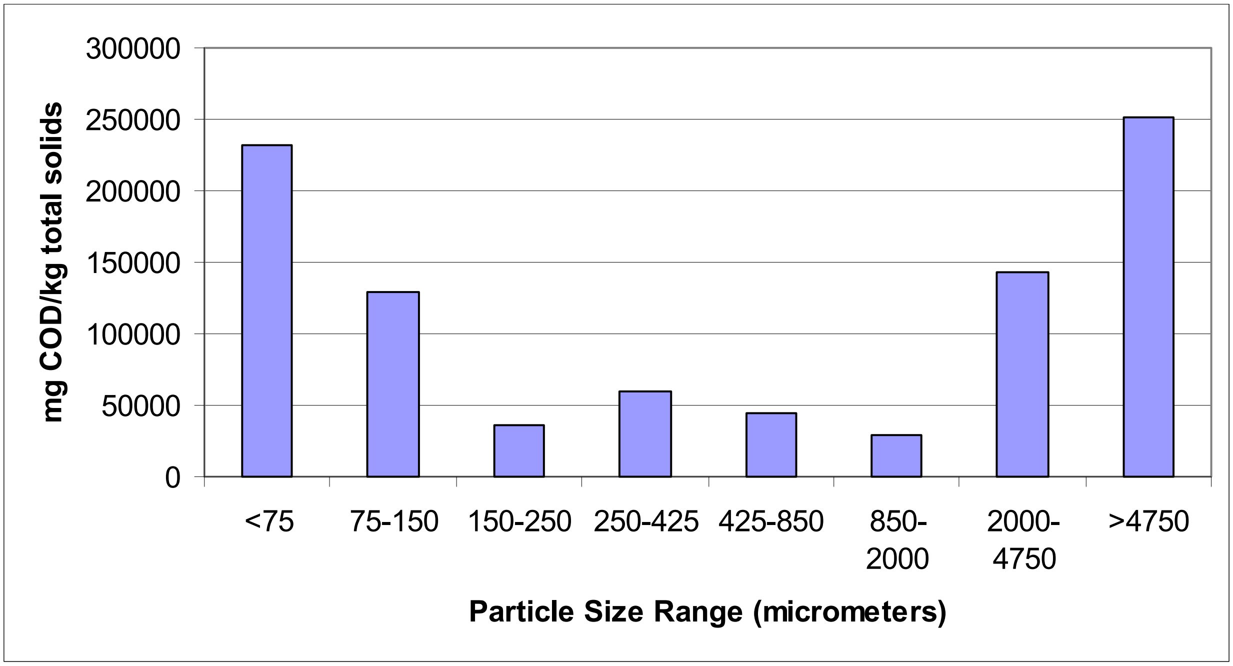
Appendix E: Sump Sediment Quality and Quantity Data

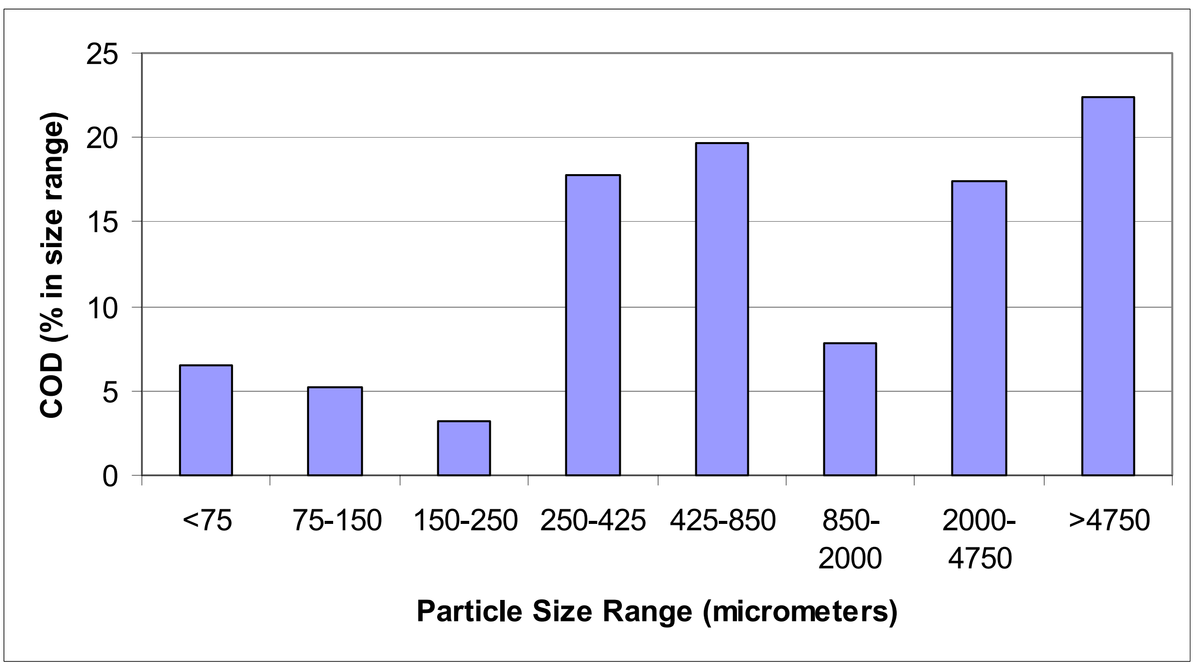
Total Solids in Up-Flo™ Filter Sump

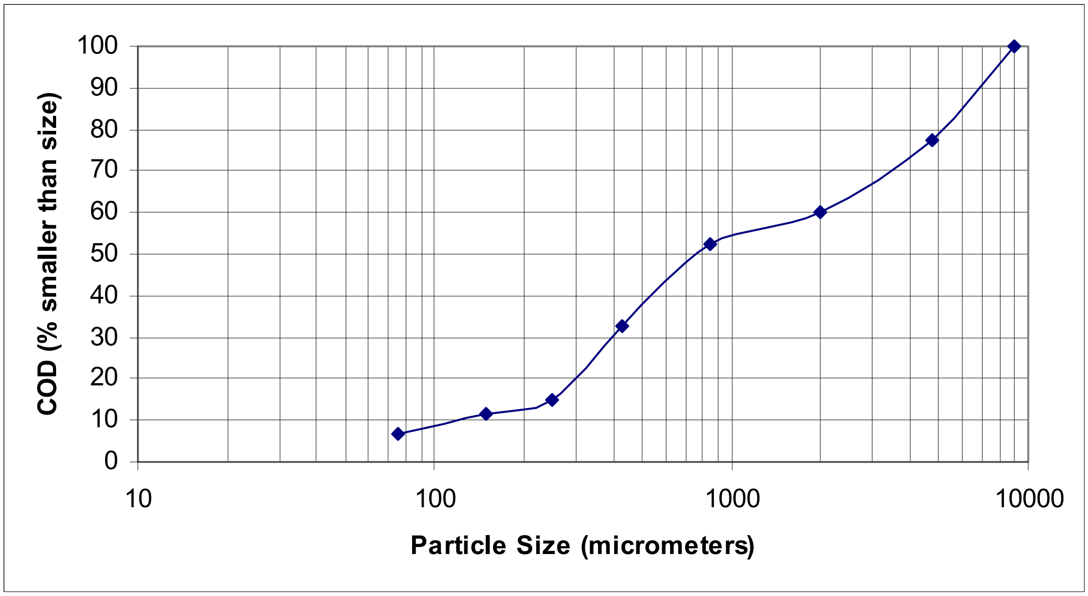



100
90
80
70
60
50
40
30
20
10
0
Percent smaller than Size
10
100
1000
10000
Particel Size (micrometers)

Chemical Oxygen Demand in Up-Flo™ Filter Sump

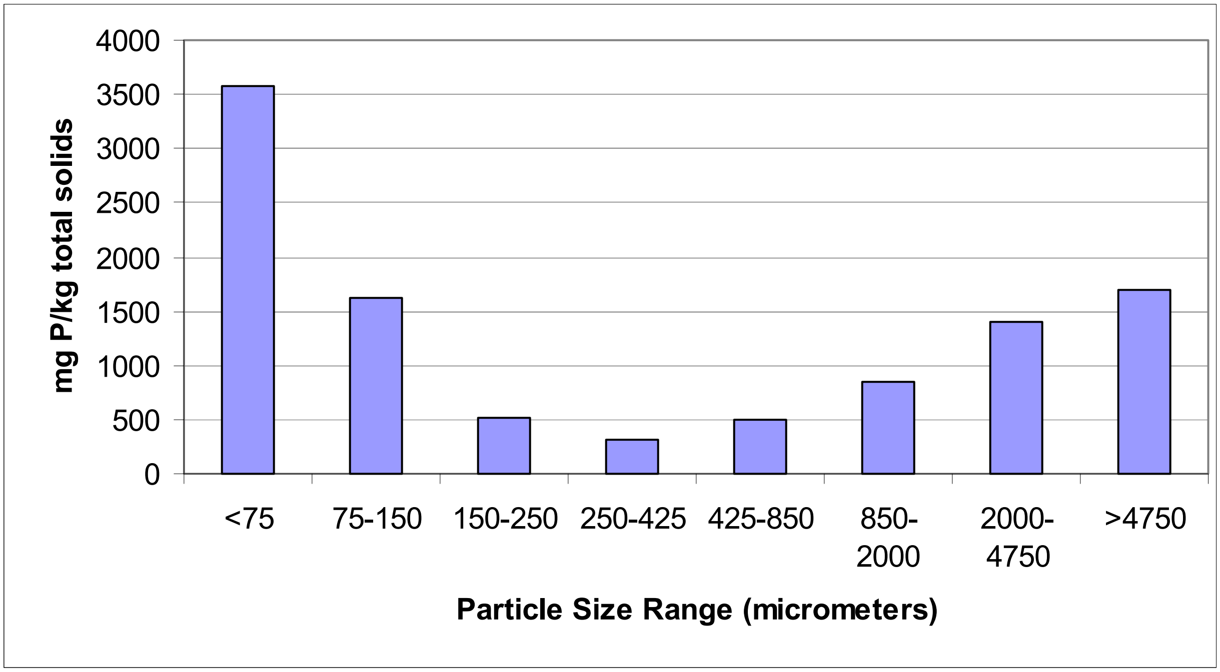


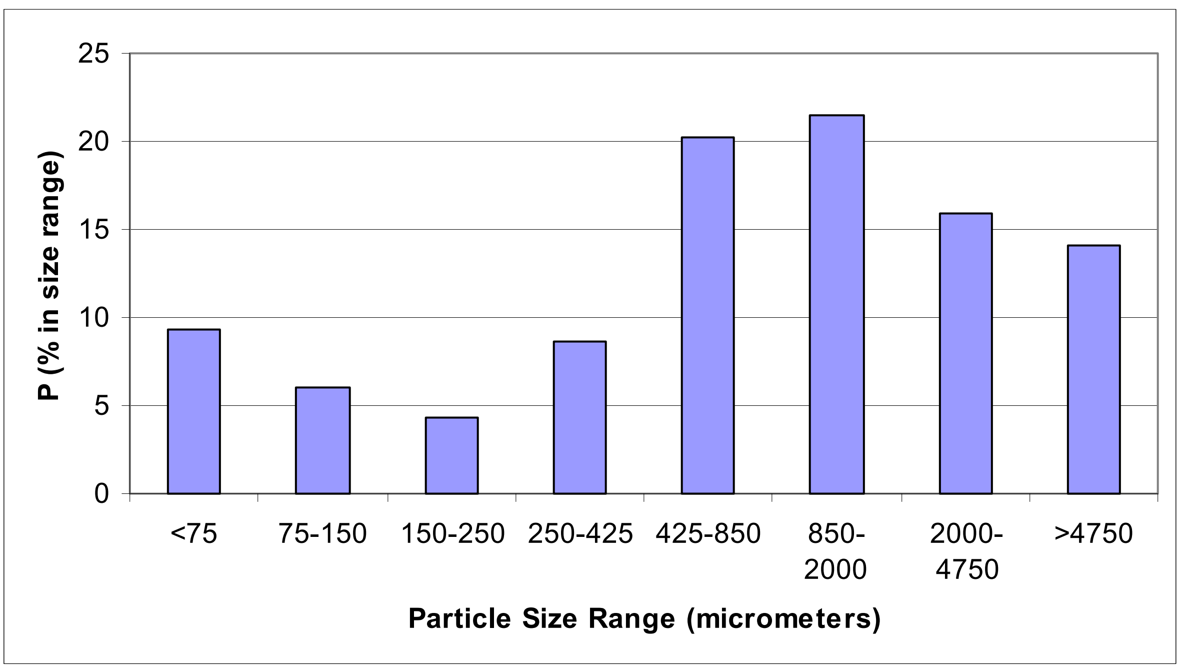


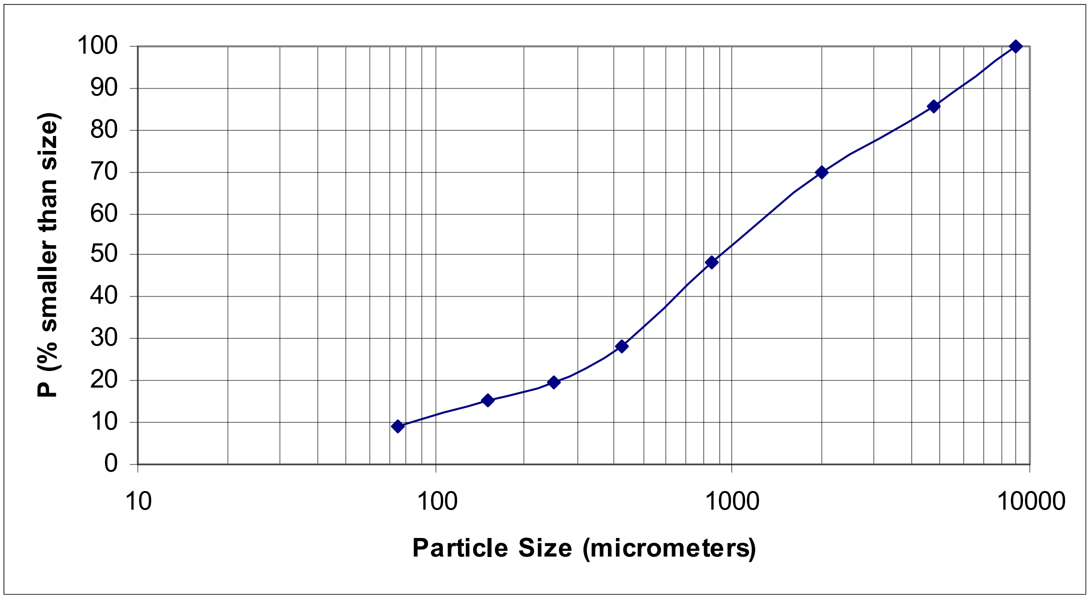


COD (% smaller than size)
100
90
80
70
60
50
40
30
20
10
0
10
100
1000
10000
Particle Size (micrometers)

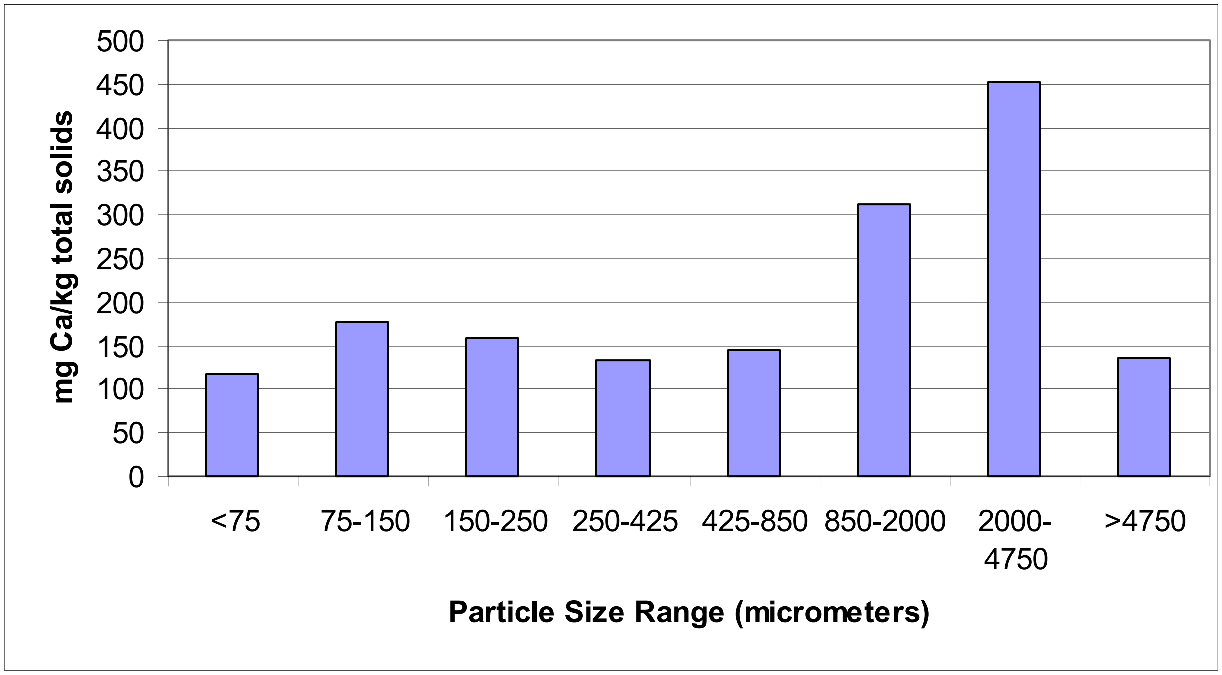
Total Phosphorus in Up-Flo™ Filter Sump

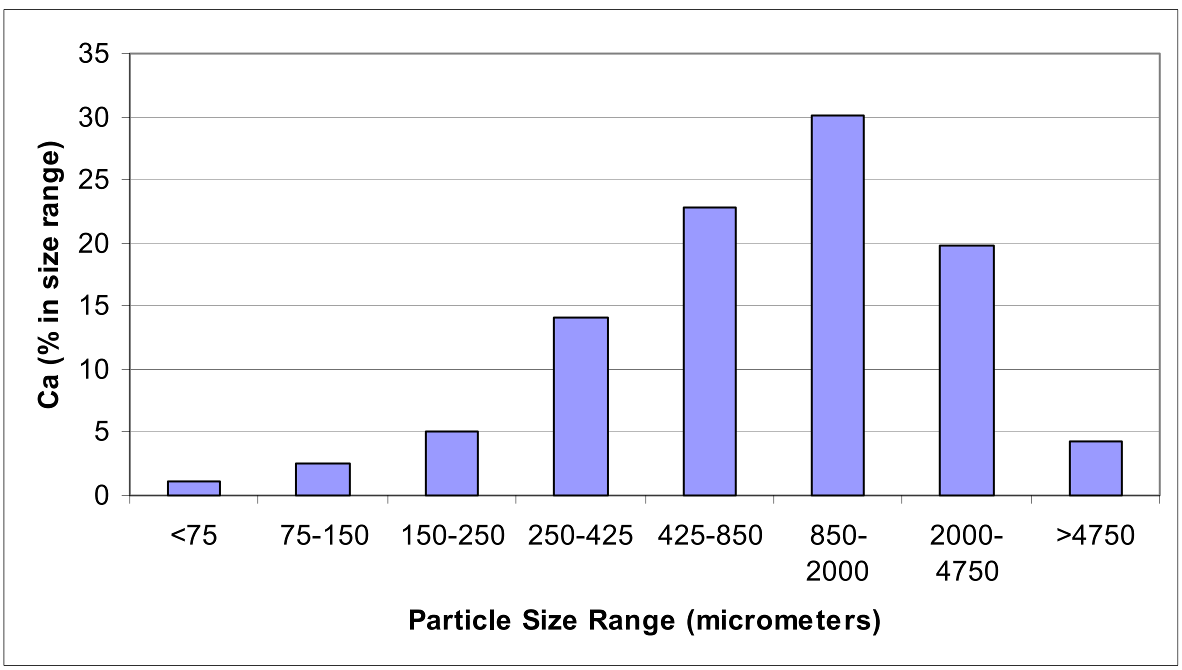


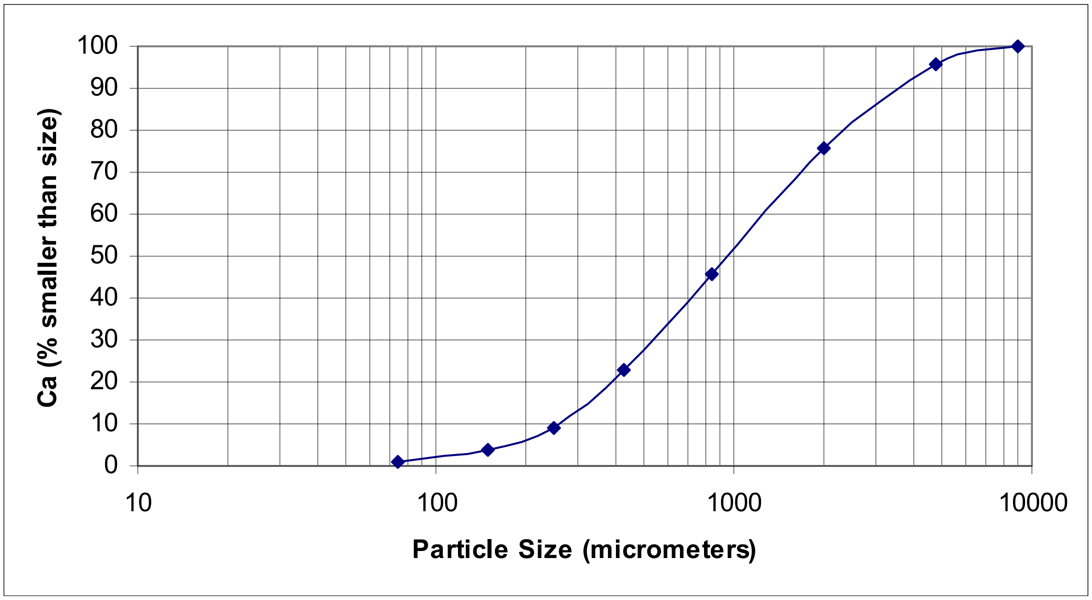



P (% smaller than size)
0
10
20
30
40
50
60
70
80
90
100
10
100
1000
10000
Particle Size (micrometers)

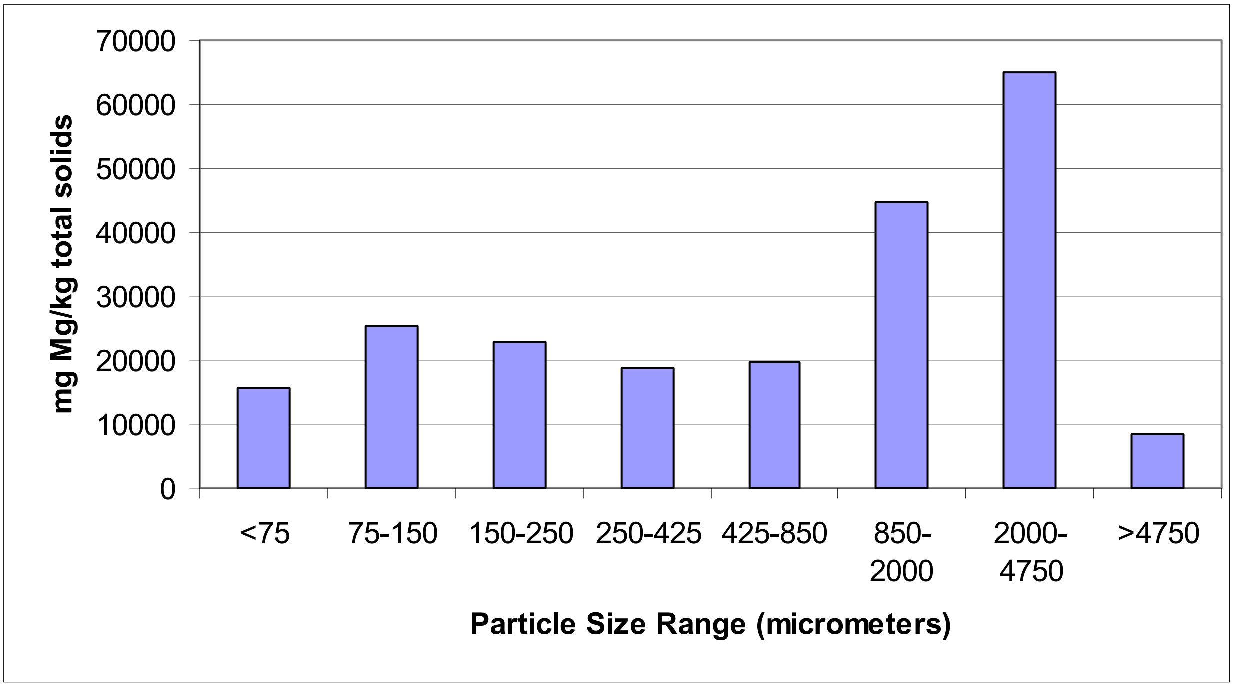
Calcium in Up-Flo™ Filter Sump

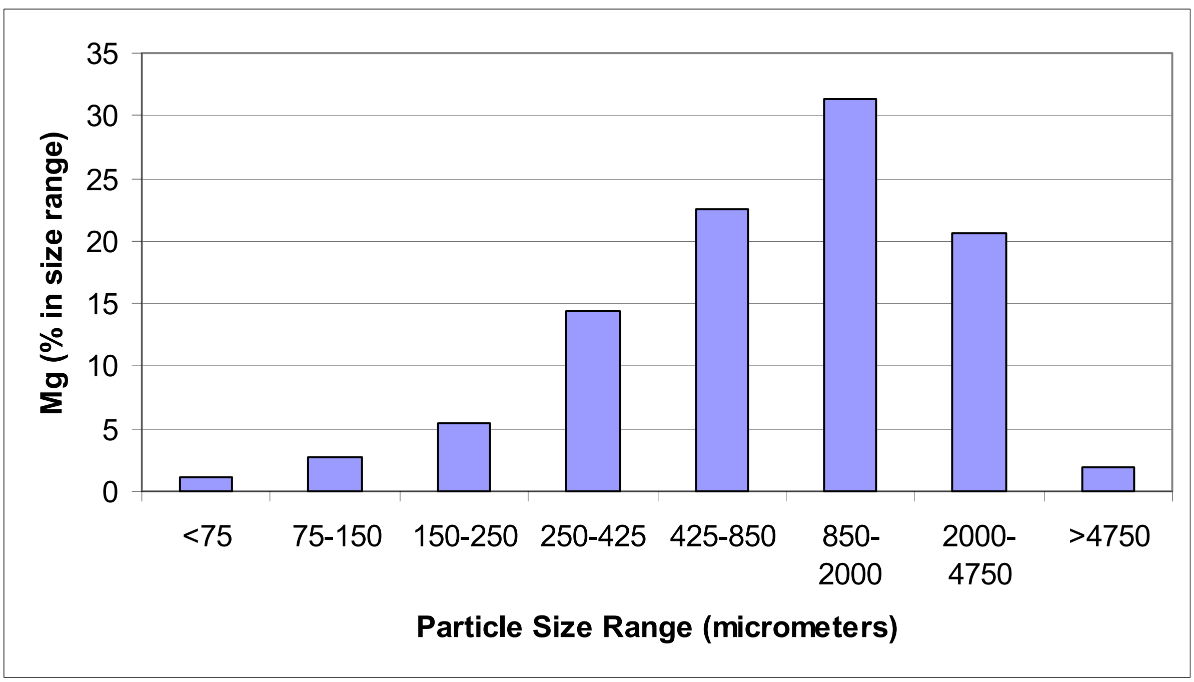


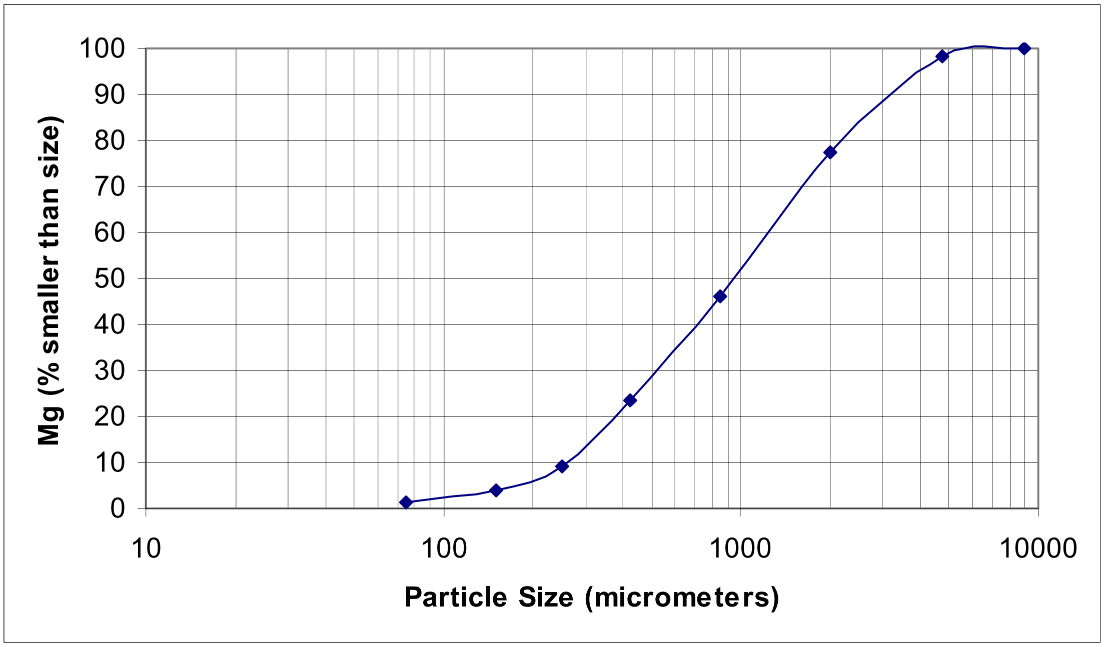



100
90
80
70
60
50
40
30
20
10
0
Ca (% smaller than size)
10
100
1000
10000
Particle Size (micrometers)

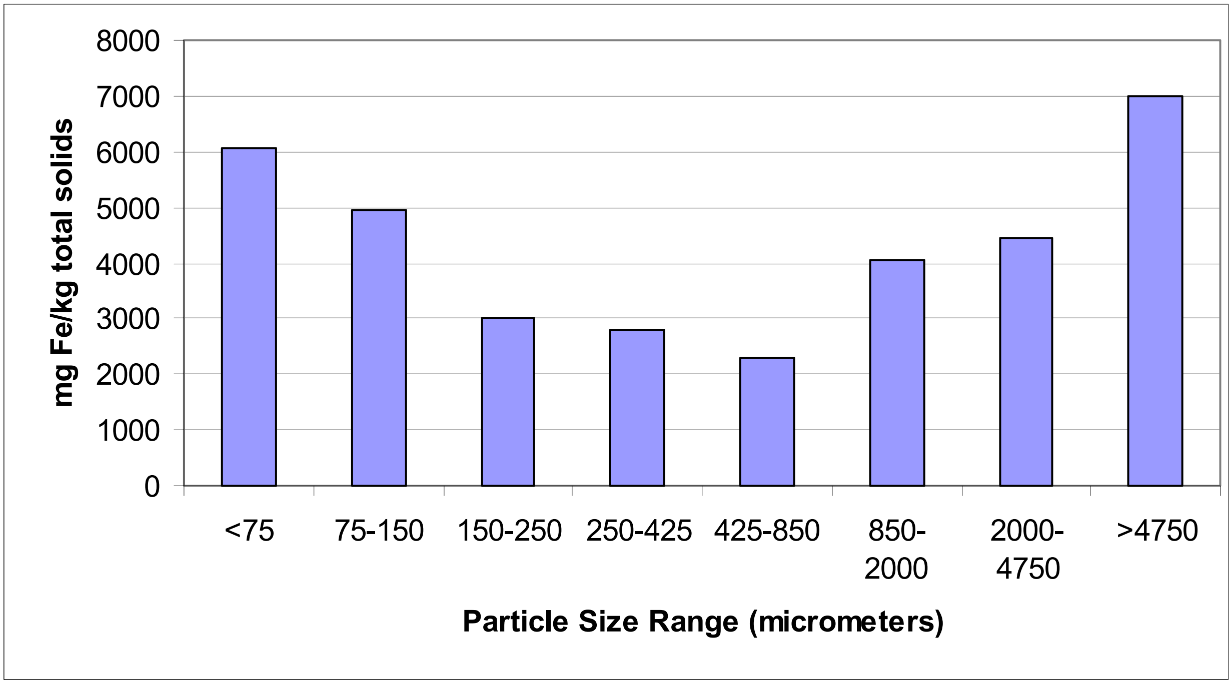
Magnesium in Up-Flo™ Filter Sump

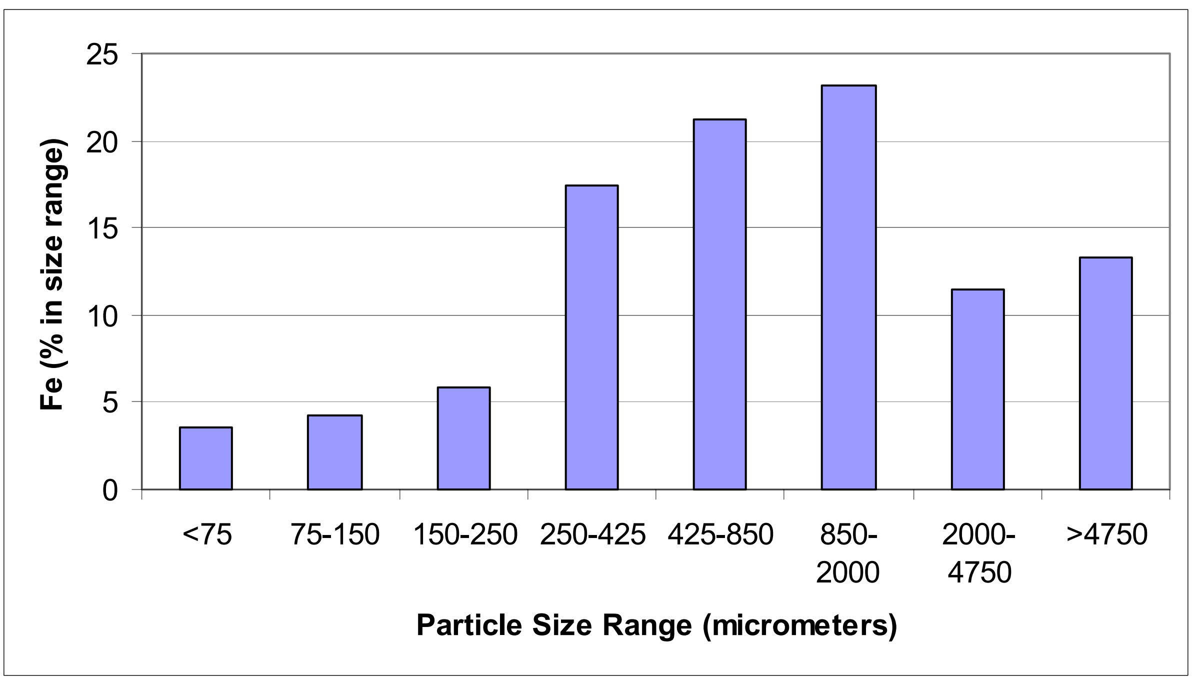


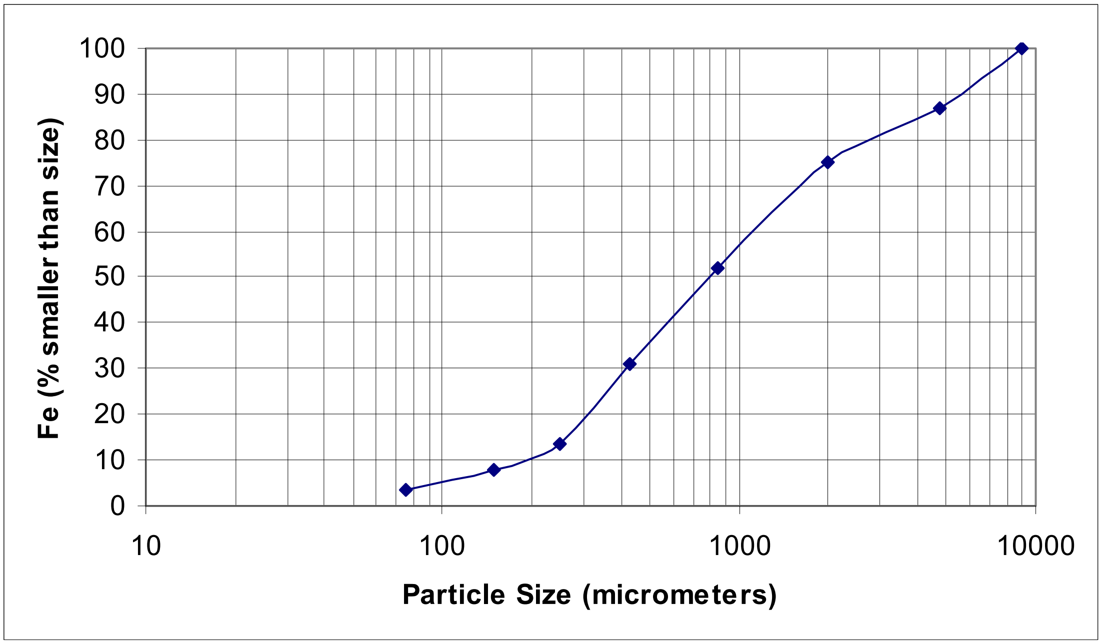



Mg (% smaller than size)
100
90
80
70
60
50
40
30
20
10
0
10
100
1000
10000
Particle Size (micrometers)

Iron in Up-Flo™ Filter Sump

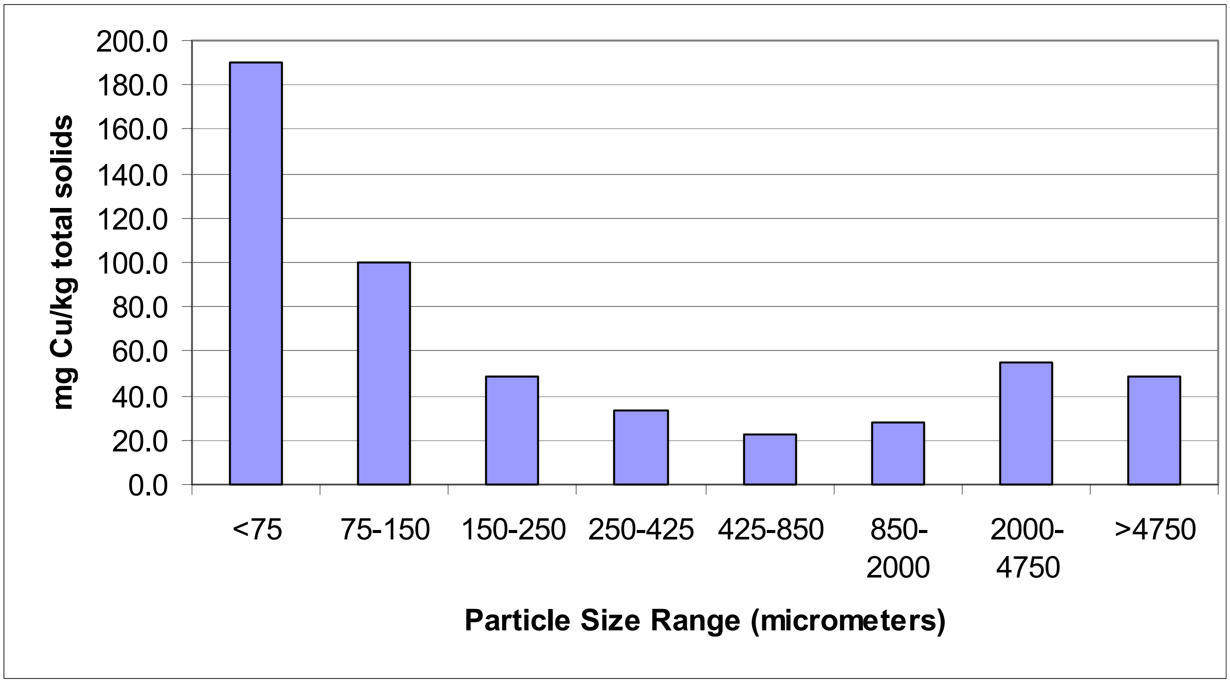


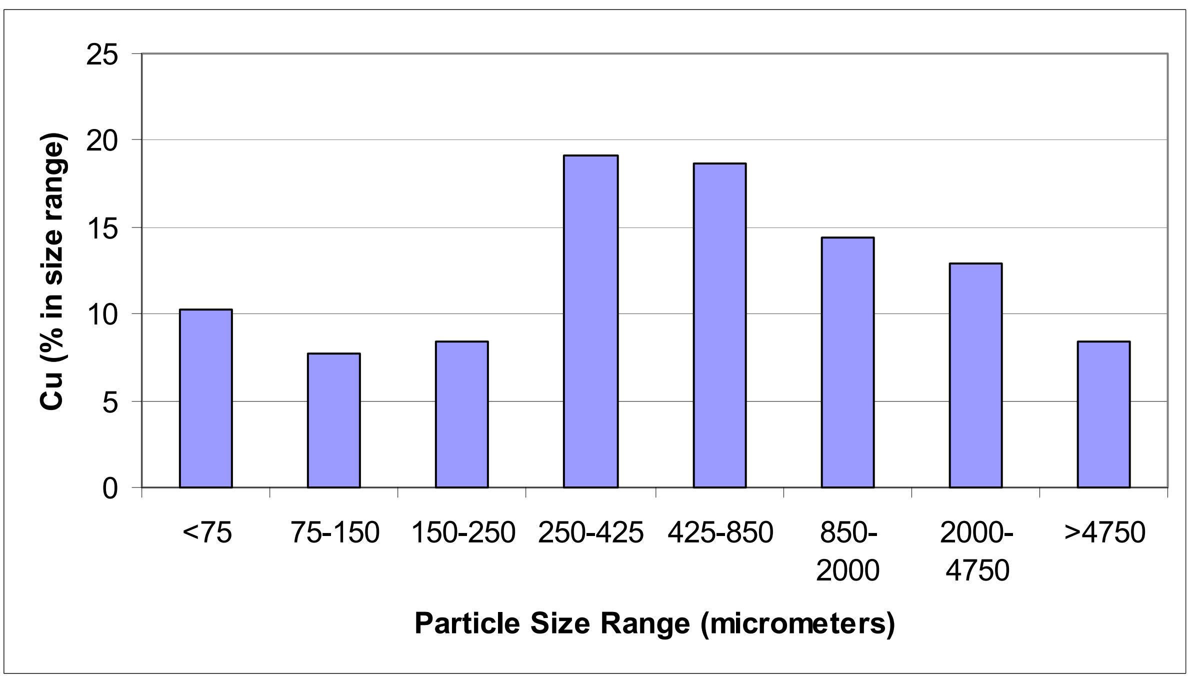


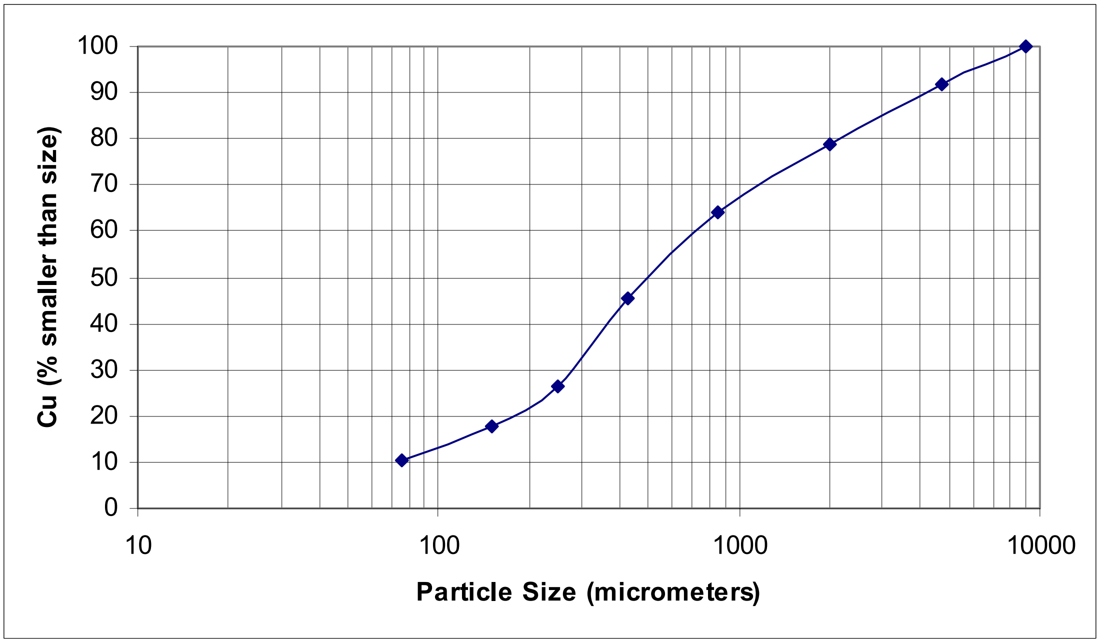


Fe (% smaller than size)
100
90
80
70
60
50
40
30
20
10
0
10
100
1000
10000
Particle Size (micrometers)

Copper in Up-Flo™ Filter Sump

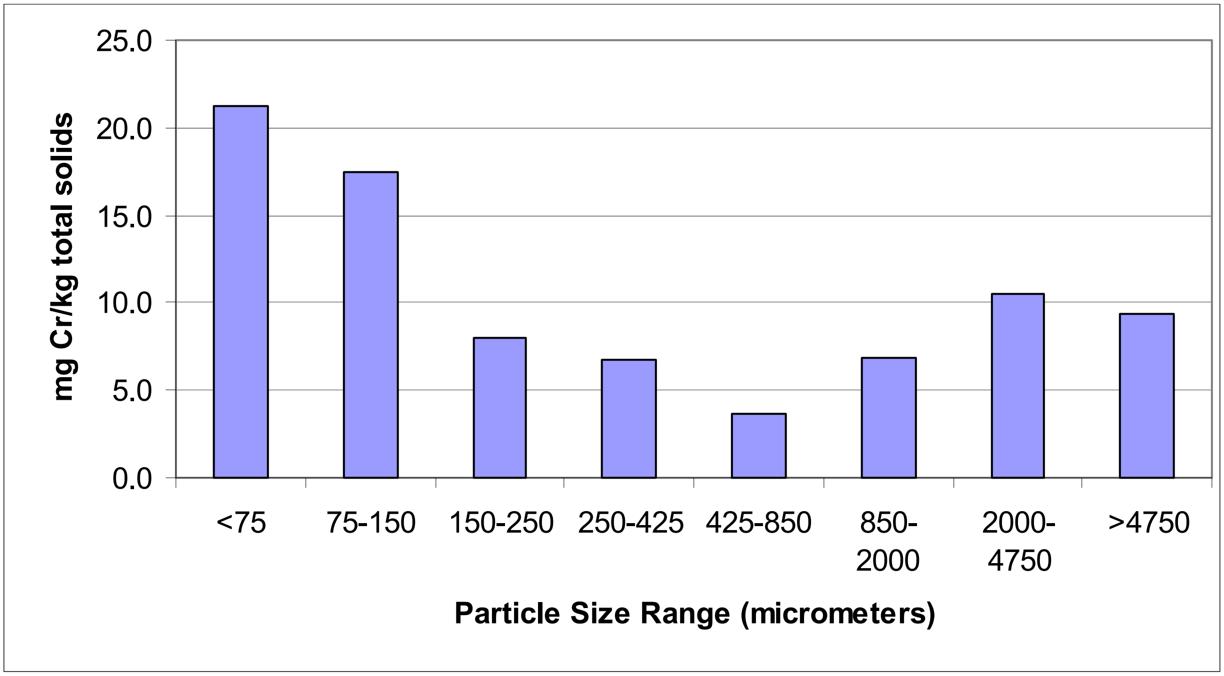


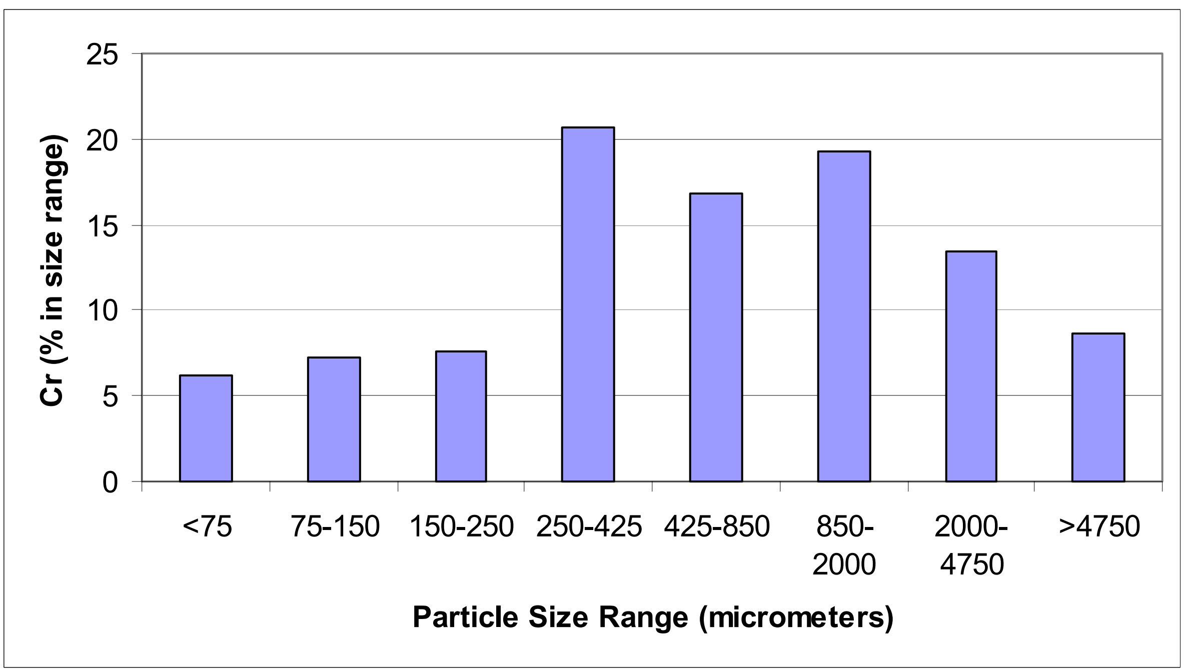


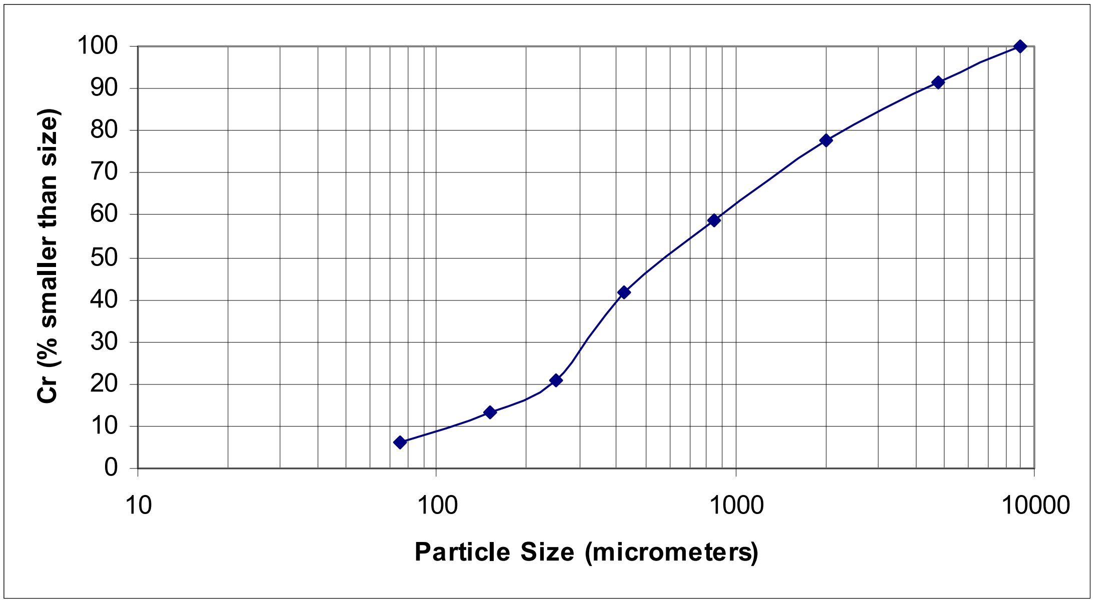


Cu (% smaller than size)
100
90
80
70
60
50
40
30
20
10
0
10
100
1000
10000
Particle Size (micrometers)

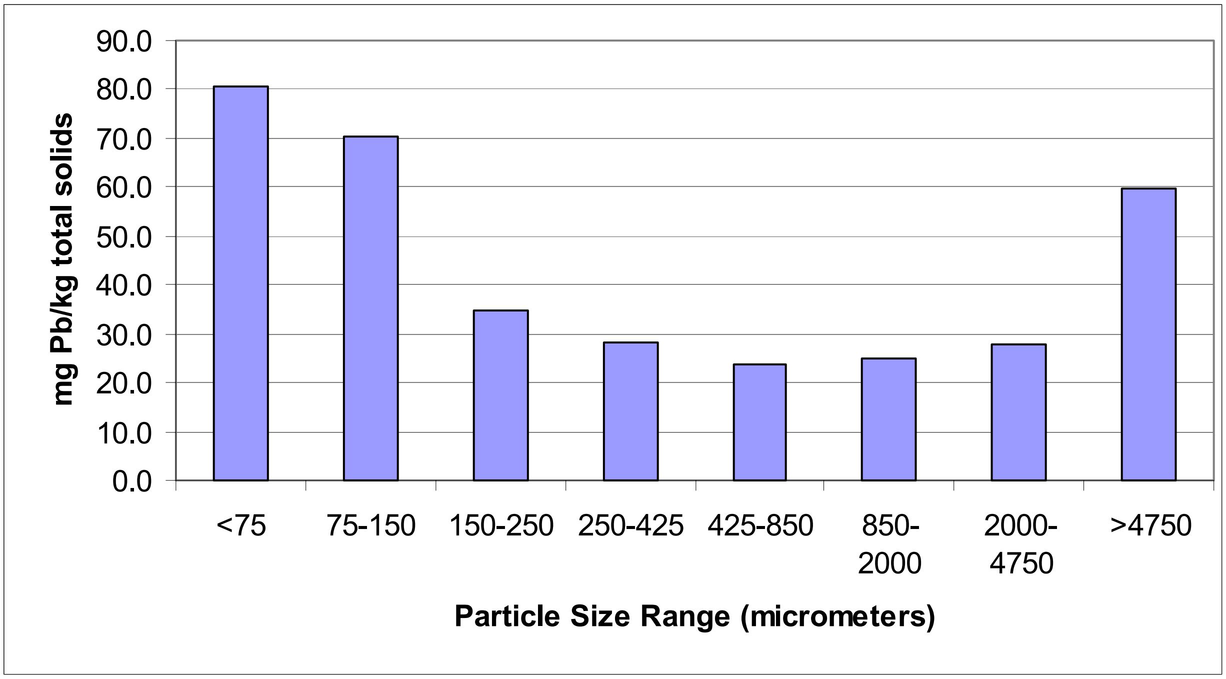
Chromium in Up-Flo™ Filter Sump

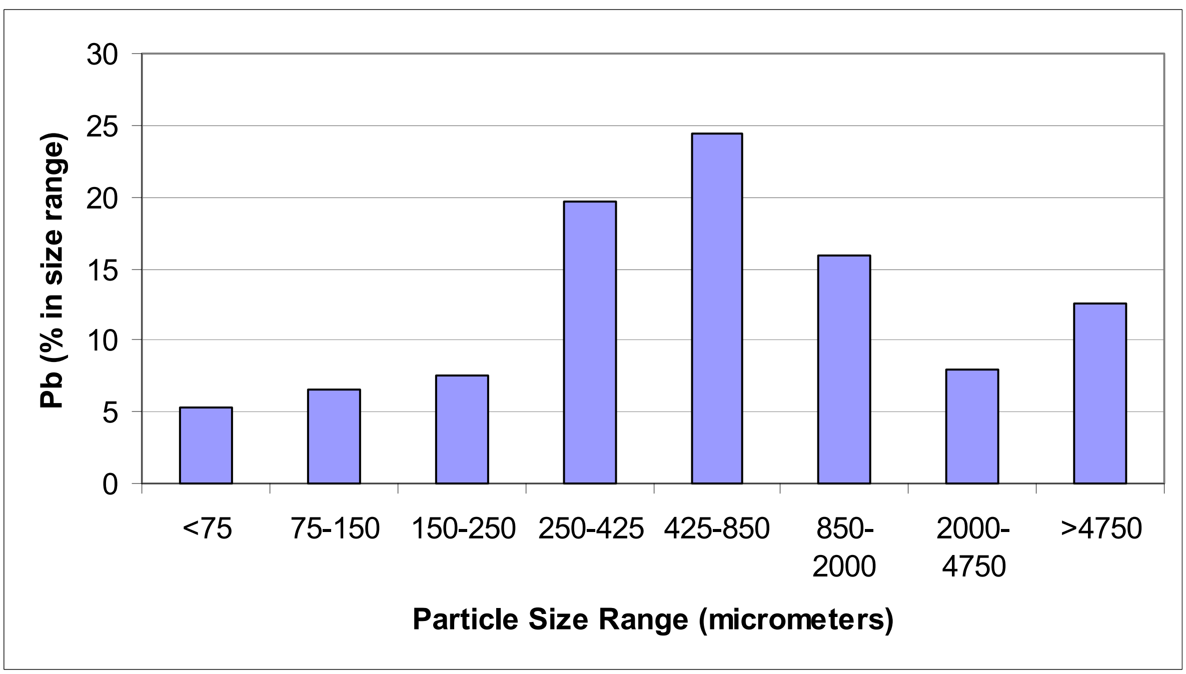


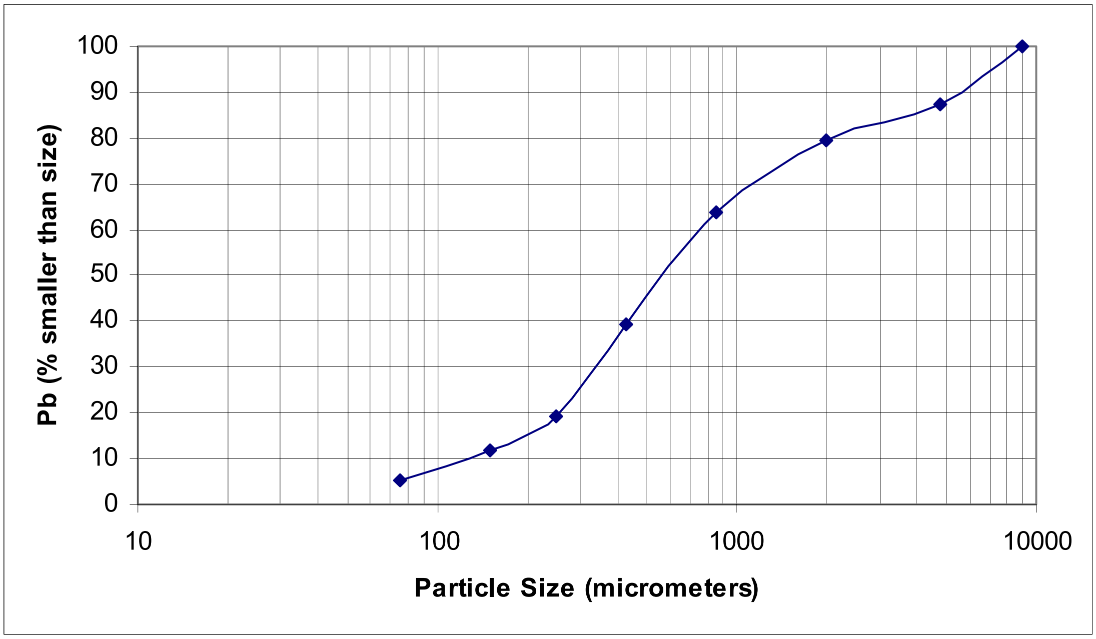



100
90
80
70
60
50
40
30
20
10
0
Cr (% smaller than size)
10
100
1000
10000
Particle Size (micrometers)

Lead in Up-Flo™ Filter Sump

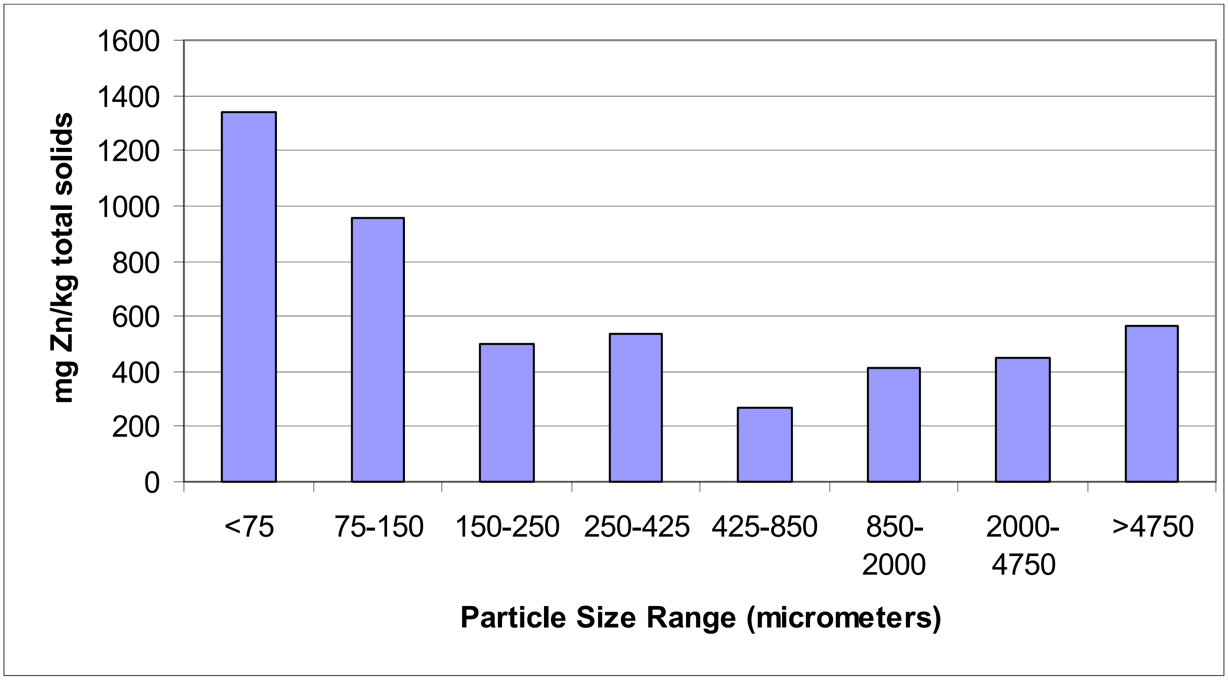


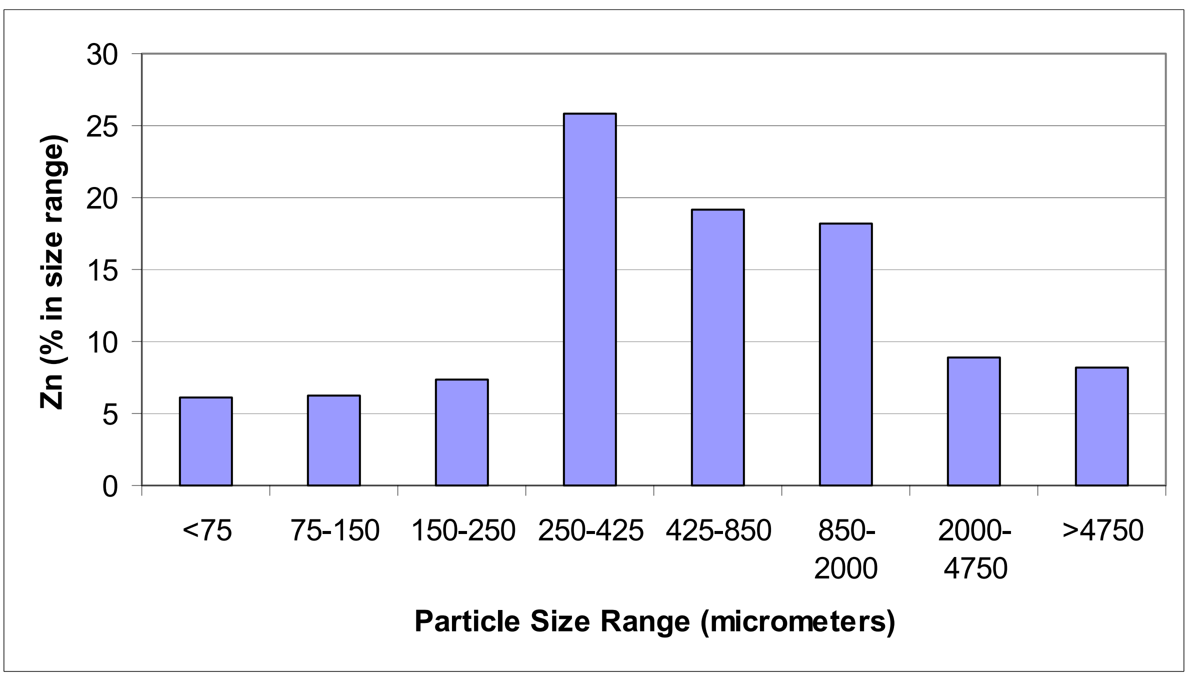


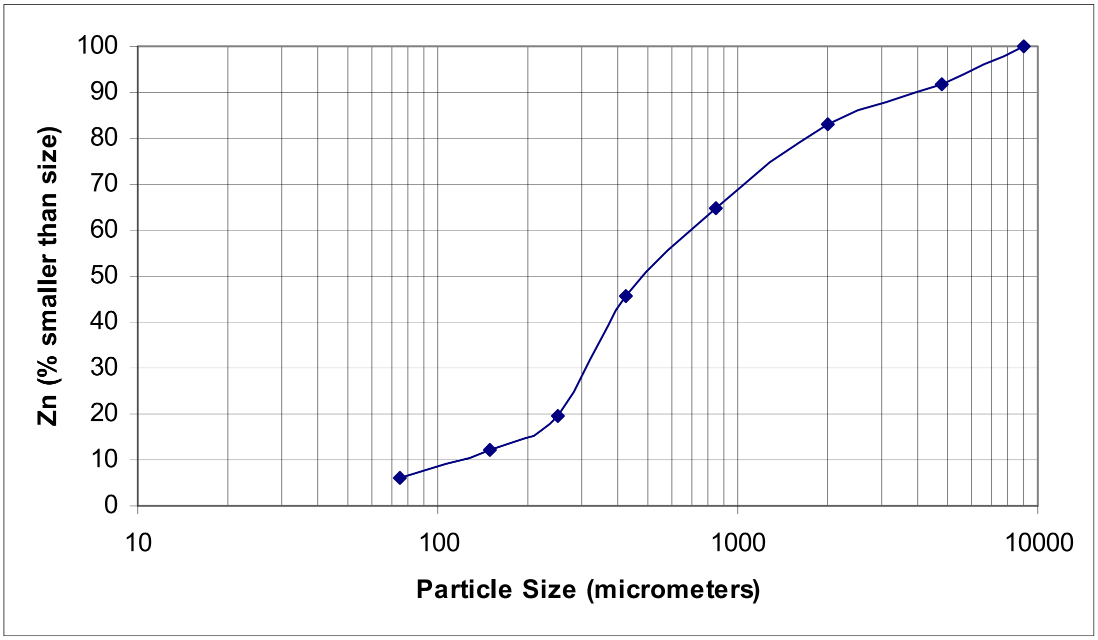


Pb (% smaller than size)
100
90
80
70
60
50
40
30
20
10
0
10
100
1000
10000
Particle Size (micrometers)

Zinc in Up-Flo™ Filter Sump






Zn (% smaller than size)
0
10
20
30
40
50
60
70
80
90
100
10
100
1000
10000
Particle Size (micrometers)