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Evaluating the Stormwater Treatment Performance of AbTech Industries Smart Sponge® Plus, Landry, N

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Disclaimer

The inclusion of specific products in this document does not constitute or imply their endorsement or recommendation by the New Hampshire Department of Environmental Services, the New Hampshire Estuaries Project, the University of New Hampshire or the U. S. Environmental Protection Agency.

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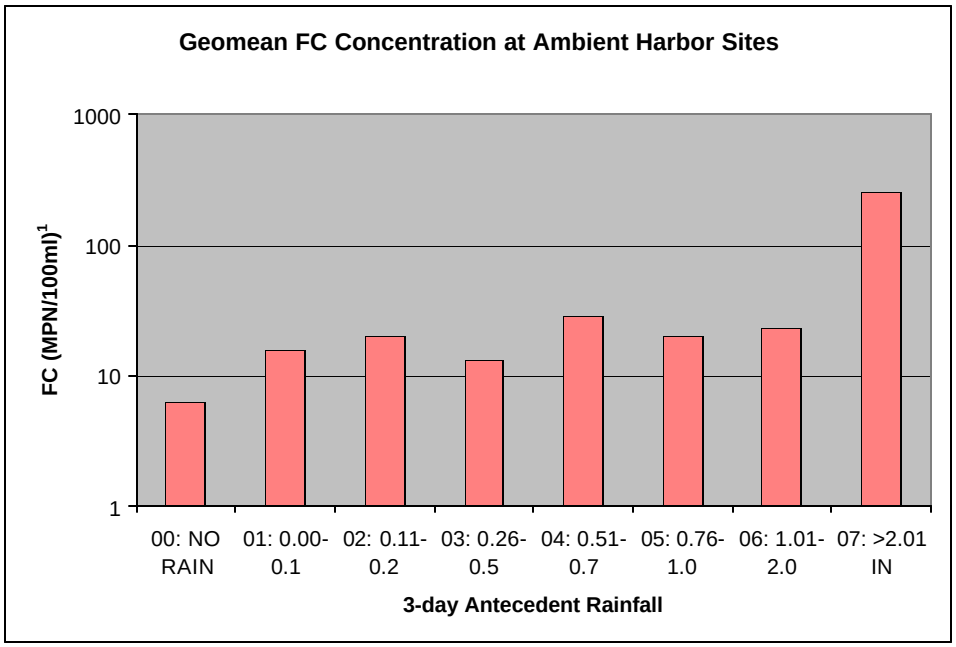
EXECUTIVE SUMMARY

The ability of AbTech's Smart Sponge® Plus to remove fecal-borne bacteria from stormwater was evaluated in a storm drainage system located in Seabrook, New Hampshire. The Smart Sponge® Plus was installed into a water quality inlet and samples were collected from influent (pre-treatment) and effluent (post-treatment) for analysis of bacterial concentrations and loadings during 15 storm events from September 3, 2003 to May 24, 2004, excluding winter months. The 15 storms included events with a range of rainfall intensities and amounts, as well as accompanying runoff volumes. Flow-weighted composite samples were analyzed for fecal coliforms, *Escherichia coli* and enterococci to determine if concentrations were lowered as stormwater passed through the Smart Sponge® Plus material. In most cases, bacterial concentrations were reduced within the treatment system, but to varying degrees. The efficiency ratio based on reduction in event mean concentration for each bacterial indicator in the flow was calculated for each storm event. The values ranged most widely for fecal coliforms, whereas the range of ratios was narrower and the values were more consistent for enterococci. The overall load reductions for the bacterial indicators were 50.3% for fecal coliforms, 51.3% for *Escherichia coli* and 43.2% for enterococci. Relatively consistent pH values were observed in influent and effluent samples. The overall range of pH values was large, ranging from 5.21 units in influent from storm event #11 to 7.64 units in influent from storm event #1. Conductivity values were greater in the effluent in 14 of the 15 storm events, especially in storm events #12 and #13 when effluent conductivities were >50% higher than influent values. Quality assurance/quality control procedures supported the methods and results of the study. Overall, the observed reductions in bacterial concentrations in post-treatment stormwater would still result in discharge of elevated bacterial levels that would continue to limit uses in receiving waters.

INTRODUCTION

Hampton/Seabrook Harbor and its tributaries were included on the New Hampshire Department of Environmental Services 1998, 2000 and 2002 303(d) lists of impaired waterbodies due to bacterial pollution (primarily during wet weather) that impairs its use for shellfishing (DES, 1998; DES, 2000; and DES, 2003). Waterbodies are listed on the State 303(d) if they do not meet designated uses or water quality criteria as authorized in RSA 485-A:8, I-V and State Water Quality Regulations. Bacterial contamination during wet weather events, especially during September-October, has been an ongoing factor limiting the harvest of soft-shell clams in the harbor (Nash, 2002). Using 1988-2001 DES Shellfish Program routine ambient monitoring data from Hampton/Seabrook Harbor, the geometric mean concentration of fecal coliform was calculated for rainfall events of various ranges (Trowbridge, 2002). The National Sanitary Shellfish Program (NSSP) standard of 14 MPN/100 ml was exceeded during all rainfall event types (Figure 1).



[1] The NSSP standard for geometric mean FC is 14 MPN/100ml.

Figure 1 Geometric mean concentration of fecal coliforms (FC) at Hampton/Seabrook Harbor sites from 1988-2001. (Source: Trowbridge, 2002)

Previous Studies

Over the past several years, DES and other agencies have focused on identifying pollution sources that contribute to wet weather contamination of Hampton/Seabrook Harbor. Jones and Landry (2003) reported a variety of different source species in the harbor based on *Escherichia coli* ribotyping. The most significant source species was humans, suggesting leaks from sewage infrastructure, septic systems, and untreated discharges from WWTFs and boats as causes of this pollution source. In October, 2002, sampling of stormwater discharge from the same stormwater pipe targeted for this study was conducted during a 12-hour storm in which 1.39" of rain fell (Trowbridge, 2003). *Escherichia coli* concentrations ranged from 14,400 to 1,120,000 cfu/100 ml during the storm, following a pattern of gradual rise to a peak followed by a sharp decline (Jones, 2003). Ribotyping of *Escherichia coli* isolates suggested humans and cormorants were the most significant sources of the bacterial contamination discharging from the stormdrain pipe. Even though the effluent sampled included input from other catchments of the stormwater system besides the portion targeted in the present study, this report showed how significant the contamination is from this pipe and the dynamics of bacterial concentrations during storms.

Study Goal

The goal of this project was to evaluate the pollutant removal efficiencies of the AbTech Smart Sponge® Plus installed in an existing stormwater treatment system using an

independent Environmental Technology Verification (ETV) program and to disseminate the findings of the study to New Hampshire stormwater managers. The AbTech material was selected based on its potential ability to reduce bacterial concentrations in stormwater.

Description of AbTech's Smart Sponge® Plus

AbTech Industries, Inc. is known in the stormwater treatment field for its patented technology based on a proprietary blend of synthetic polymers aimed at removal of hydrocarbons and oil derivatives from surface water. The AbTech process creates a porous structure with hydrophobic and oleophilic characteristics capable of selectively removing hydrocarbons while allowing high flow rates according to the company's promotional literature. This structure is highly porous; as hydrocarbons are absorbed into its structure, the Smart Sponge® swells and maintains porosity and filtering capabilities.

Smart Sponge® Plus

According to information published on AbTech Industries website (http://www.abtechindustries.com/smartspongeplus.asp), the company worked on the development of a new solution capable of treating microorganisms as well as hydrocarbons named the Smart Sponge® Plus. The company claimed to have developed a technology capable of binding an antimicrobial agent to its proprietary polymers thereby modifying their surface and adding micro biostatic features while maintaining the oil absorbing capabilities. The agent used for this innovative technology was described as an Organosilane derivative, which is widely used in a variety of fields including medical, consumables, pool equipment and consumer goods, according to the company's website.

Its mode of action, according to AbTech Industries, Inc. is very simple and neither introduces chemicals into the treated water nor produces toxic metabolites. During the initial phase of the study, the authors met with AbTech Industries, Inc. representatives and were told that the antimicrobial agent is chemically and permanently bound to the polymer surface and it does not leach or leak, therefore avoiding any downstream toxicity issues. The antimicrobial mechanism is based on the agent's electromagnetic interaction with the microorganism cell membrane, causing the microorganism disruption, but no chemical or physical change in the agent. Antimicrobial activity does not reduce the agent capability or cause its depletion and, therefore, maintains long-term effectiveness.

The address for AbTech Industries, Inc. is 4110 North Scottsdale Road, Suite 235, Scottsdale, Arizona, 85251.

TEST SITE DESCRIPTION

The test site is located in the Town of Seabrook in southeast New Hampshire. The AbTech Smart Sponge® Plus was installed west of Rt. 1A just south of the bridge that stretches across the mouth of Hampton/Seabrook Harbor. This storm drainage system is of concern because of the high bacterial loading it discharges to the harbor during storms

(Jones, 2003). The watershed area for the storm drainage system is approximately 60 acres with at least 65% impervious cover. Its land use is mainly high density residential with commercial establishments along Route 1A. The watershed area can be divided into three individual catchments. The catchment for this study is a series of pipes and catch basins on residential streets east of Route 1A and north of Hooksett Street up to and including Plymouth Street that collect stormwater via leaching basins and perforated and solid pipes to a pump station located on Route 1A across from Tilton Street (Figure 2). Stormwater is then pumped via a 16-inch force main to a drain manhole at the intersection of River Street and Route 1A. The second catchment area collects runoff from River Street, which then pumps via an 8-inch force main into a drain manhole at the intersection of River Street and Route 1A. Stormwater deposited into this shared manhole flows via gravity through a 24-inch pipe to the outfall. A third catchment area associated with this system consists of Route 1A from River Street to the outfall.

The outfall consists of a headwall structure with two drains and is located across from Tyngsboro Street on the western side of Route 1A. Both drains are fitted with tide flex valves to prevent salt water from entering the drainage network. The northern drain is connected to the subject watershed area, and the southern drain is connected to the residential streets east of Route 1A and south of Hooksett Street to Dracut Street. After exiting the outfall, the runoff is retained within a plunge pool, from which it slowly drains via culverts on Cross Beach Road through the salt marsh to the tidal creek to the harbor (Foote, 2003). Refer to Foote (2003) for a watershed analysis conducted by Millennium Engineering, Inc.

Figure 2 Aerial photo of storm drainage catchment for test site (green). (Sources: Photo-Foote, 2003; Graphics-C. Edwards [DES])

The AbTech material was placed in an existing water quality inlet (Figure 3) situated upstream of the pump station and across from Tilton Street. The property is owned by the Town of Seabrook.

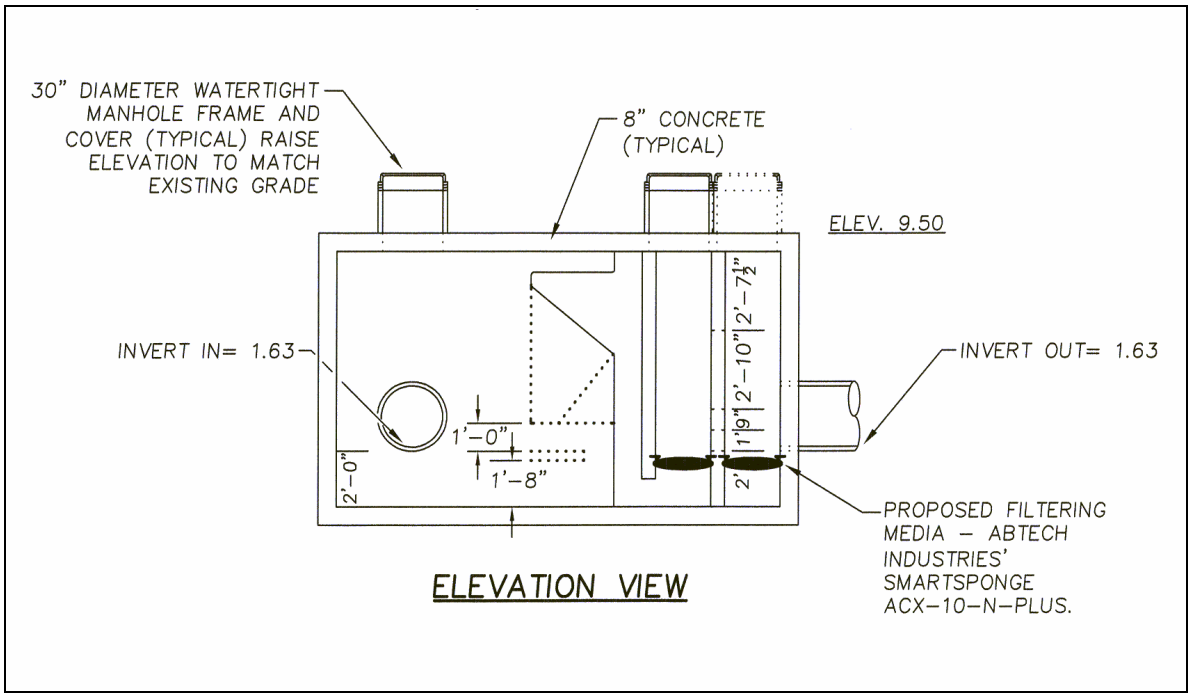


Figure 3 Side view of existing water quality inlet and location of AbTech Smart Sponge® Plus. (Source: Millennium Engineering, Inc. in Foote, 2003)

FIELD AND LABORATORY PROCEDURES

The sample collection procedures and laboratory methodologies are documented in the *Seabrook Stormwater Verification Project Quality Assurance Project Plan* (QAPP) by Nolan (2003). The QAPP was reviewed and approved by the DES Quality Assurance Manager and the Environmental Protection Agency (EPA). Table 1 lists the location of the monitoring equipment set-up and the storm drainage system outfall. Refer to Figure 2 for an aerial map showing the location of the monitoring set up.

Table 1 Location of monitoring equipment set up and storm drainage system outfall.

Site Description	Site Location	Latitude (degree, minutes, seconds)	Longitude (degree, minutes, seconds)
AbTech monitoring location	West of Route 1A and across from Tilton Street	42° 53' 25" N	-70°49' 06" W
Storm drainage system outfall	West of Route 1A and across from Tyngsboro Street	42° 53' 03" N	-70°49' 10" W

Field Procedures

The field procedures are written in detail in the QAPP. Brief summaries of the procedures used during this study are described below.

Rain and Flow Measurements

An ISCO Model 674 rain gauge was secured to a pole six feet above ground level in an open area away from trees and structures impacting rainfall measurements (Figure 4). The rain gauge was connected to and powered by the flow meter. The rain gauge transmitted a signal via the cable for each tip of the collector which represented 0.01 inches of rain. Prior to any samples being collected, the rain gauge and flow meter were monitored during three storms forecasted for at least 0.2 inches of rain. The rain gauge was calibrated using standard calibration techniques described in the operation manuals. Rainfall was measured for each storm event and data were recorded by the data logger.

Figure 4 Monitoring site with view of rain gauge.

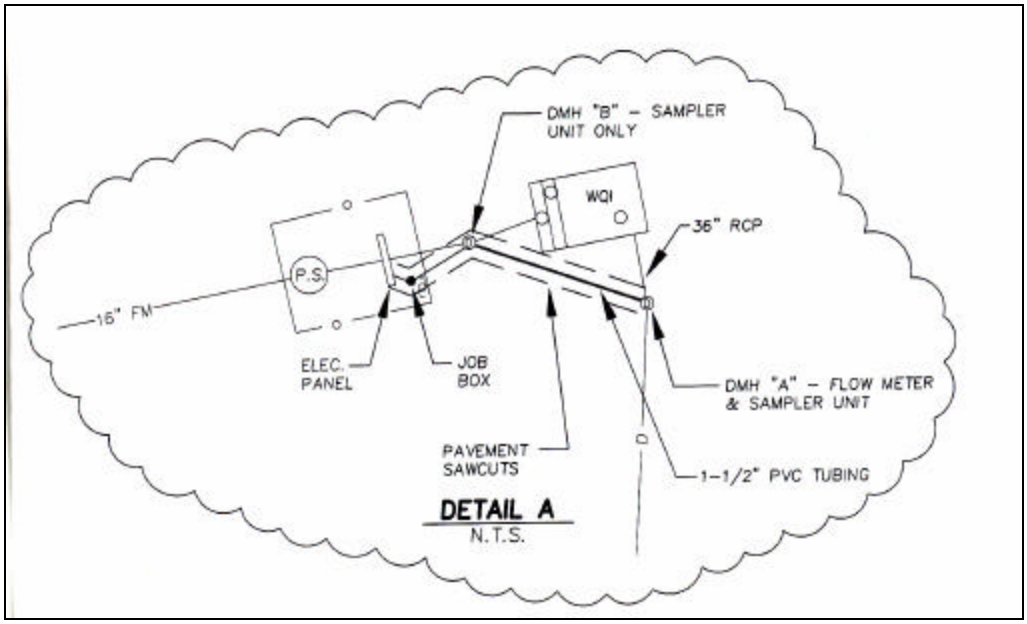
Flow measurements were made during the course of each event using an ISCO 4220 flow meter pressure transducer. The pressure transducer was mounted within the stormdrain pipe using an ISCO mounting ring. The pressure transducer was connected to the flow meter which was powered by an on-site electrical source. The flow meter had an external DC battery as a back up.

Rainfall intensities and flow data were measured for several storms before any sampling occurred to help refine the sampling design and procedures. All data collected from the testing phase of the project were kept in a project notebook. An ISCO 674 rain gauge was used to collect rainfall data. Two ISCO 6712FR refrigerated samplers were used to collect the influent and effluent samples and an ISCO 4220 flow meter pressure

transducer measured flow. When activated the influent and effluent samplers collected, in a slightly staggered fashion, five samples each over the duration of each storm. The effluent sample collection was initiated 5 minutes following the initial influent sample collection. The influent and effluent samples were tested for bacterial indicators, conductivity and pH. Flow and rainfall data were collected simultaneously with the water samples.

Water Sample Collection

Samples were collected using ISCO Model 6712 refrigerated samplers with 24 discrete bottles at two locations within the stormwater discharge system. One sampler collected samples from a pre-treatment location just upstream of the Smart Sponge® Plus treatment material. The other sampler collected samples downstream of the Smart Sponge® Plus. See Figure 5 for a schematic showing the sampling locations.



Note: DMH "A" is the location of influent sampling collection and DMH "B" is the location of effluent sampling.

Figure 5 Schematic showing locations of influent and effluent sampling points. (Source: Millennium Engineering, Inc. in Foote, 2003)

Sample Collection

Each autosampler (Figure 6) held up to 24 bottles in the chamber. A minimum of 8 (5 influent or effluent, 2 field duplicates and 1 field blank), 1000-mL sample bottles were placed in each autosampler chamber prior to each rain event (Table 2).

Figure 6 Autosamplers in enclosure at monitoring site.

Table 2 Position and purpose of sampling bottles.

Position/Bottle Number	Purpose
1-21	Bacteria Indicators, pH and conductivity
22 and 23	Field duplicate- Bacterial indicators, pH and conductivity.
24	Field Blank

Prior to each rain event the total forecasted duration for the storm was determined and divided by the number of discrete samples to be collected for each analysis. Total storm duration divided by number of discrete samples gave the time lapse between each sample to be collected. Time interval was recorded on Time Interval Log Sheets. At least five discrete influent and effluent samples were collected according to a pre-programmed time for bacteria indicators, pH and conductivity. Flow-proportional composite sample results were calculated based on flow levels.

Each composite sample was comprised of a minimum of aliquots from 5 discreet samples including at least 2 samples on the rising limb of the hydrograph, one near the peak, and two on the falling limb.

A field blank (sterilized, deionized water) remained in the samplers for the duration of the event from the time the sterile sample bottles were placed in the automated sampler. A single set of duplicate samples were collected for bacterial indicators, pH and conductivity during each event. Duplicate samples were collected by installing a clean,

sterile split tube which allowed for sampling an identical sample in two bottles. These samples were taken at a random time during each event.

Upon collection, samples were stored in the refrigerated ISCO samplers at 4 degrees C. At the end of each event the samples were transported to the Microbiology Lab at the University of New Hampshire Jackson Estuarine Laboratory (JEL) with ice/ice packs and analyzed within 2 hours. Bacterial samples were filtered immediately. Samples were held according to the sample hold times and preservation requirements. All samples were labeled for proper identification, including sample identification, date and analysis.

Lab Procedures

The bacterial analyses for this project were conducted at JEL. The *Quality Assurance Plan for the Jackson Estuarine Laboratory Microbiology Lab* (Jones, 2002) was reviewed and approved by the EPA on December 2, 2002.

Analytical Methods

Analyses included fecal coliforms, *Escherichia coli* and enterococci membrane filtration methods (Table 3). Briefly, a sterile gridded 0.45 µm membrane filter was placed on the filter base of a sterile 250 ml filter and a magnetic filter tower was attached. The sample was vigorously shaken and the volume to be filtered was measured in a sterile graduated cylinder or a sterile pipette Samples were decimally diluted from 10^{-1} to 10^{-7} by adding 1.0 ml sample to 9.0 ml sterile BPW. Sample volumes of up to 100 ml were filtered at 25 millibar until all water passed through the filter.

Filters were placed onto mTEC medium plates for detection of fecal coliforms and *E. coli*, grid side up, by rolling the filter onto the agar surface to minimize air bubbles under the filter. All plates were incubated at 35±0.5 °C for 2 h and at 44.5±0.2 °C for 22 hours (USEPA, 1986). Yellow colonies for each sample/site at the best dilutions (10-30 readable colonies) were counted and recorded as fecal coliforms (Rippey et al., 1986). Filters were then rolled onto urea solution-soaked cellulose pads and incubated for 10-20 minutes at room temperature. The remaining yellow/yellow brown colonies were counted and recorded as *E. coli.* One colony from a plate from each sample batch was inoculated in MacConkey agar, trypticase broth for indole, urea agar, MRVP broth and Simmons citrate agar and incubated at 35±0.5 º C overnight. An oxidase test was conducted on isolates that met *E. coli* criteria to that point. Oxidase negative isolates were confirmed *E. coli* isolates.

For detection of enterococci, filters were placed onto mE medium plates and incubated at 41±0.5 °C for 48 h (USEPA, 1986). Membrane filters were then transferred to EIA agar plates and incubated at 41±0.5 °C for 20 min. Pink-red colonies that formed black to reddish-brown precipitates in the agar below the colony were counted and recorded as enterococci. One colony from a plate from each sample batch and was inoculated onto brain heart infusion (BHI) agar and incubated at 35±0.5 º C overnight. Catalase negative/gram positive cultures were further tested in BHI broth at 45±0.5 °C for 48 h

and BHI broth with 6.5% NaCl incubated at 35±0.5 °C for 48 h. Growth on both media indicated that the isolates were enterococci.

Table 3 Water bacterial indicators and reference limits.

Indicator	Analytical method SOP Reference	Analytical/Achievable Method Detection Limit	Project Quantitation Limit
Escherichia coli	Membrane Filter Procedure, EPA 600/4-85/076; Standard Method 9213D.3 (APHA, 1995)	0+ cts/100 mL (depends on dilution and sample volume)	0+ cts/100 mL (depends on dilution and sample volume)
Fecal coliforms	Membrane Filter Procedure, EPA 600/4-85/076	0+ cts/100 mL (depends on dilution and sample volume)	0+ cts/100 mL (depends on dilution and sample volume)
Enterococci	Membrane Filter Procedure, EPA 600/4-85/076; Standard Method 9230C (APHA, 1998)	0+ cts/100 mL (depends on dilution and sample volume)	0+ cts/100 mL (depends on dilution and sample volume)

RESULTS AND DISCUSSION

The AbTech Smart Sponge® Plus, installed in an existing water quality inlet along Route 1A in Seabrook, was evaluated for pollutant removal efficiencies based on water quality and quantity data collected during 15 rain events during the summer of 2003 through the spring of 2004. Pollutants that were measured included three bacterial indicators (*E. coli*, enterococci, fecal coliforms), conductivity and pH. The Smart Sponge® Plus was evaluated through the monitoring of influent and effluent samples that were collected using automated samplers.

This project relied on the *Draft Verification Protocol for Stormwater Source Area Treatment Technologies Draft 4.1* (also referred to as ETV)(EPA, 2002) as a guide to test the ability of the AbTech Smart Sponge® Plus media to reduce bacterial loads and concentrations into Hampton/Seabrook Harbor from a storm drainage system.

As part of fulfilling the requirements of the ETV, 15 storm events were sampled for bacterial indicators in stormwater prior to and after entering the AbTech material within the storm drainage system. The period of time during which sampling occurred was September 3, 2003 to May 24, 2004. The general data, including sample timing, storm characteristics and bacterial event mean concentrations (EMCs), are summarized for each event in Table 4. The complete summary of bacterial analyses is in Appendix A. Storms with a range of intensities were sampled twice during summer, eight times during autumn, not sampled in winter and sampled five times during spring.

The storm events ranged from 0.24 to 1.43 inches of rain and the maximum hourly rainfall intensity ranged from 0.10 to 0.47 inches/hour. The runoff volume ranged from ~138,000 gallons to 2,705,000 gallons.

EPA (2002) requires the use of two primary performance indicators to characterize the pollutant removal efficiency of the technology being tested. The first indicator is load reduction based on the percentage of the total amount of pollutant removed and the second is an efficiency ratio based on reduction in event mean concentration of the pollutant in the flow for each storm event. Both indicators are expressed as percentages. See equations in following sections. Both indicators were calculated and reported for the individual storms monitored and as averages over all the sampled rain events (Tables 5 and 6). The performance indicators are intended to describe how the unit performs under the conditions of the types of storm events (Table 4) that occurred during the sampling period.

Table 4 Storm event characteristics and event mean concentrations for bacterial indicators.

Event	Start date/ time	End date/ time	Event rainfall depth (in)	Max hourly rainfall intensity (in/hour)	Runoff volume through device (gallons)	Influent Fecal Coliforms (cfu/100 ml)	Effluent Fecal Coliforms (cfu/100 ml)	Influent *E. coli* (cfu/100 ml)	Effluent *E. coli* (cfu/100 ml)	Influent Enterococci (cfu/100 ml)	Effluent Enterococci (cfu/100 ml)
1	4Sept03 8:45	4Sept04 12:30	0.35	0.20	821469	21800	22800	21200	21600	9450	5850
2	15Sept03 04:30	15Sept03 09:00	0.24	0.10	997397	134000	44500	122500	40000	50000	20500
3	23Sept04 16:00	23Sept04 17:30	0.48	0.47	No data[1]	12500	8500	11000	8000	9000	7500
4	4Oct03 16:10	4Oct03 18:30	0.31	0.14	529758	1000	150	1000	150	1250	600
5	15Oct03 3:30	15Oct03 12:30	1.43	0.33	2705091	5100	2950	4750	2750	4200	4000
6	27Oct03 21:30	28Oct03 5:15	0.25	0.11	992717	10500	10000	10000	8000	4850	3750
7	29Oct03 3:00	29Oct03 16:00	1.09	0.21	1521207	1850	1900	1750	1800	1900	1250
8	29Nov03 00:55	29Nov03 6:00	0.48	0.10	163485	205	105	200	100	900	600
9	11Dec03 14:00	11Dec03 19:00	0.60	0.25	688679	690	650	660	630	435	360
10	17Dec03 20:15	18Dec03 2:00	0.62	0.20	1067249	150	145	145	135	750	750
11	1April04 12:10	1April04 3:15	0.79	0.46	461870	2600	2600	2300	2250	5450	4650
12	4May04 2:45	4May04 5:50	0.49	0.21	463933	215	160	200	160	190	155
13	22May04 8:00	22May04 9:30	0.34	0.12	137711	815	275	805	240	685	435
14	23May04 3:00	23May04 5:00	0.62	0.40	527781	2120	1030	2050	985	405	350
15	24May04 4:30	24May04 7:00	0.30	0.13	389949	915	910	880	875	225	165

[1]Technical problem with flow meter.

Load Reduction Efficiency

The loads for each bacterial indicator in influent and effluent stormwater for each storm event are summarized in Table 5. Due to a technical problem with the flow meter, there are no data for storm event #3. The overall load reduction efficiency was calculated as follows:

$$\% \text{ Load Reduction Efficiency} = 100 \times (1-(A/B))$$

Where: A = sum of effluent load = (effluent EMC_1)(flow $volume_1$) + (effluent EMC_2)(flow $volume_2$) +…(effluent EMC_n)(flow $volume_n$)

B = sum of influent load = (influent EMC_1)(flow $volume_1$) + (influent EMC_2)(flow $volume_2$) +…(influent EMC_n)(flow $volume_n$)

The % load reduction efficiencies for the bacterial indicators were 50.3% for fecal coliforms, 51.3% for *E. coli* and 43.2% for enterococci (Table 5). Considering the high concentrations of bacteria observed in the stormwater pipe during some of the storms, this level of reduction does not appear to be sufficient to have a significant impact on water quality.

Table 5 Load reduction efficiencies for bacterial indicators.

Event	Fecal coliforms		*E. coli*		Enterococci	
	IL	EL	IL	EL	IL	EL
1	6.78E+11	7.09E+11	6.59E+11	6.72E+11	2.94E+11	1.82E+11
2	5.06E+12	1.68E+12	4.63E+12	1.51E+12	1.89E+12	7.74E+11
3	no data	no data	no data	no data	no data	no data
4	2.01E+10	3.01E+09	2.01E+10	3.01E+09	2.51E+10	1.20E+10
5	5.22E+11	3.02E+11	4.86E+11	2.82E+11	4.30E+11	4.10E+11
6	3.94E+11	3.75E+11	3.75E+11	3.00E+11	1.82E+11	1.41E+11
7	3.87E+11	3.97E+11	3.66E+11	3.76E+11	3.97E+11	2.61E+11
8	7.68E+08	3.94E+08	7.50E+08	3.75E+08	3.37E+09	2.25E+09
9	1.80E+10	1.69E+10	1.72E+10	1.64E+10	1.13E+10	9.38E+09
10	6.06E+09	5.86E+09	5.86E+09	5.45E+09	3.03E+10	3.03E+10
11	4.55E+10	4.55E+10	4.02E+10	3.93E+10	9.53E+10	8.13E+10
12	3.78E+09	2.81E+09	3.51E+09	2.81E+09	3.34E+09	2.72E+09
13	4.25E+09	1.43E+09	4.20E+09	1.25E+09	3.57E+09	2.27E+09
14	4.24E+10	2.06E+10	4.10E+10	1.97E+10	8.09E+09	6.99E+09
15	1.35E+10	1.34E+10	1.30E+10	1.29E+10	3.32E+09	2.44E+09
TOTAL	**7.19E+12**	**3.57E+12**	**6.66E+12**	**3.24E+12**	**3.37E+12**	**1.92E+12**
% Load Reduction Efficiency =		**50.3**		**51.3**		**43.2**

Note: IL = influent load and EL = effluent load

Bacterial Concentration Reduction Efficiency Ratio

The concentration efficiency ratio for each bacterial indicator and storm event was calculated (Table 6). The efficiency ratio (expressed as a percentage) for each event was calculated as follows:

Efficiency Ratio = 100 x (1-(effluent EMC)/(influent EMC))

The values ranged from –5 to 85% for fecal coliforms, -2 to 85% for *E. coli* and 0 to 59% for enterococci. Efficiency ratios were quite low (<10%) during 7, 6 and 2 storm events for fecal coliforms, *E. coli* and enterococci, respectively. The range of ratios was narrower and the values were more consistent for enterococci compared to the other two indicators.

Table 6 Bacterial concentration reduction efficiency ratios (expressed as percentages).

	Efficiency Ratio		
Event	**Fecal coliforms**	***E. coli***	**Enterococci**
1	-5	-2	38
2	67	67	59
3	32	27	17
4	85	85	52
5	42	42	5
6	5	20	23
7	-3	-3	34
8	49	50	33
9	6	5	17
10	3	7	0
11	0	2	15
12	26	20	18
13	66	70	36
14	51	52	14
15	1	1	27

In most cases, bacterial concentrations were reduced within the treatment system, but to varying degrees. Fecal coliform and *E. coli* concentrations increased during two events, and enterococci and fecal coliform concentrations were equal in pre- and post-treatment samples during one event. Bacterial concentrations decreased from pre- to post-treatment samples during all other events.

Schueler and Holland (2000) state that stormwater treatment practices must be extremely efficient if they are to produce storm outflows that meet a fecal coliform standard of 200 MPN at a site. And they further state in the same publication that a stormwater practice would need to achieve a 99% removal rate for fecal coliform to meet the standard. The greatest bacterial concentration reduction achieved with the Smart Sponge® Plus was 85% for fecal coliform and *E. coli* during a storm event (event #4) that totaled 0.31 inches. Based on the highly variable removal efficiencies (Table 6) and intense

maintenance requirement for the removal of trash (Table 8), the installation of a Smart Sponge® Plus in a water quality inlet of an intensely developed watershed is not practical.

Other Parameters

Flow rate and rainfall data were collected for each event in accordance with the QAPP (Nolan, 2003) as were conductivity and pH measurements.

Flow rate and rainfall

All flow rate and rainfall information was recorded successfully with the exception of flow rate data during the third storm event (9/23/04). The rainfall intensity combined with the volume of runoff caused problems with the storm drainage pump system and as a result the flow rate data are invalid for that storm. Flow and rainfall data are provided in Appendix E.

Conductivity and pH

Conductivity and pH were measured in influent and effluent samples for each storm event (Table 7), using the same composite samples used for measuring bacterial indicator concentrations. Relatively consistent pH values were observed in influent and effluent samples, and these were evenly divided between increases and decreases in the effluent. However, the overall range of pH values was large, ranging from 5.21 in influent from storm event #11 to 7.64 in influent from storm event #1. Conductivity values were greater in the effluent in 14 of the 15 storm events, especially in storm events #12 and #13 when effluent conductivities were >50% higher than influent values.

Table 7 Conductivity and pH measurements for pre-treatment (influent) and post-treatment (effluent) samples.

Event	Pre-treatment	Post-treatment
	pH	
1	7.64	7.58
2	6.79	6.96
3	7.55	7.46
4	6.21	6.04
5	6.01	6.5
6	6.54	5.49
7	5.87	5.89
8	7.42	7.33
9	7.49	7.58
10	6.47	6.56
11	5.21	5.61
12	6.17	6.14
13	5.77	5.88
14	5.74	5.72
15	6.09	6.17
Average =	6.46	6.46

Event	Pre-treatment	Post-treatment
	Conductivity (µS)	
1	163	170
2	186	204
3	178	189
4	202	236
5	239	281
6	159	181
7	197	204
8	137	181
9	896	950
10	1463	1191
11	51.7	68.3
12	16.2	24.9
13	70.8	120
14	55.9	74.8
15	15.6	20.2
Average =	269	273

QA/QC Results

The methods and procedures used during this study were approved by the Environmental Protection Agency (EPA) and documented in the *Seabrook Stormwater Verification Project Quality Assurance Project Plan* (Nolan, 2003). Quality assurance and control data are provided in appendices B, C and D.

Two field duplicates were collected separately from the composite sample during each event. The duplicate samples were analyzed twice for each bacterial indicator (see Appendix B). The relative percent difference (RPD) for duplicates was calculated for each event as follows:

$$RPD = (X_1 - X_2)/((X_1 + X_2)/2))*100$$

The target RPD was $\leq$20%, as described in the QAPP. The overall average RPD for all events was <10% for each indicator. The measured RPD values were >20% in two events for fecal coliforms and enterococci, and in one event for *E. coli.* Thus, the RPD values were consistently less than 20%.

Equipment blanks were sampled prior to the start and at the end of the event sampling (see Appendix C). The bacterial indicator concentrations were relatively low in the early samples, and somewhat higher in the last samples. Considering the load of bacteria that flowed through the treatment device and that were exposed to the tubing during sampling, these numbers of bacteria probably contributed little to concentrations during events.

All bacterial media and lab equipment blanks gave no colonies. No bacterial indicator colonies were detected in any of the field blank samples included with each event. All positive and negative controls gave expected results, i.e. growth of positive controls and no growth of negative controls on any given medium and incubation conditions.

The RPDs for duplicate analyses of all samples were calculated for each event and bacterial indicator (see Appendix D). RPDs were consistently low except for event #4. The concentrations of bacterial indicators were much lower in event #4 stormwater than what had been observed in the previous 3 events, and dilutions used to enumerate bacteria were too high to yield plates with 20-60 colonies. Use of plates with fewer colonies often yields more variable results. More dilutions were used thereafter to ensure use of plates with adequate numbers of colonies. Repeated counting of colonies by the same analyst gave results that met the QAPP target ($\leq$5% difference) and repeated counts by different analysts also gave results that met the QAPP target ($\leq$20% difference).

OPERATION AND MAINTENANCE PROCEDURES

Table 8 describes a record of operation and maintenance procedures performed during the project, before, during and after the monitoring period. This record was maintained by the field technician and was kept, in part, to record the maintenance required to keep the system free of debris. Intense maintenance of trash removal makes this set up of a Smart Sponge® Plus set into water quality inlet labor intensive and would be a hardship for regular checks by public works personnel.

Table 8 Operation and maintenance records for entire study period.

Date	Description of Maintenance
6/26/02	Conduit put in place
3/13/03	Media bags put in place (Smart Sponge Plus)
3/14/03	Cell phone antenna changed out
3/20/03	Floatables removed
4/10/03	Floatables removed
6/19/03	Floatables removed
8/28/03	Floatables removed
9/02/03	New fencing placed on top of media bags
9/23/03	This storm caused the storm drainage system pumps to short out and backed up the system for 4+ days.
11/06/03	Floatables removed
11/12/03	Heat tape placed on tipping bucket
12/10/03	Visual inspection of media bags and fencing
1/14/04	Contacted by Seabrook Wastewater dept that the pump station pump shorted. Removed media bags from pump station. Installed bags back into chamber and placed new fencing over bags.
3/10/04	Site visit. Power failure. Needed to re-program both autosamplers.
4/5/04	Floatables removed
6/3/04	Media removed from site
6/4/04	Equipment removed from site

ACKNOWLEDGEMENTS

We appreciate all the help we received from the following people. Andrea Donlon (formerly DES) for her assistance with the QAPP; Phil Maltais (Seabrook Sewer Department) for his assistance with the installation of the monitoring equipment and power source; Sue Foote (Seabrook Conservation Commission) for her continuous support of the project from beginning to end; Mike Colin (Seabrook Wastewater Treatment Facility) for his assistance with sample collection during the initial stages of the study development; and, Colin Edwards for the creation of certain graphics used in this report. Thanks to the US EPA, DES and the New Hampshire Estuaries Project for the financial support for the study.

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APPENDICES OF RAW, ANALYZED AND QA/QC DATA

Appendix A. Bacterial concentrations (cfu/100 ml) in pre- and post-treatment storm water samples.

Storm date	Fecal coliforms		*E. coli*		Enterococci	
	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment
9/4/03	22800	23200	22400	22400	9200	5600
	20800	22400	20000	20800	9700	6100
9/16/03	126000	41000	114000	39000	48000	22000
	142000	48000	131000	41000	52000	19000
9/23/03	11000	6000	10000	6000	10000	7000
	14000	11000	12000	10000	8000	8000
10/4/03	1300	300	1300	300	1600	700
	700	0	700	0	900	500
10/15/03	5000	3100	4700	2800	4400	4000
	5200	2800	4800	2700	4000	4000
10/28/03	10000	10000	10000	9000	5100	3800
	11000	10000	10000	7000	4600	3700
10/29/03	1700	2000	1600	1800	2000	1200
	2000	1800	1900	1800	1800	1300
11/29/03	230	110	220	110	1000	600
	180	100	180	90	800	600
12/11/03	660	680	640	650	410	380
	720	620	680	610	460	340
12/17/03	140	130	140	120	700	700
	160	160	150	150	800	800
4/1/04	2400	2200	2200	1900	5800	4700
	2800	3000	2400	2600	5100	4600
5/4/04	250	180	240	180	180	150
	180	140	160	140	200	160
5/22/04	840	210	820	180	640	410
	790	340	790	300	730	460
5/23/04	2080	1070	2000	1010	410	360
	2160	990	2100	960	400	340
5/24/04	890	950	860	910	210	170
	940	870	900	840	240	160

Appendix B. Bacterial concentrations (cfu/100 ml) and relativ percent differences (RPD) for field duplicate samples.

	Fecal coliforms						
	Sample	"A"		Sample	"B"		
Event	A-1	A-2	Average	B-1	B-2	Average	RPD
1	46600	48400	47500	51200	49600	50400	6
2	29600	30800	30200	31200	30400	30800	2
3	12000	11000	11500	9000	9000	9000	24
4	300	200	250	300	200	250	0
5	44000	38000	41000	35000	39000	37000	10
6	13000	10000	11500	10000	12000	11000	4
7	700	1100	900	1400	1100	1250	33
8	80	100	90	110	80	95	5
9	720	680	700	610	640	625	11
10	190	250	220	200	180	190	15
11	4400	5200	4800	4100	5000	4550	5
12	180	200	190	190	220	205	8
13	610	640	625	690	730	710	13
14	3960	3560	3760	4240	3200	3720	1
15	680	720	700	680	780	730	4
						Average	**9**
Event	***E. coli***						
1	44800	47200	46000	49600	48000	48800	6
2	28000	30000	29000	28500	29200	28850	1
3	10000	11000	10500	9000	9000	9000	15
4	300	200	250	300	200	250	0
5	43000	38000	40500	33000	37000	35000	15
6	10000	10000	10000	7000	11000	9000	11
7	600	900	750	1300	900	1100	38
8	70	90	80	110	70	90	12
9	680	650	665	590	610	600	10
10	180	220	200	180	160	170	16
11	4100	4700	4400	3600	4700	4150	6
12	160	200	180	170	200	185	3
13	600	610	605	650	700	675	11
14	3600	3360	3480	4000	3080	3540	2
15	650	680	665	600	760	680	2
						Average	**10**
Event	**Enterococci**						
1	10400	10400	10400	10000	10300	10150	2
2	7800	8400	8100	7200	8100	7650	6
3	8000	10000	9000	6000	10000	8000	12
4	300	400	350	500	400	450	25
5	4400	4200	4300	4400	4600	4500	5
6	4100	3800	3950	3800	3900	3850	3
7	800	900	850	1100	1200	1150	30
8	600	500	550	700	600	650	17
9	380	370	375	390	370	380	1
10	2800	3000	2900	2800	2700	2750	5
11	4300	3900	4100	4500	4100	4300	5
12	250	280	265	210	270	240	10
13	280	270	275	240	290	265	4
14	TNTC*	TNTC		TNTC	TNTC		
15	840	800	820	760	840	800	
						Average	**9.57**

TNTC = Too Numerous To Count

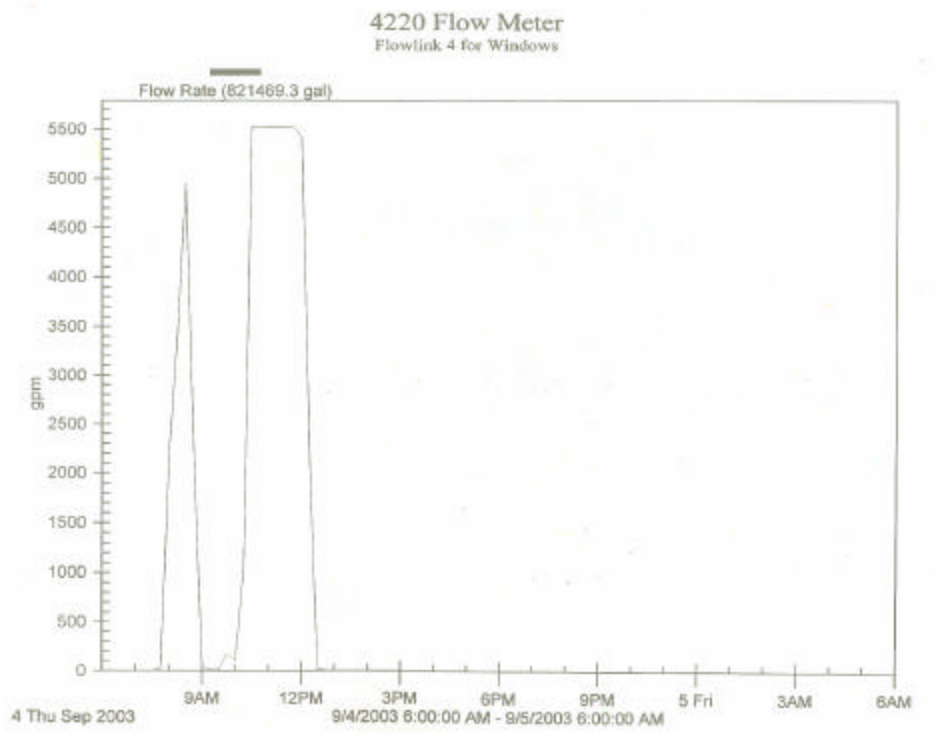
Appendix C. Bacterial and water quality analysis of equipment blank samples.

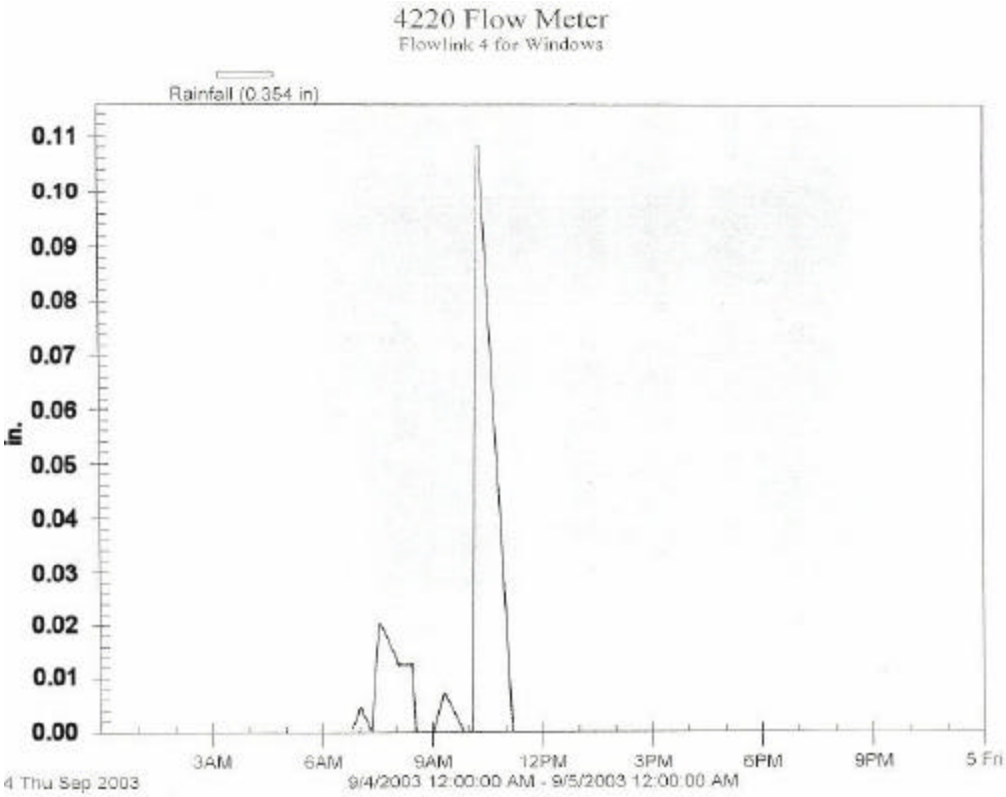
Bacteria						
Date	**Fecal coliforms**		***E. coli***		**Enterococci**	
	pre	post	pre	post	pre	post
	cfu/ 100 ml		cfu/ 100 ml		cfu/ 100 ml	
9/11/03	10	20	6	10	3	4
5/17/04	35.5	23.5	31.5	22	14.5	9
	Water Quality					
	pH		**Conductivity (µohm)**			
	pre	post	pre	post		
9/11/03						
5/17/04	6.75	6.81	2.5	2.8		

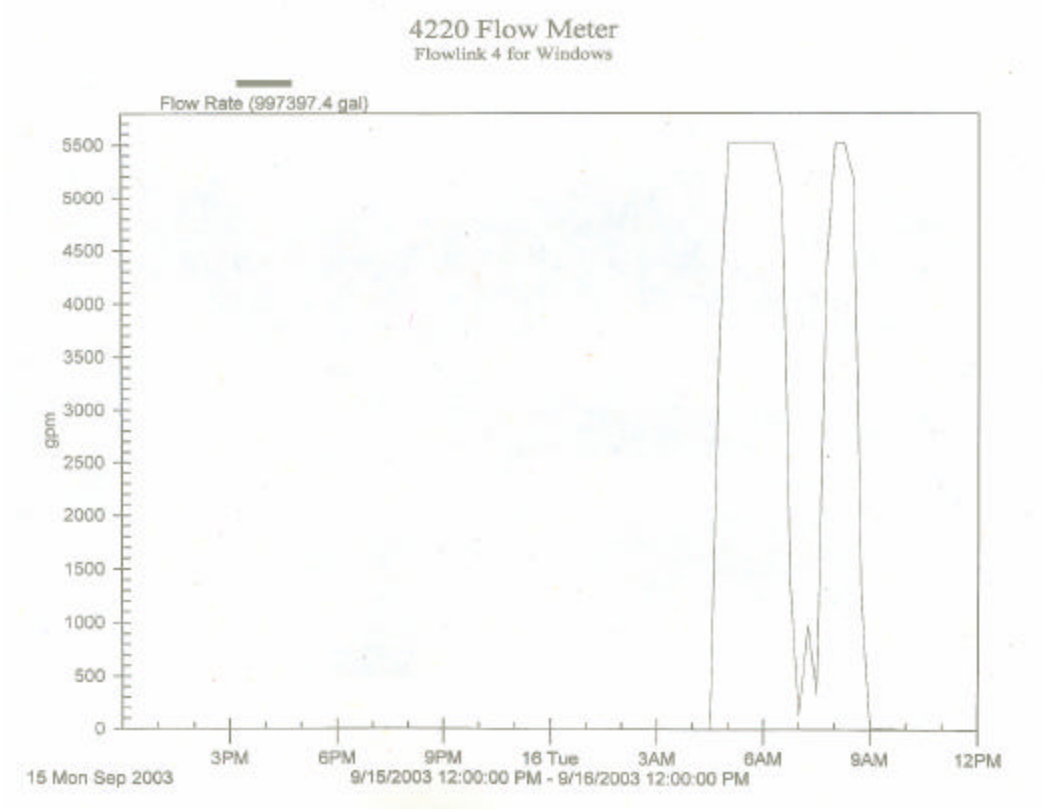
Appendix D. Percent differences between analytical duplicates for each event and overall.

Event	Fecal coliforms		*E. coli*		Enterococci	
1	9%	4%	11%	7%	5%	9%
2	12%	16%	14%	5%	8%	15%
3	24%	59%	18%	50%	22%	13%
4	60%	200%	60%	200%	56%	33%
5	4%	10%	2%	4%	10%	0%
6	10%	0%	0%	25%	10%	3%
7	16%	11%	17%	0%	11%	8%
8	24%	10%	20%	20%	22%	0%
9	9%	9%	6%	6%	11%	11%
10	13%	21%	7%	22%	13%	13%
11	15%	31%	9%	31%	13%	2%
12	33%	25%	40%	25%	11%	6%
13	6%	47%	4%	50%	13%	11%
14	4%	8%	5%	5%	2%	6%
15	5%	9%	5%	8%	13%	6%
Average	16%	31%	14%	31%	15%	9%

Appendix E Flow Rate and Rainfall Data by Date



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4000
3500
3000
2500
2000
1500
1000
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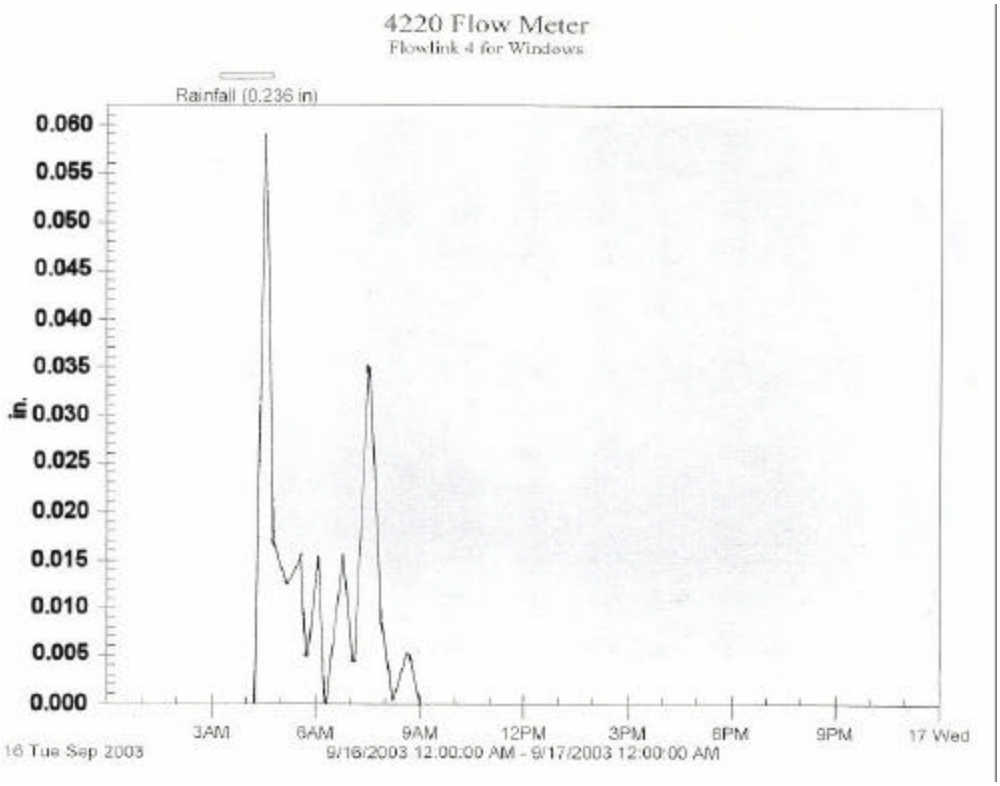
12PM
15 Mon Sep 2003
9/15/2003 12:00:00 PM - 9/16/2003 12:00:00 PM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0.045
0.040
0.035
0.030
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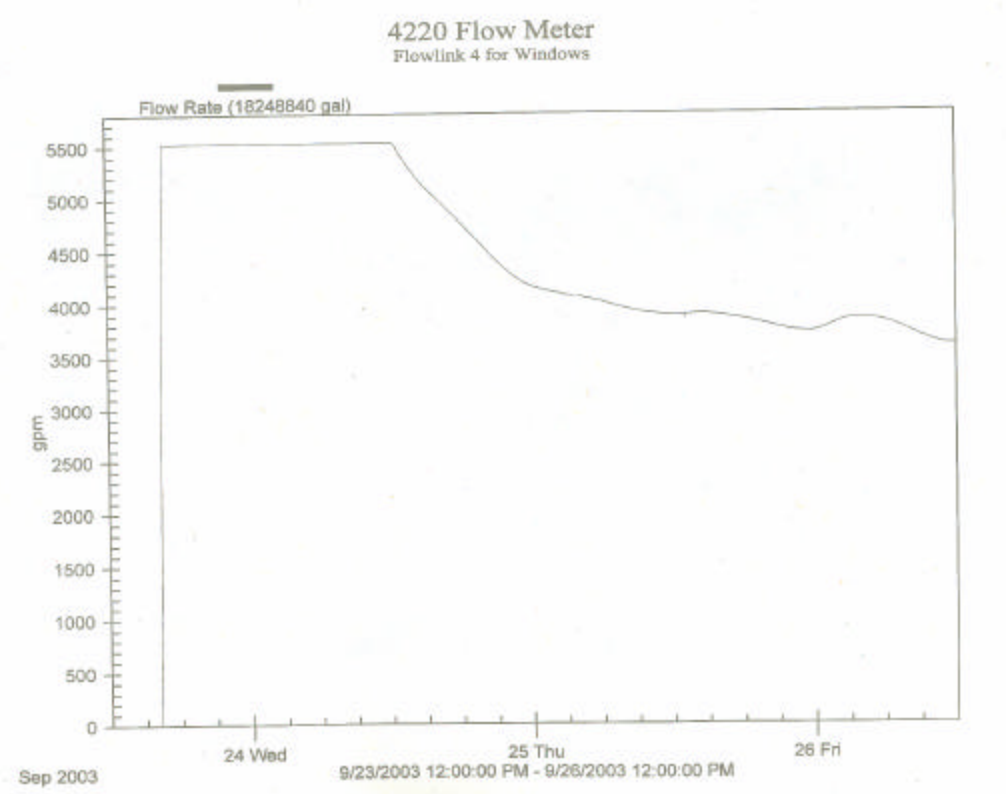
9/16/2003 12:00:00 AM - 9/17/2003 12:00:00 AM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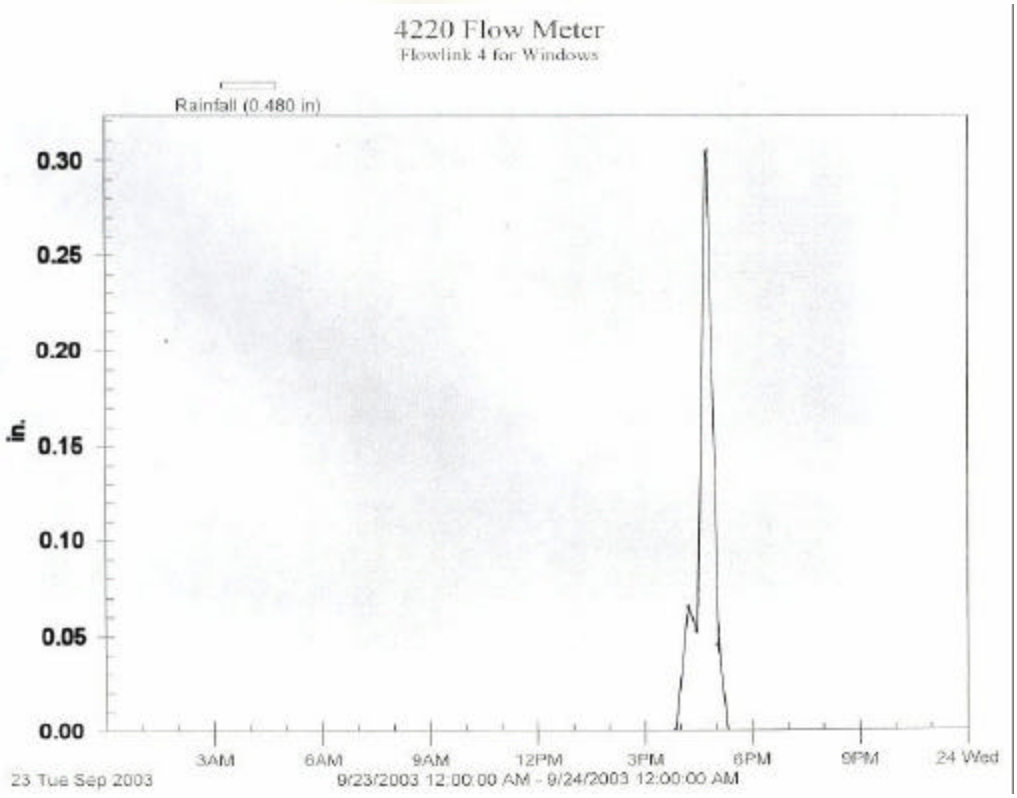
Sep 2003
9/23/2003 12:00:00 PM - 9/26/2003 12:00:00 PM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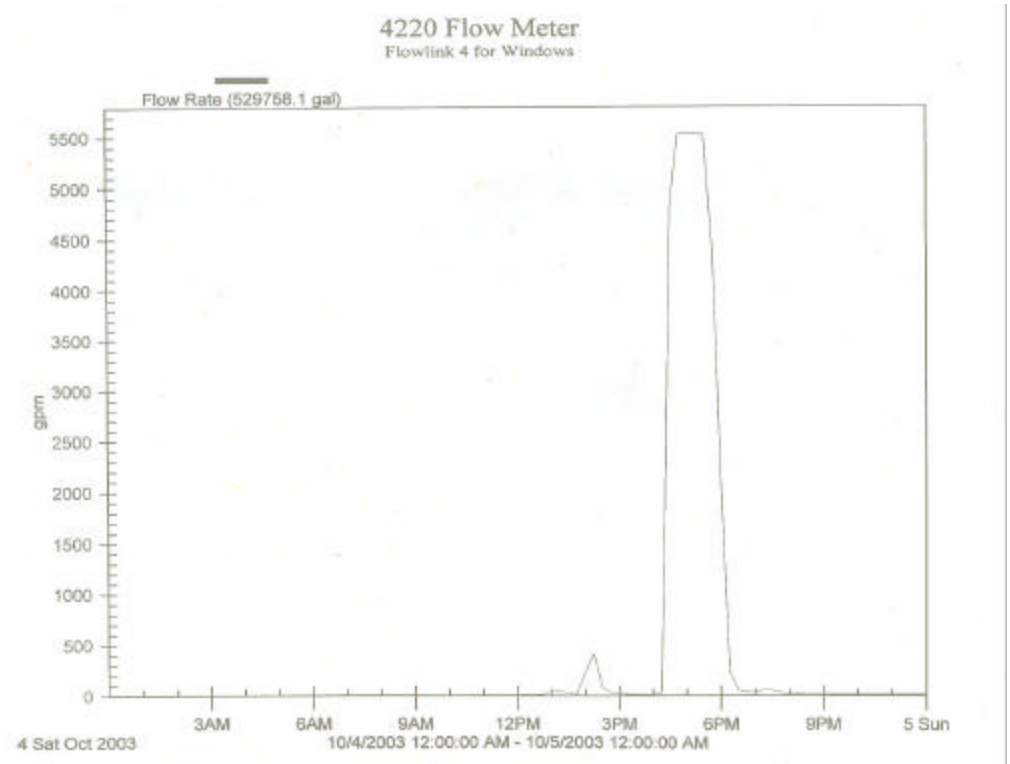
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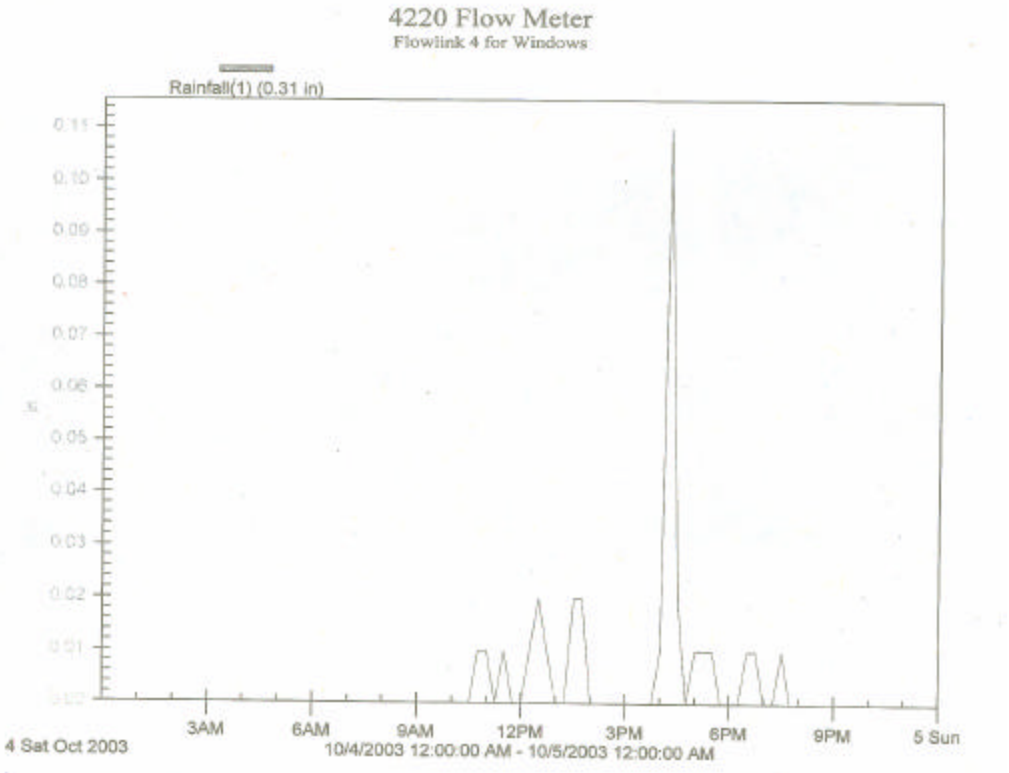
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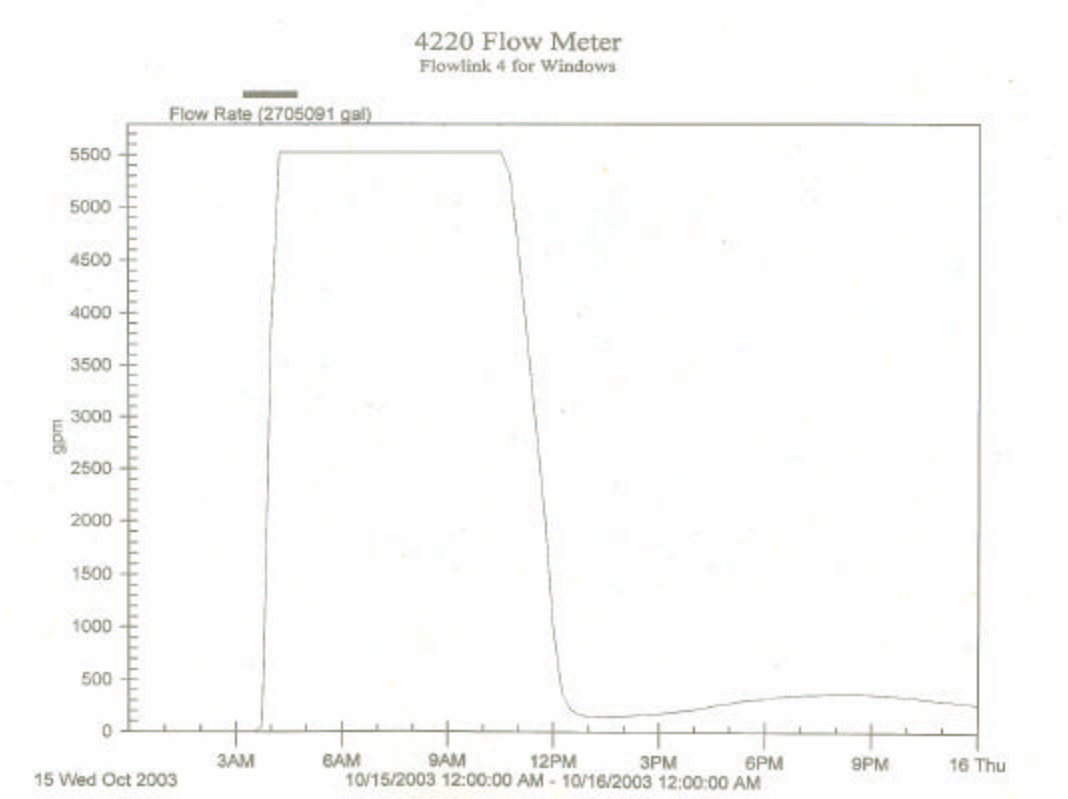
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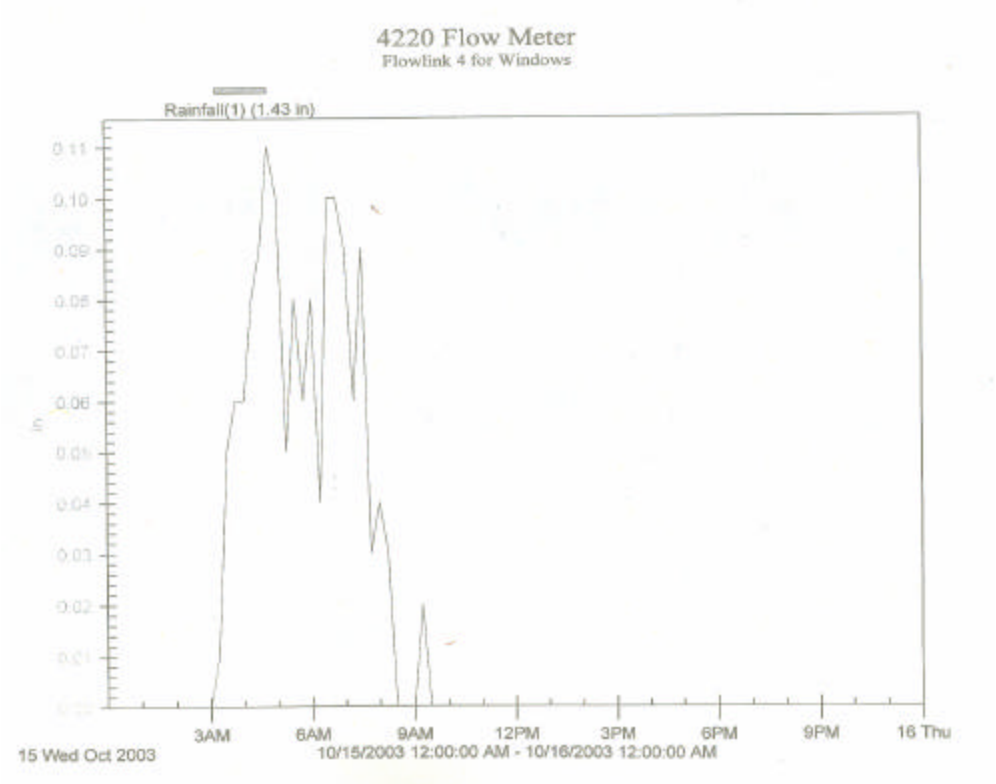
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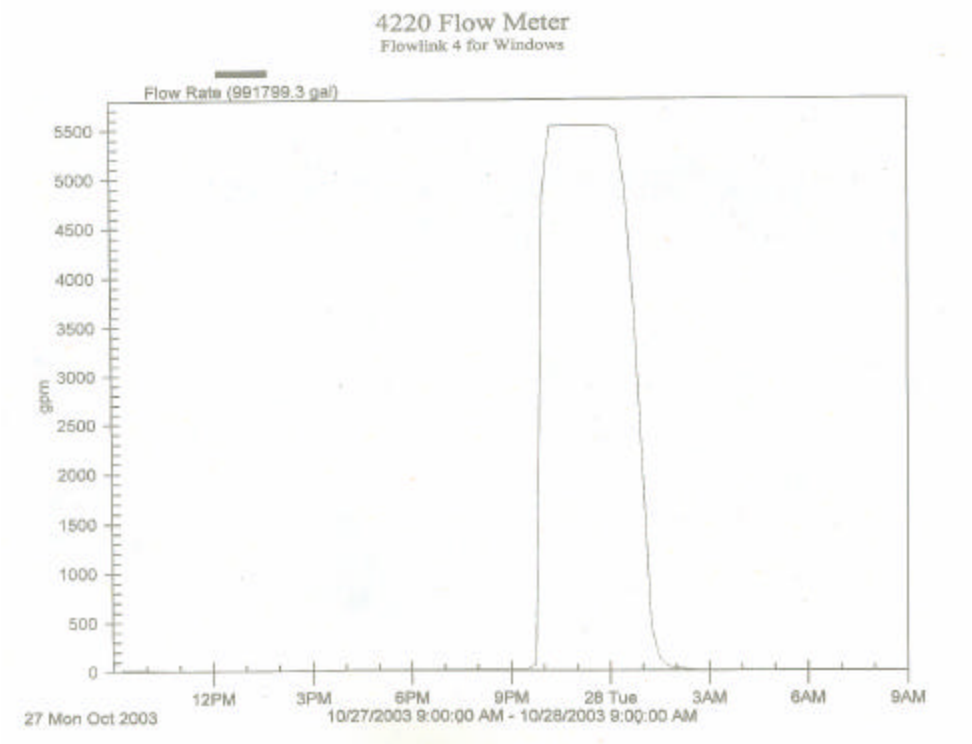
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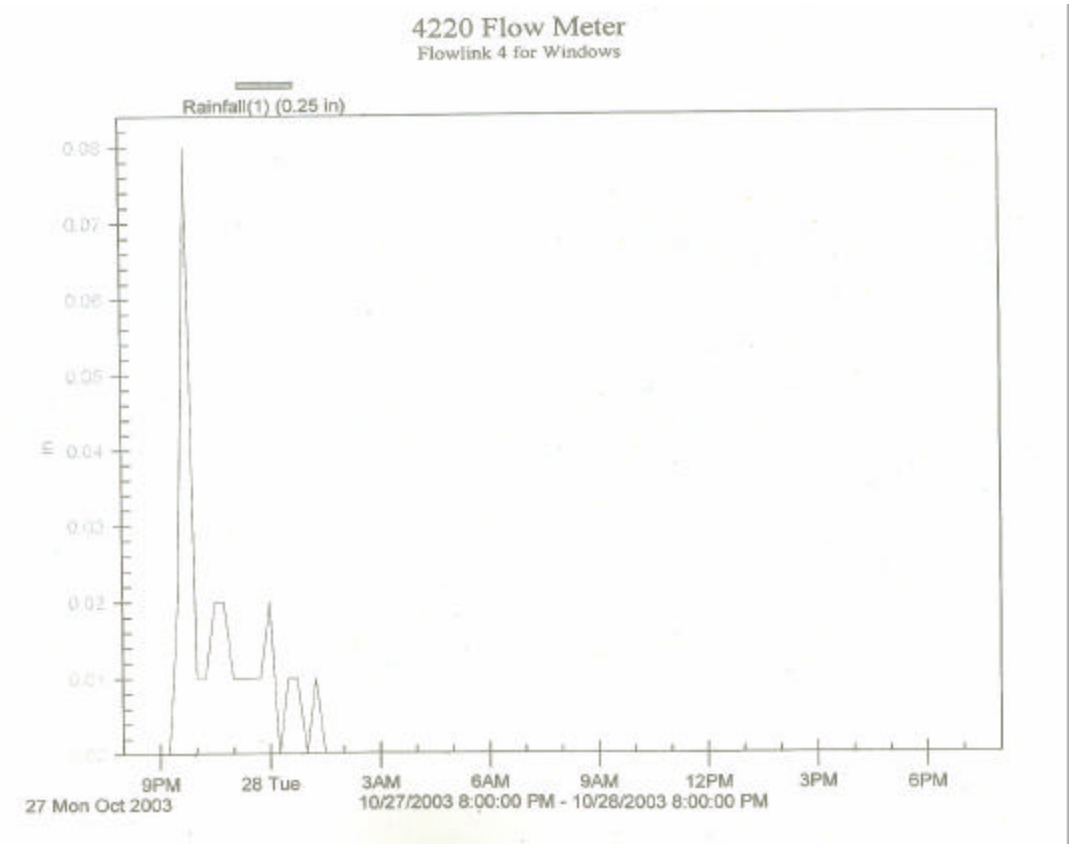
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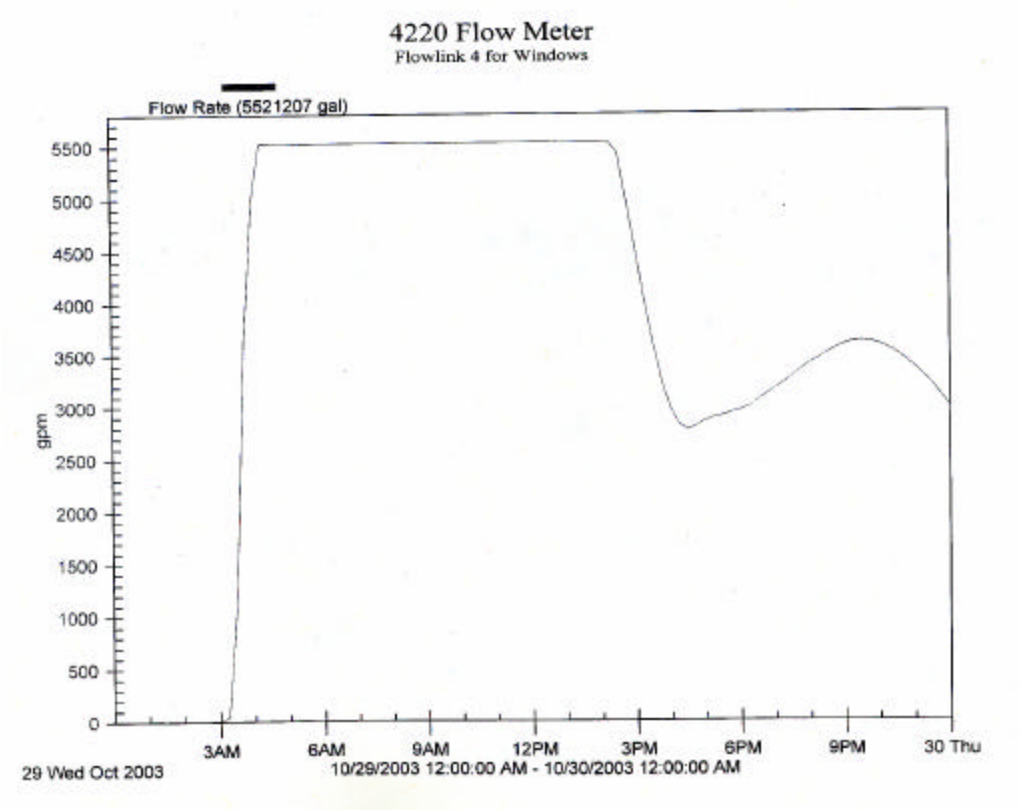
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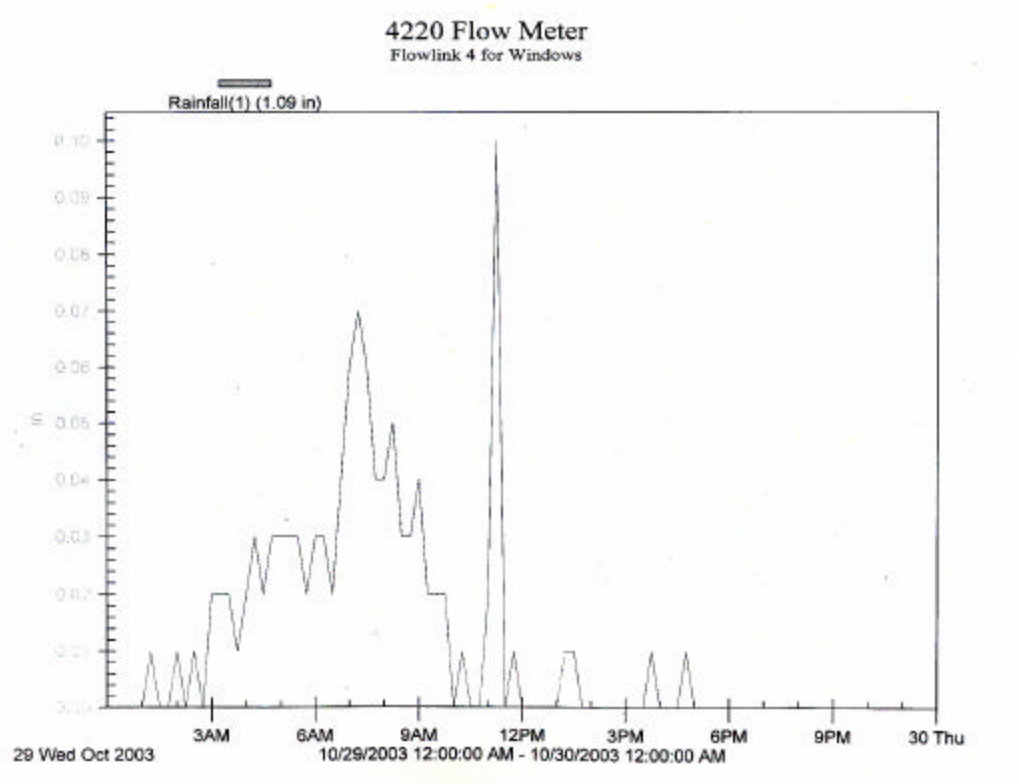
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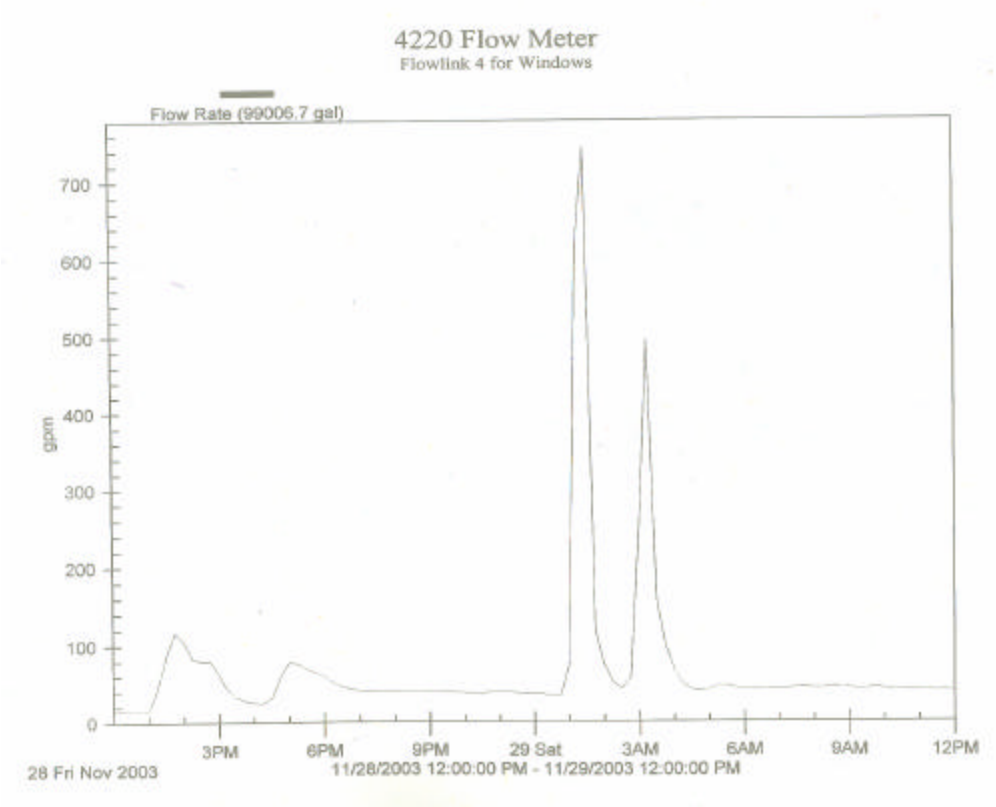
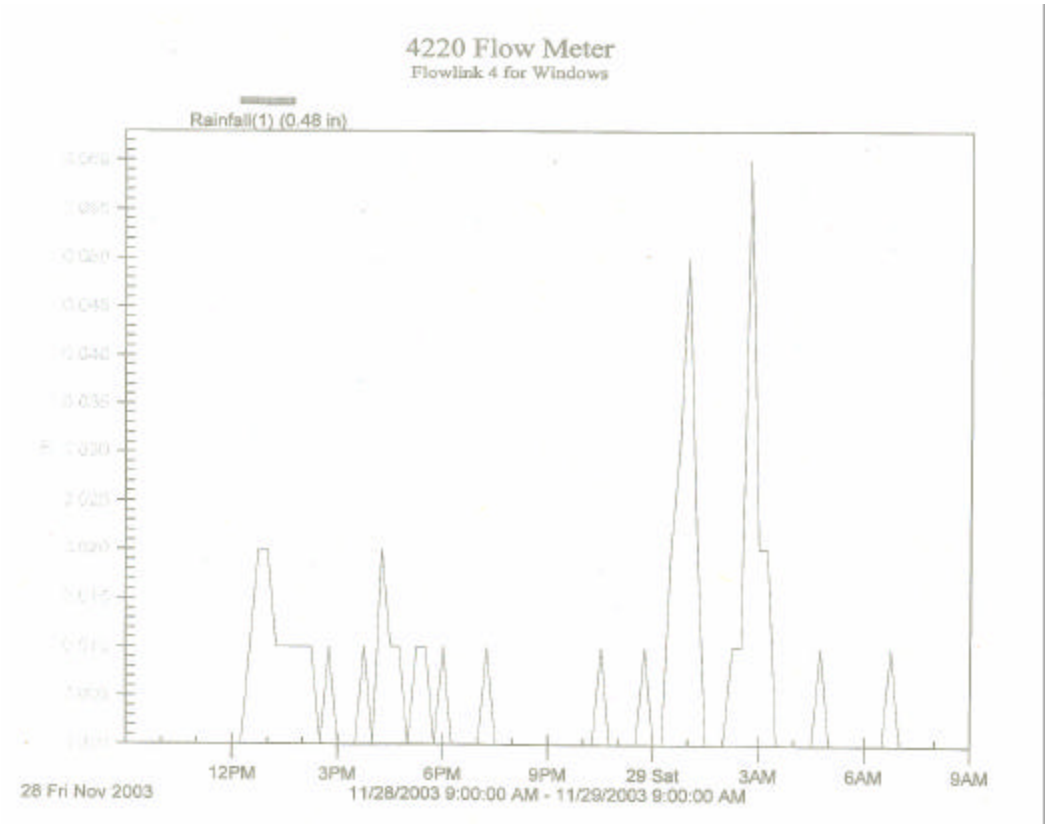
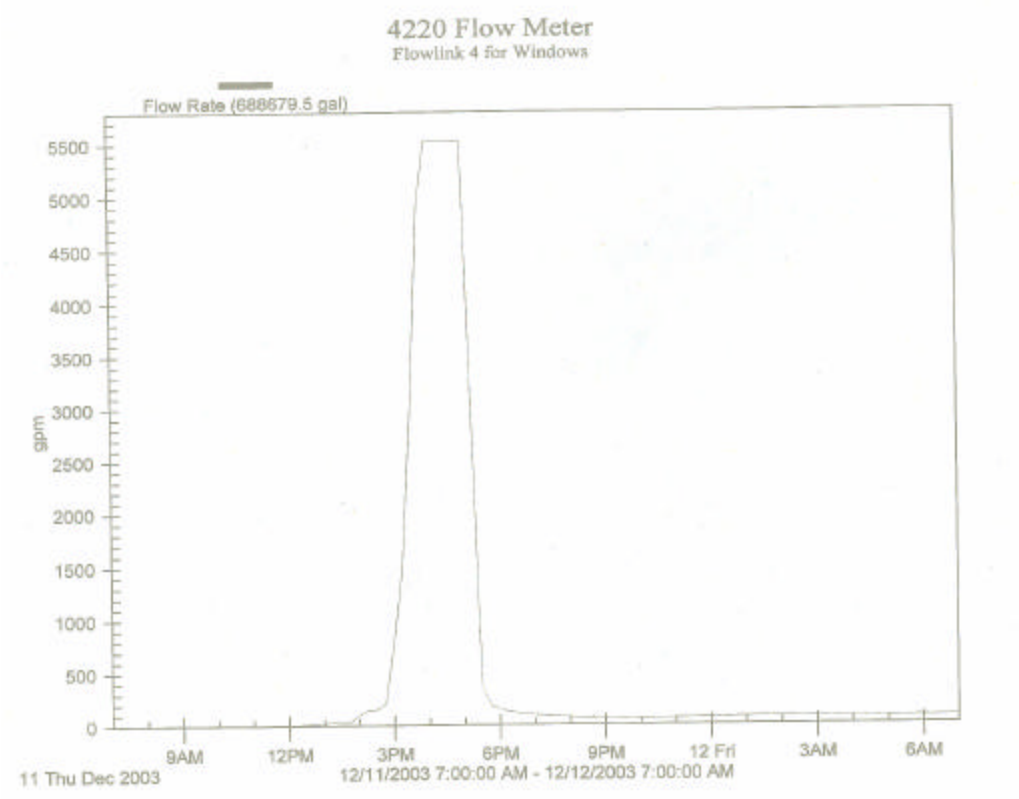
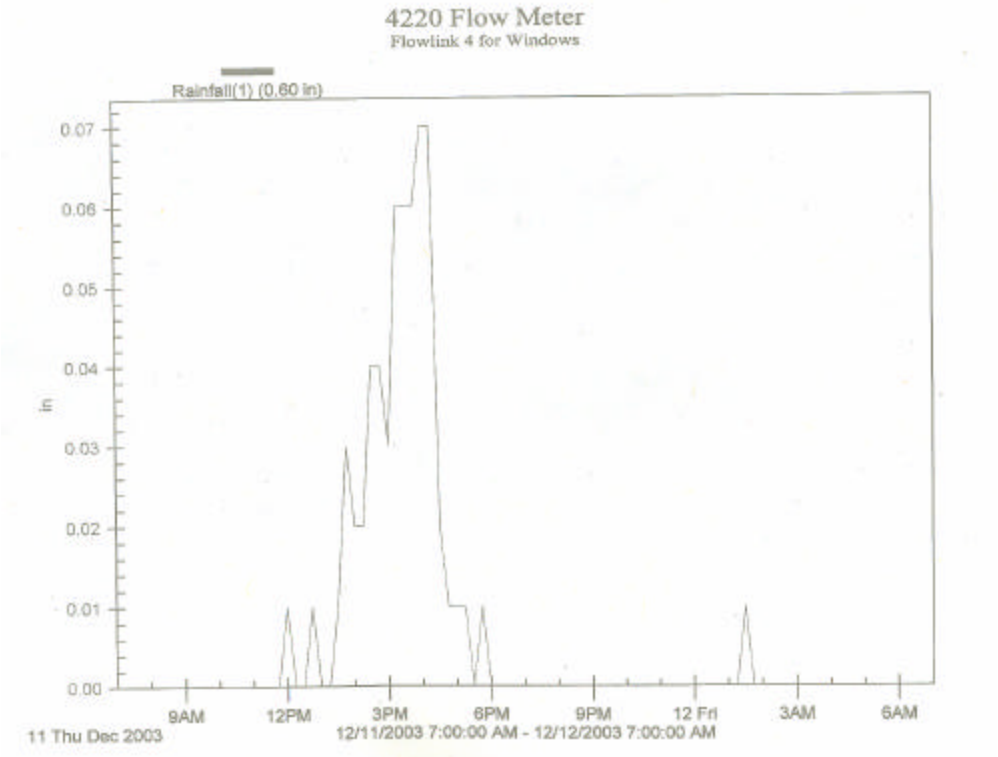
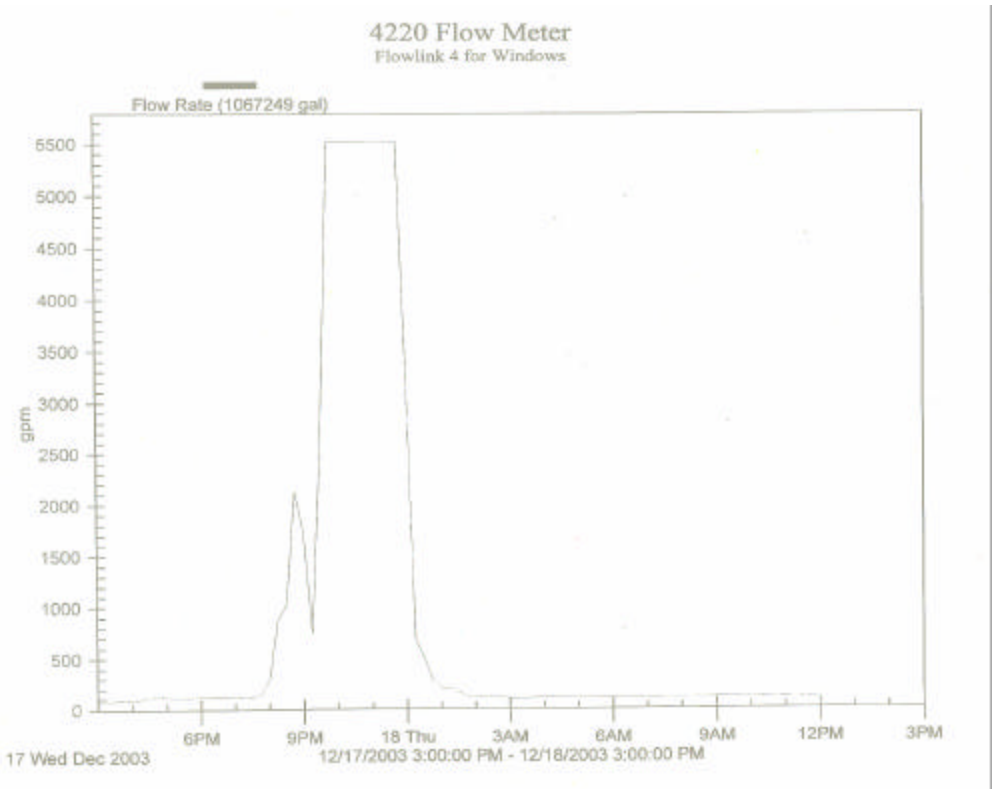
29 Wed Oct 2003
10/29/2003 12:00:00 AM - 10/30/2003 12:00:00 AM

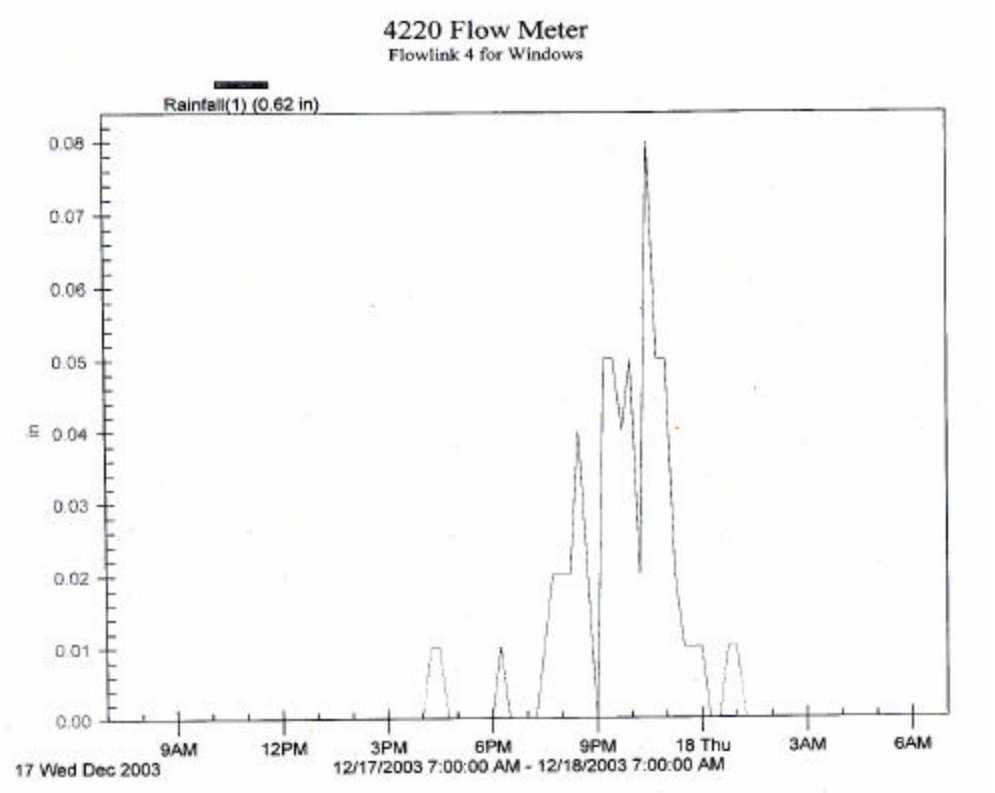

4220 Flow Meter
Flowlink 4 for Windows
Flow Rate (99006.7 gal)
gpm
700
600
500
400
300
200
100
0
3PM
6PM
9PM
29 Sat
3AM
6AM
9AM
12PM
28 Fri Nov 2003
11/28/2003 12:00:00 PM - 11/29/2003 12:00:00 PM

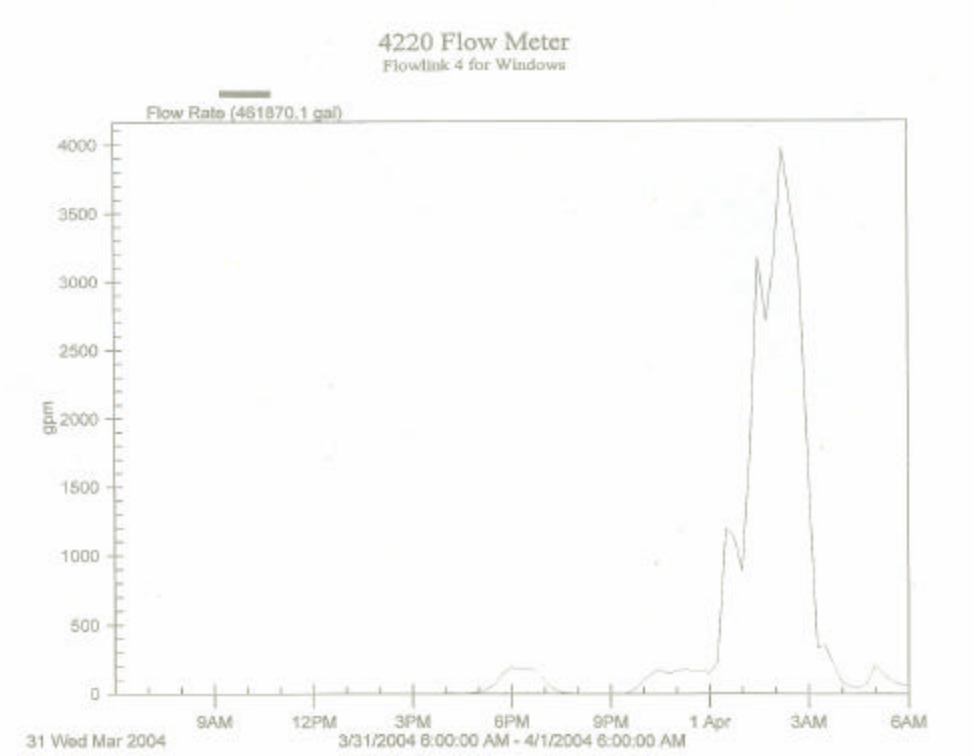

4220 Flow Meter
Flowlink 4 for Windows
Rainfall(1) (0.48 in)
12PM
3PM
6PM
9PM
29 Sat
3AM
6AM
9AM
28 Fri Nov 2003
11/28/2003 9:00:00 AM - 11/29/2003 9:00:00 AM

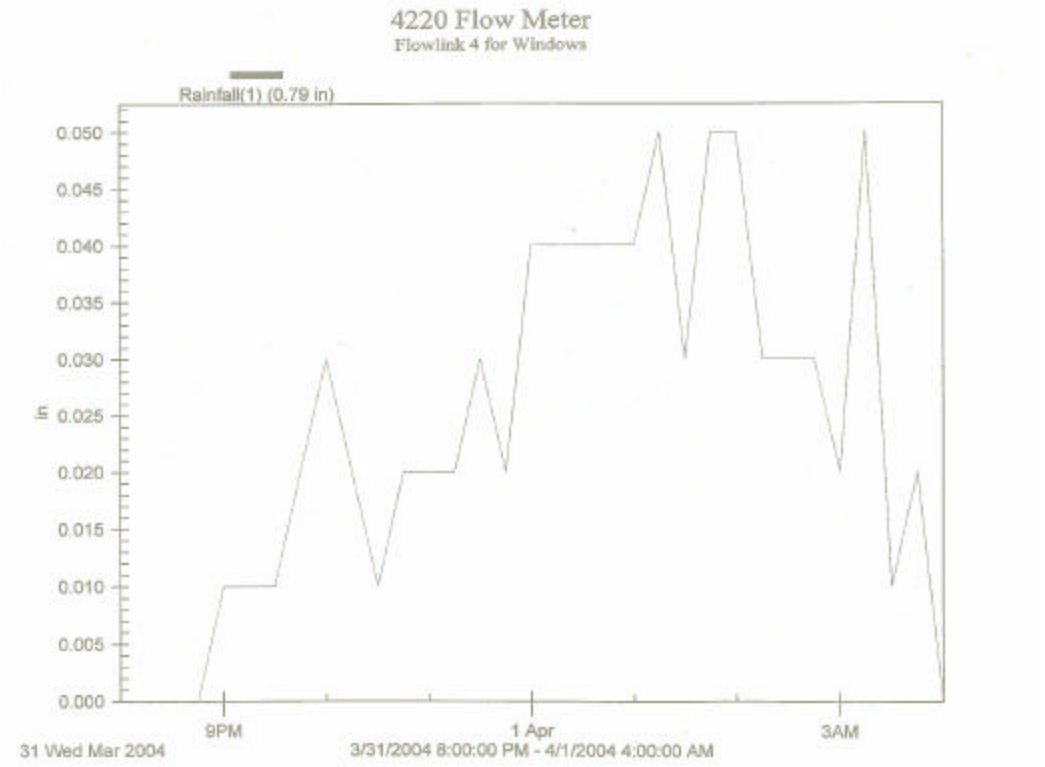

4220 Flow Meter
Flowlink 4 for Windows
Flow Rate (688679.5 gal)
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
gpm
9AM
12PM
3PM
6PM
9PM
12 Fri
3AM
6AM
11 Thu Dec 2003
12/11/2003 7:00:00 AM - 12/12/2003 7:00:00 AM

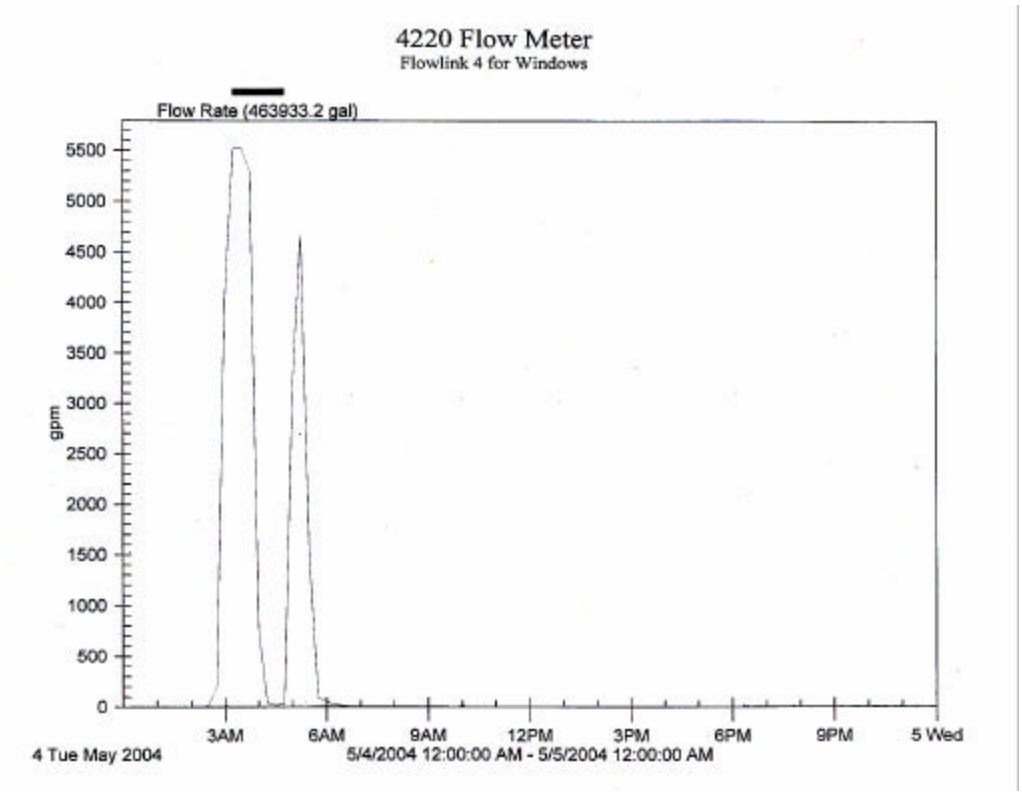

4220 Flow Meter
Flowlink 4 for Windows
Rainfall(1) (0.60 in)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
in
9AM
12PM
3PM
6PM
9PM
12 Fri
3AM
6AM
11 Thu Dec 2003
12/11/2003 7:00:00 AM - 12/12/2003 7:00:00 AM

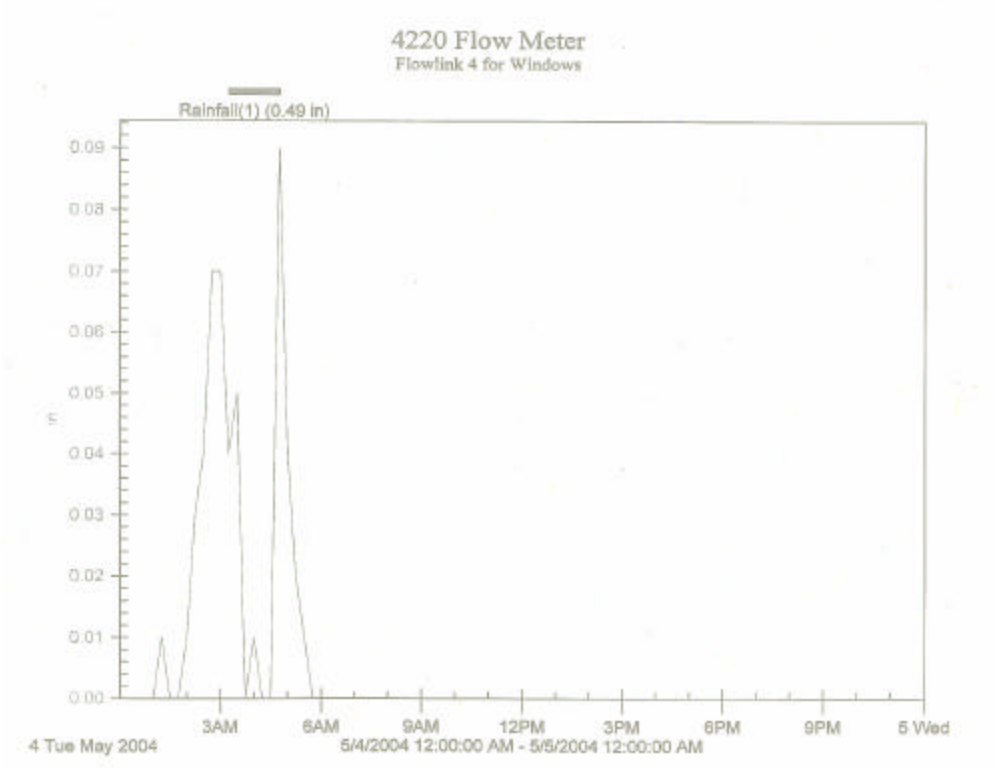

4220 Flow Meter
Flowlink 4 for Windows
Flow Rate (1067249 gal)
gpm
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
6PM
9PM
18 Thu
3AM
6AM
9AM
12PM
3PM
17 Wed Dec 2003
12/17/2003 3:00:00 PM - 12/18/2003 3:00:00 PM

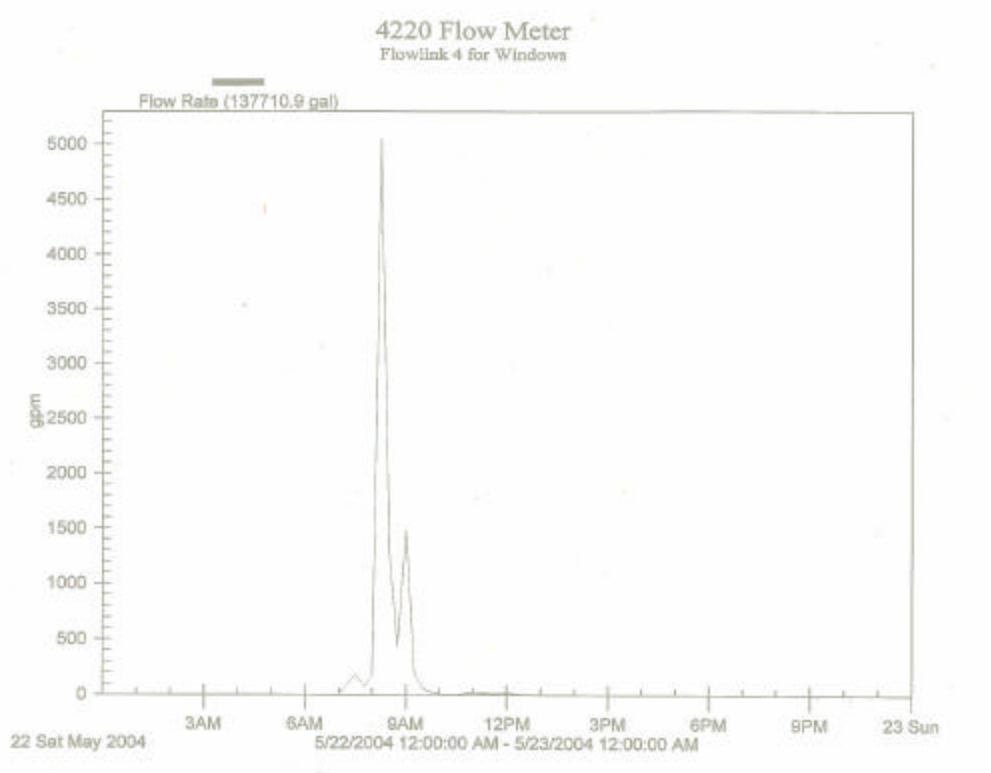

4220 Flow Meter
Flowlink 4 for Windows
Rainfall(1) (0.62 in)
in
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
9AM
12PM
3PM
6PM
9PM
18 Thu
3AM
6AM
17 Wed Dec 2003
12/17/2003 7:00:00 AM - 12/18/2003 7:00:00 AM

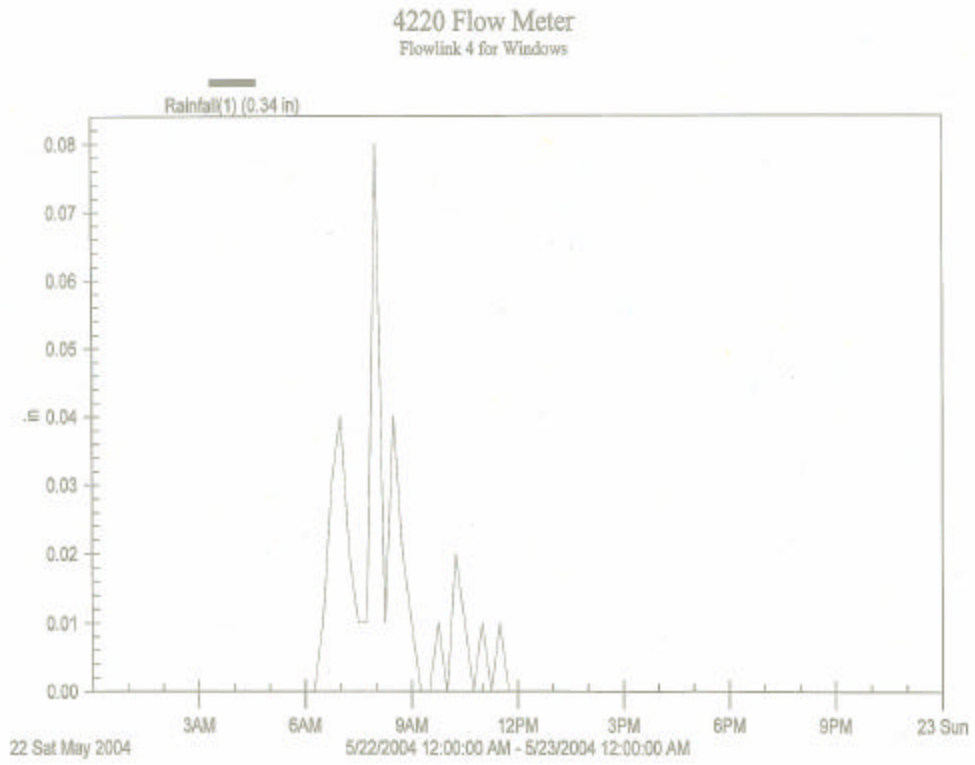

4220 Flow Meter
Flowlink 4 for Windows
Flow Rate (461870.1 gal)
gpm
4000
3500
3000
2500
2000
1500
1000
500
0
9AM
12PM
3PM
6PM
9PM
1 Apr
3AM
6AM
31 Wed Mar 2004
3/31/2004 6:00:00 AM - 4/1/2004 6:00:00 AM

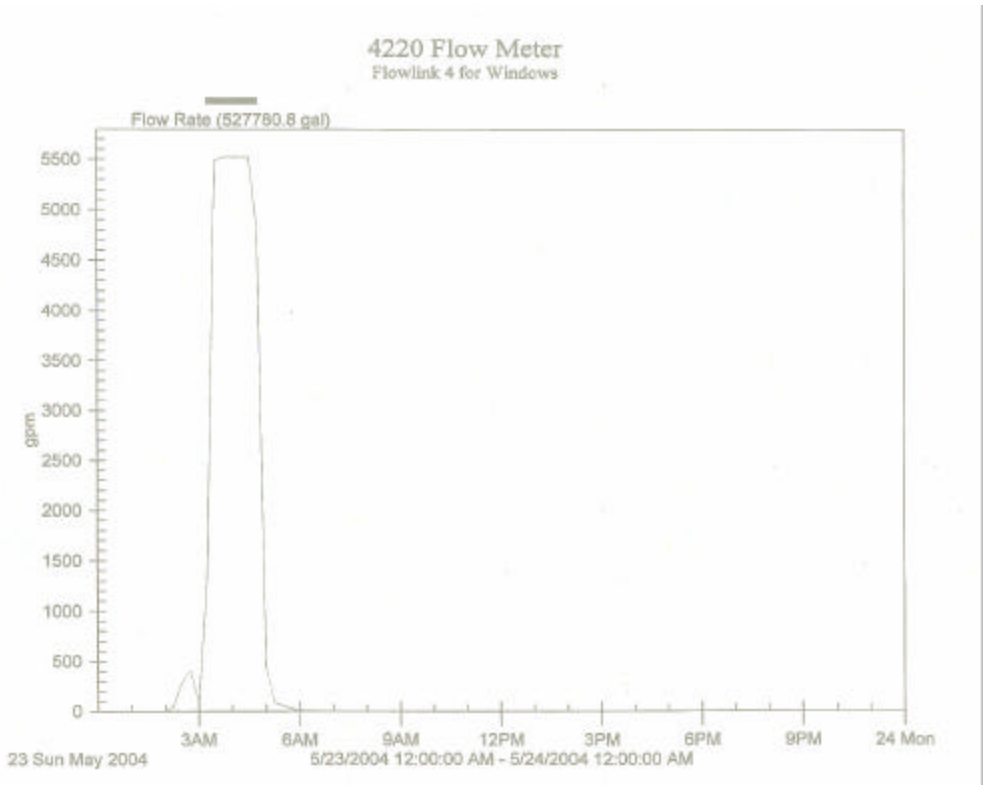

4220 Flow Meter
Flowlink 4 for Windows
Rainfall(1) (0.79 in)
in
0.050
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
9PM
1 Apr
3AM
31 Wed Mar 2004
3/31/2004 8:00:00 PM - 4/1/2004 4:00:00 AM

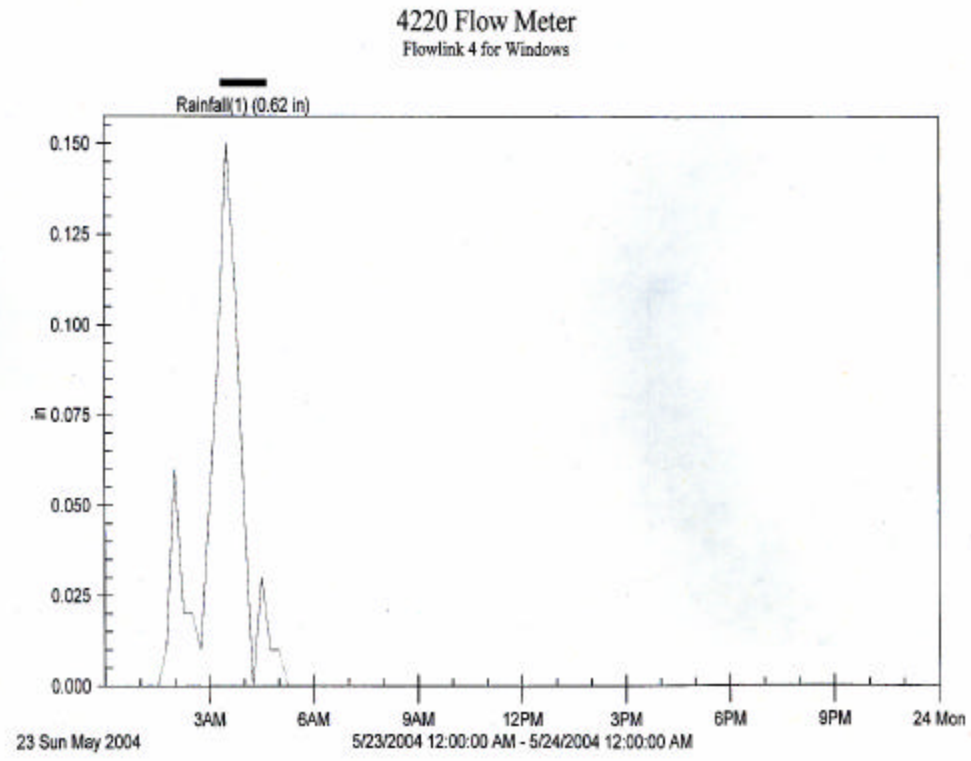

4220 Flow Meter
Flowlink 4 for Windows
Flow Rate (463933.2 gal)
gpm
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
3AM
6AM
9AM
12PM
3PM
6PM
9PM
5 Wed
4 Tue May 2004
5/4/2004 12:00:00 AM - 5/5/2004 12:00:00 AM

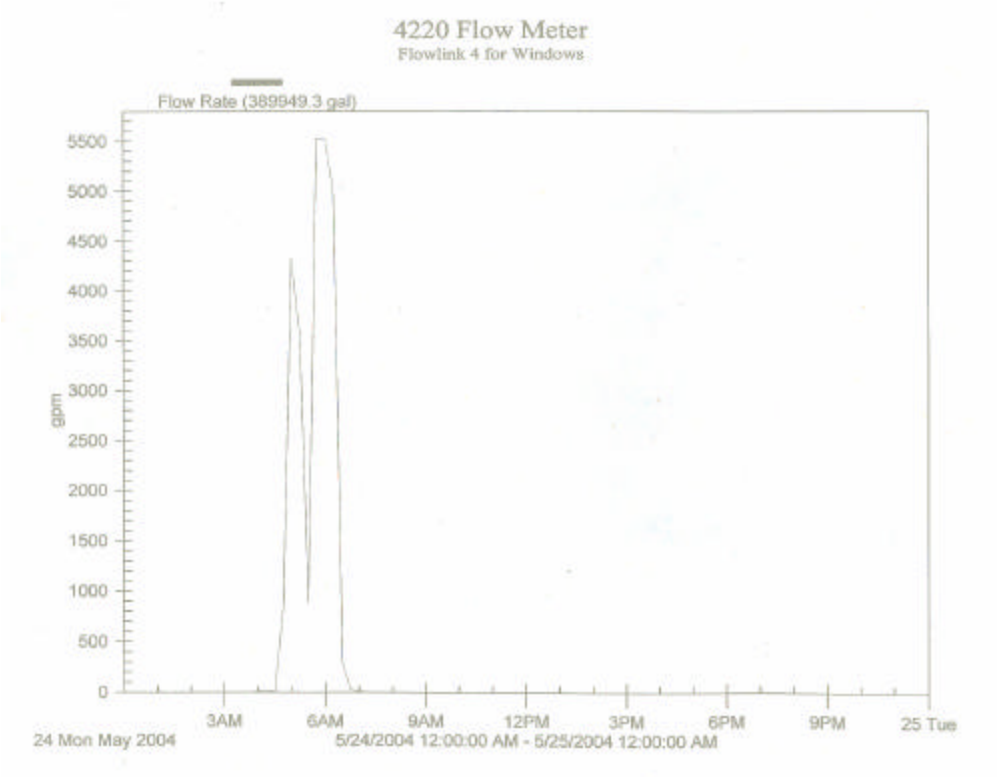

4220 Flow Meter
Flowlink 4 for Windows
Rainfall(1) (0.49 in)
in
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
3AM
6AM
9AM
12PM
3PM
6PM
9PM
5 Wed
4 Tue May 2004
5/4/2004 12:00:00 AM - 5/5/2004 12:00:00 AM

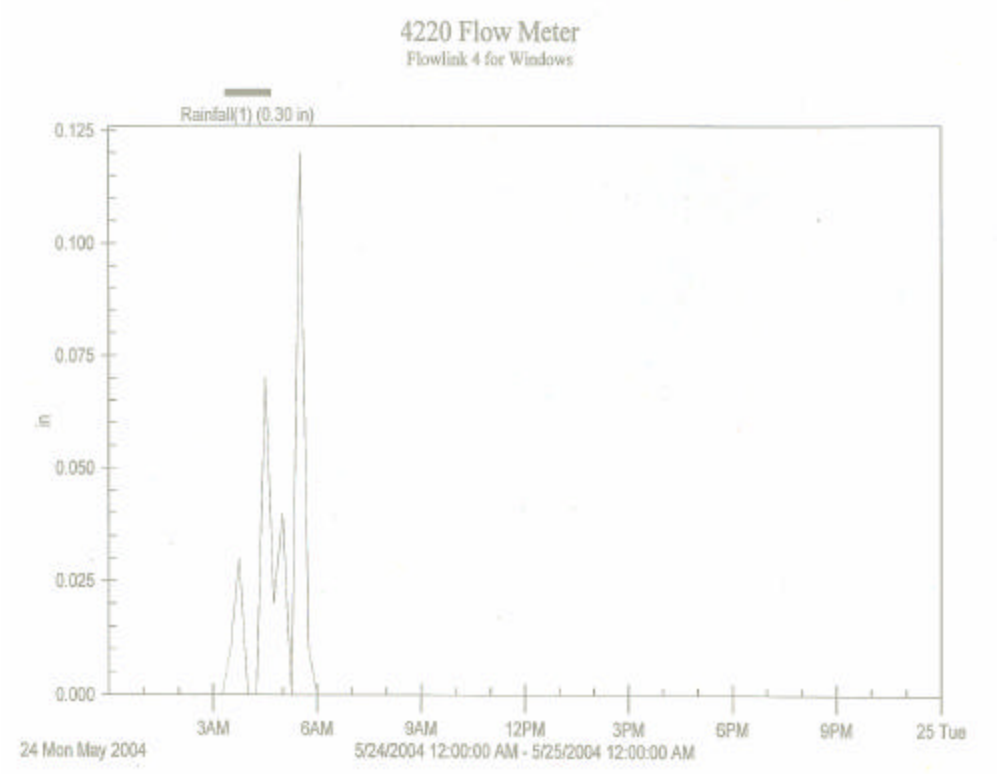

4220 Flow Meter
Flowlink 4 for Windows
Flow Rate (137710.9 gal)
gpm
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
3AM
6AM
9AM
12PM
3PM
6PM
9PM
23 Sun
22 Sat May 2004
5/22/2004 12:00:00 AM - 5/23/2004 12:00:00 AM


4220 Flow Meter
Flowlink 4 for Windows
Rainfall(1) (0.34 in)
in
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
3AM
6AM
9AM
12PM
3PM
6PM
9PM
23 Sun
22 Sat May 2004
5/22/2004 12:00:00 AM - 5/23/2004 12:00:00 AM


4220 Flow Meter
Flowlink 4 for Windows
Flow Rate (527760.8 gal)
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
gpm
3AM
6AM
9AM
12PM
3PM
6PM
9PM
24 Mon
23 Sun May 2004
5/23/2004 12:00:00 AM - 5/24/2004 12:00:00 AM


4220 Flow Meter
Flowlink 4 for Windows
Rainfall(1) (0.62 in)
0.150
0.125
0.100
0.075
0.050
0.025
0.000
in
3AM
6AM
9AM
12PM
3PM
6PM
9PM
24 Mon
23 Sun May 2004
5/23/2004 12:00:00 AM - 5/24/2004 12:00:00 AM


4220 Flow Meter
Flowlink 4 for Windows
Flow Rate (389949.3 gal)
gpm
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
3AM
6AM
9AM
12PM
3PM
6PM
9PM
25 Tue
24 Mon May 2004
5/24/2004 12:00:00 AM - 5/25/2004 12:00:00 AM


4220 Flow Meter
Flowlink 4 for Windows
Rainfall(1) (0.30 in)
in
0.125
0.100
0.075
0.050
0.025
0.000
3AM
6AM
9AM
12PM
3PM
6PM
9PM
25 Tue
24 Mon May 2004
5/24/2004 12:00:00 AM - 5/25/2004 12:00:00 AM