April 2004
04/15/WQPC-WWF
EPA/600/R-04/084

# Environmental Technology Verification Report

## Stormwater Source Area Treatment Device

## Arkal Pressurized Stormwater Filtration System

Prepared by

NSF International

Under a Cooperative Agreement with
U.S. Environmental Protection Agency

ETV ETV ETV

# THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

# ETV Joint Verification Statement

| | | |
|---|---|---|
| TECHNOLOGY TYPE: | **STORMWATER TREATMENT TECHNOLOGY** | |
| APPLICATION: | **SEDIMENT REMOVAL** | |
| TECHNOLOGY NAME: | **ARKAL PRESSURIZED STORMWATER FILTRATION SYSTEM** | |
| TEST LOCATION: | **GREEN BAY, WISCONSIN** | |
| COMPANY: | **ZETA TECHNOLOGY, INC.** | |
| ADDRESS: | **416 Flamingo Avenue**<br>**Stuart, Florida 34966** | PHONE: **(772) 781-7000**<br>FAX: **(772) 781-7001** |
| WEB SITE: | **http://www.zetatechnology.com** | |
| EMAIL: | **zeta@zetatechnology.com** | |

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV program is to further environmental protection by accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer-reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; stakeholder groups which consist of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

NSF International (NSF), in cooperation with the EPA, operates the Water Quality Protection Center (WQPC), one of six centers under ETV. The WQPC recently evaluated the performance of the Arkal Pressurized Stormwater Filtration System distributed by Zeta Technologies, Inc., a system designed to remove solids from stormwater runoff. The system was installed at St. Mary's Hospital in Green Bay, Wisconsin. Earth Tech, Inc. and the United States Geologic Survey (USGS) performed the testing.

## TECHNOLOGY DESCRIPTION

The following description of the Arkal Pressurized Stormwater Filtration (Arkal) System was provided by the vendor and does not represent verified information.

The key components of the Arkal system are the filtration processes, which are manufactured by Arkal. Ancillary components not manufactured by Arkal, including a splitter manhole and storage tank, were combined with the filtration processes to form a system designed to remove suspended solids from stormwater. Stormwater entered a sump where coarse solids settled and was then diverted either to a 9,200 $ft^3$ storage tank that fed the filtration processes, or an overflow bypass pipe that diverted water directly to the municipal storm sewer system without additional treatment.

The filtration processes consisted of two pressurized systems operating in series. The first filtration process consisted of four towers, each containing three "StarFilter" disk filter units designed to remove particles 50 microns and larger. The second filtration stage consisted of a series of five 48-inch diameter sealed sand filter tanks, designed to remove particles five microns and larger. Both filtration processes backwashed automatically when pressure differentials exceeded preset levels. The provision of multiple filters in each process allowed for filtration and backwash to occur simultaneously. The backwash wastewater was discharged to the municipal sanitary sewer, while the treated stormwater was discharged to the municipal storm sewer.

The vendor claims that the treatment system can remove 80 percent of the suspended solids greater than five microns in the stormwater.

## VERIFICATION TESTING DESCRIPTION

### *Methods and Procedures*

The test methods and procedures used during the study are described in the *Test Plan for Verification of the Arkal Filtration Systems, Inc. Pressurized Stormwater Filtration System, St. Mary's Hospital, Green Bay, WI* (Earth Tech, January 2001) (VTP). The Arkal system treats the hospital's 5.49-acre drainage area, which consists of paved parking areas, the building's roof, and landscaped areas. Green Bay receives an average of nearly 29 inches of precipitation, approximately 35 percent of which occurs during the summer months.

Verification testing consisted of collecting data during 15 qualified events that met the following criteria:

- The total rainfall depth for the event, measured at the site, was 0.2 inches (5 mm) or greater (snow fall and snow melt events do not qualify);
- Flow through the treatment device was successfully measured and recorded over the duration of the runoff period;
- A flow-proportional composite sample was successfully collected for both the influent and effluent over the duration of the runoff event;
- Each composite sample was comprised of a minimum of five aliquots, including at least two aliquots on the rising limb of the runoff hydrograph, at least one aliquot near the peak, and at least two aliquots on the falling limb of the runoff hydrograph; and
- There was a minimum of six hours between qualified sampling events.

Automated sample monitoring and collection devices were installed and programmed to collect composite samples from the influent, the treated effluent, and the untreated bypass during qualified flow events. Samples were analyzed for the following parameters:

| *Sediments* | *Nutrients* | *Metals* |
|---|---|---|
| • total suspended solids (TSS) | • total phosphorus | • total calcium |
| • total dissolved solids (TDS) | • dissolved phosphorus | • total magnesium |
| • particle size analysis | • nitrate and nitrite | • total zinc |
| • suspended sediment concentration (SSC) | • total Kjeldahl nitrogen (TKN) | |

In addition to the flow and analytical data, operation and maintenance (O&M) data were recorded. Power consumption costs were calculated based on the manufacturer's rated pump specifications and length of operation during event periods.

## VERIFICATION OF PERFORMANCE

Verification testing of the Arkal system lasted nearly 16 months. No bypassing occurred during the testing period, so all of the influent entering the system was treated and discharged as treated effluent to the storm sewer or as backwash filtrate to the sanitary sewer.

### *Test Results*

The precipitation data for the 15 rain events are summarized in Table 1.

**Table 1. Rainfall Data Summary**

| Event No. | Start Date | Start Time | Rainfall Depth (inches) | Rainfall Duration (hr:min) | Rainfall Volume[1] ($ft^3$) |
|---|---|---|---|---|---|
| 1 | 6/2/01 | 3:45 | 0.81 | 7:24 | 16,070 |
| 2 | 6/10/01 | 12:26 | 0.41 | 2:54 | 6,307 |
| 3 | 6/11/01 | 22:38 | 0.20 | 1:49 | 2,367 |
| 4 | 6/15/01 | 10:20 | 0.38 | 1:50 | 5,374 |
| 5 | 8/25/01 | 2:45 | 0.34 | 6:52 | 4,467 |
| 6 | 12/12/01 | 22:18 | 0.39 | 2:55 | 5,495 |
| 7 | 4/18/02 | 4:27 | 0.40 | 3:32 | 4,959 |
| 8 | 4/24/02 | 15:07 | 0.63 | 3:39 | 8,044 |
| 9 | 4/27/02 | 20:15 | 1.13 | 10:33 | 16,332 |
| 10 | 5/1/02 | 22:19 | 0.22 | 3:12 | 2,557 |
| 11 | 5/25/02 | 8:31 | 1.27 | 35:40 | 16,114 |
| 12 | 6/13/02 | 23:48 | 0.31 | 14:01 | 4,640 |
| 13 | 6/21/02 | 17:15 | 0.36 | 1:05 | 4,985 |
| 14 | 7/25/02 | 17:39 | 0.40 | 1:08 | 5,728 |
| 15 | 9/19/02 | 4:48 | 0.23 | 2:24 | 2,929 |

[1] Rainfall volume was measured at the influent monitoring point.

The monitoring results were evaluated using event mean concentration (EMC) and sum of loads (SOL) comparisons.

The EMC or efficiency ratio comparison evaluates treatment efficiency on a percentage basis by dividing the effluent concentration by the influent concentration and multiplying the quotient by 100.

The efficiency ratio was calculated for each analytical parameter and each individual storm event. In order for efficiency ratio calculations to show a high treatment percentage, the influent parameter concentrations needed to be relatively high. This was not always the case because of the inherent variability of stormwater.

The SOL comparison evaluates the treatment efficiency on a percentage basis by comparing the sum of the influent and effluent loads (the product of multiplying the parameter concentration by the precipitation volume) for all 15 storm events. The calculation is made by subtracting the quotient of the total effluent load divided by the total influent load from one, and multiplying by 100. The analytical data ranges, EMC range and SOL reduction values are shown in Table 2.

**Table 2. Analytical Data, EMC Range, and SOL Reduction Results**

| Parameter | Units | Influent Range | Effluent Range | EMC Range (percent) | SOL Reduction (percent) |
|---|---|---|---|---|---|
| TSS | mg/L | 10 – 426 | <2 – 61 | 47 – >94 | 82 |
| SSC | mg/L | 12 – 340 | 2 – 67 | 32 – 95 | 82 |
| Total zinc | µg/L | 24 – 210 | <16 – 26 | 21 – 82 | 58 |
| Total phosphorus | mg/L as P | 0.023 – 0.32 | <0.005 – 0.13 | 23 – >96 | 55 |
| TKN | mg/L as N | 0.32 – 2.2 | 0.35 – 1.0 | -47 – 59 | 26 |
| Dissolved phosphorus | mg/L as P | <0.005 – 0.17 | <0.005 – 0.12 | -75 – 50 | 13 |
| Nitrate and nitrite | mg/L as N | 0.29 – 1.7 | 0.67 – 2.1 | -170 – 3.6 | -76 |
| TDS | mg/L | 38 – 550 | 190 – 950 | -1,100 – -31 | -190 |
| Total magnesium | mg/L | 2.3 – 16 | 8.3 – 41 | -570 – 53 | -190 |
| Total calcium | mg/L | 6.5 – 64 | 19 – 77 | -340 – -18 | -210 |

The reductions in TSS and SSC exceeded the vendor's performance claim of 80 percent solids reduction, based on the SOL evaluation method. Additionally, constituents commonly found in particulate form or attached to sediment particles, such as phosphorus, TKN, and total zinc, were removed as sediments were removed. However, dissolved-phase parameters, such as TDS, phosphorus, nitrate, and nitrite, were not removed by the Arkal system. This is consistent with the vendor's performance claim.

The negative efficiencies for TDS, total calcium, and total magnesium were attributed to groundwater infiltration into the storm sewer system through cracks or poorly sealed joints. Calculation of the infiltration dilution effect, however, did not show the infiltration to have an impact on the TSS or SSC SOL evaluation. The infiltration issue is explained in greater detail in the verification report.

Particle size distribution analysis was conducted on the solids trapped in the sump and in samples when adequate sample volume was collected. Ninety percent of the particles trapped in the sump were larger than 250 microns, with 70 percent being larger than 2,000 microns. Twelve of the 15 qualified events had adequate influent sample volume to complete a sand\silt split (greater or less than 62 microns) analysis. None of the effluent samples had sufficient volume to complete the visual accumulator and pipette analyses.

The influent analysis indicated a sand/silt split of 25.8 percent to 74.2 percent, while the effluent had a sand/silt split of 16.2 percent to 83.8 percent. Furthermore, three events had adequate influent sample volume to conduct particle size analyses for particles as small as one micron. For these three events, the influent had a range of 17.3 to 38.9 percent of solids passing a four-micron sieve. In order for the Arkal system to achieve 82 percent sum of loads efficiency for these three events, it had to treat a portion of the solids passing a four-micron sieve. This substantiates the vendor's performance claim of being able to treat particles five microns or larger.

***System Operation***

The Arkal system was installed prior to verification testing, so verification of installation procedures on the system was not documented.

Aside from routine monitoring and maintenance, eight maintenance events were performed during the testing period. Maintenance typically consisted of cleaning and disinfecting the StarFilter rings, which would develop microbial growth during long dry periods. A total of 84 hours of staff time and $260 in direct costs were used in maintaining the system during the testing period. No system downtime occurred as a result of maintenance activities.

Based on system operating time and equipment horsepower, electrical power consumption was calculated to be approximately 78 kWh per event.

***Quality Assurance/Quality Control***

NSF personnel completed a technical systems audit during testing to ensure that the testing was in compliance with the test plan. NSF also completed a data quality audit of at least 10 percent of the test data to ensure that the reported data represented the data generated during testing. In addition to QA/QC audits performed by NSF, EPA personnel conducted an audit of NSF's QA Management Program.

*Original Signed By*
*Lawrence W. Reiter, Ph. D.* *July 27, 2004*
Lawrence W. Reiter, Ph.D. Date
Acting Director
National Risk Management Laboratory
Office of Research and Development
United States Environmental Protection Agency

*Original Signed By*
*Gordon E. Bellen* *August 4, 2004*
Gordon E. Bellen Date
Vice President
Research
NSF International



**Availability of Supporting Documents**

Copies of the *ETV Verification Protocol, Stormwater Source Area Treatment Technologies Draft 4.1, March 2002,* the verification statement, and the verification report (NSF Report Number 04/15/WQPC-WWF) are available from:

ETV Water Quality Protection Center Program Manager (hard copy)
NSF International
P.O. Box 130140
Ann Arbor, Michigan 48113-0140
NSF website: http://www.nsf.org/etv (electronic copy)
EPA website: http://www.epa.gov/etv (electronic copy)

Appendices are not included in the verification report, but are available from NSF upon request.

Environmental Technology Verification Report

for

Stormwater Source Area Treatment Device

# ARKAL PRESSURIZED STORMWATER FILTRATION SYSTEM

Prepared for:

NSF International
Ann Arbor, Michigan

Prepared by:

Earth Tech Inc.
Madison, Wisconsin

With assistance from:

United States Geologic Survey (Wisconsin Division)
Wisconsin Department of Natural Resources

Under a cooperative agreement with the U.S. Environmental Protection Agency

Raymond Frederick, Project Officer
ETV Water Quality Protection Center
National Risk Management Research Laboratory
Water Supply and Water Resources Division
U.S. Environmental Protection Agency
Edison, New Jersey

April 2004

# Notice

The U.S. Environmental Protection Agency (EPA) through its Office of Research and Development has financially supported and collaborated with NSF International (NSF) on this verification under a Cooperative Agreement. The Water Quality Protection Center, operating under the Environmental Technology Verification (ETV) Program, supported this verification effort. This document has been peer reviewed and reviewed by NSF and EPA and recommended for public release. Mention of trade names or commercial products does not constitute endorsement or recommendation by the EPA for use.

## Foreword

The following is the final report on an Environmental Technology Verification (ETV) test performed for NSF International (NSF) and the United States Environmental Protection Agency (EPA). The verification test for the Arkal Pressurized Stormwater Filtration System was conducted at St. Mary's Hospital in Green Bay, Wisconsin.

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Lawrence W. Reiter, Acting Director.
National Risk Management Research Laboratory

# Contents

## Figures

# Tables

## Abbreviations and Acronyms

| | |
|---|---|
| BMP | Best Management Practice |
| BPSV | Back pressure sustaining valve |
| cfs | Cubic feet per second |
| dia | Diameter |
| DQI | Data quality indicators |
| EMC | Event mean concentration |
| EPA | U.S. Environmental Protection Agency |
| ETV | Environmental Technology Verification |
| $ft^2$ | Square foot (feet) |
| $ft^3$ | Cubic feet |
| g | Gram |
| gal | Gallon |
| gpm | Gallon per minute |
| hp | Horsepower |
| hr | Hour |
| in | Inch(es) |
| kg | Kilogram |
| kWh | Kilowatt hour |
| L | Liters |
| lb | Pound |
| NRMRL | National Risk Management Research Laboratory |
| µg/L | Microgram per liter (ppb) |
| µm | Micron |
| mg/L | Milligram per liter |
| mL | Milliliter |
| NSF | NSF International, formerly known as National Sanitation Foundation |
| NIST | National Institute of Standards and Technology |
| O&M | Operations and maintenance |
| psi | Pounds per square inch |
| QA | Quality assurance |
| QC | Quality control |
| SSC | Suspended sediment concentration |
| SOL | Sum of loads |
| SOP | Standard Operating Procedure |
| TDS | Total dissolved solids |
| TKN | Total Kjeldahl nitrogen |
| TO | Testing Organization |
| TP | Total phosphorus |
| TSS | Total suspended solids |
| USGS | United States Geological Survey |
| VA | Visual accumulator |
| VO | Verification Organization (NSF) |
| VTP | Verification test plan |
| WDNR | Wisconsin Department of Natural Resources |
| WSLH | Wisconsin State Laboratory of Hygiene |

# Chapter 1
# Introduction

## 1.1 ETV Purpose and Program Operation

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV program is to further environmental protection by substantially accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer-reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; stakeholder groups, which consist of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting verification tests, collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

NSF International (NSF), in cooperation with the EPA, operates the Water Quality Protection Center (WQPC). The WQPC evaluated the performance of the Arkal Pressurized Stormwater Filtration System, a stormwater treatment device designed to remove sediments from wet-weather runoff.

It is important to note that verification of the equipment does not mean that the equipment is "certified" by NSF or "accepted" by EPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations for those conditions tested by the Testing Organization (TO).

## 1.2 Testing Participants and Responsibilities

The ETV testing of the Arkal Pressurized Filtration System, distributed in the United States by Zeta Technology, Inc., was a cooperative effort among the following participants:

- U.S. Environmental Protection Agency
- NSF International
- U.S. Geologic Survey (USGS)
- Wisconsin Department of Natural Resources
- Wisconsin State Laboratory of Hygiene
- USGS Sediment Laboratory
- Earth Tech, Inc.
- Zeta Technology, Inc.

The following is a brief description of each ETV participant and their roles and responsibilities.

*1.2.1 U.S. Environmental Protection Agency*

The EPA Office of Research and Development, through the Urban Watershed Branch, Water Supply and Water Resources Division, National Risk Management Research Laboratory (NRMRL), provides administrative, technical, and quality assurance guidance and oversight on all ETV Water Quality Protection Center activities. In addition, EPA provides financial support for operation of the Center and partial support for the cost of testing for this verification.

The key EPA contact for this program is:


Mr. Ray Frederick, ETV WQPC Project Officer
(732) 321-6627
email: Frederick.Ray@epamail.epa.gov

U.S. EPA, NRMRL
Urban Watershed Management Research Laboratory
2890 Woodbridge Avenue (MS-104)
Edison, New Jersey 08837-3679


*1.2.2 Verification Organization*

NSF is the verification organization (VO) administering the WQPC in partnership with EPA. NSF is a not-for-profit testing and certification organization dedicated to public health, safety, and protection of the environment. Founded in 1946 and located in Ann Arbor, Michigan, NSF has been instrumental in developing consensus standards for the protection of public health and the environment. NSF also provides testing and certification services to ensure that products bearing the NSF name, logo and/or mark meet those standards.

NSF personnel provided technical oversight of the verification process. NSF also provided review of the verification test plan (VTP) and this verification report. NSF's responsibilities as the VO include:

- Review and comment on the VTP;
- Review quality systems of all parties involved with the TO, and qualify the TO;
- Oversee TO activities related to the technology evaluation and associated laboratory testing;
- Conduct an on-site audit of test procedures;
- Provide quality assurance/quality control (QA/QC) review and support for the TO;
- Oversee the development of the verification report and verification statement; and,
- Coordinate with EPA to approve the verification report and verification statement.

Key contacts at NSF are:

Mr. Thomas Stevens, Program Manager
(734) 769-5347
email: stevenst@nsf.org

Mr. Patrick Davison, Project Coordinator
(734) 913-5719
email: davison@nsf.org

NSF International
789 North Dixboro Road
Ann Arbor, Michigan 48105

### *1.2.3 Testing Organization*

The TO for the verification testing was Earth Tech, Inc. of Madison, Wisconsin, (Earth Tech), which was assisted by the U.S. Geological Service (USGS), located in Middleton, Wisconsin. USGS provided testing equipment, helped define field procedures, conducted the field testing, coordinated with the analytical laboratories, and conducted initial data analyses.

The TO provided all needed logistical support, established a communications network, and scheduled and coordinated activities of all participants. The TO was responsible for ensuring that the testing location and conditions were such that the verification testing could meet its stated objectives. The TO prepared the VTP; oversaw the testing; and managed, evaluated, interpreted and reported on the data generated by the testing, as well as evaluating and reporting on the performance of the technology. TO employees established test conditions, and measured and recorded data during the testing. The TO's Project Manager provided project oversight.

The key personnel and contacts for the TO are:

Earth Tech, Inc.:

Mr. Jim Bachhuber, P.H.
(608) 828-8121
email: jim_bachhuber@earthtech.com

Mr. Jay Kemp
(608) 828-8164
email: jay_kemp@earthtech.com

Earth Tech, Inc.
1210 Fourier Drive
Madison, Wisconsin 53717

United States Geologic Survey:

Mr. Steve Corsi
(608) 821-3835
email: scorsi@usgs.gov

Ms. Judy Horwatich
(608) 821-3874
email: jawierl@usgs.gov

USGS
8505 Research Way
Middleton, Wisconsin 53562

*1.2.4 Analytical Laboratories*

Except for particle size and suspended sediment concentration analysis, the Wisconsin State Laboratory of Hygiene (WSLH), located in Madison, Wisconsin, analyzed the stormwater samples for the parameters identified in the VTP. The USGS Sediment Laboratory, located in Iowa City, Iowa, performed the suspended sediment concentration separations and particle size analysis.

The key analytical laboratory contacts are:

Mr. George Bowman
(608) 224-6279
email: gtb@mail.slh.wisc.edu

WSLH
2601 Agriculture Drive
Madison, Wisconsin 53718

Ms. Pam Smith
(319) 358-3602
email: pksmith@usgs.gov

USGS Sediment Laboratory
Federal Building Room 269
400 South Clinton Street
Iowa City, Iowa 52240

*1.2.5 Vendor*

Zeta Technology, Inc. (Zeta) of Stuart, Florida, is the vendor of the Arkal Pressurized Stormwater Filtration System, and was responsible for supplying a field-ready system. Zeta was also responsible for providing technical support and was available during the tests to provide technical assistance as needed.

The key contact for Zeta Technology is:

Mr. Eric Crawford
(772) 781-7000
email: zetatech@bellsouth.net

Zeta Technology, Inc.
416 Flamingo Avenue
Stuart, Florida 34966

*1.2.6 Verification Testing Site*

The verification testing was performed at St. Mary's Hospital in Green Bay, Wisconsin. Hospital personnel were responsible for providing site access and were the liaison for overall system and day-to-day activities.

The key contact for St. Mary's Hospital is:

Mr. David Behrendt
(920) 613-3747
email: dbehrend@stmgb.org

St. Mary's Hospital
1726 Shawano Avenue
Green Bay, Wisconsin 54606

# Chapter 2
# Technology Description

The combination of the Arkal Pressurized Stormwater Filter devices and ancillary components (the flow splitter, storage tank, and mechanical housing unit were not manufactured by Arkal) form a system designed to remove sediments from stormwater. Each component of the system is described in this section, and a schematic diagram and profile for the St. Mary's Hospital installation is shown in Figure 2-1.

Additional equipment specifications, test site descriptions, testing requirements, sampling procedures, and analytical methods were detailed in the *Test Plan for the Verification of Arkal Filtration Systems, Inc. Pressurized Stormwater Filtration System, St. Mary's Hospital, Green Bay, WI* (January 2, 2001). The Verification Test Plan (VTP) is included in Appendix C.

## 2.1 Ancillary System Components

### *2.1.1 Flow Splitter*

Stormwater falling on the hospital's paved parking lot was diverted by drains to a manhole. Two pipes were installed in the manhole. A 15-inch pipe diverted low volume wet-weather flows to the Arkal treatment system, while an 18-inch pipe bypassed high volume wet-weather flows. A sump was installed in the manhole below the 15-inch pipe to provide for retention of coarse solids.

The 15-inch pipe discharged to an underground concrete holding tank that supplied water for the Arkal system. The pipe was designed with a flow capacity to carry a two-year, 30-minute duration event having a calculated peak flow of 7.74 cfs. Based on the long-term precipitation data for the area, the system, as designed, would treat approximately 76 percent of the annual average runoff volume. During construction, the 15-inch pipe was found to surcharge and was subsequently re-installed at a slope slightly steeper than designed to alleviate the situation. This design modification increased the maximum flow of the pipe to approximately 15 cfs, nearly twice the original design capacity.

The 18-inch diameter pipe was installed in the manhole to allow for bypass to the municipal storm sewer during high volume storm events. The invert of the bypass pipe was set 1.8 feet higher in the manhole than the 15-inch pipe, and was equipped with a backflow prevention gate. The profile for the manhole is shown in Figure 2-2.

### *2.1.2 Holding Tank*

The 15-inch pipe discharged to a 9,200 $ft^3$ (dimensions 56.8 ft x 20 ft x 8 ft) subsurface concrete holding tank. The tank was sized to completely hold the runoff from two-year, 30-minute event, taking into account the pumping rate to the filtration system (approximately 450 gpm, or 1 cfs).

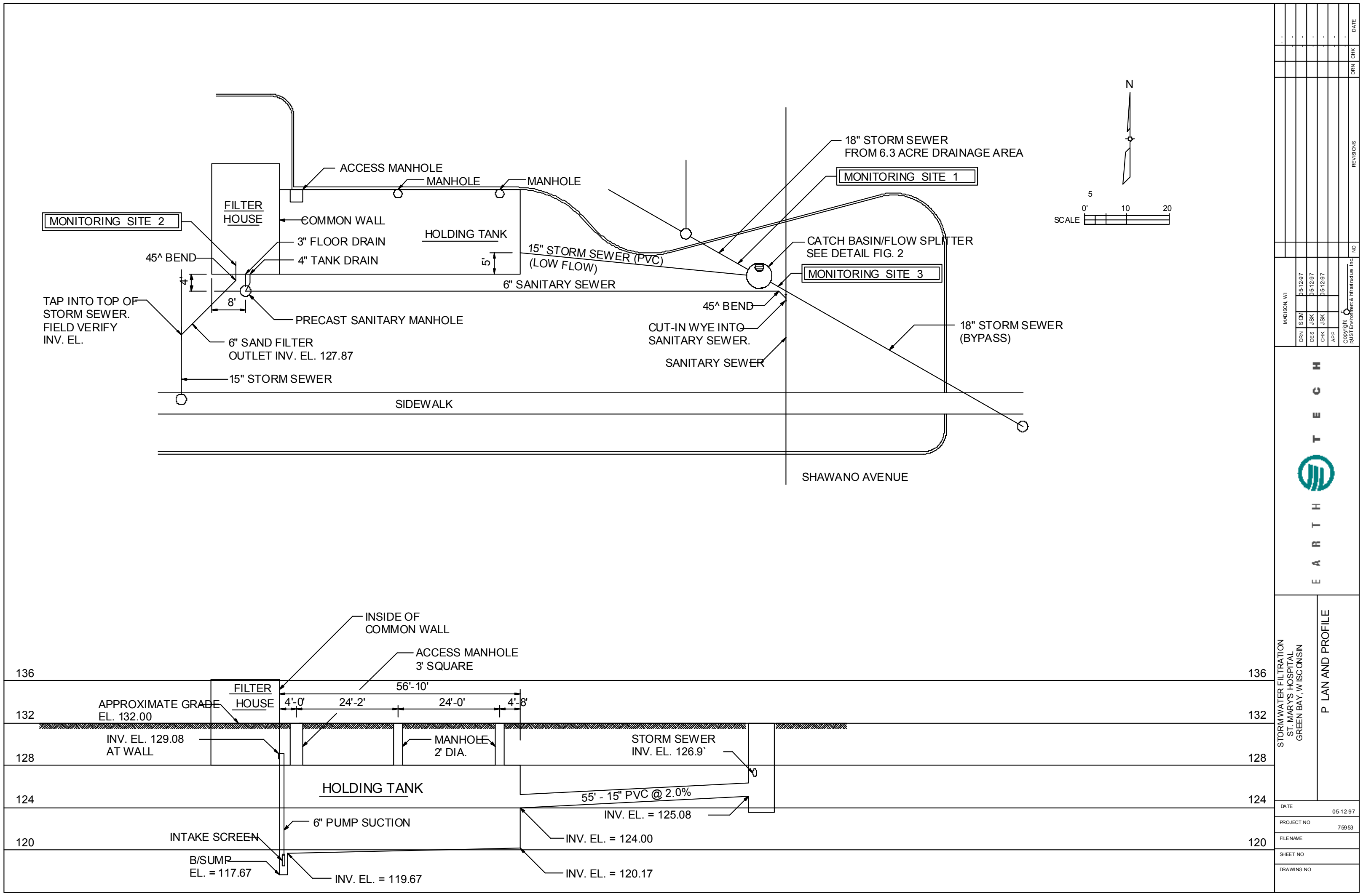



**Figure 2-1. Arkal system plan and profile.**

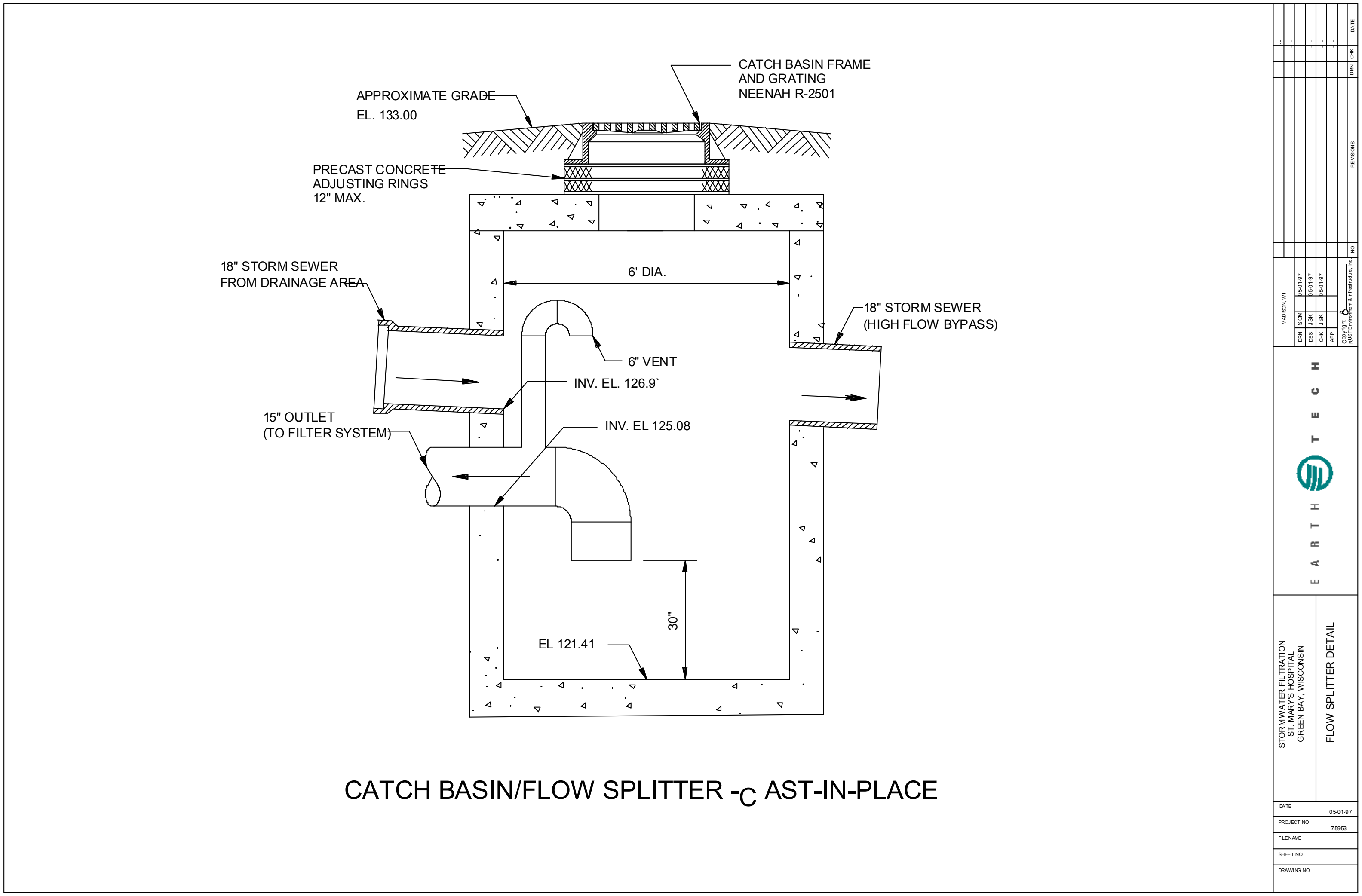



**Figure 2-2. Catch basin flow splitter.**

The stormwater in the holding tank was pumped to the filtration system by a self-priming solids-handling pump. The pump was activated by float switches. A high float switch set approximately 18 inches above the base of the tank turned the pump on; and a low float switch set approximately six inches above the base of the tank turned the pump off. In the event of pump failure during a wet-weather event, the system was designed so that the tank would fill to capacity and additional runoff would bypass the system through the flow splitter and discharge to the storm sewer system.

The tank was manually inspected periodically to check for solids accumulation. During the course of verification testing, the tank did not have sediment buildup sufficient to interfere with the system's operation.

### *2.1.3 Mechanical Housing Unit*

The solids-handling pump, backwash booster pump, two-phase filtration system, backwash tank, and the Arkal Filtration System's control panel were housed in the mechanical housing unit. The 300 $ft^2$ unit was located approximately four feet below grade, and had electrical power, municipal water, and a sanitary discharge hookup (for backwash water). A plan view showing the location of the system components in the housing unit is shown in Figure 2-3.

## 2.2 Filtration Process

The stormwater treatment process consisted of two pressurized filtration systems, in series. The first stage was designed to remove particles greater than 50 microns, while the second stage was designed to remove particles down to five microns. The treated stormwater was discharged back to the storm sewer system, while backwash residuals were discharged to a sanitary sewer.

### *2.2.1 First-Stage Filtration*

The first-stage filtration process consisted of four "towers" of disk filters manufactured by Arkal Filtration Systems. Each tower contained three "StarFilter" disk filter units, with sets of grooved rings within each disk filter. According to the vendor, the size of the grooves determines the particle size removed from the stormwater. The rings can be sized to filter particles down to 25 microns. The disk filters at the test site were equipped with 50-micron rings.

The disk filter units operate in a pressurized mode, with flow from outside the disk filter to inside. A backwash cycle was automatically initiated when the pressure differential across the filter rings exceeded 15 psi. A separate booster pump was used to increase the system pressure during backwash, while a pressure-sustaining valve closed down to throttle the system output. The system design allowed for simultaneous filtration with three towers while the fourth tower was in a backwash mode. When the pressure differential was actuated, the towers were backwashed in sequence. The system was set up so that only one disk filter backwashed at any one time. The pressurized filtrate was the source of the backwash water. This configuration allowed the system's filtration process to continue during the backwash cycle. The backwash water was temporarily stored in a backwash tank and then discharged to a sanitary sewer at the end of the runoff period. The pre-filtered stormwater was sent to a second filtration stage.

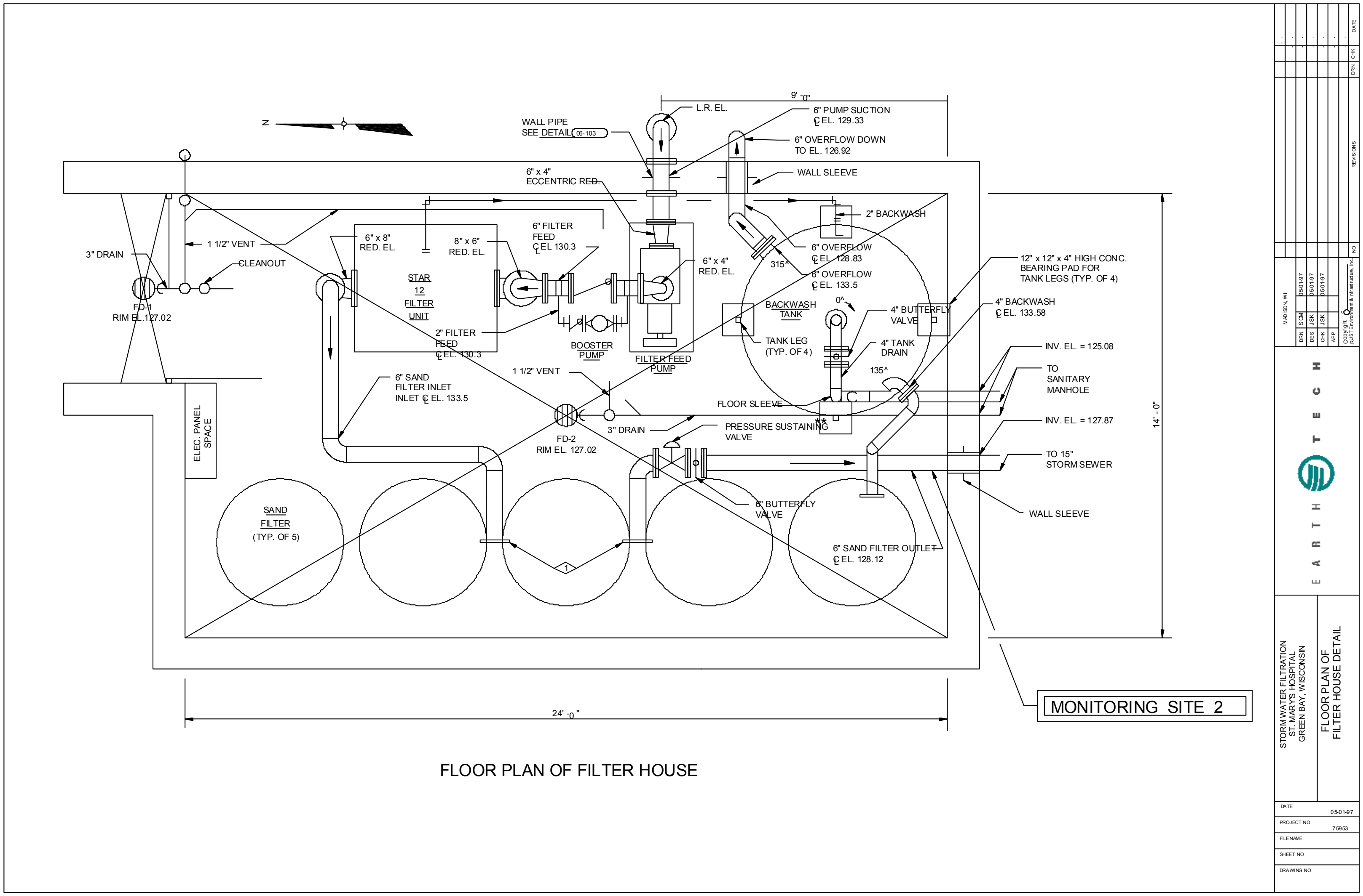



Figure 2-3. Floor plan of filter house detail and profile.

### 2.2.2 *Second-Stage Filtration*

The second-stage filtration process consisted of a series of five 48-inch diameter sealed sand filter tanks, also manufactured by Arkal Filtration Systems. According to the vendor, the sand filters are designed to remove particles five microns and larger from the stormwater. The tanks were sealed to maintain pressurized flow. The five sand filter tanks received filtered water from the disk filters through a manifold distribution system. The sand filter tanks had an automatic backwash cycle, which initiated when the pressure differential across the sand filter exceeded 15 psi. The five tanks in series created a redundant system so four tanks could operate while the fifth tank backwashed.

The second-stage backwash cycle was initiated independently of the first-stage backwash cycle, but was controlled by the Arkal system's control panel to prevent the first- and second-stage filtration systems from backwashing simultaneously.

### ***2.2.3 Backwash Tank***

Backwash water for both filtration processes was stored in a backwash tank that had a volume of approximately 113 $ft^3$ (dimensions 6 ft diameter x 4 ft tall). The backwash tank was designed to capture, concentrate, and discharge the solids to the sanitary sewer. The tank was designed to create a vortex action, which directed solids to the bottom of the tank from which they were discharged to the sanitary sewer.

If the backwash flow exceeded the storage capacity and discharged to sanitary sewer, the tank's overflow outlet discharged back to the concrete storage tank. This water was subsequently re-pumped through the filtration system.

The total volume of backwash water discharged from both filter systems to the sanitary sewer for each storm event was about 200 $ft^3$ (1,500 gallons), or about 1.5 percent of the total volume from a two-year, 30-minute event. Figure 2-4 is a photo of the two filtration systems in the mechanical housing unit.

## 2.3 Technology Application and Limitations

Arkal filtration systems are flexible in terms of the flow they can treat. By varying the holding tank size, pump rate, or number of filtration pods, the treatment capacity can be modified to accommodate runoff from various size watersheds.

The filtration system at St. Mary's Hospital was designed to bypass stormwater under high flow conditions. Based on hydrologic modeling of the drainage area, storm sewer system, holding tank size, and pumping rate, calculations were made to predict events that would result in bypass conditions. Table 2-1 summarizes the outcome of the bypass modeling.

## 2.4 Performance Claim

The vendor claims that the Arkal Filtration System will remove 80 percent of the suspended solids greater than five microns (5 µm) in the stormwater treated by the system.

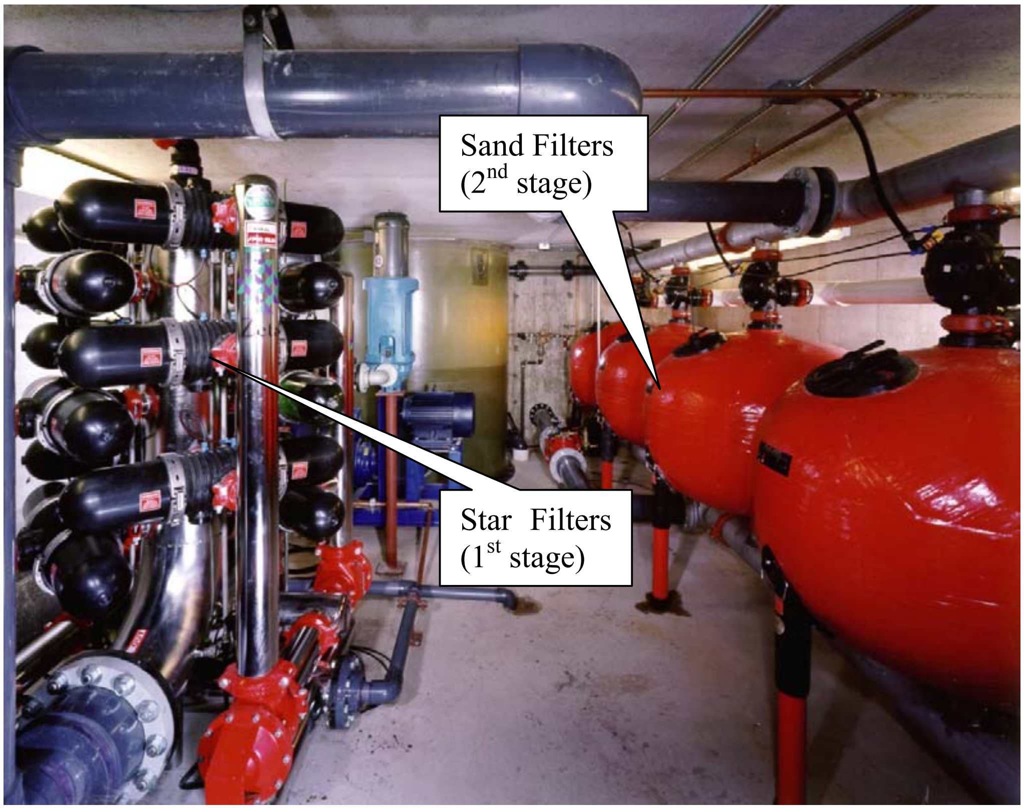



**Figure 2-4. View inside filter house with equipment.**

**Table 2-1. Percent of Event Volume Bypassing Treatment System**

| Rainfall Duration (hours) | Percent Bypass as Function of Rainfall | | | | |
|---|---|---|---|---|---|
| | 0.5 in | 1 in | 1.5 in | 2 in | 2.5 in |
| 0.5 | 0 | 37 | 56 | 65 | 70 |
| 1 | 0 | 33 | 54 | 64 | 69 |
| 6 | 0 | 0 | 10 | 33 | 44 |
| 12 | 0 | 0 | 0 | 6 | 22 |
| 24 | 0 | 0 | 0 | 0 | <1 |

# Chapter 3
# Test Site Description

## 3.1 Location and Land Use

The area draining to the Arkal system is located on the property owned by St. Mary's Hospital. The hospital grounds cover about 21 acres, with a variety of land uses. Figure 3-1 provides an aerial view of St. Mary's property, showing the site conditions, including the drainage area and storm sewer collection system. Table 3-1 summarizes the area for each land use within the drainage area.

**Table 3-1. Drainage Area (Acres) by Land Use**

| | Parking Lot & Driveways | Roof | Landscape[1] | Total Area |
|---|---|---|---|---|
| Area (acres) | 3.42 | 1.35 | 0.72 | 5.49 |

[1] Includes ground cover, such as Kentucky bluegrass, ornamental shrubs, and annual flowerbeds.

The total drainage area tributary to the filtration system is 5.49 acres, which is 0.81 acres less than indicated in the VTP. Inspections of the drainage area conducted during rain events in 2001 refined the drainage boundaries to those shown in Figure 3-1.

## 3.2 Contaminant Sources and Site Maintenance

The main contaminant contributions within the drainage area were from automobile traffic, snow removal storage, parking lot surfaces, and rooftop drainage. There were no trash receptacles or solid waste collection sites within the drainage area.

Hospital staff and visitor parking for approximately 225 cars was provided within the drainage area. Automobile traffic counts for the parking lots and roadways were not available. The roadways and parking lots were swept two or three times per year, including at least one cleanup in the spring. Sand and salting operations occurred in winter as needed.

A private landscaping firm maintained the lawn areas, applying fertilizers and pesticides to the lawns in spring and fall. Hospital maintenance staff maintained the flower and shrub areas. No vehicle maintenance or cleaning occurred on the hospital grounds.

Except for the flow splitter manhole, the storm sewer catch basins did not have sumps. There were no other stormwater treatment devices within the drainage area.

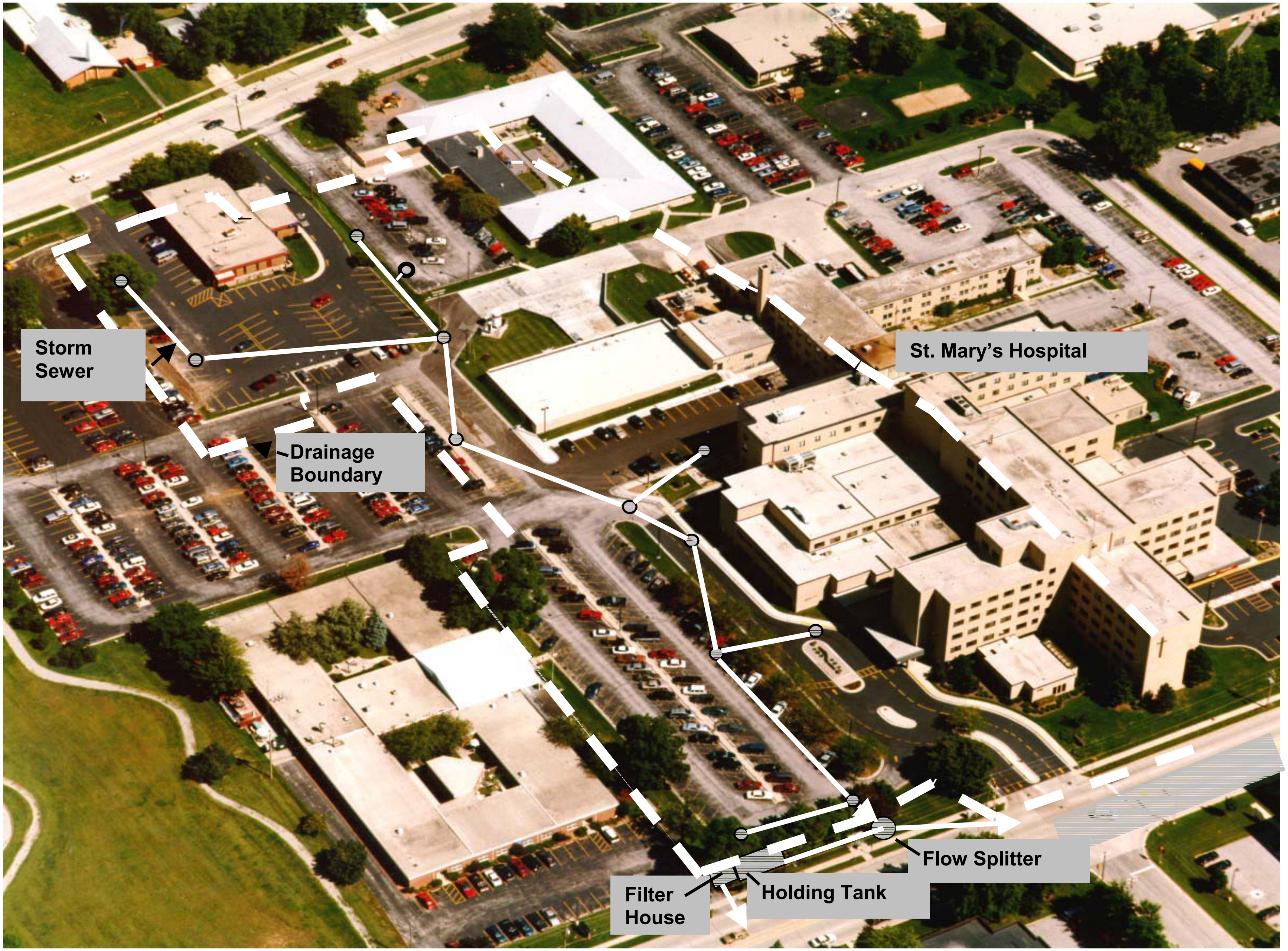



Figure 3-1. Aerial photo of drainage area.

## 3.3 Stormwater Conveyance System

The drainage area was totally drained by a subsurface storm sewer collection system. Before installation of the Arkal system, the site drained to a municipally-owned storm sewer without treatment. With the installation of the flow splitter, the initial runoff was diverted to the treatment system. Higher flows bypass the system and continue to discharge to the storm sewer without treatment.

The treated stormwater from the Arkal system is discharged to the municipal storm sewer system on Shawano Avenue, approximately 150 feet west (upstream) of the point where the bypass pipe enters the municipal storm pipe. Soon after installation of the Arkal system, it was discovered that under certain flow conditions the treated discharge flowing in the public storm pipe could cause stormwater to flow from the city pipe back into the hospital's storm sewer at the bypass location. This backwater problem was solved with a backflow prevention valve installed in the bypass pipe. The valve was installed before ETV verification monitoring began.

## 3.4 Local Meteorological Conditions

The VTP (Appendix C) includes summary temperature and precipitation data from the National Weather Service station at the Green Bay Airport and the statistical rainfalls for a series of recurrence and duration precipitation events (Huff *et al*., 1992). The climate of Green Bay is typically continental with some modification created by Lake Michigan and Lake Superior. Green Bay experiences cold, snowy winters, and warm to hot summers. Average annual precipitation is nearly 29 inches, with an average annual snowfall of 48.5 inches. Approximately 35 percent of the annual precipitation occurs during the summer months.

# Chapter 4
# Sampling Procedures and Analytical Methods

Descriptions of the sampling locations and methods used during verification testing are summarized in this section. Additional detail may be found in the VTP, which is included as Appendix C.

## 4.1 Sampling Locations

Three locations in the test site storm sewer system were selected as sampling and monitoring sites to determine the treatment capability of the Arkal Pressurized Stormwater Filtration System. The locations are shown in Figure 2-1.

### *4.1.1 Site 1 - Influent Ahead of Flow Splitter*

This sampling and monitoring site was selected to characterize the untreated stormwater from the entire drainage area. A velocity meter and sampler suction tubing were located in the influent pipe, approximately two feet upstream from the flow splitter manhole. The arrangement of the velocity/stage meter and sampler tubing is shown in Figure 4-1. The site and test equipment are shown in Figure 4-2.

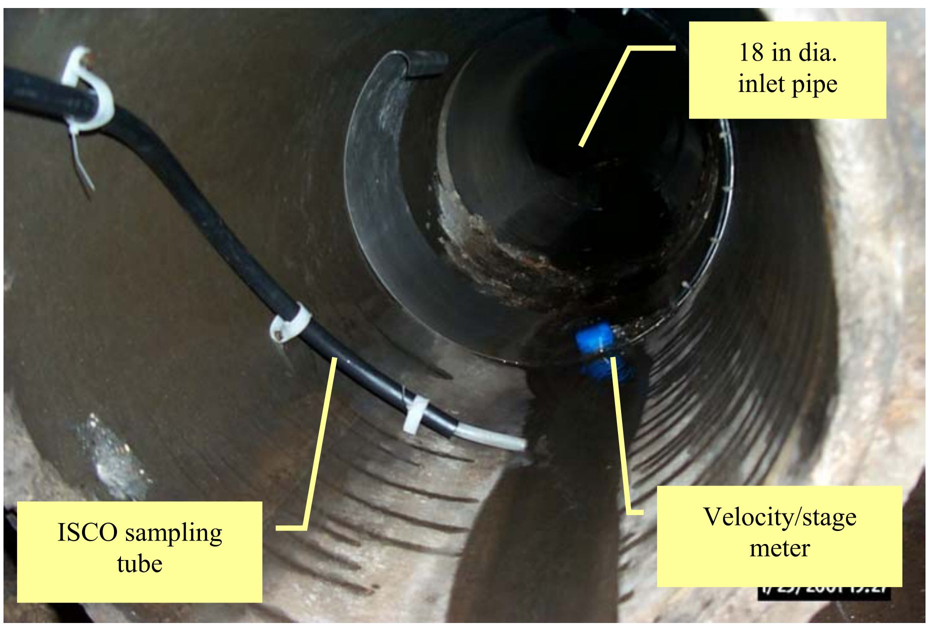



**Figure 4-1. View of Monitoring Site 1.**

### *4.1.2 Site 2 - Treated Effluent*

This sampling and monitoring site was selected to characterize the stormwater treated by the Arkal Pressurized Stormwater Filtration System. A velocity meter and sampler suction tubing were located in an eight-inch diameter plastic pipe in the filter house downstream from all filtering equipment. The treated effluent outlet point was always pressurized and was under full-pipe conditions at discharge times. The site and test equipment are shown in Figure 4-3.

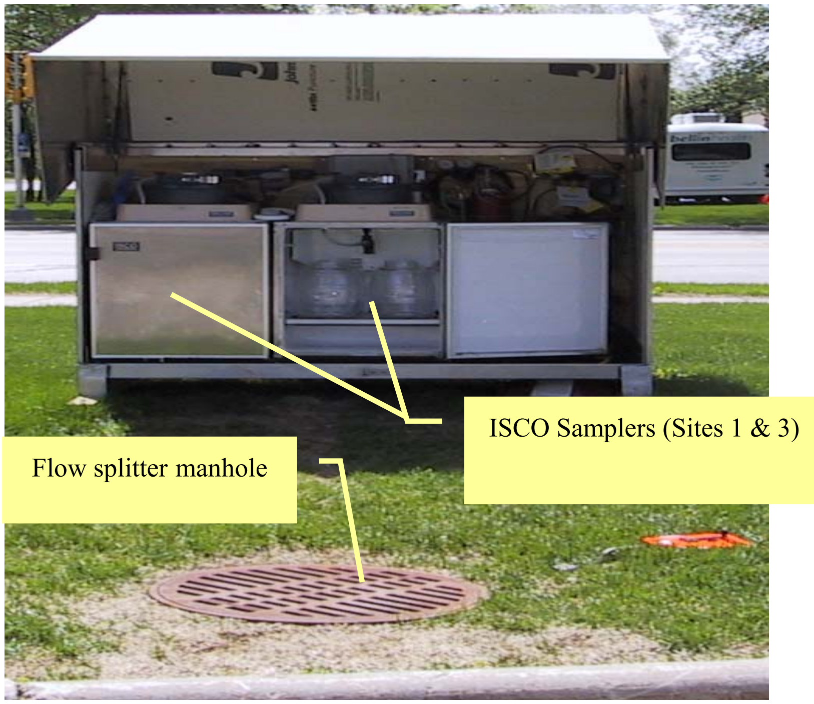



**Figure 4-2. View of sampling equipment for Monitoring Sites 1 and 3.**

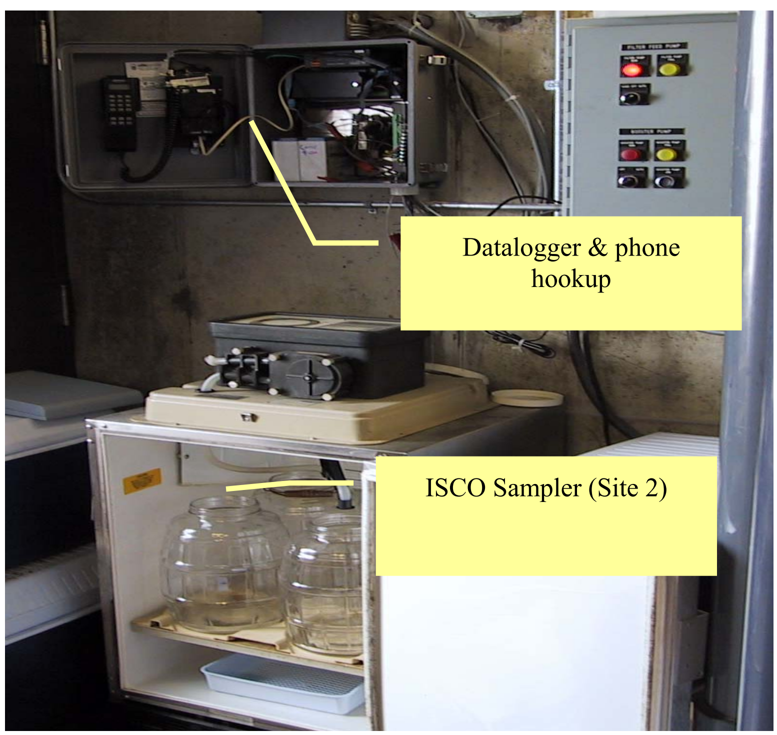



**Figure 4-3. View of Monitoring Site 2 sampler and datalogger.**

#### *4.1.3 Site 3 - Overflow Bypass*

This sampling and monitoring site was selected to characterize the stormwater that bypassed the treatment system during larger runoff events. A velocity meter and sampler suction tubing were located in the 18-inch diameter concrete storm sewer pipe, approximately two feet downstream from the flow splitter manhole. The site and test equipment are shown in Figures 4-2 and 4-4.

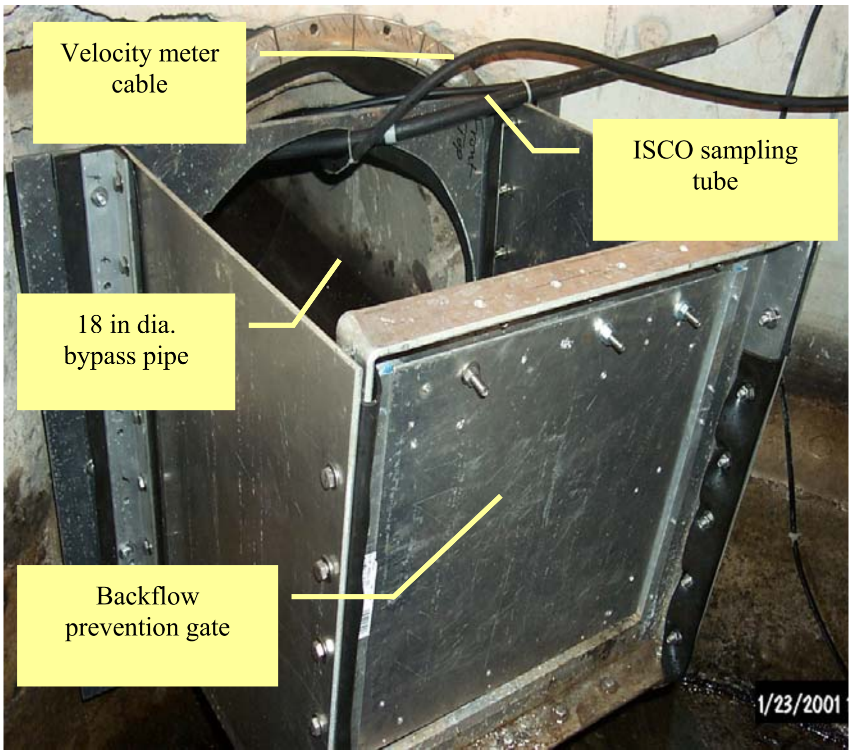



**Figure 4-4. View of Monitoring Site 3 (bypass and backflow prevention gate).**

#### *4.1.4 Other Monitoring Locations*

In addition to the three sampling and monitoring sites, a recording water-level measurement device was installed in the concrete holding tank described in Section 2.1.2. The data from this device were used to verify the filtration system's flow rate. A rain gauge was located adjacent to the drainage area to monitor the volume of precipitation from storm events. The data were used to characterize the events to determine if they met the requirements for a qualified storm event. The rain gauge is shown in Figure 4-5.

### 4.2 Monitoring Equipment

The specific equipment used for monitoring flow, sampling water quality, and measuring rainfall is listed in Table 4-1.


**Figure 4-5. View of site rain gauge.**

**Table 4-1. Field Monitoring Equipment**

| Equipment | Site 1 | Site 2 | Site 3 | Rain Gauge | Holding Tank |
|---|---|---|---|---|---|
| Water Quality Sampler | ISCO 6700 refrigerated automatic sampler (4, 10 L sample bottles) | ISCO 3700 refrigerated automatic sampler (4, 10 L sample bottles) | ISCO 6700 refrigerated automatic sampler (4, 10 L sample bottles) | | |
| Flow Measurement | Marsh-McBirney Velocity Meter Model 270 | Dynasonics M3-902 Doppler Meter | Marsh-McBirney Velocity Meter Model 270 | | |
| Stage Meter | Accubar PS2 Pressure Transducer | | | | Accubar PS2 Pressure Transducer |
| Datalogger | Campbell Scientific Inc. CR10X datalogger | Campbell Scientific Inc. CR10X datalogger | Campbell Scientific Inc. CR10X datalogger | Campbell Scientific Inc. CR10X datalogger | Campbell Scientific Inc. CR10X datalogger |
| Rain Gauge | | | | Sierra Misco | |

## 4.3 Contaminant Constituents Analyzed

The list of constituents analyzed in the stormwater samples is shown in Table 4-2. The vendor's performance claim addresses only the ability to remove sediments from the runoff water. Total suspended solids (TSS) and total dissolved solids (TDS) analyses were the primary testing parameters to evaluate the vendor's performance claim.

Suspended sediment concentration (SSC) analysis was added to the constituent list, though it was not specified in the VTP. The requirement for SSC analysis was added to the *ETV Verification Protocol Stormwater Source Area Treatment Technologies, Version 4.1* (March 2002) after the VTP was prepared.

The vendor's claims do not include the ability to remove nutrients or metals from runoff water. With the vendor's agreement, additional (secondary) constituents, including nutrients and metals, were added to the constituent list to provide information for stormwater assessments.

**Table 4-2. Constituent List for Water Quality Monitoring**

| Parameter | Reporting Units | Limit of Detection | Limit of Quantification | Method |
|---|---|---|---|---|
| TDS | mg/L | 7 | NA | SM2540C |
| TSS | mg/L | 5 | NA | EPA 160.2 |
| SSC | mg/L | 0.1 | 0.5 | ASTM D3977-97 |
| Total Kjeldahl nitrogen | mg/L | 0.14 | 0.4 | EPA 351.2 |
| Nitrate and nitrite | mg/L as N | 0.01 | 0.031 | EPA 353.2 |
| Total phosphorus | mg/L as P | 0.005 | 0.016 | EPA 365.1 |
| Dissolved phosphorus | mg/L as P | 0.002 | 0.006 | EPA 365.1 |
| Total calcium[1] | mg/L | 0.02 | 0.05 | EPA 200.7 |
| Total magnesium[1] | mg/L | 0.02 | 0.05 | EPA 200.7 |
| Total zinc[1] | µg/L | 0.008 | 0.028 | EPA 200.7 |
| Sand-silt split | NA | NA | NA | Fishman *et al.* |
| Five point sedigraph | NA | NA | NA | Fishman *et al.* |
| Sand fractionation | NA | NA | NA | Fishman *et al.* |

[1] Samples for the first four events were analyzed by Method SW846, 6010B; in the spring of 2001, WSLH changed to EPA Method 200.7.

## 4.4 Sampling Schedule

USGS personnel installed the monitoring equipment under a contract with the WDNR. Earth Tech provided support and assistance on the operation of the system, property access, safety issues, and landowner relations.

The monitoring equipment was installed in the spring of 2001. In April and May 2001, several trial events were monitored and the equipment tested and calibrated. Verification testing began in June 2001, and ended in September 2002 after verification data from 15 qualified storm events were collected from the system. Table 4-3 summarizes the sample collection data from the 15 storm events. These storm events met the requirements of a "qualified event," as defined in the VTP:

1. The total rainfall depth for the event, measured at the site rain gauge, was 0.2 inches (5 mm) or greater (snow fall and snow melt events did not qualify).

2. Flow through the treatment device was successfully measured and recorded over the duration of the runoff period.

3. A flow-proportional composite sample was successfully collected for both the influent and effluent over the duration of the runoff event.

4. Each composite sample collected was comprised of a minimum of five aliquots, including at least two aliquots on the rising limb of the runoff hydrograph, at least one aliquot near the peak, and at least two aliquots on the falling limb of the runoff hydrograph.

5. There was a minimum of six hours between qualified sampling events.

Table 4-4 summarizes the storm data for the qualified events. Detailed information on each storm's runoff hydrograph and the rain depth distribution over the event period are included in Appendix A.

The sample collection starting times for the influent and effluent samples, as well as the number of sample aliquots collected, varied from event to event. The influent sampler was activated when the influent velocity meter sensed flow in the pipe. Effluent flow would not occur until water in the holding tank reached a certain level, which initiated the pumps for the filtration process. The effluent sampler was activated when the filtration process discharged treated effluent.

**Table 4-3. Summary of Events Monitored for Verification Testing**

| Event | Influent Sampling Point (Site 1) | | | | | Effluent Sampling Point (Site 2) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Start Date | Start Time | End Date | End Time | No. of Aliquots | Start Date | Start Time | End Date | End Time | No. of Aliquots |
| 1 | 6/2/01 | 3:45 | 6/2/01 | 11:23 | 11 | 6/2/01 | 4:18 | 6/2/01 | 12:15 | 22 |
| 2 | 6/10/01 | 12:26 | 6/10/01 | 15:36 | 8 | 6/10/01 | 13:18 | 6/10/01 | 17:18 | 10 |
| 3 | 6/11/01 | 22:38 | 6/12/01 | 00:27 | 5 | 6/11/01 | 23:00 | 6/12/01 | 1:05 | 5 |
| 4 | 6/15/01 | 10:20 | 6/15/01 | 12:36 | 19 | 6/15/01 | 11:18 | 6/15/01 | 14:30 | 17 |
| 5 | 8/25/01 | 2:45 | 8/25/01 | 10:47 | 16 | 8/25/01 | 7:31 | 8/25/01 | 19:00 | 33 |
| 6 | 12/12/01 | 22:18 | 12/13/01 | 01:33 | 13 | 12/12/01 | 22:49 | 12/13/01 | 1:31 | 18 |
| 7 | 4/18/02 | 4:27 | 4/18/02 | 08:43 | 21 | 4/18/02 | 6:12 | 4/18/02 | 8:35 | 11 |
| 8 | 4/24/02 | 15:07 | 4/24/02 | 19:04 | 13 | 4/24/02 | 17:24 | 4/24/02 | 20:58 | 20 |
| 9 | 4/27/02 | 20:15 | 4/28/02 | 08:07 | 19 | 4/27/02 | 18:26 | 4/28/02 | 7:29 | 31 |
| 10 | 5/1/02 | 22:19 | 5/2/02 | 01:00 | 5 | 5/1/02 | 23:20 | 5/2/02 | 0:28 | 8 |
| 11 | 5/25/02 | 8:31 | 5/27/02 | 08:08 | 37 | 5/25/02 | 9:24 | 5/27/02 | 8:42 | 29 |
| 12 | 6/13/02 | 23:48 | 6/14/02 | 11:33 | 11 | 6/13/02 | 23:12 | 6/14/02 | 11:25 | 20 |
| 13 | 6/21/02 | 17:15 | 6/21/02 | 18:57 | 13 | 6/21/02 | 17:56 | 6/21/02 | 21:09 | 29 |
| 14 | 7/25/02 | 17:39 | 7/25/02 | 19:56 | 24 | 7/25/02 | 17:26 | 7/25/02 | 21:21 | 15 |
| 15 | 9/19/02 | 4:48 | 9/19/02 | 07:46 | 9 | 9/19/02 | 5:45 | 9/19/02 | 7:57 | 15 |

**Table 4-4. Rainfall Summary for Monitored Events**

| Event Number | Start Date | Start Time | End Date | End Time | Rainfall Amount (inches) | Rainfall Duration (hr:min) | Rainfall Volume[1] ($ft^3$) |
|---|---|---|---|---|---|---|---|
| 1 | 6/2/2001 | 03:42 | 6/2/2001 | 11:08 | 0.81 | 7:24 | 16,070 |
| 2 | 6/10/2001 | 12:16 | 6/10/2001 | 15:10 | 0.41 | 2:54 | 6,307 |
| 3 | 6/11/2001 | 22:13 | 6/12/2001 | 00:02 | 0.20 | 1:49 | 2,367 |
| 4 | 6/15/2001 | 10:13 | 6/15/2001 | 12:03 | 0.38 | 1:50 | 5,374 |
| 5 | 8/25/2001 | 02:42 | 8/25/2001 | 09:34 | 0.34 | 6:52 | 4,467 |
| 6 | 12/12/2001 | 21:54 | 12/13/2001 | 00:49 | 0.39 | 2:55 | 5,495 |
| 7 | 4/18/2002 | 04:14 | 4/18/2002 | 07:46 | 0.40 | 3:32 | 4,959 |
| 8 | 4/24/2002 | 14:53 | 4/24/2002 | 18:32 | 0.63 | 3:39 | 8,044 |
| 9 | 4/27/2002 | 20:02 | 4/28/2002 | 07:35 | 1.13 | 11:33 | 16,332 |
| 10 | 5/1/2002 | 21:55 | 5/2/2002 | 01:07 | 0.22 | 3:12 | 2,557 |
| 11 | 5/25/2002 | 08:11 | 5/27/2002 | 07:51 | 1.27 | 35:40 | 16,114 |
| 12 | 6/13/2002 | 20:45 | 6/14/2002 | 10:46 | 0.31 | 14:01 | 4,640 |
| 13 | 6/21/2002 | 17:14 | 6/21/2002 | 18:19 | 0.36 | 1:05 | 4,985 |
| 14 | 7/25/2002 | 17:29 | 7/25/2002 | 18:37 | 0.40 | 1:08 | 5,728 |
| 15 | 9/19/2002 | 04:48 | 9/19/2002 | 07:12 | 0.23 | 2:24 | 2,929 |

[1] Rainfall volume measured at the inlet monitoring point.

## 4.5 Field Procedures for Sample Handling and Preservation

Data gathered by the on-site datalogger were accessible to USGS personnel by means of a modem and phone-line hookup. USGS personnel collected samples and performed a system inspection after a qualified event occurred.

Water samples were collected with ISCO automatic samplers. A peristaltic pump on the sampler pumped water from the sampling location through Teflon™-lined sample tubing to the pump head where water passed through approximately three feet of silicone tubing and into one of four 10-liter sample collection bottles. Samples were capped and removed from the sampler, placed on ice in coolers, and chain of custody forms were completed. The samples were then transported to the USGS field office in Madison, Wisconsin, where they were split into multiple aliquots using a 20-liter Teflon-lined churn splitter. The analytical laboratories provided sample bottles. Samples were preserved per method requirements and analyzed within the holding times allowed by the methods. Particle size and SSC samples were shipped to the USGS sediment laboratory in Iowa City, Iowa. All other samples were hand-delivered to the Wisconsin State Laboratory of Hygiene in Madison, Wisconsin. Chain of custody forms accompanied the sample bottles to their final destinations.

# Chapter 5
# Monitoring Results and Discussion

The monitoring results related to contaminant reduction over the 15 events are reported in two formats:

1. Efficiency ratio comparison, which evaluates the effectiveness of the system on an event mean concentration (EMC) basis.

2. Sum of loads comparison, which evaluates the effectiveness of the system on a constituent mass (concentration times volume) basis.

The Arkal system is designed to remove suspended solids from wet-weather flows. The VTP required that a suite of analytical parameters, including solids, metals, and nutrients, also be evaluated because stormwater management assessments often require evaluating the potential reduction of other constituents commonly found in stormwater. The data obtained during the verification testing are presented in two sections: the primary parameter section, which evaluates the sediment data and addresses the vendor's claim of suspended solids removal; and the secondary parameter section, which evaluates metals and nutrient data, of interest for water quality purposes but not part of the vendor's performance claim.

## 5.1 Monitoring Results: Performance Parameters

### *5.1.1 Concentration Efficiency Ratio*

The concentration efficiency ratio reflects the treatment capability of the device using the event mean concentration (EMC) data obtained for each runoff event. The concentration efficiency ratios are calculated by:

$$\text{Efficiency ratio (ER)} = 100 \times (1-[EMC_{effluent}/EMC_{influent}]) \quad (5\text{-}1)$$

The mean concentrations for influent and effluent samples, along with the efficiency ratios calculated from the analytical data, are summarized in Table 5-1.

The mean influent TSS concentration for the 15 events was 72 mg/L, and the mean effluent concentration was approximately 13 mg/L. The efficiency ratio for TSS reduction for the individual events ranged from 47 percent to greater than 94 percent. The volume of sample collected for events was not always sufficient to complete all of the required analyses and the SSC, so there were two influent and three effluent events where the SSC was not determined. For the events where the SSC was determined, the mean influent SSC concentration was 82 mg/L and the mean effluent concentration was 14 mg/L. The efficiency ratio for SSC ranged from a low of 32 percent to a high of 95 percent. The wide fluctuations of reductions from event to event can make the data difficult to interpret. For example, the low percent reductions in EMC generally occur when the runoff water concentrations are low (relatively "clean" runoff). It is more difficult to obtain a high percentile reduction in TSS or SSC when the influent water has low concentrations of TSS or SSC.

**Table 5-1. Monitoring Results and Efficiency Ratios for Primary Parameters**

| | | Total Suspended Solids | | | Suspended Sediment [1] | | | Total Dissolved Solids | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Event | Rainfall (in) | Influent (mg/L) | Effluent (mg/L) | Efficiency Ratio | Influent (mg/L) | Effluent (mg/L) | Efficiency Ratio | Influent (mg/L) | Effluent (mg/L) | Efficiency Ratio |
| 1 | 0.81 | 10 | <3 | >70 | 12 | -- | -- | 38 | 190 | -400 |
| 2 | 0.41 | 38 | 7 | 82 | 47 | 4 | 91 | 62 | 610 | -880 |
| 3 | 0.20 | 20 | <2 | >90 | -- | -- | -- | 110 | 500 | -370 |
| 4 | 0.38 | 23 | 4 | 83 | 25 | 4 | 84 | 74 | 370 | -400 |
| 5 | 0.34 | 32 | <2 | >94 | 31 | 2 | 94 | 160 | 250 | -56 |
| 6 | 0.39 | 17 | 3 | 82 | 14 | 3 | 79 | 54 | 380 | -600 |
| 7 | 0.40 | 150 | 45 | 71 | 140 | 43 | 70 | 280 | 650 | -130 |
| 8 | 0.63 | 430 | 61 | 86 | 340 | 67 | 80 | 550 | 770 | -40 |
| 9 | 1.13 | 25 | 9 | 64 | 28 | 19 | 32 | 170 | 450 | -170 |
| 10 | 0.22 | 15 | 8 | 47 | -- | -- | -- | 200 | 950 | -380 |
| 11 | 1.27 | 14 | 4 | 71 | 13 | 5 | 62 | 120 | 280 | -130 |
| 12 | 0.31 | 19 | 3 | 84 | 16 | 4 | 75 | 190 | 340 | -80 |
| 13 | 0.36 | 88 | 8 | 91 | 122 | 7 | 94 | 120 | 570 | -380 |
| 14 | 0.40 | 180 | 25 | 86 | 240 | 12 | 95 | 68 | 810 | -1100 |
| 15 | 0.23 | 21 | 6 | 71 | 43 | 2 | 95 | 210 | 560 | -170 |

[1] Captured water volume not always sufficient to conduct the SSC analysis.

### *5.1.2 Groundwater Infiltration*

The TDS data showed a higher effluent concentration of dissolved solids than the influent. The likely reason for this is the infiltration of groundwater with elevated TDS concentrations into the storm sewer system through cracks and poorly sealed joints. This is supported by the observation of water flowing in the storm sewer collection system during dry-weather periods. Also, during the installation of the system's holding tank, groundwater and mottled soil were encountered at depths of approximately five to six feet below grade, the same depth as the storm sewer pipes. Finally, before testing began, all possible non-stormwater connections (cooling water, air conditioner condensate, etc.) were identified and eliminated from the storm sewer network.

Samples of the non-stormwater flow were collected and analyzed for TDS, total calcium, and total magnesium during a dry weather period (August 8, 2001). The results are shown in Table 5-2.

**Table 5-2. Dry Weather (Groundwater) Analytical Results**

| Time | Sample No./Location | TDS (mg/L) | Total Calcium (mg/L) | Total Magnesium (mg/L) |
|---|---|---|---|---|
| 1445 | 1 (Holding Tank) | 774 | 81.5 | 49.0 |
| 1514 | 2 (Site 1) | 836 | 73.2 | 47.9 |
| 1620 | 3 (Holding Tank) | 780 | 78.0 | 46.2 |
| 1520 | 4 (Site 3) | 782 | 80.9 | 48.0 |
| | **Mean** | **793** | **78.4** | **47.7** |

Average TDS concentrations in the dry-weather flow (793 mg/L) were considerably higher than average influent concentrations observed during the 15 qualified events (161 mg/L). Water flowing into the system entered the holding tank during dry-weather periods, which prompted the pump cycle to initiate every 2 to 2½ days. This occurrence was monitored by the stage meter located inside the holding tank and the effluent flow meter, and was recorded by the TO's monitoring equipment operated by USGS. This pattern appears consistently throughout the monitoring period. Based on this time interval and the volume of the tank, which is drained during one pump cycle (approximately 8,500 gal), the system was experiencing infiltration at a rate of approximately two to three gpm. During storm events, runoff water with lower TDS concentrations would mix with the high TDS ground water in the holding tank. The combined water was then pumped through the system, resulting in TDS concentrations in the treated effluent that were higher than in the influent.

Assuming the infiltration into the storm sewer occurred at the same rate during the 15 monitored events, the groundwater volume was not sufficient to impact the influent mass loadings to a mathematical or statistical significance.

### *5.1.3 Sum of Loads*

The Sum of Loads (SOL) calculation provides a measure of the efficiency of Arkal system performance. SOL results reflect the mass pollutant load (concentration times event volume) of a constituent for all 15 captured events, and is calculated using the following equation:

$$SOL = 100 \times (1-[SOL_{effluent}/SOL_{influent}]) \quad (5\text{-}2)$$

The SOL data for sediments is summarized in Table 5-3.

**Table 5-3. Sum of Loads**

| Event | TSS (lb) | | SSC (lb) | | TDS (lb) | |
|---|---|---|---|---|---|---|
| **No.** | **Inlet** | **Outlet** | **Inlet** | **Outlet** | **Inlet** | **Outlet** |
| 1 | 10 | 1.5 | 12 | 0 | 38 | 187 |
| 2 | 15 | 2.8 | 18.5 | 1.6 | 24 | 240 |
| 3 | 3 | 0.1 | 0 | 0 | 16 | 74 |
| 4 | 7.7 | 1.3 | 8.4 | 1.3 | 25 | 123 |
| 5 | 8.9 | 0.3 | 8.6 | 0.6 | 45 | 70 |
| 6 | 5.8 | 1 | 4.8 | 1 | 19 | 130 |
| 7 | 47.4 | 13.9 | 43.7 | 13.3 | 87 | 200 |
| 8 | 214 | 30.6 | 171 | 33.6 | 274 | 386 |
| 9 | 26 | 9.3 | 29.1 | 19.7 | 176 | 465 |
| 10 | 2.4 | 1.3 | 0 | 0 | 33 | 152 |
| 11 | 14.1 | 4 | 13.1 | 5 | 123 | 284 |
| 12 | 5.5 | 0.9 | 4.6 | 1.2 | 55 | 100 |
| 13 | 27.4 | 2.5 | 38 | 2.2 | 38 | 179 |
| 14 | 62.9 | 8.9 | 85.1 | 2.2 | 24 | 289 |
| 15 | 3.8 | 1.1 | 7.9 | 0.4 | 38 | 102 |
| **Total** | **453.8** | **79.7** | **444.5** | **82.1** | **1,019** | **2,980** |
| **SOL** | **82** | | **82** | | **-192** | |

The SOL analyses indicate sediment (TSS and SSC) reductions slightly better than the vendor's claim of 80 percent sediment reduction. As discussed in Section 5.1.2, the TDS data showed a negative efficiency.

The effluent flow measurements were not considered to be reliable (see Section 6.2.2), so the influent flow volumes were used to calculate the SOL values. During the monitored events, the stormwater entering the system was discharged either as treated effluent to the storm sewer or untreated backwash to the sanitary sewer. Since backwashing occurred during each event, the treated effluent volume was less than the influent volume. Substitution of the higher influent volume for the effluent volume in Equation 5-2 decreases the SOL values. The result is that the calculated SOL values presented in Table 5-3 are conservative values.

### 5.2 Particle Size Distribution

Particle size distribution analysis was conducted in three different ways:

1. A "sand/silt split" analysis determined the percentage of sediment (by weight) larger than 62 µm (defined as sand) and less than 62 µm (defined as silt).

2. A Visual Accumulator (VA) tube analysis (Fishman et. al., 1994) defined the percent of sediment (by weight) sized less than 1000, 500, 250, 125, and 62 µm.

3. A pipette analysis (Fishman et al., 1994) was conducted to further define the silt portion of a sample as the percent of sediment (by weight) sized less than 31, 16, 8, 4, and 2 µm.

The autosamplers did not always collect an adequate volume of sample to conduct the full suite of particle size analyses. Influent and effluent samples from 12 of the 15 qualified events were analyzed for sand/silt split (Table 5-4). Of the 12 events, six influent samples had sufficient sediment content and sample volume to conduct the VA tube analysis, and three samples also had sufficient sediment content to conduct the pipette analysis to provide a full definition of the particle size distribution (Table 5-5). No effluent samples contained sufficient sediment content and sample volume for the VA tube and pipette analyses.

**Table 5-4. Sand/Silt Split Analysis for 12 Events**

| Event | | Inlet (percent) | | Outlet (percent) | |
|---|---|---|---|---|---|
| Number | Date | >62 (µm) | <62 (µm) | >62 (µm) | <62 (µm) |
| 2 | 6/10/2001 | 44.0 | 56.0 | 29.1 | 70.9 |
| 4 | 6/15/2001 | 23.8 | 76.2 | 21.7 | 78.3 |
| 5 | 8/25/2001 | 32.9 | 67.1 | 54.8 | 45.2 |
| 6 | 12/12/2001 | 9.7 | 90.3 | 20.6 | 79.4 |
| 7 | 4/18/2002 | 1.9 | 98.1 | 2.3 | 97.7 |
| 8 | 4/24/2002 | 0.9 | 99.1 | 8.8 | 91.2 |
| 9 | 4/27/2002 | 19.4 | 80.6 | 7.6 | 92.4 |
| 11 | 5/25/2002 | 10.0 | 90.0 | 1.4 | 98.6 |
| 12 | 6/13/2002 | 18.5 | 81.5 | 24.7 | 75.3 |
| 13 | 6/21/2002 | 42.5 | 57.5 | 17.7 | 82.3 |
| 14 | 7/25/2002 | 37.9 | 62.1 | 3.0 | 97.0 |
| 15 | 9/19/2002 | 67.9 | 32.1 | 2.4 | 97.6 |

**Table 5-5. Particle Size Distribution for Six Influent Sampling Events**

| | Sieve Passage Rate (Percent) | | | | | |
|---|---|---|---|---|---|---|
| Sieve Size (µm) | Event 7 4/18/02 | Event 8 4/24/02 | Event 9 4/27/02 | Event 13 6/21/02 | Event 14 7/25/02 | Event 15 9/19/02 |
| <1000 | 100 | 100 | 87.6 | 79.0 | 94.3 | 40.2 |
| <500 | 100 | 100 | 86.8 | 72.2 | 85.1 | 40.2 |
| <250 | 99.6 | 100 | 82.2 | 60.4 | 75.2 | 36.0 |
| <125 | 98.7 | 99.8 | 80.8 | 57.5 | 68.8 | 32.5 |
| <62 | 98.1 | 99.1 | 80.6 | 57.5 | 62.1 | 32.1 |
| <31 | 94.4 | 95.5 | N/A | N/A | 44.4 | N/A |
| <16 | 81.4 | 78.8 | N/A | N/A | 32.6 | N/A |
| <8 | 58.9 | 56.4 | N/A | N/A | 25.2 | N/A |
| <4 | 35.3 | 38.9 | N/A | N/A | 17.3 | N/A |
| <2 | 17.9 | 23.9 | N/A | N/A | 13.5 | N/A |

The flow splitter catch basin had a three-foot deep sump that trapped coarse material, preventing it from entering the holding tank. For the purposes of this verification, the sump was considered to be part of the Arkal system's treatment process at this installation. The sump was emptied prior to the verification monitoring period (May 2001). At the end of the verification monitoring period (November 2002), the volume of sediment trapped in the sump was evaluated and core samples were collected. The sediment depths varied from 14 inches near the inlet to one inch on the opposite side of the inlet. As shown in Table 5-6, the sediment trapped in the flow splitter sump was primarily large and coarse. Three composite samples were collected and analyzed for the particle size distribution analyses. These data are summarized in Table 5-6.

**Table 5-6. Particle Size Distribution for Material from Flow Splitter Sump**

| Sieve Size (µm) | Sieve Passage Rate (percent) | | | |
|---|---|---|---|---|
| | Sample 1 | Sample 2 | Sample 3 | Mean |
| <2000 | 70 | 68 | 71 | 70 |
| <1000 | 51 | 49 | 54 | 51 |
| <500 | 34 | 34 | 39 | 36 |
| <250 | 16 | 16 | 21 | 18 |
| <125 | 6 | 7 | 8 | 7 |
| <62 | 3 | 3 | 4 | 3 |

## 5.3 Monitoring Results: Secondary Parameters

As previously stated, the vendor's claim is applicable only to TSS and SSC (as reported in Tables 5-1 and 5-3). However, for the purpose of stormwater management assessment, it is often necessary to evaluate the potential for reduction of other constituents commonly found in stormwater. The VTP included secondary parameters such as nutrients (TKN, nitrates and phosphorus) and metals (magnesium, calcium, and zinc) commonly found in urban runoff, which are of concern to water resource managers. These data are summarized in Tables 5-7 through 5-9.

The EMC and SOL data on the non-performance parameters indicated that the system removed phosphorus, TKN, and zinc from the runoff. These constituents commonly attach to sediment particles and the treatment was likely the result of the constituents attached to treated sediment particles. Dissolved-phase nutrients and metals passed through the system without treatment.

As discussed in Section 5.1.2, the groundwater infiltration issue also likely affected the calcium and magnesium analyses (see Table 5-2).

**Table 5-7. Event Mean Concentration for Secondary Parameters (Nutrients)**

| Event No. | TKN[1] (mg/L as N) | | | $NO_2 + NO_3$ as N (mg/L) | | | Total Phosphorus (mg/L as P) | | | Dissolved Phosphorus[2] (mg/L as P) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Inlet | Outlet | Percent Change | Inlet | Outlet | Percent Change | Inlet | Outlet | Percent Change | Inlet | Outlet | Percent Change |
| 1 | 0.32J | 0.39J | -22 | 0.286 | 0.674 | -136 | 0.023 | 0.015J | 35 | 0.005 | <0.005 | 50 |
| 2 | 0.51 | 0.59 | -16 | 0.641 | 1.70 | -165 | 0.07 | <0.005 | 96 | <0.005 | <0.005 | 0.0 |
| 3 | 1.0 | 0.55 | 45 | 0.889 | 1.49 | -67.6 | 0.059 | 0.028 | 53 | <0.005 | <0.005 | 0.0 |
| 4 | 0.62 | 0.57 | 8.1 | 0.557 | 1.10 | -97.5 | 0.061 | 0.037 | 39 | 0.020 | 0.014J | 30 |
| 5 | 1.3 | 0.53 | 59 | 1.69 | 1.63 | 3.55 | 0.061 | 0.025 | 59 | 0.012 | 0.021 | -75 |
| 6 | 0.42 | 0.43 | -2.4 | 0.357 | 0.931 | -161 | 0.043 | 0.033 | 23 | 0.021 | 0.025 | -19 |
| 7 | 2.1 | 1.71 | 19 | 1.34 | 1.80 | -34.3 | 0.17 | 0.087 | 49 | 0.038 | 0.028 | 26 |
| 8 | 2.2 | 1.0 | 55 | 0.743 | 0.906 | -21.9 | 0.32 | 0.087 | 73 | 0.026 | 0.021 | 19 |
| 9 | 0.33J | 0.35J | -6.1 | 0.393 | 0.839 | -113 | 0.069 | 0.051 | 26 | 0.022 | 0.021 | 4.5 |
| 10 | 0.56 | 0.43 | 23 | 0.697 | 1.88 | -170 | 0.053 | 0.034 | 36 | 0.024 | 0.017 | 29 |
| 11 | 0.84 | 0.51 | 39 | 0.599 | 0.789 | -31.7 | 0.056 | 0.033 | 41 | 0.014J | 0.015J | -7.1 |
| 12 | 0.51 | 0.75 | -47 | 0.587 | 0.935 | -59.3 | 0.05 | 0.032 | 36 | 0.015J | 0.011J | 27 |
| 13 | 0.84 | 0.57 | 32 | 0.623 | 1.34 | -115 | 0.11 | 0.034 | 69 | 0.016 | 0.0080J | 50 |
| 14 | 1.1 | 0.78 | 29 | 0.839 | 2.09 | -149 | 0.21 | 0.067 | 68 | 0.017 | 0.025 | -47 |
| 15 | 0.78 | 0.46 | 41 | 0.839 | 1.24 | -47.8 | 0.26 | 0.13 | 50 | 0.168 | 0.119 | 29 |

[1] One of four field blank results for TKN showed a concentration above the MDL, below the LOQ (inlet sample: 0.24 mg/L); see Section 6.1.1, Table 6-1.

[2] Dissolved phosphorus for the first four events was analyzed as ortho phosphorus.

[J] Denotes an estimated concentration. Concentration is above the MDL and below the LOQ.

**Table 5-8. Event Mean Concentration for Secondary Parameters (Metals)**

| Event No | Total Zinc (µg/L) Inlet | Total Zinc (µg/L) Outlet | Total Zinc (µg/L) Pct. Change | Total Calcium[1] (mg/L) Inlet | Total Calcium[1] (mg/L) Outlet | Total Calcium[1] (mg/L) Pct. Change | Total Magnesium[1] (mg/L) Inlet | Total Magnesium[1] (mg/L) Outlet | Total Magnesium[1] (mg/L) Pct. Change |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 24J | 19J | 21 | 6.50 | 19.2 | -195 | 2.3 | 8.3 | -260 |
| 2 | 50 | 20J | 60 | 11.5 | 60.3 | -424 | 4.3 | 29 | -570 |
| 3 | 36J | 24J | 33 | 12.8 | 48.4 | -278 | 4.6 | 23 | -400 |
| 4 | 45J | 25J | 44 | 10.6 | 36.9 | -248 | 4.1 | 17 | -320 |
| 5 | 72 | 19J | 74 | 21.8 | 25.7 | -18.0 | 8.5 | 11 | -29 |
| 6 | 45J | <16 | 82 | 7.70 | 41.6 | -440 | 3.1 | 23 | -640 |
| 7 | 130 | 56 | 58 | 33.6 | 47.2 | -40.0 | 12 | 20 | -67 |
| 8 | 210 | 50 | 76 | 63.6 | 35.3 | 44.0 | 30 | 14 | 53 |
| 9 | 35J | 26J | 26 | 13.2 | 33.3 | -152 | 5.4 | 15 | -180 |
| 10 | 36J | 18J | 50 | 17.4 | 77.2 | -344 | 7.4 | 36 | -390 |
| 11 | 53 | 22J | 58 | 12.0 | 25.0 | -108 | 4.5 | 11 | -140 |
| 12 | 31J | 18J | 42 | 23.8 | 34.1 | -43.0 | 10 | 15 | -50 |
| 13 | 73 | 21J | 71 | 21.1 | 51.9 | -146 | 9.8 | 26 | -170 |
| 14 | 130 | 22J | 83 | 34.6 | 75.9 | -119 | 16 | 41 | -160 |
| 15 | 52 | 17J | 67 | 22.5 | 47.4 | -111 | 11 | 28 | -160 |

[1] Field blank results for calcium and magnesium showed constituents at concentrations above MDL; see Section 6.1.1, Table 6-1.

[J] Denotes an estimated concentration. Concentration is above the MDL but below the LOQ.

R Denotes duplicate sample.

**Table 5-9. Sum of Loads for Secondary Parameters**

| Event No. | TKN (lb as N) | | NO2 + NO3 (lb as N) | | Dissolved Phosphorus (lb as P) | | Total Phosphorus (lb as P) | | Total Zinc (lb) | | Total Calcium (lb) | | Total Magnesium (lb) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Inlet | Outlet | Inlet | Outlet | Inlet | Outlet | Inlet | Outlet | Inlet | Outlet | Inlet | Outlet | Inlet | Outlet |
| 1 | 0.32 | 0.39 | 0.29 | 0.68 | 0.005 | 0.003 | 0.023 | 0.015 | 0.02 | 0.02 | 6.5 | 19.1 | 2.3 | 8.3 |
| 2 | 0.20 | 0.23 | 0.25 | 0.67 | 0.001 | 0.001 | 0.028 | 0.001 | 0.02 | 0.01 | 11.0 | 60.2 | 4.3 | 29.1 |
| 3 | 0.15 | 0.08 | 0.13 | 0.22 | 0.000 | 0.000 | 0.009 | 0.004 | 0.01 | 0.00 | 13.0 | 49.2 | 4.6 | 23.1 |
| 4 | 0.21 | 0.19 | 0.19 | 0.37 | 0.007 | 0.005 | 0.020 | 0.012 | 0.02 | 0.01 | 11.0 | 37.1 | 4.1 | 17.1 |
| 5 | 0.37 | 0.15 | 0.47 | 0.45 | 0.003 | 0.006 | 0.017 | 0.007 | 0.02 | 0.01 | 21.9 | 25.8 | 8.5 | 11.0 |
| 6 | 0.14 | 0.15 | 0.12 | 0.32 | 0.007 | 0.009 | 0.015 | 0.011 | 0.02 | 0.00 | 7.7 | 41.7 | 3.1 | 23.1 |
| 7 | 0.63 | 0.53 | 0.41 | 0.56 | 0.012 | 0.009 | 0.051 | 0.027 | 0.04 | 0.02 | 33.7 | 47.4 | 12.0 | 20.1 |
| 8 | 1.11 | 0.52 | 0.37 | 0.45 | 0.013 | 0.011 | 0.159 | 0.044 | 0.10 | 0.03 | 63.8 | 35.4 | 30.1 | 14.0 |
| 9 | 0.33 | 0.35 | 0.40 | 0.85 | 0.022 | 0.021 | 0.070 | 0.052 | 0.04 | 0.03 | 13.2 | 33.4 | 5.4 | 15.0 |
| 10 | 0.09 | 0.07 | 0.11 | 0.30 | 0.004 | 0.003 | 0.008 | 0.005 | 0.04 | 0.02 | 17.5 | 77.5 | 7.4 | 36.1 |
| 11 | 0.84 | 0.51 | 0.60 | 0.79 | 0.014 | 0.015 | 0.056 | 0.033 | 0.04 | 0.02 | 12.0 | 25.1 | 4.5 | 11.0 |
| 12 | 0.15 | 0.22 | 0.17 | 0.27 | 0.004 | 0.003 | 0.014 | 0.009 | 0.02 | 0.01 | 23.9 | 34.2 | 10.0 | 15.0 |
| 13 | 0.26 | 0.18 | 0.19 | 0.42 | 0.005 | 0.002 | 0.035 | 0.011 | 0.01 | 0.01 | 21.2 | 52.1 | 9.8 | 26.1 |
| 14 | 0.38 | 0.28 | 0.30 | 0.75 | 0.006 | 0.009 | 0.076 | 0.024 | 0.03 | 0.01 | 34.7 | 76.1 | 16.1 | 41.1 |
| 15 | 0.14 | 0.08 | 0.15 | 0.23 | 0.031 | 0.022 | 0.047 | 0.025 | 0.01 | 0.00 | 22.6 | 47.6 | 11.0 | 28.1 |
| **Total:** | **5.35** | **3.94** | **4.17** | **7.33** | **0.135** | **0.118** | **0.629** | **0.280** | **0.42** | **0.18** | **18.0** | **51.7** | **8.0** | **25.1** |
| **SOL (Percent):** | **26** | | **-76** | | **13** | | **55** | | **58** | | **-188** | | **-213** | |

NOTE: For purposes of statistical analysis, parameters below detection level were assigned a value of one-half of the detection level.

## Chapter 6
## QA/QC Results and Summary

The Quality Assurance Project Plan (QAPP) in the VTP identified critical measurements and established several QA/QC objectives. The verification test procedures and data collection followed the QAPP. QA/QC summary results are reported in this section, and the full laboratory QA/QC results and supporting documents are presented in Appendix B.

### 6.1 Laboratory/Analytical Data QA/QC

#### *6.1.1 Bias (Field Blanks)*

Field blanks were collected at both the inlet and outlet samplers on two separate occasions to evaluate the potential for sample contamination through the entire sampling process, including automatic sampler, sample-collection bottles, splitters, and filtering devices. "Milli-Q" reagent water was pumped through the automatic sampler, and collected samples were processed and analyzed in the same manner as event samples. The first field blank was collected on 11/09/00 (before the first event was sampled), allowing the USGS to review the results as early as possible in the monitoring schedule and to make adjustments. The next field blank was taken on June 25, 2001 (between events 4 and 5). Results for both field blanks are shown in Table 6-1.

**Table 6-1. Field Blank Analytical Data Summary**

| | Blank 1 | | Blank 2 | |
|---|---|---|---|---|
| Parameter (mg/L) | Inlet | Outlet | Inlet | Outlet |
| TSS | <5.0 | <5.0 | <5.0 | <5.0 |
| TDS | <7.01 | <7.01 | <20[1] | <20[1] |
| TKN | <0.14 | <0.14 | 0.24 | <0.14 |
| $NO_2 + NO_3$ | <0.01 | <0.01 | <0.01 | <0.01 |
| Dissolved phosphorus | <0.005 | <0.005 | <0.005 | <0.005 |
| Total phosphorus | <0.005 | <0.005 | <0.005 | <0.005 |
| Total calcium | 0.05 | 0.34 | 0.22 | 0.05 |
| Total magnesium | <0.03 | 1.50 | 0.12 | <0.03 |
| Total zinc | <0.019 | <0.019 | <0.019 | <0.019 |

[1] The WSLH increased TDS detection limits in July of 2001, between the field blank sample dates.

The field blank results show no detectable levels for dissolved solids, suspended solids, and total and dissolved phosphorus. A low concentration of TKN (0.24 mg/L) was detected in the inlet sample from the second inlet blank. This concentration was above the MDL, but below the LOQ, for the method. The possible source of this contamination is not known. The data for TKN, presented in Table 5-7, has been flagged with a footnote, indicating that the field blank result was positive for one sample. Also, low concentrations of calcium and magnesium were detected in the field blank samples. The data, presented in Table 5-8, have been flagged with a footnote indicating that the field blanks showed positive results. Field contamination could contribute a positive bias to the inlet data, if present during all events, and should be considered when evaluating the data. The outlet data, apparently influenced by the presence of groundwater infiltration, showed higher concentration of calcium and magnesium, so any bias due to field contamination would be lower than for the inlet data.

### *6.1.2 Replicates (Precision)*

Precision measurements were performed by the collection and analysis of duplicate samples. Field duplicates were collected to monitor the overall precision of the sample collection and laboratory analyses. Two duplicate samples from Sites 1 and 2 were collected to evaluate precision in the sampling process and analysis. No replicates from Site 3 were collected since a bypass event did not occur. The duplicate samples were obtained on April 7, 2002 (Event 9) and June 21, 2002 (Event 13). The samples were taken from the composite sample collected at each site for each event and split into two separate samples. They were processed, delivered to the laboratory, and analyzed in the same manner as the regular samples. The relative percent difference (RPD) recorded from the sample analyses was calculated to evaluate precision. RPD is calculated using the following formula:

$$\%RPD = \left(\frac{|x_1 - x_2|}{\bar{x}}\right) \times 100\% \qquad (6\text{-}1)$$

where:

$x_1$ = Concentration of compound in sample

$x_2$ = Concentration of compound in duplicate

$\bar{x}$ = Mean value of $x_1$ and $x_2$

Summaries of the field duplicate data are presented in Table 6-2. The duplicate analyses were within the RPD limits for all samples with the exception of the TSS outlet sample during the first replicate sample event. This difference occurred on replicate samples with low TSS concentrations (13 and 9 mg/l). These concentrations are only two to three times the method detection limit, which is commonly a measurement range that has lower precision. The field duplicate precision results for TSS are within the typical range for stormwater or wastewater samples, particularly at low concentrations.

### *6.1.3 Accuracy*

Method accuracy was determined and monitored using a combination of matrix spike/matrix spike duplicates (MS/MSD) and laboratory control samples (known concentration in blank water). The MS/MSD data are evaluated by calculating the deviation from perfect recovery (100 percent), while laboratory control data are evaluated by calculating the deviation from the laboratory control concentration. Accuracy was in control throughout the verification test. Tables 6-3 and 6-4 summarize the matrix spikes and lab control sample recovery data, respectively.

**Table 6-2. Duplicate Sample RPD Data Summary**

| Parameter | | Rep. 1a (mg/L) | Rep. 1b (mg/L) | RPD 1 (pct) | Rep. 2a (mg/L) | Rep. 2b (mg/L) | RPD 2 (pct) | Limit (pct) |
|---|---|---|---|---|---|---|---|---|
| TSS | Influent | 25 | 25 | **0** | 85 | 88 | **3.5** | **30** |
| | Effluent | 13 | 9 | **36** | 7 | 8 | **13** | |
| TDS | Influent | 170 | 174 | **2.3** | 110 | 122 | **10** | **30** |
| | Effluent | 470 | 488 | **3.8** | 582 | 574 | **1.4** | |
| Nitrates | Influent | 0.393 | 0.386 | **1.8** | 0.623 | 0.637 | **2.2** | **25** |
| | Effluent | 0.839 | 0.858 | **2.2** | 1.34 | 1.36 | **1.5** | |
| Dissolved phosphorus | Influent | 0.022 | 0.021 | **4.7** | 0.016 | 0.015 | **6.5** | **20** |
| | Effluent | 0.021 | 0.021 | **0** | 0.008 | 0.007 | **13** | |
| Total phosphorus | Influent | 0.069 | 0.068 | **1.5** | 0.114 | 0.114 | **0** | **25** |
| | Effluent | 0.051 | 0.049 | **4.0** | 0.034 | 0.034 | **0** | |
| Total calcium | Influent | 13.2 | 13 | **1.5** | 21.1 | 17.9 | **16** | **25** |
| | Effluent | 33.3 | 32.7 | **1.8** | 51.9 | 51.5 | **0.8** | |
| Total magnesium | Influent | 5.4 | 5.2 | **3.8** | 9.8 | 8 | **20** | **25** |
| | Effluent | 15 | 15 | **0** | 26 | 25 | **3.9** | |
| Total zinc | Influent | 35 | 37 | **5.6** | 73 | 69 | **5.6** | **25** |
| | Effluent | 26 | 25 | **3.9** | 21 | 21 | **0** | |

**Table 6-3. Laboratory MS/MSD Data Summary**

| Parameter | Count | Average (percent) | Maximum (percent) | Minimum (percent) | Std. Dev. (percent) | Range (Pct) |
|---|---|---|---|---|---|---|
| Total calcium | 14 | 94 | 100 | 89 | 2.75 | 85-115 |
| Total magnesium | 14 | 95 | 98 | 92 | 2.03 | 85-115 |
| Dissolved nitrates | 14 | 100 | 107 | 94 | 3.50 | 90-110 |
| Dissolved phosphorus | 13 | 103 | 106 | 99 | 2.02 | 90-110 |
| TKN | 16 | 99 | 109 | 92 | 5.37 | 90-110 |
| Total phosphorus | 21 | 102 | 105 | 97 | 2.29 | 90-110 |
| Dissolved zinc | 6 | 96 | 98 | 93 | 1.65 | 85-115 |
| Total zinc | 13 | 94 | 99 | 89 | 2.35 | 85-115 |

The balance used for solids (TSS, TDS, and total solids) analyses was calibrated routinely with weights that were NIST traceable. The laboratory maintained calibration records. The temperature of the drying oven was also monitored using a thermometer that was calibrated with an NIST traceable thermometer.

**Table 6-4. Laboratory Control Sample Data Summary**

| Parameter | Count | Mean (percent) | Minimum (percent) | Maximum (percent) | Std. Dev. (percent) |
|---|---|---|---|---|---|
| Total magnesium | 18 | 2.5 | 0.3 | 7.4 | 2.0 |
| Nitrate & nitrite | 13 | 4.9 | 2 | 9.0 | 2.5 |
| TSS | 13 | 9.5 | 3 | 20 | 6.5 |
| Dissolved phosphorus | 3 | 0.3 | 0.3 | 0.5 | 0.1 |
| TDS | 15 | 9.9 | 0 | 22 | 8.2 |
| TKN | 23 | 2.6 | 0.3 | 4.3 | 1.4 |
| Total phosphorus | 19 | 1.0 | 0.2 | 3.1 | 0.8 |
| SSC | 13 | 11 | 2.2 | 19 | 5.0 |
| Total zinc | 22 | 3.2 | 0.3 | 6.4 | 1.8 |

### *6.1.4 Representativeness*

The field procedures were designed to ensure that representative samples were collected of both influent and effluent stormwater. Field duplicate samples and supervisor oversight provided assurance that procedures were being followed. The challenge in sampling stormwater is obtaining representative samples. The data indicated that while individual sample variability may occur, the long-term trend in the data was representative of the concentrations in the stormwater, and redundant methods of evaluating key constituent loadings in the stormwater were utilized to compensate for the variability of the laboratory data.

The laboratories used standard analytical methods, with written SOPs for each method, to provide a consistent approach to all analyses. Sample handling, storage, and analytical methodology were reviewed to verify that standard procedures were being followed. The use of standard methodology, supported by proper quality control information and audits, ensured that the analytical data were representative of actual stormwater conditions.

### ***6.1.5 Completeness***

The flow data and analytical records for the verification study are 100 percent complete.

## 6.2 Flow Measurement Calibration

### *6.2.1 Influent*

Calibration of influent flow (Site 1) was based on stage measurements from the holding tank during runoff periods. At the inlet, a Marsh-McBirney Model 270 Velocity Meter measured velocity and stage. Calibration of flow measurement at the inlet was achieved by comparing a mass balance between the calculated runoff volume at the inlet (using the recording velocity meter and stage recorder) and the stage/volume measured in the holding tank, before the filter pump turned on. The two calculated volumes were compared and used as a basis for correction of inlet flow values. Table 6-5 summarizes the comparisons of the holding tank volumes and the inlet runoff volumes for 29 events, covering the time frame of this verification. The maximum absolute difference between methods was 12.4 percent and the average difference over the 29 events was 0.3 percent. Because of the small difference in the average difference, no adjustments were made to the inlet Marsh-McBirney flow or volume measurements.

### *6.2.2 Treated Effluent*

Calibration of the treated effluent site (Site 2) used a similar approach as the influent. During non-runoff periods, the known volume of water in the tank (derived from groundwater flow) was drawn down and the volume of draw down was compared to the measured volume that passed through the effluent site as calculated by the Doppler velocity meter measurements, assuming a full-pipe condition. Full-pipe conditions were assumed because the municipal storm sewer receiving the treated flow was surcharged under small runoff events. This surcharging would maintain a full-pipe condition at Site 2 during runoff periods. Dry-weather periods were used for this analysis because inflow to the holding tank was at a minimum during these periods, and the tank volume draw down rate was not being influenced by inflow.

The evaluation of the Site 2 Doppler velocity meter was conducted throughout the monitoring period (a total of 54 dry-weather evaluations were conducted). The regression between the tank volumes and the outlet volumes did not prove to be sufficiently accurate for the purposes of this study. It is believed the poor regression results were due to one or more of the following:

1. The Doppler velocity meter at Site 2 had difficulties measuring accurate velocities at times due to the very low suspended solids concentrations in the filtered water. The principles of operation for the Doppler velocity meter are based on the reflection of an acoustic signal off the suspended solids. If suspended solids concentrations are low, the acoustic signal strength can be compromised. Published specifications for the velocity meter state minimum requirements of 25 mg/L TSS of 30-µm particles, while Table 5-1 shows that the TSS concentrations at Site 2 were less than 25 mg/L for 12 of the 15 events.

2. Back flushing of the system may have occurred during the draw down periods used in the calibration process and this volume of water was not accounted for (the backwash water discharges to a sanitary sewer).

**Table 6-5. Comparison of Runoff Volumes - Holding Tank Measurements Versus Inlet Velocity/Stage Meter Calculations**

| Test No. | Date | Tank Volume ($ft^3$) | Inlet Volume ($ft^3$) | Difference (percent) |
|---|---|---|---|---|
| 1 | 4/11/01 | 910.2 | 941.76 | 3.5 |
| 2 | 6/1/01 | 665.8 | 596.16 | -10.5 |
| 3 | 6/10/01 | 1117.4 | 1140.48 | 2.1 |
| 4 | 6/15/01 | 1168.7 | 1192.32 | 2.0 |
| 5 | 7/20/01 | 270.5 | 276.48 | 2.2 |
| 6 | 7/28/01 | 615.5 | 622.08 | 1.1 |
| 7 | 8/25/01 | 531.0 | 527.04 | -0.8 |
| 8 | 9/7/01 | 3823.9 | 3818.88 | -0.1 |
| 9 | 9/19/01 | 419.4 | 406.08 | -3.2 |
| 10 | 10/10/01 | 549.1 | 578.88 | 5.4 |
| 11 | 10/13/01 | 3275.7 | 3222.72 | -1.6 |
| 12 | 4/12/02 | 288.7 | 267.84 | -7.2 |
| 13 | 4/18/02 | 1122.4 | 1192.32 | 6.2 |
| 14 | 4/24/02 | 197.1 | 172.8 | -12.3 |
| 15 | 4/27/02 | 910.2 | 907.2 | -0.3 |
| 16 | 5/6/02 | 299.7 | 302.4 | 0.9 |
| 17 | 5/25/02 | 473.7 | 466.56 | -1.5 |
| 18 | 5/27/02 | 193.1 | 198.72 | 2.9 |
| 19 | 6/3/02 | 357.0 | 380.16 | 6.5 |
| 20 | 6/10/02 | 3965.7 | 3473.28 | -12.4 |
| 21 | 6/11/02 | 534.1 | 570.24 | 6.8 |
| 22 | 6/13/02 | 2026.6 | 1944 | -4.1 |
| 23 | 6/22/02 | 842.8 | 846.72 | 0.5 |
| 24 | 6/26/02 | 432.5 | 475.2 | 9.9 |
| 25 | 7/25/02 | 286.6 | 276.48 | -3.5 |
| 26 | 8/4/02 | 3082.6 | 2998.08 | -2.7 |
| 27 | 8/11/02 | 518.0 | 535.68 | 3.4 |
| 28 | 8/21/02 | 5679.5 | 5581.44 | -1.7 |
| 29 | 9/19/02 | 933.3 | 993.6 | 6.5 |
| | | **Maximum Absolute Difference:** | | **12.4** |
| | | **Minimum Absolute Difference:** | | **0.1** |
| | | **Mean Difference:** | | **0.3** |

3. Buildup of biomass on the StarFilter rings resulted in high backwash rates resulting in low volumes passing the velocity meter and more frequent discharges to the sanitary sewer than anticipated.

For these reasons, the effluent flow measurements and resulting volume calculations were considered to be unreliable.

Since the calibrated influent flow values were considered to be sufficiently accurate, the influent flow volumes were used to calculate both the influent and the effluent constituent loads. Given that no bypassing occurred (Site 3) during the 15 qualified events reported, the flow entering the system through the influent must equal the sum of the flows through the effluent and the backwash to the sanitary sewer. Using the influent flow as the flow through the Arkal system assumes that the amount of flow discharged to the sanitary sewer is small relative to the treated flow discharged to the storm sewer. Based on use of the influent flow data as representative of the effluent flow, loading reduction (SOL) calculations conducted for this report provide a conservative estimate of the reduction in loads through the stormwater treatment system (actual loading reductions are greater than reported).

In spite of the accuracy issues encountered with the Site 2 flowmeter, the flowmeter did trigger the auto sampler in an appropriate manner, which in turn sampled the outlet flow in a flow proportional manner throughout the discharge period.

# Chapter 7
# Operations and Maintenance Activities

## 7.1 System Operation and Maintenance

Installation of the Arkal system at St. Mary's Hospital was completed in December 1998. During 1999, the system was placed into operation and adjustments to the system were completed, including replacement of the backwash booster pump and enlarging the Star Filter backwash discharge pipe. The sampling equipment for the ETV verification testing was set up by USGS in October 2000, and final adjustments and preparation of the system for ETV testing were completed in the spring of 2001. Preparation included replacement of a leaking sand pod and replacement of the sand media in all pods. The staff time to complete this effort was 48 hours. A new roof hatch was added to the system and the backwash tank cleaned just prior to the start of the testing, requiring staff time of 16 hours and a contractor cost of $1,000.

Table 7-1 summarizes the maintenance activities and major activities related to the Arkal system during the verification testing. The reported staff hours for maintenance activities include those of St. Mary's Hospital, Earth Tech, and Zeta Technology staff. The maintenance activities were conducted during dry weather periods and did not result in system downtime.

**Table 7-1. Operation and Maintenance During Verification Testing**

| Date | Activity | Personnel Time/Cost |
|---|---|---|
| September 2001 | Star filter rings not opening during backwash. Bacteria/slime growth suspected to cause them to bind together | None associated with identification of problem |
| October 2-3, 2001 | Hospital staff removed and cleaned star filter rings | 16 hours labor |
| October 4, 2001 | Filter system disinfected with chlorine solution; water solenoid valve converted to an air-driven system | 16 hours labor; $260 for air compressor |
| October 25, 2001 | Backpressure sustaining valve, star filter valves, and main pump functions checked | 16 hours labor |
| November 2, 2001 | Main pump sheaves changed to improve pumping rate | 12 hours labor |
| December 5, 2001 | Maintenance check completed; pressure gauges installed; system disinfected with chlorine solution | 18 hours labor |
| June 2002 | All nine backwash valves disassembled and inspected for sediment fouling; none found | 6 hours labor |

## 7.2 System Power Usage

Table 7-2 summarizes the estimate of the Arkal System power usage, measured in kilowatt hours (kWh), during the monitored events. Based on a statistical evaluation of over 50 years of Green Bay precipitation records conducted by the USGS, the average length of an event is 5.5 hours, the same average duration of the 15 qualified events sampled during this verification. Costs are computed on an average event basis assuming a total runtime averaging 6.5 hours per event (there is a runoff storage and lag time for each event). The costs shown in Table 7-2 are based on the average precipitation year and are not based on actual costs incurred during the monitoring period. The power costs for pumping groundwater infiltration (between events) are not included in these estimates because this situation may vary greatly from location to location.

**Table 7-2. Power Costs for Arkal System on an Average Event Basis**

| Equipment | Power (kWh) | Rate | Cost/Event |
|---|---|---|---|
| 15 hp self-priming solids handling pump | 70.9 | $0.08 | $5.67 |
| 5 hp vertical in-line centrifugal process pump | 5.9 | $0.08 | $0.47 |
| Controllers | 0.22 | $0.08 | $0.11 |
| 5 hp air compressor | 0.28 | $0.08 | $0.02 |
| **Total Costs/Event** | | | **$6.27** |
| **Annual Power Costs**[1] | | | **$689.70** |

[1] Assuming average of 110 runoff events per year

# Chapter 8
# References


1. Huff, F. A., Angel, J. R. *Rainfall Frequency Atlas of the Midwest*, Midwestern Climate Center, National Oceanic and Atmospheric Administration, and Illinois State Water Survey, Illinois Department of Energy and Natural Resources. Bulletin 71, 1992.

2. Fishman, M. J., Raese, J. W., Gerlitz, C. N., Husband, R. A., U.S. Geological Survey. *Approved inorganic and organic methods for the analysis of water and fluvial sediment*, 1954-94, USGS OFR 94-351, 1994.

3. NSF International; and Earth Tech. *Test Plan for the Verification of Arkal Filtration Systems, Inc. Pressurized Stormwater Filtration System, St. Mary's Hospital, Green Bay, WI*. January 2, 2001.

4. NSF International. *ETV Verification Protocol Stormwater Source Area Treatment Technologies.* U.S. EPA Environmental Technology Verification Program; EPA/NSF Wet-weather Flow Technologies Pilot. March 2002 (v. 4.1).

## Glossary

**Accuracy** - a measure of the closeness of an individual measurement or the average of a number of measurements to the true value and includes random error and systematic error.

**Bias** - the systematic or persistent distortion of a measurement process that causes errors in one direction.

**Comparability** – a qualitative term that expresses confidence that two data sets can contribute to a common analysis and interpolation.

**Completeness** – a quantitative term that expresses confidence that all necessary data have been included.

**Precision** - a measure of the agreement between replicate measurements of the same property made under similar conditions.

**Protocol** – a written document that clearly states the objectives, goals, scope and procedures for the study. A protocol shall be used for reference during Vendor participation in the verification testing program.

**Quality Assurance Project Plan** – a written document that describes the implementation of quality assurance and quality control activities during the life cycle of the project.

**Residuals** – the waste streams, excluding final effluent, which are retained by or discharged from the technology.

**Representativeness** - a measure of the degree to which data accurately and precisely represent a characteristic of a population parameter at a sampling point, a process condition, or environmental condition.

**Wet-weather Flows Stakeholder Advisory Group** - a group of individuals consisting of any or all of the following: buyers and users of in drain removal and other technologies, developers and Vendors, consulting engineers, the finance and export communities, and permit writers and regulators.

**Standard Operating Procedure** – a written document containing specific procedures and protocols to ensure that quality assurance requirements are maintained.

**Technology Panel** - a group of individuals with expertise and knowledge of stormwater treatment technologies.

**Testing Organization** – an independent organization qualified by the Verification Organization to conduct studies and testing of mercury amalgam removal technologies in accordance with protocols and Test Plans.

**Vendor** – a business that assembles or sells treatment equipment.

**Verification** – to establish evidence on the performance of in drain treatment technologies under specific conditions, following a predetermined study protocol(s) and Test Plan(s).

**Verification Organization** – an organization qualified by USEPA to verify environmental technologies and to issue Verification Statements and Verification Reports.

**Verification Report** – a written document containing all raw and analyzed data, all QA/QC data sheets, descriptions of all collected data, a detailed description of all procedures and methods used in the verification testing, and all QA/QC results. The Test Plan(s) shall be included as part of this document.

**Verification Statement** – a document that summarizes the Verification Report reviewed and approved and signed by USEPA and NSF.

**Verification Test Plan** – A written document prepared to describe the procedures for conducting a test or study according to the verification protocol requirements for the application of in drain treatment technology. At a minimum, the Test Plan shall include detailed instructions for sample and data collection, sample handling and preservation, precision, accuracy, goals, and quality assurance and quality control requirements relevant to the technology and application.

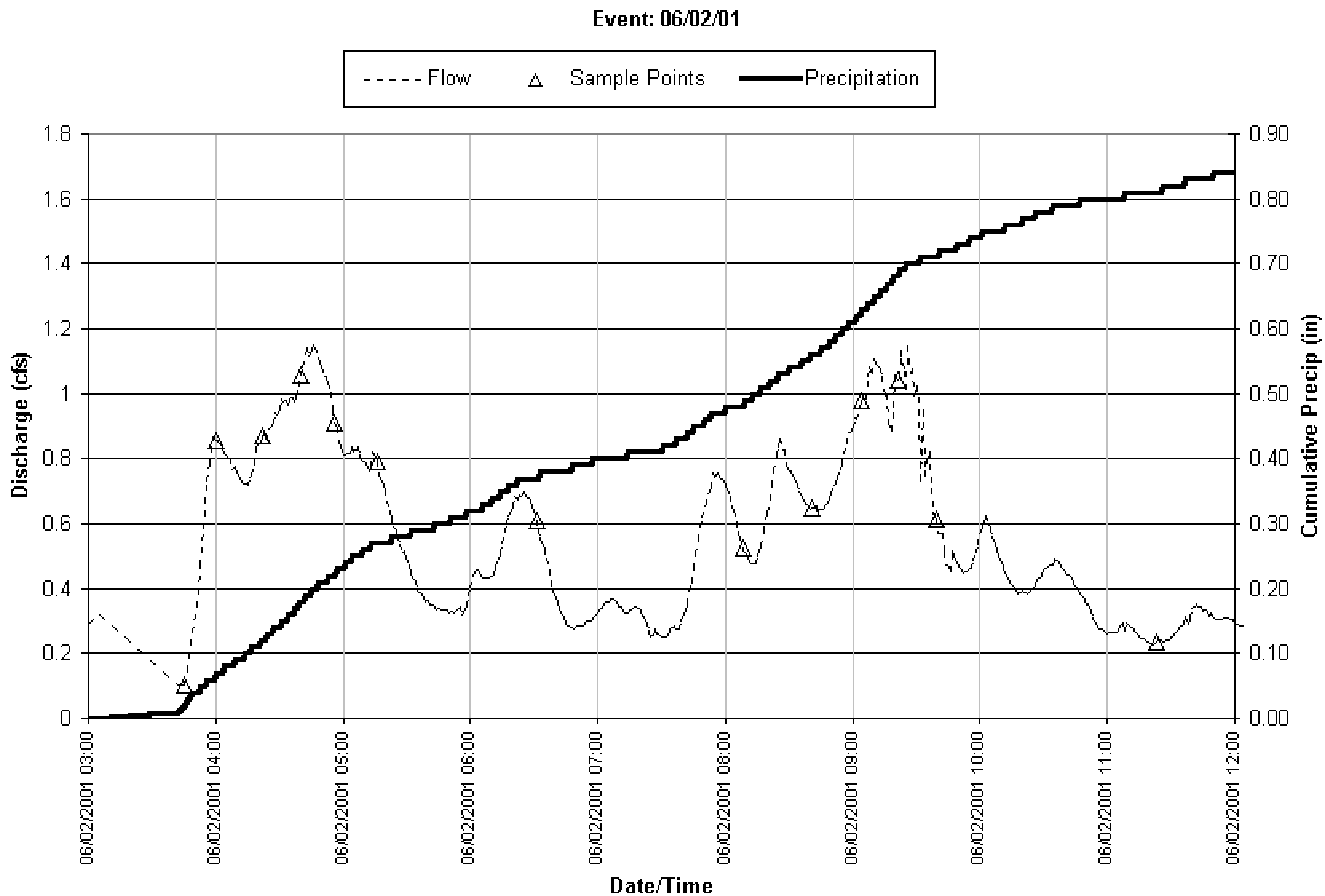
# Appendices



.

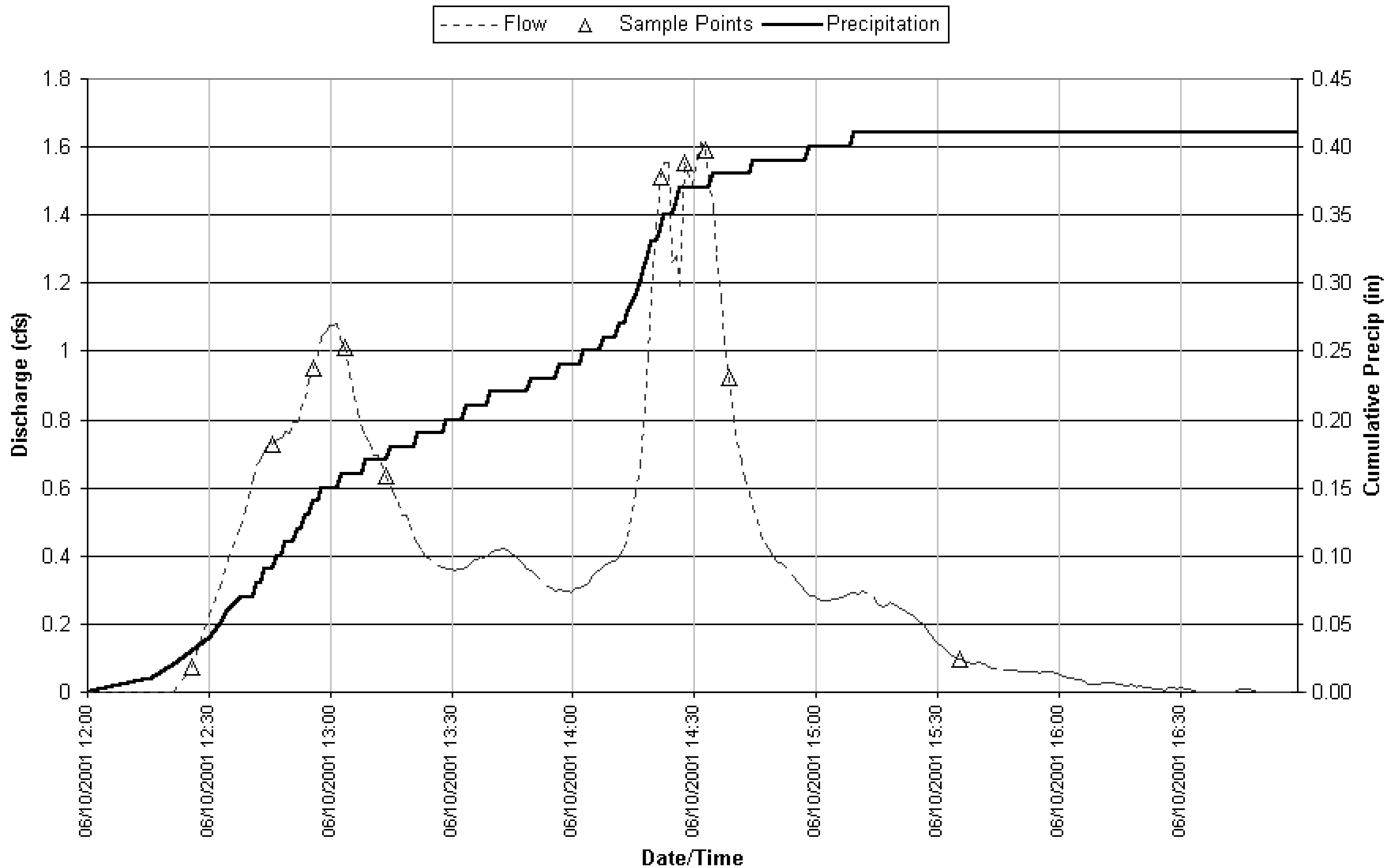
# APPENDIX A

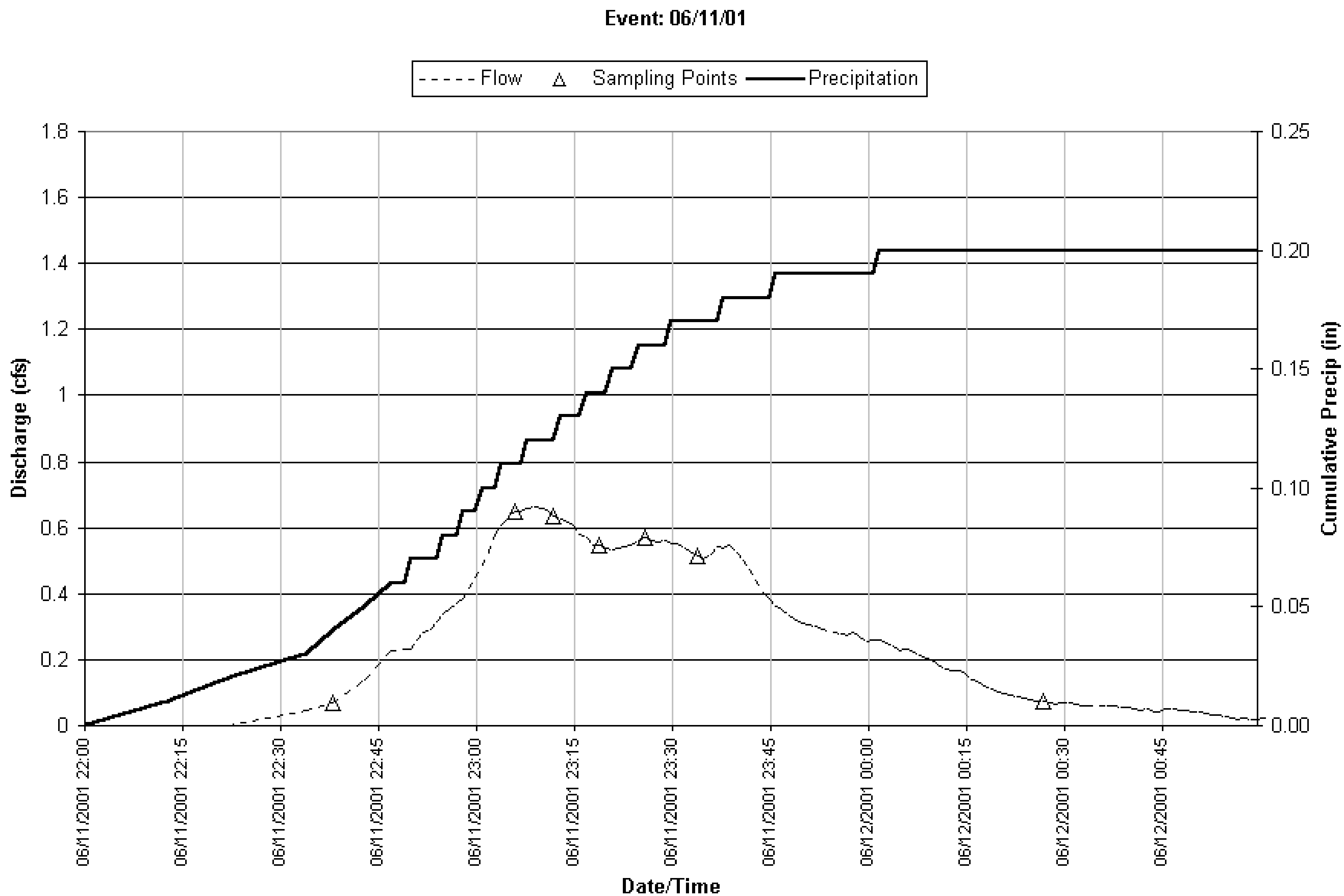
# EVENT HYDROGRAPHS AND RAIN DISTRIBUTION



Event: 06/02/01
Flow
Sample Points
Precipitation
Discharge (cfs)
Cumulative Precip (in)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
06/02/2001 03:00
06/02/2001 04:00
06/02/2001 05:00
06/02/2001 06:00
06/02/2001 07:00
06/02/2001 08:00
06/02/2001 09:00
06/02/2001 10:00
06/02/2001 11:00
06/02/2001 12:00
Date/Time

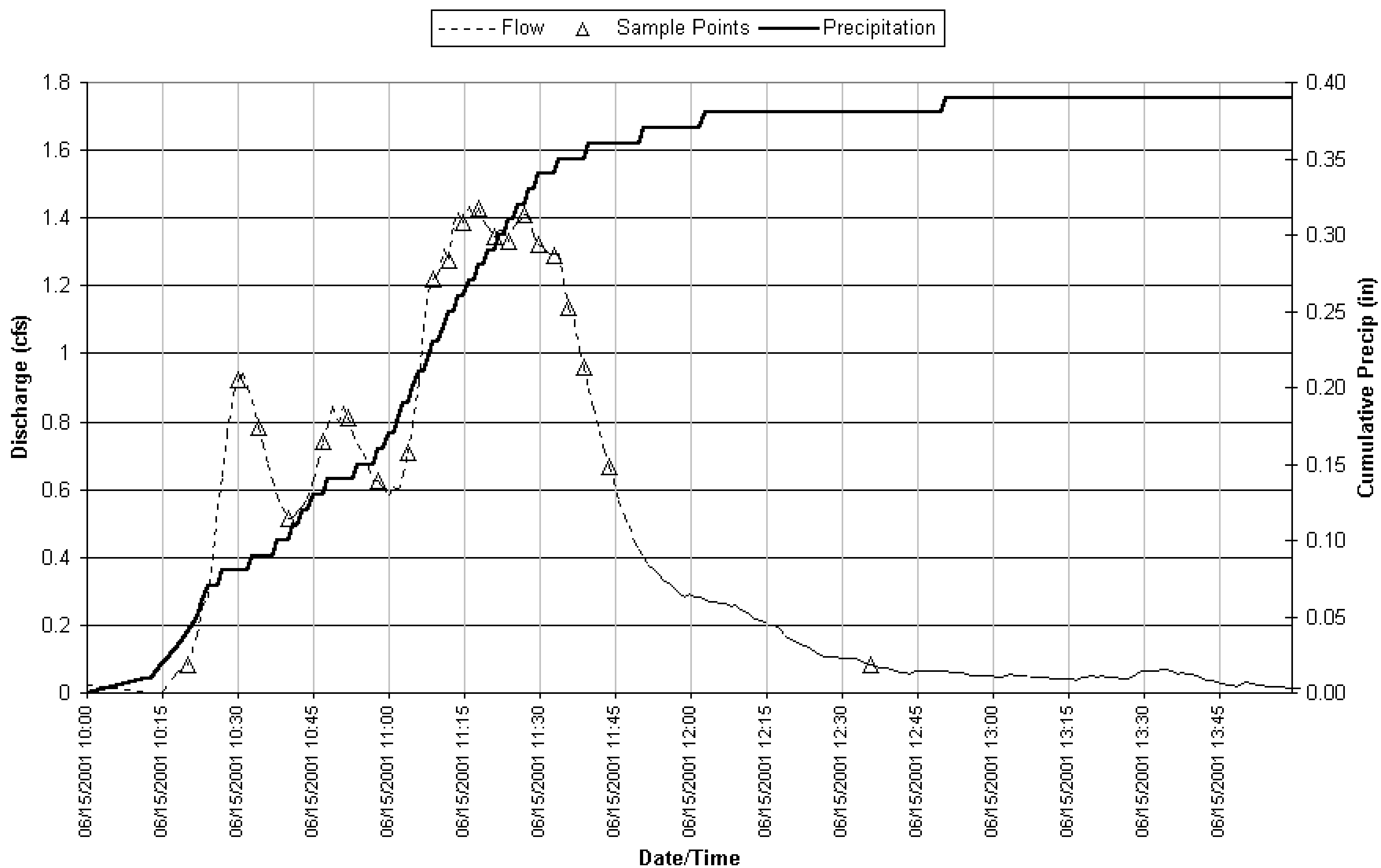
Event: 06/10/01

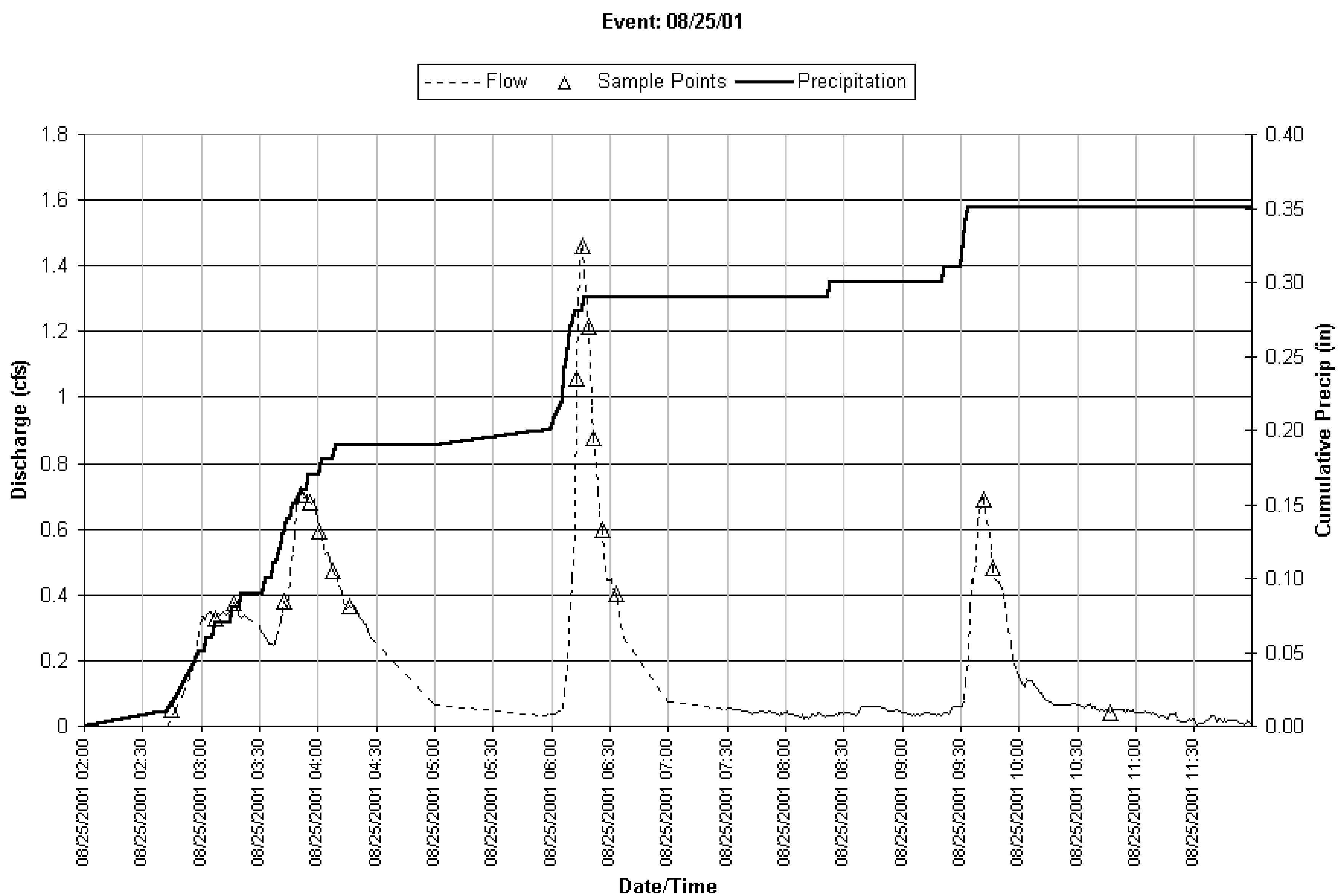




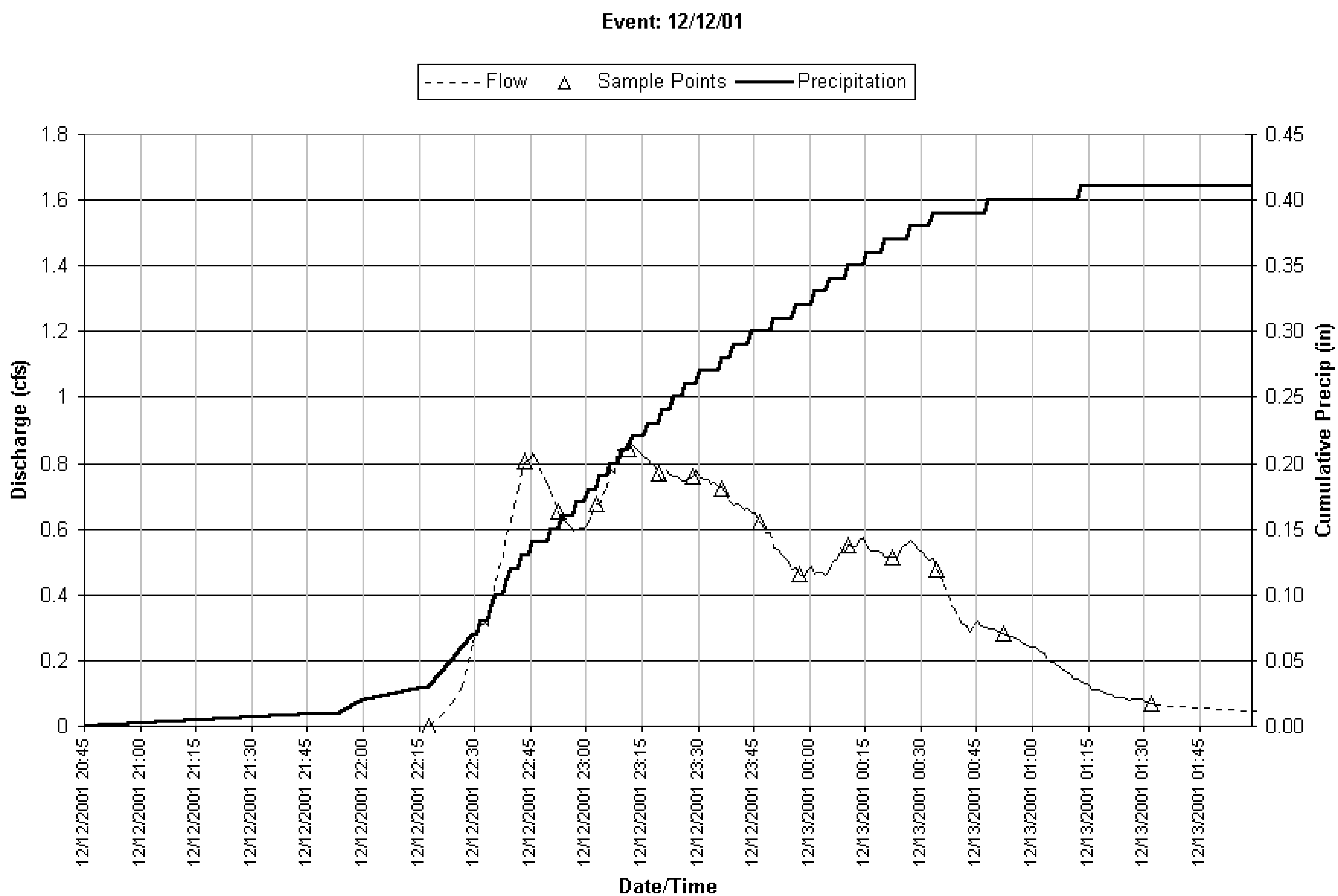
Event: 06/11/01
Flow
Sampling Points
Precipitation
Discharge (cfs)
Cumulative Precip (in)
Date/Time
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.25
0.20
0.15
0.10
0.05
0.00
06/11/2001 22:00
06/11/2001 22:15
06/11/2001 22:30
06/11/2001 22:45
06/11/2001 23:00
06/11/2001 23:15
06/11/2001 23:30
06/11/2001 23:45
06/12/2001 00:00
06/12/2001 00:15
06/12/2001 00:30
06/12/2001 00:45

Event: 06/15/01

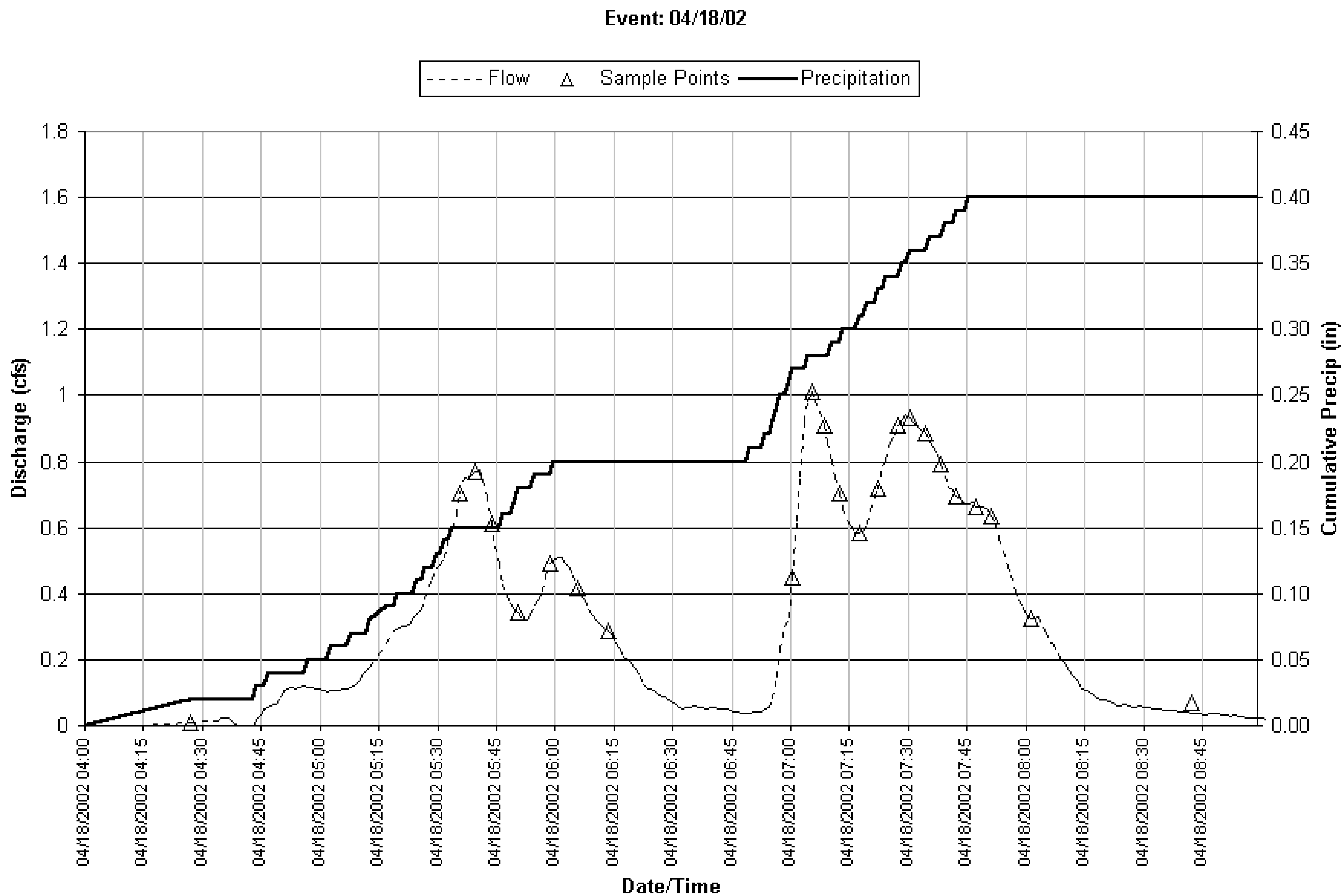




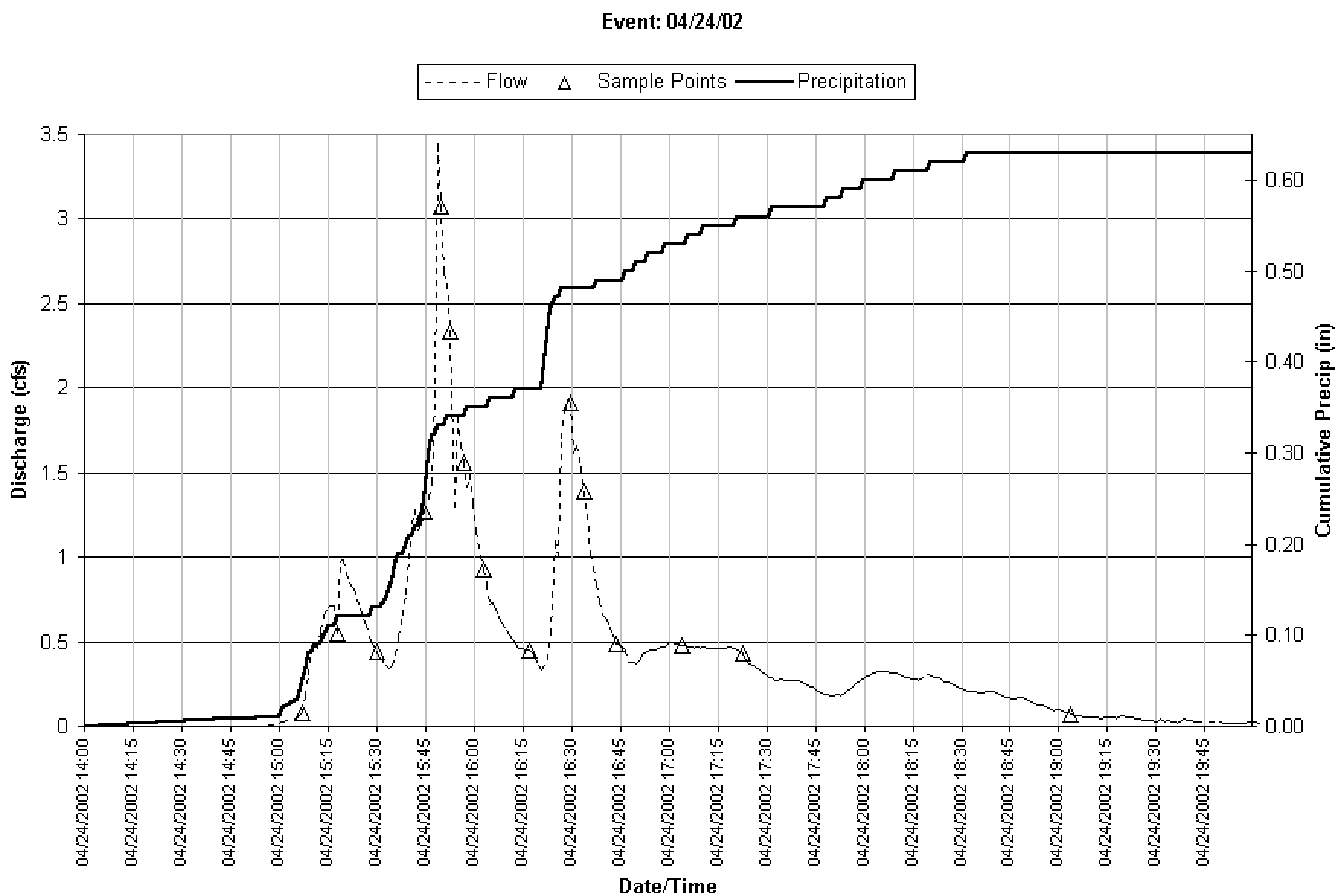
Event: 08/25/01
Flow
Sample Points
Precipitation
Discharge (cfs)
Cumulative Precip (in)
Date/Time
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
08/25/2001 02:00
08/25/2001 02:30
08/25/2001 03:00
08/25/2001 03:30
08/25/2001 04:00
08/25/2001 04:30
08/25/2001 05:00
08/25/2001 05:30
08/25/2001 06:00
08/25/2001 06:30
08/25/2001 07:00
08/25/2001 07:30
08/25/2001 08:00
08/25/2001 08:30
08/25/2001 09:00
08/25/2001 09:30
08/25/2001 10:00
08/25/2001 10:30
08/25/2001 11:00
08/25/2001 11:30

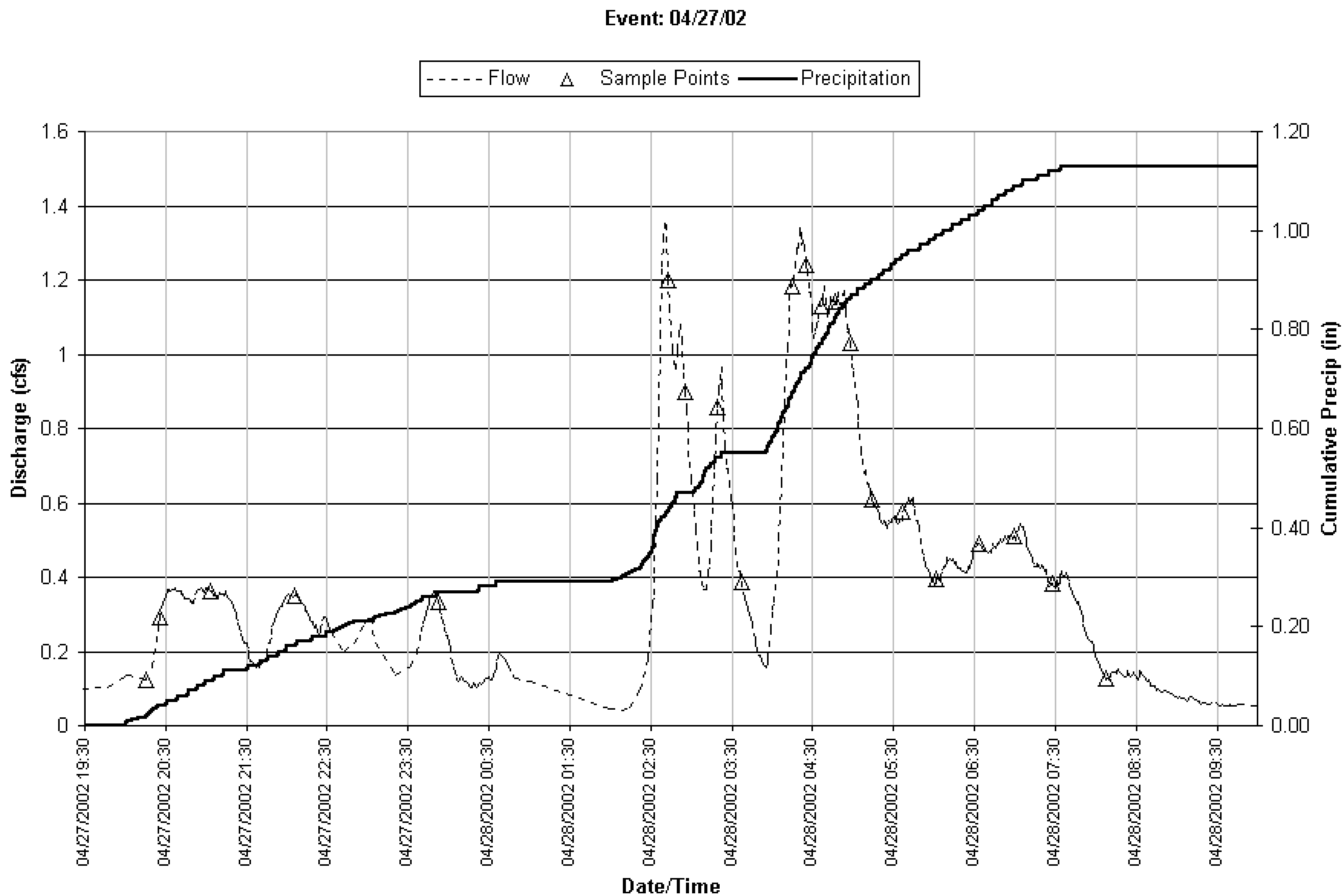


Event: 12/12/01
Flow
Sample Points
Precipitation
Discharge (cfs)
Cumulative Precip (in)
Date/Time
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
12/12/2001 20:45
12/12/2001 21:00
12/12/2001 21:15
12/12/2001 21:30
12/12/2001 21:45
12/12/2001 22:00
12/12/2001 22:15
12/12/2001 22:30
12/12/2001 22:45
12/12/2001 23:00
12/12/2001 23:15
12/12/2001 23:30
12/12/2001 23:45
12/13/2001 00:00
12/13/2001 00:15
12/13/2001 00:30
12/13/2001 00:45
12/13/2001 01:00
12/13/2001 01:15
12/13/2001 01:30
12/13/2001 01:45

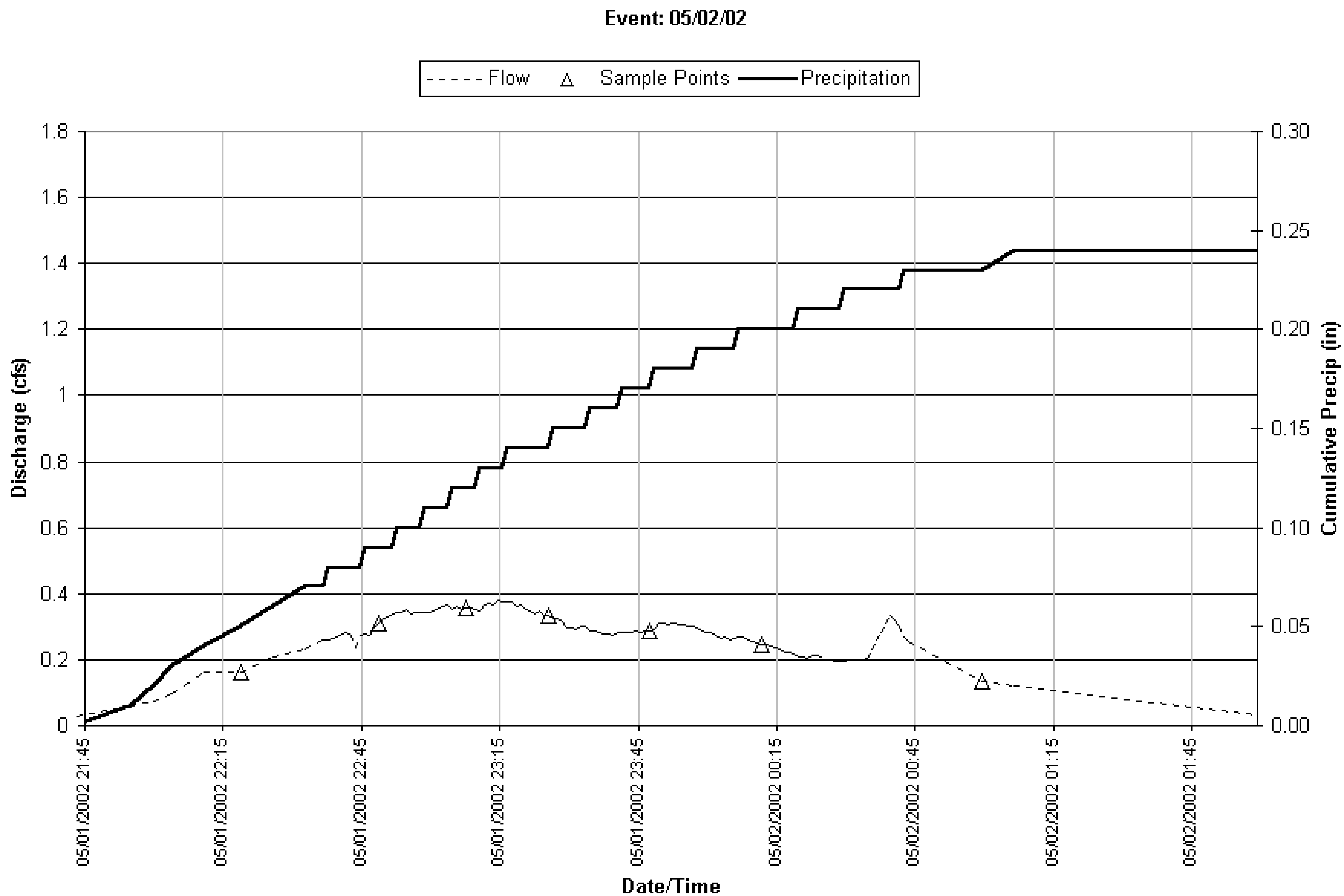


Event: 04/18/02
Flow
Sample Points
Precipitation
Discharge (cfs)
Cumulative Precip (in)
Date/Time
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
04/18/2002 04:00
04/18/2002 04:15
04/18/2002 04:30
04/18/2002 04:45
04/18/2002 05:00
04/18/2002 05:15
04/18/2002 05:30
04/18/2002 05:45
04/18/2002 06:00
04/18/2002 06:15
04/18/2002 06:30
04/18/2002 06:45
04/18/2002 07:00
04/18/2002 07:15
04/18/2002 07:30
04/18/2002 07:45
04/18/2002 08:00
04/18/2002 08:15
04/18/2002 08:30
04/18/2002 08:45

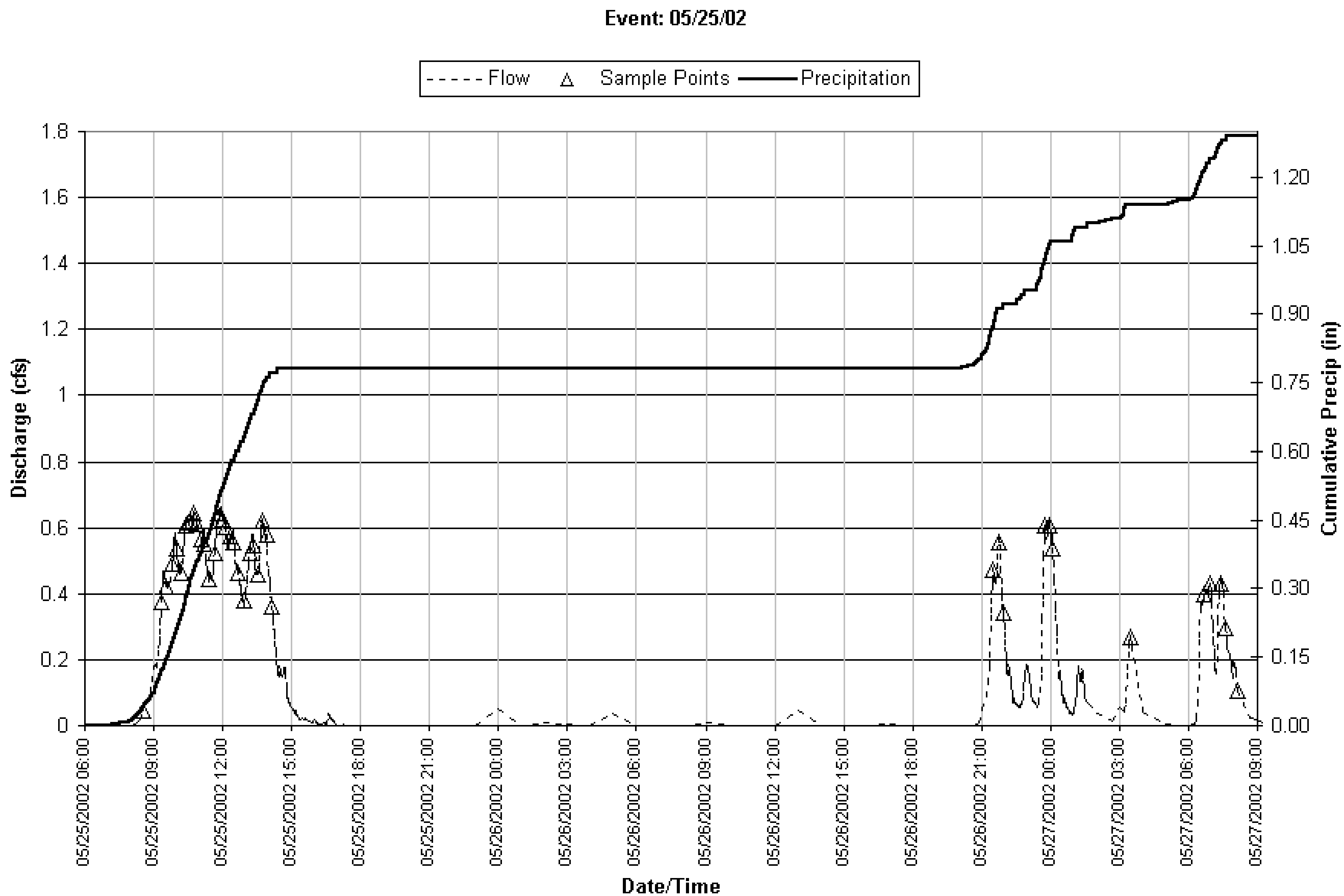

Event: 04/24/02
Flow
Sample Points
Precipitation
Discharge (cfs)
Cumulative Precip (in)
Date/Time
3.5
3
2.5
2
1.5
1
0.5
0
0.60
0.50
0.40
0.30
0.20
0.10
0.00
04/24/2002 14:00
04/24/2002 14:15
04/24/2002 14:30
04/24/2002 14:45
04/24/2002 15:00
04/24/2002 15:15
04/24/2002 15:30
04/24/2002 15:45
04/24/2002 16:00
04/24/2002 16:15
04/24/2002 16:30
04/24/2002 16:45
04/24/2002 17:00
04/24/2002 17:15
04/24/2002 17:30
04/24/2002 17:45
04/24/2002 18:00
04/24/2002 18:15
04/24/2002 18:30
04/24/2002 18:45
04/24/2002 19:00
04/24/2002 19:15
04/24/2002 19:30
04/24/2002 19:45



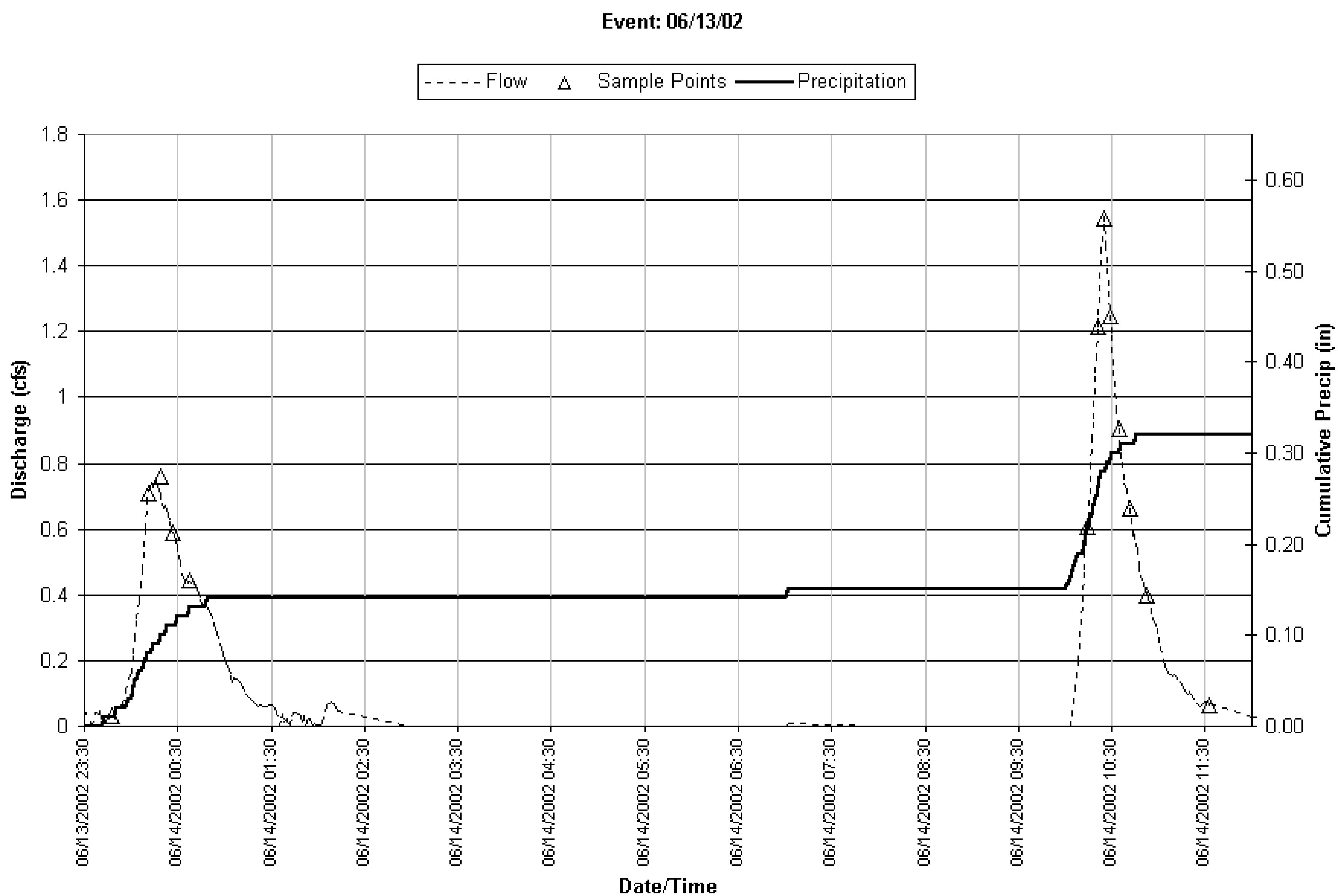
Event: 04/27/02
Flow
Sample Points
Precipitation
Discharge (cfs)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Cumulative Precip (in)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
04/27/2002 19:30
04/27/2002 20:30
04/27/2002 21:30
04/27/2002 22:30
04/27/2002 23:30
04/28/2002 00:30
04/28/2002 01:30
04/28/2002 02:30
04/28/2002 03:30
04/28/2002 04:30
04/28/2002 05:30
04/28/2002 06:30
04/28/2002 07:30
04/28/2002 08:30
04/28/2002 09:30
Date/Time



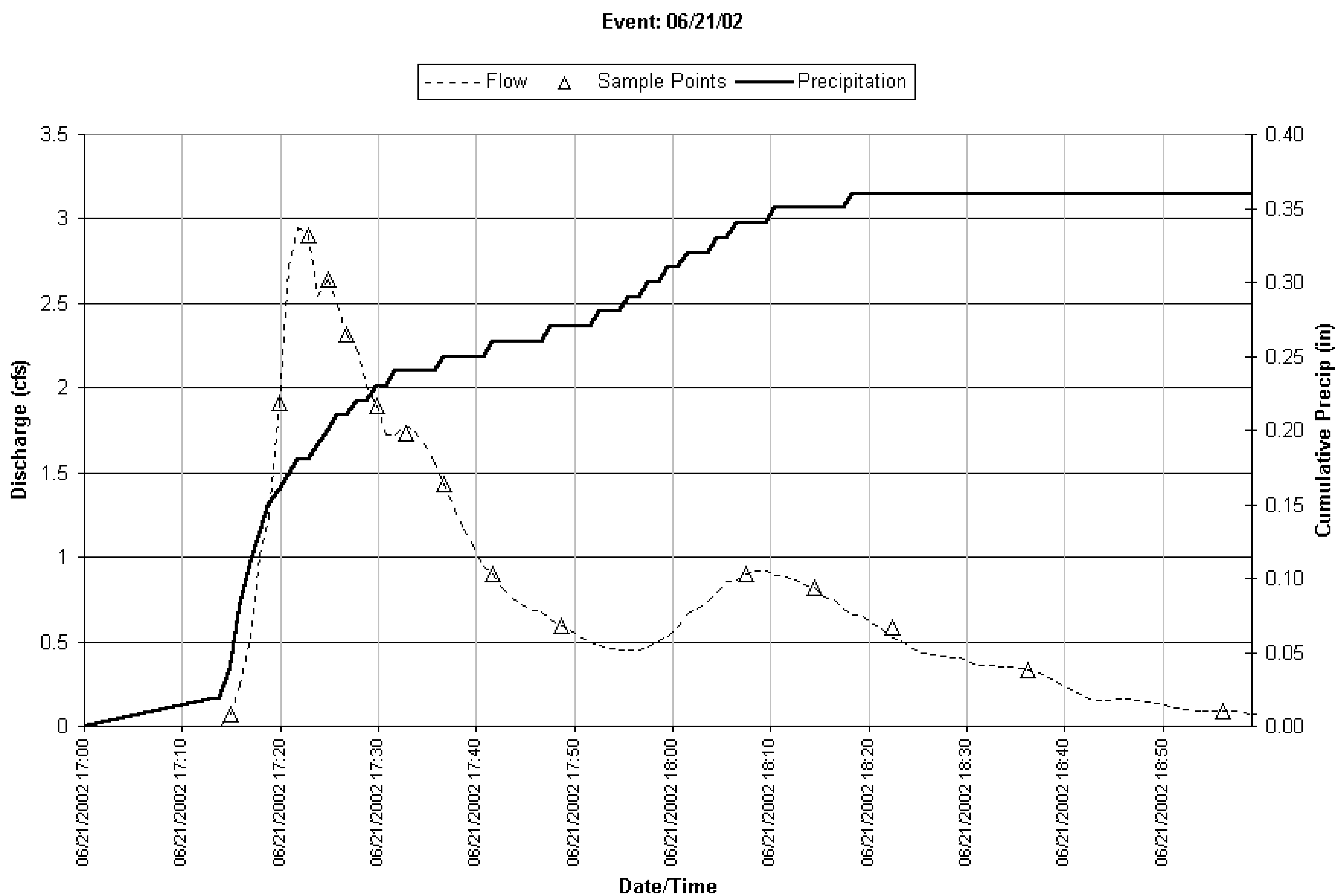
Event: 05/02/02
Flow
Sample Points
Precipitation
Discharge (cfs)
Cumulative Precip (in)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.30
0.25
0.20
0.15
0.10
0.05
0.00
05/01/2002 21:45
05/01/2002 22:15
05/01/2002 22:45
05/01/2002 23:15
05/01/2002 23:45
05/02/2002 00:15
05/02/2002 00:45
05/02/2002 01:15
05/02/2002 01:45
Date/Time



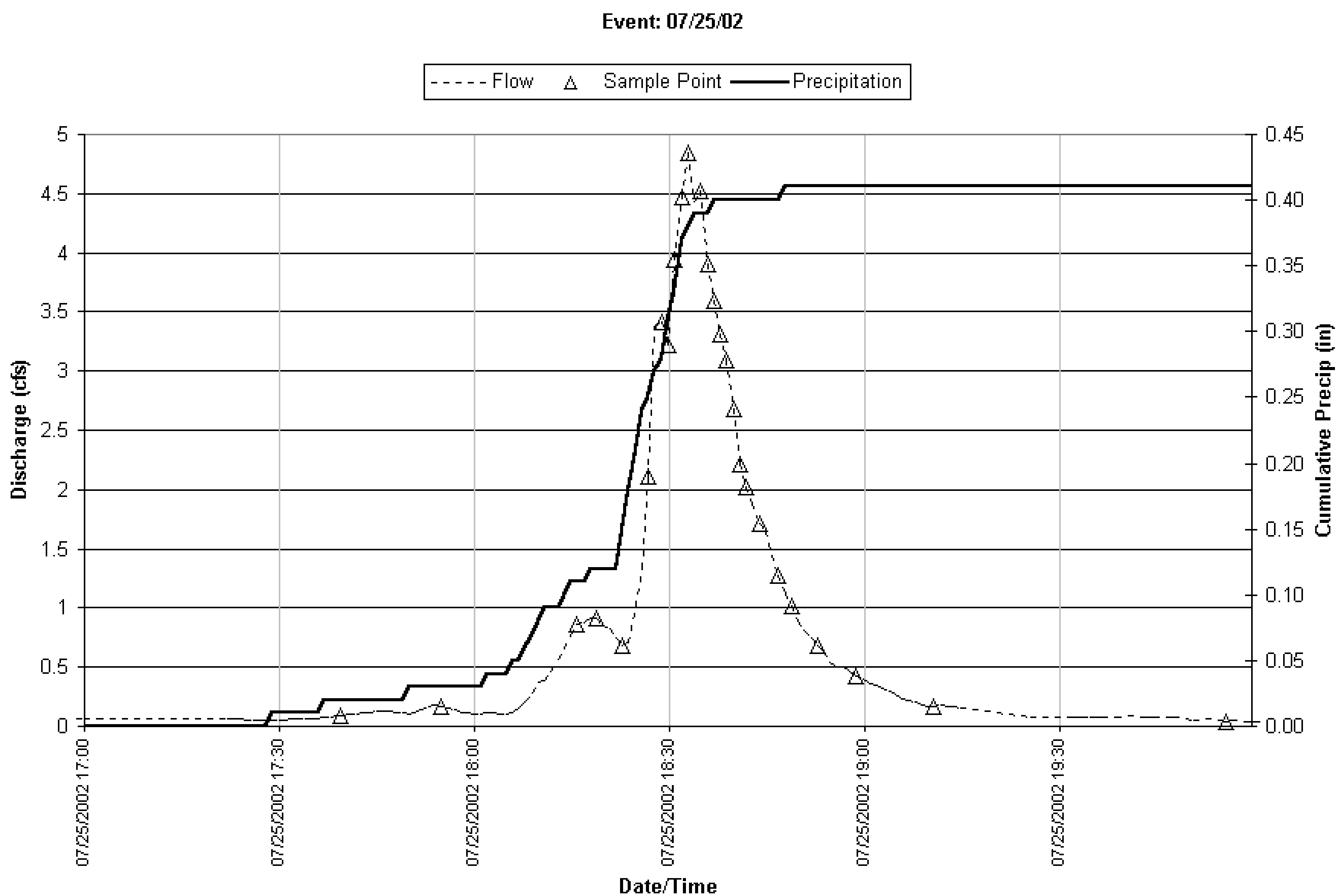
Event: 05/25/02
Flow
Sample Points
Precipitation
Discharge (cfs)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Cumulative Precip (in)
1.20
1.05
0.90
0.75
0.60
0.45
0.30
0.15
0.00
05/25/2002 06:00
05/25/2002 09:00
05/25/2002 12:00
05/25/2002 15:00
05/25/2002 18:00
05/25/2002 21:00
05/26/2002 00:00
05/26/2002 03:00
05/26/2002 06:00
05/26/2002 09:00
05/26/2002 12:00
05/26/2002 15:00
05/26/2002 18:00
05/26/2002 21:00
05/27/2002 00:00
05/27/2002 03:00
05/27/2002 06:00
05/27/2002 09:00
Date/Time

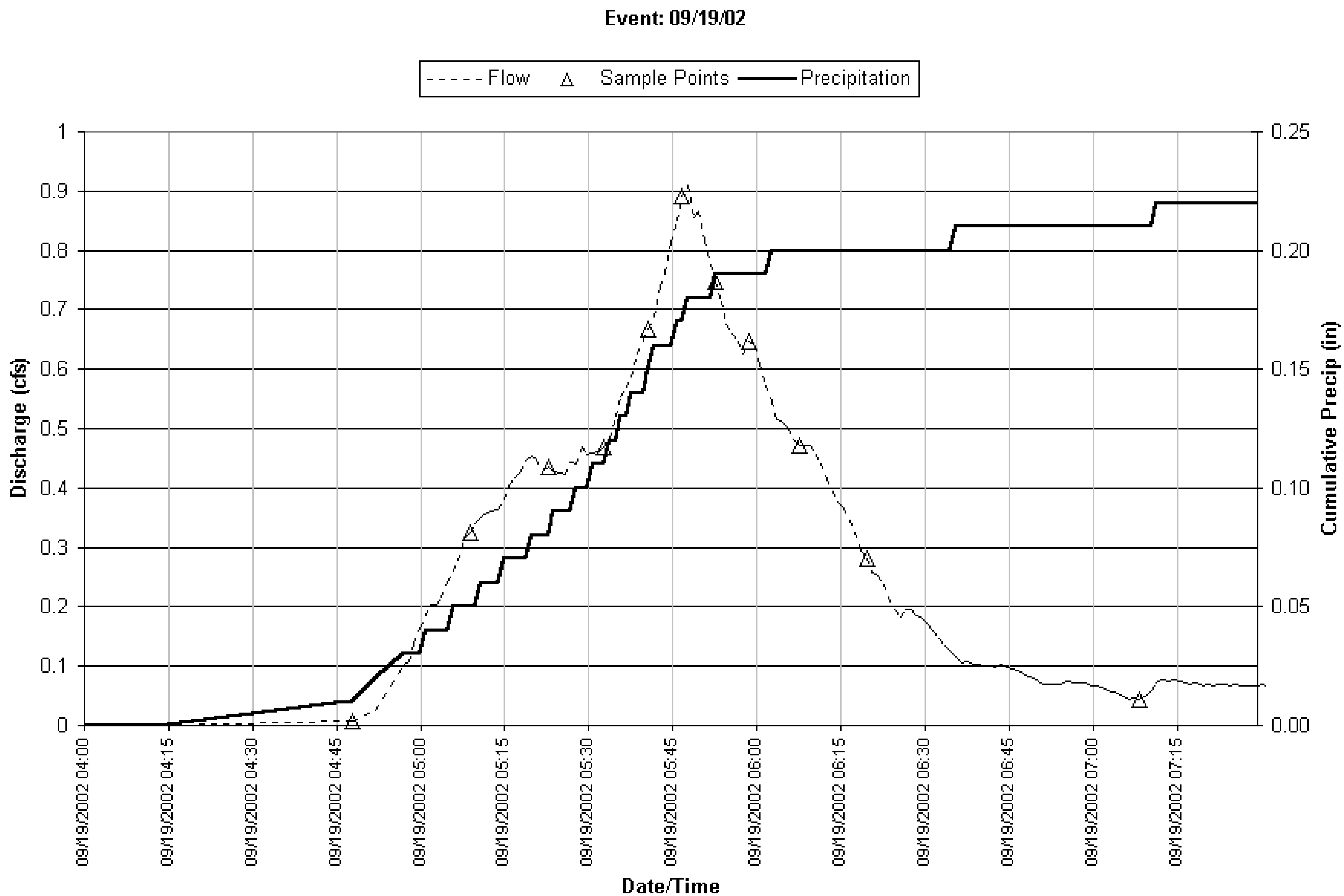


Event: 06/13/02
Flow
Sample Points
Precipitation
Discharge (cfs)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Cumulative Precip (in)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
06/13/2002 23:30
06/14/2002 00:30
06/14/2002 01:30
06/14/2002 02:30
06/14/2002 03:30
06/14/2002 04:30
06/14/2002 05:30
06/14/2002 06:30
06/14/2002 07:30
06/14/2002 08:30
06/14/2002 09:30
06/14/2002 10:30
06/14/2002 11:30
Date/Time



Event: 06/21/02
Flow
Sample Points
Precipitation
Discharge (cfs)
3.5
3
2.5
2
1.5
1
0.5
0
Cumulative Precip (in)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
06/21/2002 17:00
06/21/2002 17:10
06/21/2002 17:20
06/21/2002 17:30
06/21/2002 17:40
06/21/2002 17:50
06/21/2002 18:00
06/21/2002 18:10
06/21/2002 18:20
06/21/2002 18:30
06/21/2002 18:40
06/21/2002 18:50
Date/Time


Event: 07/25/02
Flow
Sample Point
Precipitation
Discharge (cfs)
Cumulative Precip (in)
Date/Time
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
07/25/2002 17:00
07/25/2002 17:30
07/25/2002 18:00
07/25/2002 18:30
07/25/2002 19:00
07/25/2002 19:30


Event: 09/19/02
Flow
Sample Points
Precipitation
Discharge (cfs)
Cumulative Precip (in)
Date/Time
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.00
0.05
0.10
0.15
0.20
0.25
09/19/2002 04:00
09/19/2002 04:15
09/19/2002 04:30
09/19/2002 04:45
09/19/2002 05:00
09/19/2002 05:15
09/19/2002 05:30
09/19/2002 05:45
09/19/2002 06:00
09/19/2002 06:15
09/19/2002 06:30
09/19/2002 06:45
09/19/2002 07:00
09/19/2002 07:15