

**ASSESSING EFFECTS OF HIGHWAY BRIDGE DECK RUNOFF  
ON NEARBY RECEIVING WATERS IN COASTAL MARGINS  
USING REMOTE MONITORING TECHNIQUES**

A Thesis

by

OKE NWANESHIUDU

Submitted to the Office of Graduate Studies of  
Texas A&M University  
in partial fulfillment of the requirements for the degree of  
**MASTER OF SCIENCE**

December 2004

Major Subject: Civil Engineering

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December 2004

Major Subject: Civil Engineering

## **ABSTRACT**

Assessing Effects of Highway Bridge Deck Runoff on Nearby Receiving Waters in Coastal Margins Using Remote Monitoring Techniques. (December 2004)

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Chair of Advisory Committee: Dr. Timothy Kramer

Most of the pollution found in highway runoff is both directly and indirectly contributed by vehicles such as cars and trucks. The constituents that contribute the majority of the pollution, such as metals, chemical oxygen demand, oil and grease, are generally deposited on the highways. These can become very harmful and detrimental to human health when they come in contact with our water system. The connecting tie between these harmful highway-made pollution and our water system, which includes our ground waters and surface waters, is rainfall.

The main objective of this runoff study was to characterize and assess the quantity and quality of the storm water runoff of a bridge deck that discharged into a receiving water body. The bridge deck and the creek were located in the coastal margin region in the southeast area of Texas on the border of Harris and Galveston counties.

Flow-activated water samplers and flow-measuring devices were installed to quantitatively determine the rate of flow of the bridge deck and determine different pollutant loading by sampling the receiving water body (Clear Creek). The collected samples were analyzed for total suspended solids, toxic metals, and other relevant constituents of concerns. The results illustrated that the runoff from the bridge deck

exhibited low total suspended solids concentrations (which were highest in the creek). However, other metal constituents like the zinc and copper concentration were high and above standards. The phosphate concentrations in the creek were the highest and exceeded EPA standards. Several nitrate concentrations were also noticeably above EPA standards.

## **DEDICATION**

I dedicate this work to God almighty for making everything possible and my parents and siblings for providing opportunities for me and supporting me

## **ACKNOWLEDGMENTS**

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## **1. INTRODUCTION**

### **1.1 BACKGROUND**

The subject of highway runoff pollution has recently attracted serious attention. However bridge decks which are part of the highway system have not been studied adequately. Although there are more pressing issues that arise from other runoff sources (such as buildings, farms, mines and other non point sources), highway runoff can be considered a serious problem if not handled properly (FHWA 1999). If the required best management practices are not taken for excess contaminant removal, highway runoff can have adverse effects. The most susceptible entities to contamination are the receiving surface waters like streams, ponds, lakes and rivers which are in the vicinity of the highway infrastructure.

There are also adverse environmental biological concerns due to the presence of unwanted pollutants or nutrients in ground water or surface water that interfere with vital functions of organisms either living in the water or consuming it. Additionally, ground water contamination, which is not only less visible than surface water contamination, is also very difficult and very expensive to sample and clean up. (FHWA 1999). Prevention of contamination thereby lends itself as the most effective way of protecting ground water sources.

### **1.2 IMPORTANCE AND SIGNIFICANCE OF PROJECT**

The importance of this study is that characterizing the pollutant loadings on a water body can aid in the development of the TMDL (Total Maximum Daily Load) and

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This thesis follows the style and format of *Journal of Environmental Engineering*.

the WLA (Waste Load Allocation) which specify how much of a given pollutant can be contributed by a source. These two entities (TMDL and WLA) are of great assistance in the regulation of discharges and control of pollutant loading to water resources. This research project will also provide the basis for identifying the need for and developing (if necessary) storm water treatment of bridge deck runoff.

Additionally, monitoring data and information developed by this study may also be useful for efforts such as the development of a national storm water pollutant database for bridge decks proposed by Dupuis (1999) which is a database containing a collection of monitoring data obtained by different state DOT highway and bridge deck runoff studies.

The development of such a database will not only aid in state NPDES (National Pollutant Discharge Elimination System) storm water compliance, but will also act as a resource and save time and money for practitioners who require runoff and monitoring data from a bridge deck or a highway surface located in a state where highway and or bridge deck surface runoff studies have been conducted. (Dupuis, 1999)

### **1.3 SCOPE OF WORK AND STRUCTURE OF THESIS**

The work performed during the project involved field scale monitoring of water quantity and water quality at a selected bridge deck site located in the coastal margin region. The location was at the bridge located at the intersection of Clear Creek and the FM 528 (NASA rd 1) in Houston, TX. Work performed included monitoring and sampling equipment calibration, installation, sample collection, and subsequent analysis.

Section 1, begins with an introduction giving a brief background and overview of the subject of highway runoff pollution. It will also discuss the importance, significance, and uniqueness of the project. In the form of a detailed literature review, Section 2 will then proceed to discuss prior work that has been done on the broad topic of highway runoff and also some limited literature from prior work that relates solely to the subject of bridge deck runoff. Section 3 will then present a concise problem statement discussing the currently existing problem of contaminated highway and bridge deck runoff and provide a list of contaminants of concern in the runoff and their sources.

Section 4 will provide a detailed explanation of the work that was performed during the duration of the project and how the work was performed. It will discuss pertinent information related to the site i.e. how GIS mapping was used to identify the site, details on the equipment used and how they were used. Section 5 will begin to discuss the data collected by presenting samples of the different types of data collected during the project, such as hydrographs, rainfall data, and concentrations from lab analysis. Section 6 will culminate in a presentation and discussion of the different results and data obtained during the study and interpretations of the data. The details of all the data were collected during the duration of the project will then be presented in the appendixes, which will consist of 3 main parts:

1. Programming sequence for samplers and flow meters.
2. Hydrographs and rainfall data from samples taken.
3. Concentrations data from samples after lab analysis and the analysis.



## **2. LITERATURE REVIEW**

There is a considerable body of literature that exists on the subject of the chemical characteristics and quality of loadings that are contained in highway runoff. However, only a limited number of studies have been conducted related to bridge runoff impacts on receiving waters. A study recently conducted by Dupuis (1999), addressed the topic and concluded that the unique characteristics of bridges that included bridge deck length, traffic volume, bridge deck width, runoff chemical concentrations, receiving water type are some parameters which are useful in the effective evaluation of the potential impacts of bridge deck runoff on the receiving water environment.

While bridge deck runoff impacts on receiving water quality is the main focus of this project, studies that have pertained solely to highway runoff are pertinent since bridges are a major part of highway systems. Highway studies have included: assessment of variables affecting highway runoff, the effects of runoff in karst areas, and different water mitigation efforts such as detention ponds, sedimentation ponds, constructed wetlands, and filtration systems. These issues and topics will be examined and addressed for the project and the subject of bridge deck runoff will be rigorously examined.

### **2.1 VARIABLES AFFECTING RUNOFF LOADINGS**

Different variables also affect the buildup and wash-off of constituents as concluded by studies conducted at the Center for Research in Water Resources at The University of Texas in Austin (Irish et al. 1995). Variables identified by Barrett et al. which influence highway runoff constituent loading include storm duration, storm

intensity, number of vehicles during storm, length of dry period before storm, traffic count (average volume of traffic per lane), and previous storm duration, volume, and intensity. The study of Irish et al. (1995) also determined that the most significant variables affecting storm water quality were TSS (total suspended solids). Other variables that significantly affected highway runoff constituents were nutrients, organics, oil and grease, copper, lead, iron, and zinc (Barrett et al. 1998).

## **2.2 USAGE OF SEDIMENT DETENTION PONDS IN MITIGATION OF HIGHWAY RUNOFF**

Detention ponds can be important components of highway infrastructure. They are constructed near highways to trap sediments and solid constituents such as plant and animal debris that might exist in highway runoff. Detention ponds also act as a means of suspended solids removal. Sedimentation ponds act as temporary storage to reduce peak flow discharge impacts and effects on nearby receiving environments (Barrett et al. 1997). In a study conducted for the Florida Department of Transportation by the Environmental Engineering Laboratory at the University of Central Florida, a major area of concern with highway sedimentation ponds was examined. The depth of accumulated sediments and removal efficiencies of suspended solids were the major areas of concern (Yousef et al. 1994).

In the study of Yousef et al. (1994), nine detention ponds located in various cities in Florida were chosen based on traffic volume, surrounding drainage, date of construction and surface area. Samples taken from these ponds were analyzed for heavy metals, phosphorus, nitrogen, percentage volatile solids, and percent moisture. The

accumulation of sediments in the detention ponds were also measured from the samples. The rate of accumulation in the sedimentation basin was then calculated by a modified US Environmental Protection Agency based model. The measured and calculated values were then compared. The recommendation was that for optimal function of detention ponds in the treatment of polluted highway runoff (based on measured and calculated accumulation rates) sediments should be removed from the ponds approximately every 25 years of operation.

### **2.3 EFFECTS OF HIGHWAY CONSTRUCTION ON RECEIVING WATER QUALITY**

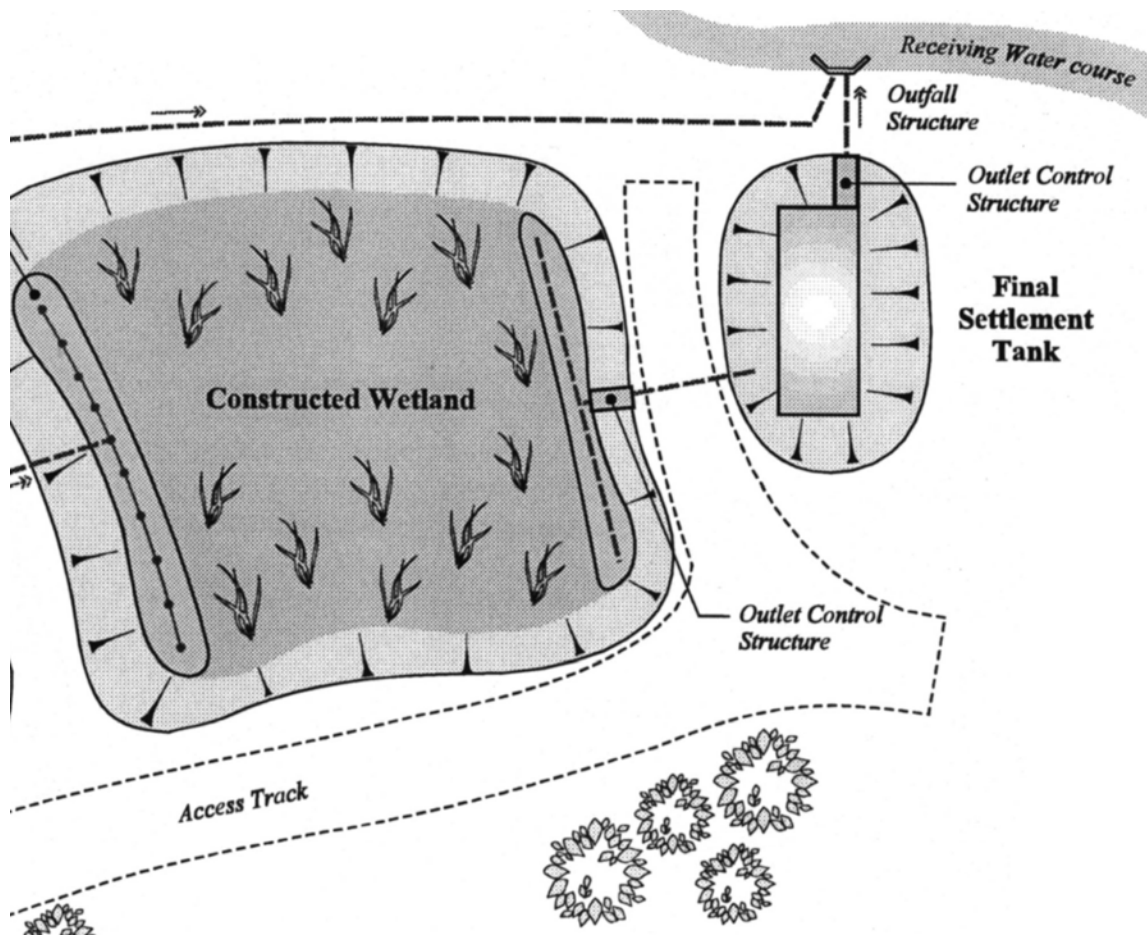
The effects of highway construction on receiving surface waters can be characterized by changes in water color, changes in turbidity of the receiving waters, and changes in the suspended solid concentrations (FHWA 1999; Irish et al. 1995). During the active phases of highway construction, prevention of erosion is necessary to minimize adverse effects on receiving waters. Erosion and sediment controls which are vegetative and often combined with slope coverings are usually not completely effective during active construction phases. However sedimentation ponds designed with high detention times prove to be more efficient. Another popular sediment and erosion control used during highway construction activity are silt fences. Unfortunately common failures of silt fences occur such as undercutting, fence collapse, over-topping, and holes and tears which can be avoided by proper installation techniques and materials (Malina et al. 1995).

## **2.4 CONSTRUCTED WETLANDS IN HIGHWAY RUNOFF TREATMENT**

Man made wetlands (as supposed to natural wetlands) built to provide wastewater treatment have been shown to be useful in treating wastewater from many sources of contamination such as, industrial, acid mine drainage, agricultural and municipal waste waters. However, artificial wetlands can also be found in transportation infrastructure and are used as means of treating highway runoff. The Urban Pollution research center at Middlesex University in London, UK recently concluded a study which investigated the environmental sensitivity analysis that has to be done to determine if a constructed wetland treatment is a best option under varying scenarios. (Shutes et al. 1999).

Shutes et al. (1999) posited that as of the late 1990's the use of constructed wetlands for the treatment of polluted highway runoff is a relatively new concept in the United Kingdom. Also, there are important factors that determine the most appropriate design criteria which are road drainage area, traffic loadings, size and type of receiving water body, water quality classification and objective, and geology.

Shutes et al. (1999) also recommended that some constructed wetlands for highway applications should include oil water separators, a silt trap, some kind of spillage containment, the constructed wetland portion, a settlement pond, a final settlement tank, an inlet, and an outlet into the receiving water course. They also displayed a good depiction of an idealized man made constructed wetland for the treatment of highway runoff as shown in Figure 2-1.



**FIG. 2-1. An idealized constructed wetland for highway runoff treatment (Shutes et al. (1999))**

## **2.5 ASSESSING CONTAMINATED BRIDGE DECK RUNOFF**

One of the most comprehensive assessments of the issue of bridge deck runoff contamination was done by CH2M-HILL under a Federal Highway and administration project. Under this project, Dupuis (1999) developed 19 different methods to manage, assess and identify bridge deck runoff that could potentially impact receiving waters.

The method of analysis that was used in the assesment of Clear Creek and the FM 528 bridge deck was a part of the 11<sup>th</sup> method stated by Dupuis (1999). There are 2

methods discussed under the 11<sup>th</sup> method which are the simple method and the intensity correlation method.

The simple method uses the mean concentration of the pollutant after each rainfall event, the rainfall depth, and the surface area of the bridge deck to calculate a pollutant loading. The intensity correlation method accounts for the first flush effect, which is the rainfall intensity effect. The simple method however, does not account for this effect. The intensity correlation method could not be used on the study done on this particular runoff project study due to the sampling procedure used in this project.

Only one sample was taken during each rainfall event. The intensity correlation method however requires that the samples be taken at one hour intervals (Dupuis 1999). The intensity correlation method requires the development of a rainfall intensity and loading relationship for hourly intervals which ultimately requires extensive monitoring of the adjacent highways and bridges. Hence, the simple method was chosen for the analysis of the Clear Creek and FM 528 bridge runoff.

Dupuis (1999) suggested that when assessing bridges that the investigator should consider what the average daily traffic in the area is and if the bridge is a retrofit or a replacement bridge because some of the methods do not apply to the analysis depending on this factor. The usage and hydrology of the receiving water should also be considered i.e. if it is freshwater, saltwater, drinking water supply, lake etc.

### 3. PROBLEM STATEMENT

#### 3.1 PROBLEM AND PROJECT MOTIVATION

Dupius (1999) posited that bridge builders historically were accustomed to design bridge runoff drainage systems to discharge directly in near by receiving waters which was considered to be very cost effective and trouble-free for maintenance concerns. However with the advent and discovery of polluted highway runoff, regulators and governing institutions such as state and local governments currently either recommend or require bridge runoff pass through some form of treatment before being discharged to the receiving water.

**TABLE 3-1. Pollutants and sources (U.S. EPA 1995)**

	Pollutant	Source
Sedimentation	Particulates	Pavement wear, vehicles, the atmosphere and maintenance activities
Nutrients	Nitrogen & Phosphorus	Atmosphere and fertilizer application
	Lead	Leaded gasoline from auto exhausts and tire wear
	Zinc	Tire wear, motor oil and grease
	Iron	Auto body rust, steel highway structures such as bridges and guardrails, and moving engine parts
	Copper	Metal platings, bearing, bearing and brushing wear, moving engine parts, brake lining wear, fungicides & insecticides
	Cadmium	Tire wear and insecticide application
Heavy Metals	Chromium	Metal Platings, moving engine parts and brake lining wear
	Nickel	Diesel fuel and gasoline, lubricating oil, metal plating, brushing wear, brake lining wear and asphalt paving
	Manganese	moving engine parts
	Cyanide	Anti-caking compounds used to keep deicing salt granular
	Sodium, calcium & chloride	Deicing salts
	Sulphates	Roadway beds, fuel and deicing salts
Hydrocarbons	Petroleum	Spills, leaks, antifreeze and hydraulic fluids and asphalt surface leachate

Most pollution found in highway bridge deck runoff is both directly and indirectly contributed by vehicles such as cars and trucks. The constituents that contribute the majority of the contamination are generally deposited on the bridge decks.

Table 3-1 which was obtained from the EPA's Guidance specifying management measures for sources of nonpoint Pollution in Coastal Waters publication lists different constituents of concern found in polluted highway bridge deck runoff and their sources (U.S. EPA, 1995). These constituents can be harmful to human health.

The connecting tie between these harmful highway made contamination and the natural water system which includes ground waters and surface waters, is rainfall. Rainfall transports most of the contaminants that are deposited on the road surfaces to the adjacent surface environments, which include open landscape, vegetation and surface waters. Through this pathway the surface waters are impacted directly and the ground waters are contaminated by infiltration, thus impacting water resources as a whole.

Numerous studies have characterized highway runoff as a source of contamination to the environment. In order to provide mitigation efforts, the clean water act, which was enacted in 1972, was amended in 1987 to include storm water discharges. The act required that states assess the conditions of surface waters in their jurisdiction. Those that were not fishable or swimmable and could not be sustained for beneficial use were to be reported to the EPA. TMDLs (Total Maximum Daily Loads) were to be developed for these water bodies as required by section 303d of the act. Thus, the 303d list was formed. Section 303d of the clean water act also lists selected constituents for which loadings should be established.



## 4. METHODS, MATERIALS AND PROCEDURES

### 4.1 METHODS

#### 4.1.1 Site characterization

The main objective of this project was to evaluate the characteristics and impacts of rainfall storm water runoff from a bridge deck on a receiving watercourse. The data, which were collected in the course of the project, were felt to be significant contributors to receiving water pollution.

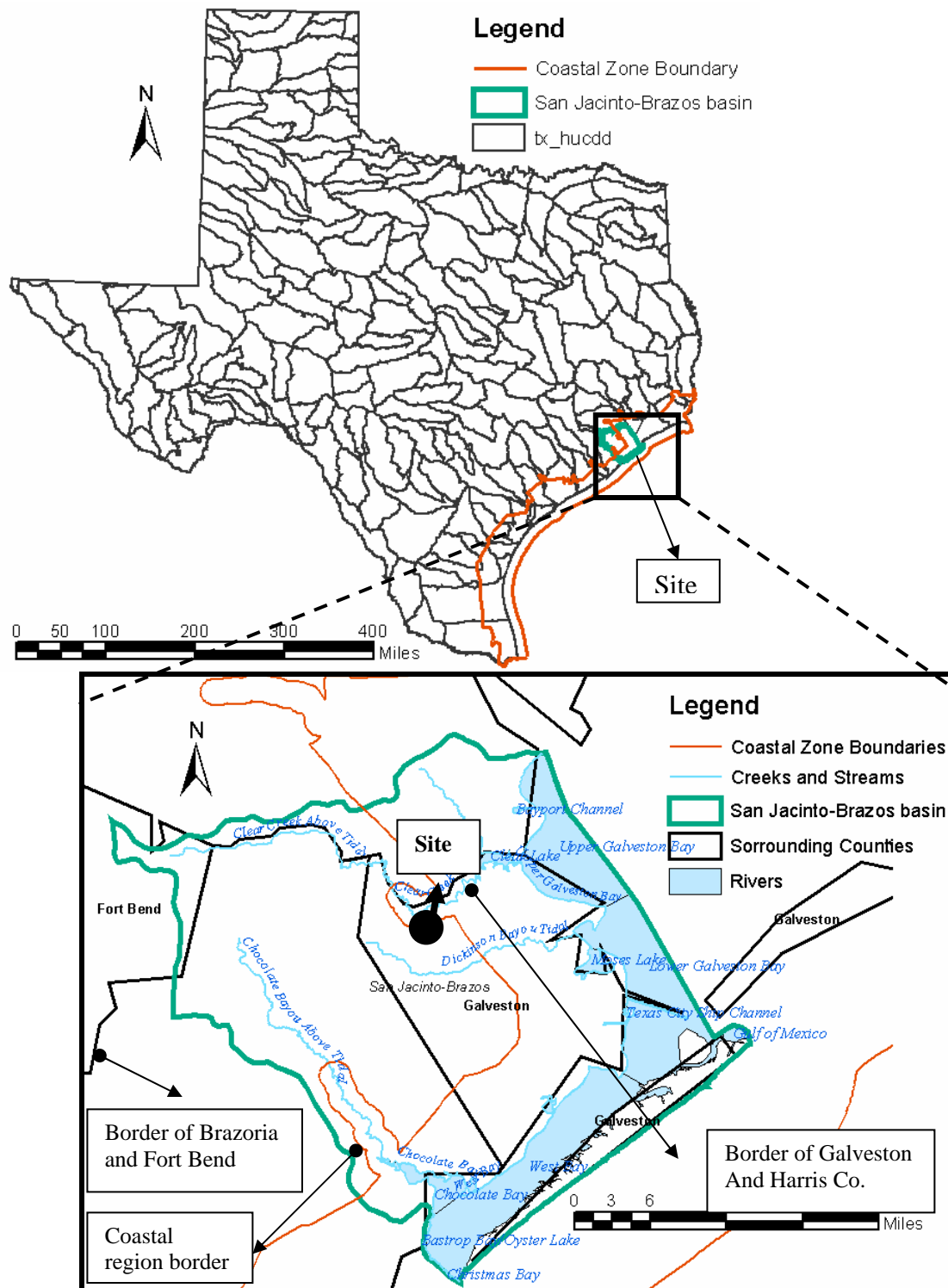
**TABLE 4-1. Pollutants analyzed for samples**

Pollutants (1)	Units (2)	Constituents (3)		
Total metals	µg/L	Zinc	Copper	Lead
Dissolved metals	µg/L	Zinc	Copper	Lead
Chemical Oxygen Demand	mg/L	COD		
Phosphates	mg/L	Total Phosphates	Dissolved phosphates	
Nitrogen	mg/L	Nitrates (as N)	Total Kjeldhal Nitrogen	
Suspended Solids	mg/L	TSS	VSS	

This data included flow levels and rainfall intensity data for the development of hydrographs, and concentrations from the analysis. The pollutants that were analyzed for are the 13 constituents of concern shown in Table 4-1. The details of the sampling procedure will be discussed in the procedure section.

#### 4.1.2 Site location

The use of GIS- Geographic Information Systems data in positioning the site



**FIG. 4-1. GIS map of the Clear Creek's path and the site in coastal margin**

spatially was crucial and it gave good insight on the location as the site basically had no address. When spatially locating a stream, lake or river, it is necessary to identify which watershed or HUC- Hydrologic Unit Code that the lake or stream is located in.

Seaber et al. (1987) defined watershed hydrologic unit codes as an 8 number classification system currently being used in the USGS (United States Geological Survey) to identify the different units which the United States is divided into. The Hydrologic Unit Codes are classified based on 4 levels of classification which are: regions, sub-regions, accounting units, and cataloging units. There are currently 21 major regions in the United States, which are divided into 222 sub regions. These sub regions are then broken up into 352 hydrologic accounting units, which are finally divided into 2150 total cataloging units (Seaber et al. 1987).

The site, which is on the Clear Creek watercourse, is in the San Jacinto –Brazos basin watershed. It can be otherwise identified by the HUC **12040204**. This means that the watershed resides in region 12, sub region 04 or 4, accounting unit 02 or 2, and cataloging unit 4.

The downloadable data of the HUC for the project site can be obtained from the Texas Commission on Environmental Quality (TCEQ) and is made available through the Texas Natural Resources Information system (TNRIS) at the following address:  
[http://www.tnris.state.tx.us/DigitalData/data\\_cat.htm#Water%20Resources](http://www.tnris.state.tx.us/DigitalData/data_cat.htm#Water%20Resources).

Furthermore, using the ArcGIS graphical user interface, these data can be displayed for better viewing and understanding as can be clearly seen in Figure 4-1. The bridge deck that was chosen for this study was is part of a bridge which is FM 528, a

major highway that runs through Harris, Galveston, and Brazoria counties. It is also displayed in Figure 4-2 along with the other surrounding highways in the area such as FM 518. The GIS highway data was obtained from the Texas Department of Transportation and is available at the following address:

[www.tnris.state.tx.us/DigitalData/data\\_cat.htm#Transportation](http://www.tnris.state.tx.us/DigitalData/data_cat.htm#Transportation), also from TNRIS. These data are maintained and developed by the FHWA (the Federal Highway Administration). The land usage immediately surrounding the site is mostly utilized for residential and commercial activities.

#### **4.1.3 Site description**

The Clear Creek watercourse is an approximately 45 mile long, tidally influenced bayou that runs through 4 counties namely Fort Bend, Brazoria, Harris, and Galveston counties. It meanders throughout its length draining a 260 square mile watershed and empties into Clear Lake before it reaches the Galveston Bay (US Army Corp of Engineers, 1982). This can be seen clearly in Figure 4-2 which was generated by the author using the ArcGIS program and geographic information systems data. It is not only one of the unchannelized bayous in the city of Houston, but it supports a wild variety of river wild life through feeding grounds and nurseries. The creek can also be seen in Figure 4-2 where it runs along the borders of the Harris and Brazoria counties.

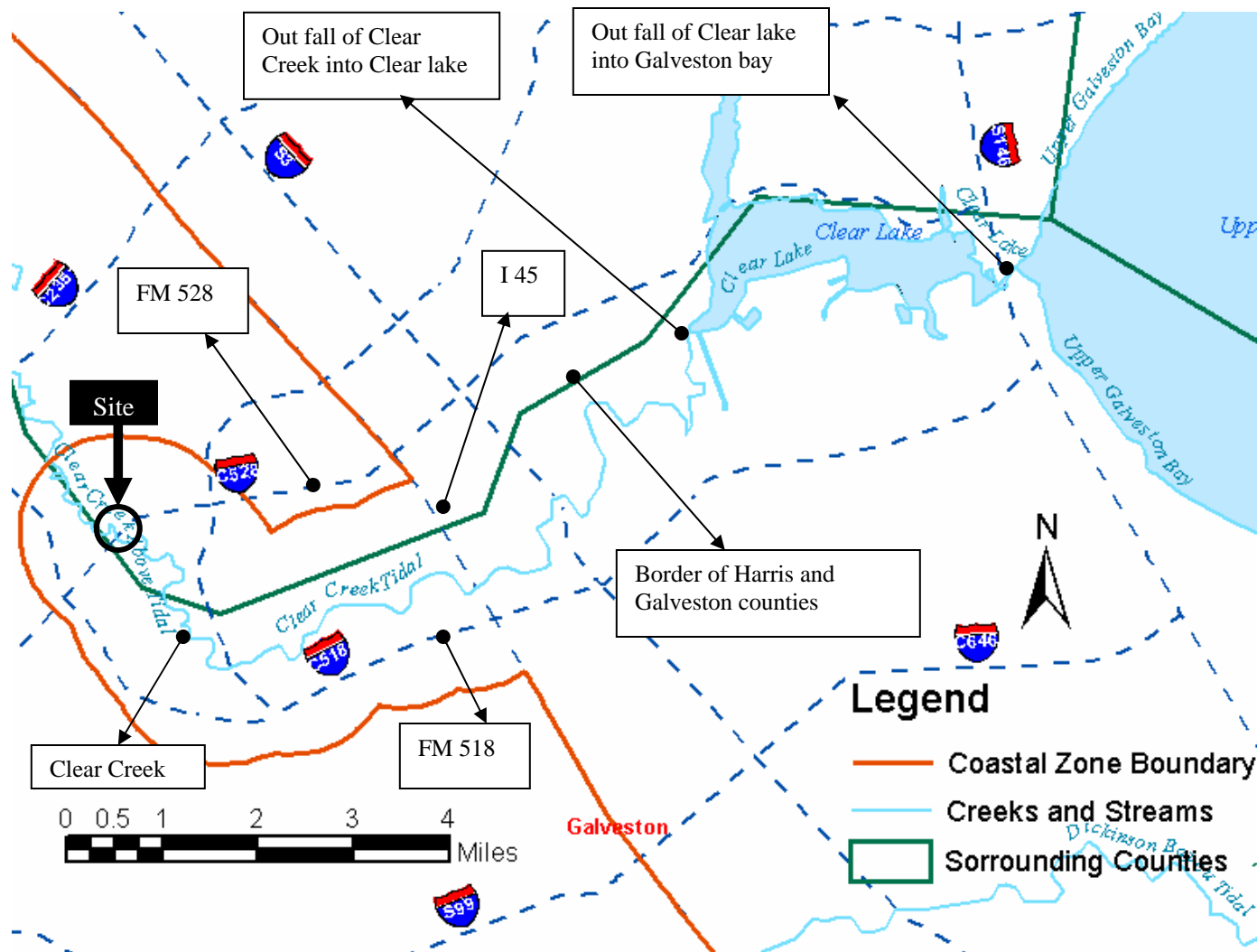


FIG. 4-2. Clear Creek, Clear Lake, Galveston Bay, FM 528, and surrounding roads

The bridge deck that was monitored (shown in Figures 4-3 and 4-4) is located on FM 528, a major highway that runs through Brazoria and Harris counties. It is a major



**FIG. 4-3. Detention pond, the Fm 528 Highway and bridge on site**

road with an average daily traffic load of about 15,000 vehicles per day. (US Army Corp of Engineers, 1988). The runoff from the FM 528 highway is currently being drained by

a 4 feet diameter drainage culvert pipe located underground parallel to the road way. There is also an approximately 105ft x 160ft rectangular detention pond located at the site adjacent to the highway above Clear Creek.



**FIG. 4-4. Clear Creek and FM 528 intersection site**

This is depicted clearly by the digital orthophoto quadrangle in Figure 4-3 which was generated by the author using the ArcGIS program and geographic information systems data obtained from TNRIS, the Texas Natural Resources Information system. Digital orthophoto quadrangles are 1-meter ground resolution aerial photos images which are scanned and modified by computers to correct distortions from terrain relief



and camera tilts. (USGS, 2001). Each quadrangle covers a 5 x 5 mile area. There are either grayscale or CIR (colored infrared) images. CIR images are generally clearer than grayscale images. The DOQ used for this study are CIR images and are not available for all parts of Texas currently. The DOQ used were obtained from TNRIS at: [www.tnris.state.tx.us/update3.cfm?Tx\\_County\\_Name=GALVESTON](http://www.tnris.state.tx.us/update3.cfm?Tx_County_Name=GALVESTON).

#### **4.2 MATERIALS / SITE APPARATUS AND EQUIPMENT**

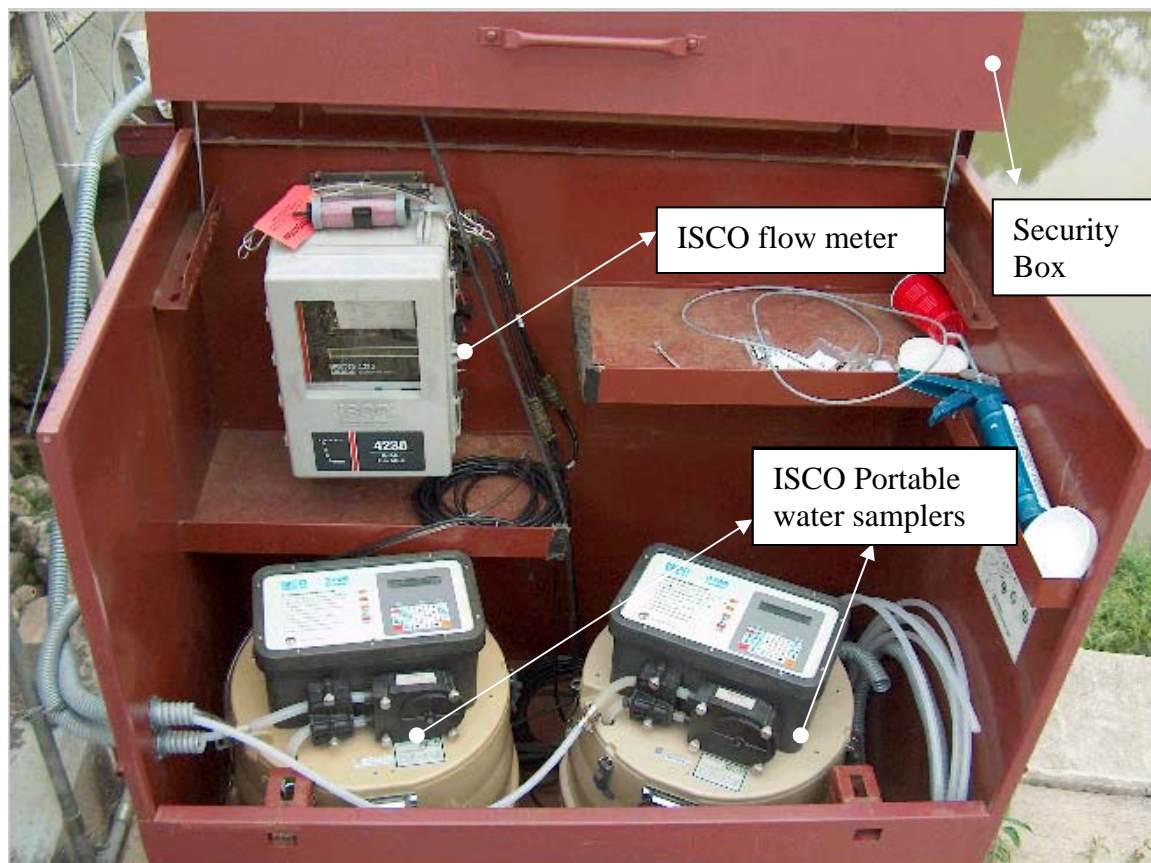
In order to efficiently characterize loadings from the site, which was a combination of both the highway and bridge deck, it was determined that 2 monitoring stations for the site would be required for the implementation. The first monitoring station was located at the road approach near the outfall of the drainage culvert and the second monitoring station namely was located at the intersection of the bridge deck and the creek.

Three sampling points at the site were utilized. These included samples from the roadway drainage culvert, the bridge deck and the creek. However only flow measurements from the bridge deck and the culvert were taken. Flow measurements from the creek were not required because there was a USGS monitoring station located on the bridge at the site and therefore the flow data could be obtained from the United States Geological Survey. The equipment and materials that were used at each monitoring station (some only located specifically at one station and others common to both) included the following: a security box with a solar panel, a rain gauge, an automatic water sampler, a flow measuring device, and a flow measuring flume and water collection system.



#### 4.2.1 ISCO 3700 full-size portable sampler

Portable field water samplers were installed at each of the 2 monitoring stations of the site to provide real time sampling after each rainfall event. Each of the samplers required programming and worked by flow paced sampling which meant that sampling



**FIG. 4-5. Examples of different types of site equipment**

by these devices would be enabled and triggered only at a certain specified set level rise of flow in the drainage media. An example of the samplers used at the site is shown in Figure 4-5.

#### 4.2.2 ISCO 4230 flow meter

The flow-measuring device that was used for the project was the ISCO 4230 flow meter (also shown in Figure 4-5) which worked by way of gas pressure sensing technology. It forced metered amounts of air through a bubble line that was submerged in the area on which the flow was being measured. The air bubbles were forced through the line by means of an internal air compressor. As the level of flow rose in the conduit, the amount of pressure needed to force the air bubbles out of the line was measured and correlated to flow depth. By knowing the amount of head or the flow level of the water flowing through the pipe or flume, the flow velocity “V” and the flow “Q” was calculated by Manning’s equation shown in equation 1 below:

Equation 1: Manning’s Equation

$$V = \frac{K}{n} \times R^{\frac{2}{3}} \times S^{\frac{1}{2}} \quad \text{And} \quad Q \left( \frac{\text{gal}}{\text{min}} \right) = V \times A \quad (1)$$

Where R (hydraulic radius) =  $\frac{A}{P_w}$  ,

A = area

P<sub>w</sub> = wetted perimeter.

During calibration of the flow meters, the values for the roughness coefficients “n” and the slope “S” and all other relevant modifications were selected and entered into program. The details of this procedure are discussed in the procedure section.

### 4.2.3 Security box, solar panel, and rain gauge

The security boxes were located at each of the 2 monitoring locations. Only one rain gauge was needed to receive data during each rain fall event which was located at the culvert monitoring station. A battery was also installed for a source of energy to the flow meters and samplers which was recharged by a solar panel located on top of each security box. The security box not only provided the housing for the full size samplers and the flow meters but also deterred any potential of obstruction and vandalism to the operation and maintenance of the equipment.

### 4.2.4 Flume and bridge runoff collection

While the 4 ft diameter storm water drainage pipe was collecting the runoff from the highway, there was no system specifically for the collection of the runoff from the bridge deck. The surface was flat and runoff had to be collected.



**FIG. 4-6. Constructed bridge runoff collection system**

A gutter which was constructed out of a transversely half cut 8 in diameter PVC pipe and attached to the bridge deck to provide an environment through which the runoff flow from the bridge can be collected through a flume and measured. This is shown clearly in Figure 4-6.

#### 4.3 SITE LAYOUT AND EQUIPMENT SETUP

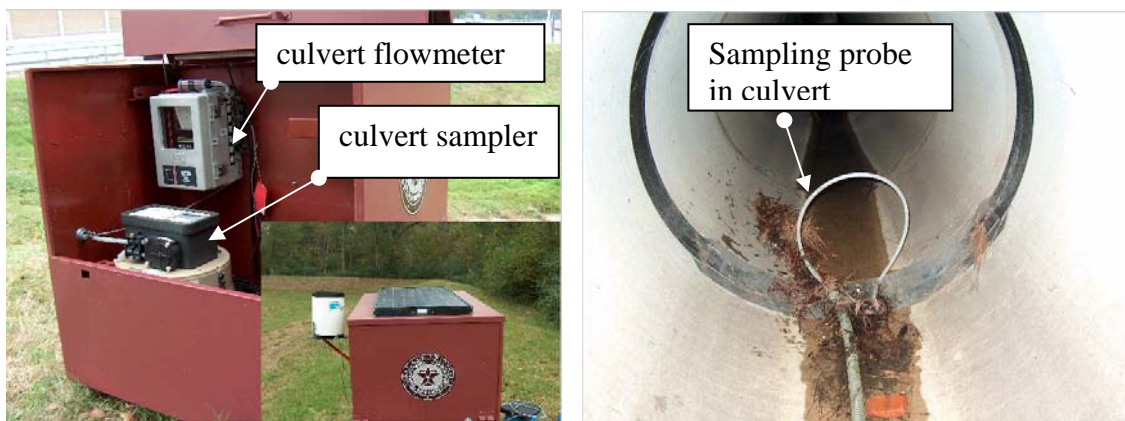


FIG. 4-7. The 2 main equipment station setups

Figure 4-7 shows an aerial depiction of the site from which the different entities at the site such as the bridge deck, Clear Creek, Highway FM 528, the detention pond, and the two different monitoring stations can be seen.

#### 4.3.1 Equipment set up at culvert

The equipment setup at the culvert area was done solely for the sampling of the



**FIG. 4-8. Details of equipment setup at culvert and inside it**

runoff coming from highway road approach before inception of the bridge, and the acquisition of the flow and level data in the culvert.

This set up is shown in Figure 4-8 and includes the following:

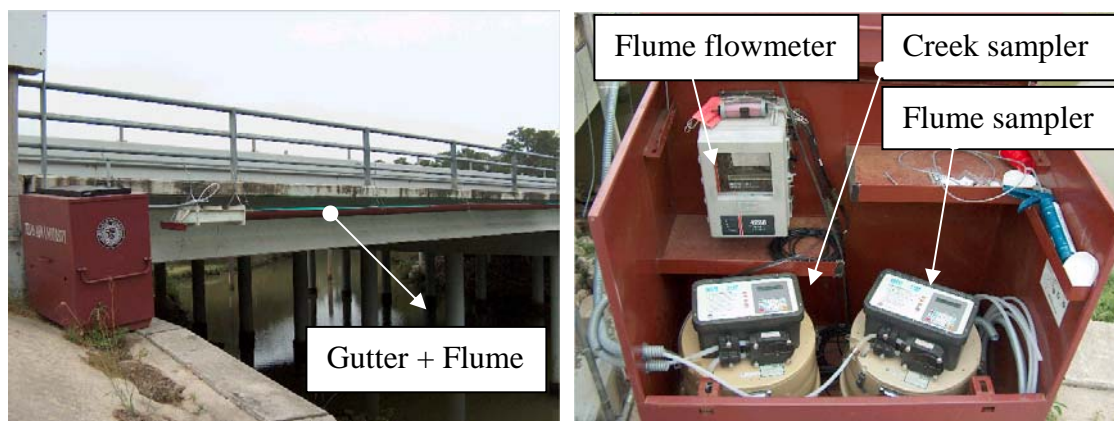
- One ISCO portable water sampler
- ISCO flow meter
- Security box
- Battery (power source)
- Solar panel (battery charger)



- Rain gauge
- Sampling probe (located in culvert shown)

#### 4.3.2 Equipment set up at bridge

This was the most important set up of the project because the objective of the project was to examine the effect of the bridge deck runoff on the receiving water. As mentioned earlier, a gutter-flume and water collection system had to be custom built and attached to the bridge deck to collect the runoff from the bridge during rainfall events



**FIG. 4-9. Details of equipment setup at the bridge deck**

for sampling, analysis, and data acquisition. This equipment is shown in Figure 4-9. The gutter that was built spanned a quarter of the bridge's surface, therefore it should be noted that any type of results developed i.e. runoff or loadings should ideally be multiplied by a factor of 4.

The equipment was also designed to sample water from the creek while the sampling of the bridge deck runoff was taking place during each rainfall event.

This setup shown in Figure 4-8 includes the following:

- Security box
- Battery (power source)
- Solar panel (battery charger)
- ISCO portable water sampler for the bridge deck and flume
- ISCO portable water sampler for the creek
- 20 ft long gutter
- ISCO flume flow meter
- 2 sampling probes for the flume and creek.

#### **4.4 PROCEDURES**

##### **4.4.1 Programming procedure**

The flow meters and samplers required pre-programmed and calibration before installation to ensure proper performance. There were 2 flow meters and 3 water samples of concern namely:

Water samplers

- Bridge and flume water sampler
- Culvert water sampler
- Creek water sampler

Flow meters

- Bridge and flume flow meter
- Culvert flow meter

Note: There was no flow meter required for the creek because the onsite USGS station provided real time stage and flow data.

The details of these programming codes are outlined in appendix A. The main features of these programming codes were the input parameters, which were predominantly physical characteristics of the pipes and flow environments and preferred automated operations. Some of the physical characteristics that were inputted included the following:

- Sample bottle size and volume- The sample bottle volume which was used in all of the ISCO water samplers were 10000 miller liters.
- Piping and tubing for water sampling recovery- As can be seen in appendix A, the type of tubing that was used at each ISCO water sampler was Teflon. The tube diameter was the same at 3/8 inches at all samplers but the total length of tubing varied at each water sampler, for example as can be seen in Appendix A (A-4) for the bridge water sampler, the total length of the suction line (tubing) was 49 feet.
- Flow meters- As can be seen in Appendix A-1, some constant physical parameters were inputted for the already existing DOT culvert were a 4 feet diameter round pipe with a slope of 0.0001 and a roughness of 0.0050. In Appendix A-2, the physical parameters that were inputted for the constructed gutter was a 0.5 feet (6 in) depth.
- Water samplers (flow paced sampling)- The samplers were programmed for flow paced samplings, which meant that they were set to begin collecting



samples every 15 minutes in the culvert or flume when the water flow level (as determined by the flow meter) rose above 0.02 ft during each rainfall event.

#### 4.4.1 Data retrieval and lab analysis



**FIG. 4-10. Data retrieval at the site**

After each rainfall event, data was retrieved from the flow meters and the samplers as shown in Figure 4-10. This data included rainfall and flow level data i.e. graphs of (rainfall (in inches) VS time) and flow level data (level VS time). The liquid samples of the rainfall runoff that were collected during each rainfall period were also

taken from the samplers following the appropriate sample collection procedures and chain-of-custody. The samples were then sent to the Lower Colorado River Authority (LCRA) lab in Austin, TX for analysis. The following 13 constituents were analyzed for:

1. Total zinc
2. Total copper
3. Total lead
4. Dissolved zinc
5. Dissolved copper
6. Dissolved lead
7. Chemical Oxygen Demand (COD)
8. Total phosphates
9. Dissolved phosphates
10. Nitrates (as N)
11. Total kjeldhal Nitrogen
12. Total suspended solids
13. Volatile suspended solids

Results from these data, (concentrations from the culvert, bridge deck, and creek) were graphically compared. The different constituent loadings for each rainfall event were calculated following the 13<sup>th</sup> method described by Dupuis (1999) by knowing the volume of the flow of each rain fall event and using the formula of equation 2.

Equation 2: Constituent Loading Calculation

$$L(mg \times 0.001)g = V \left( (gal) \times 3.7854 \frac{liters}{gal} \right) liters \times C(\mu g \times 0.001)mg \quad (2)$$

Where

L = Estimated mass loading

V = Total rainfall volume (maximum flow rate during rain fall event)

C = Concentration (from water samples taking after rainfall event)

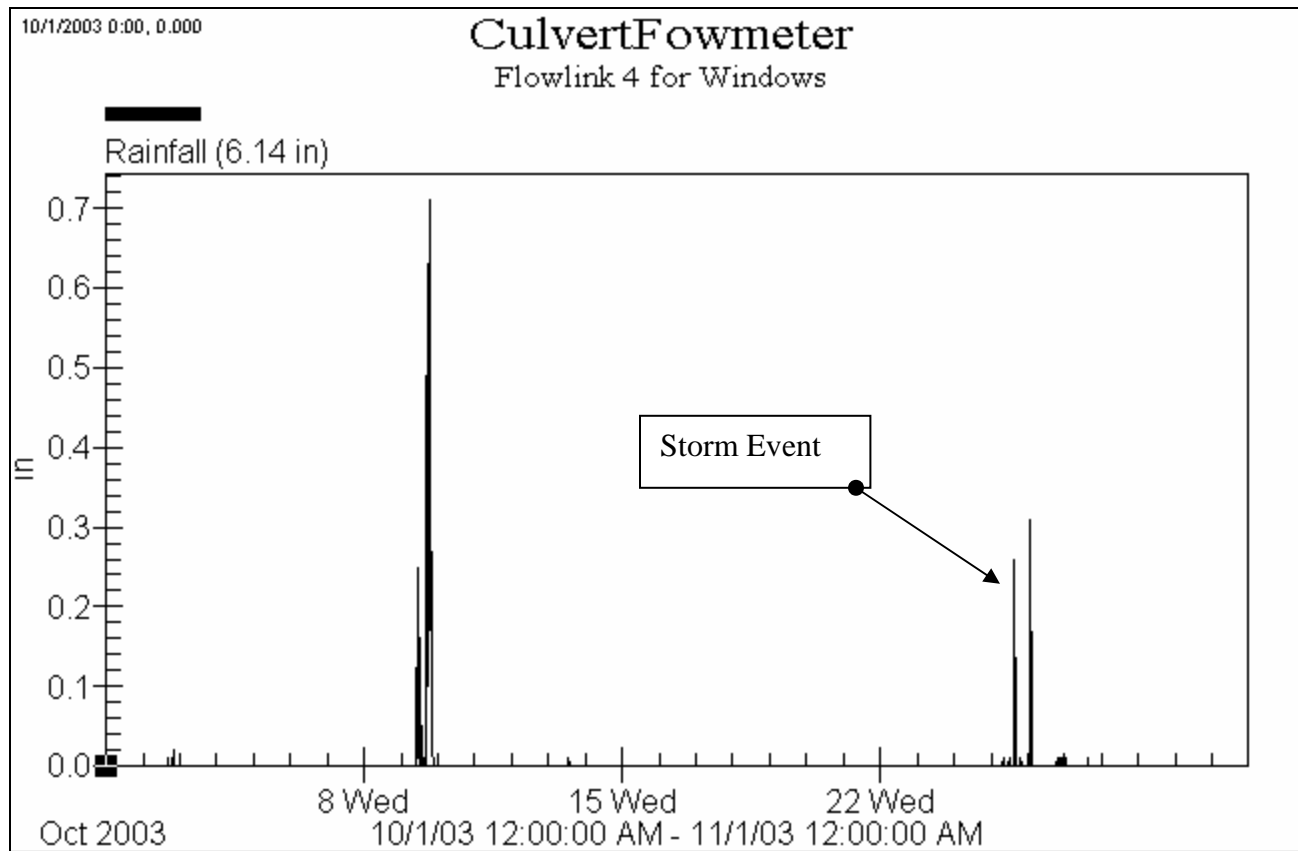
## **5. DATA DISCUSSION**

### **5.1 DATA**

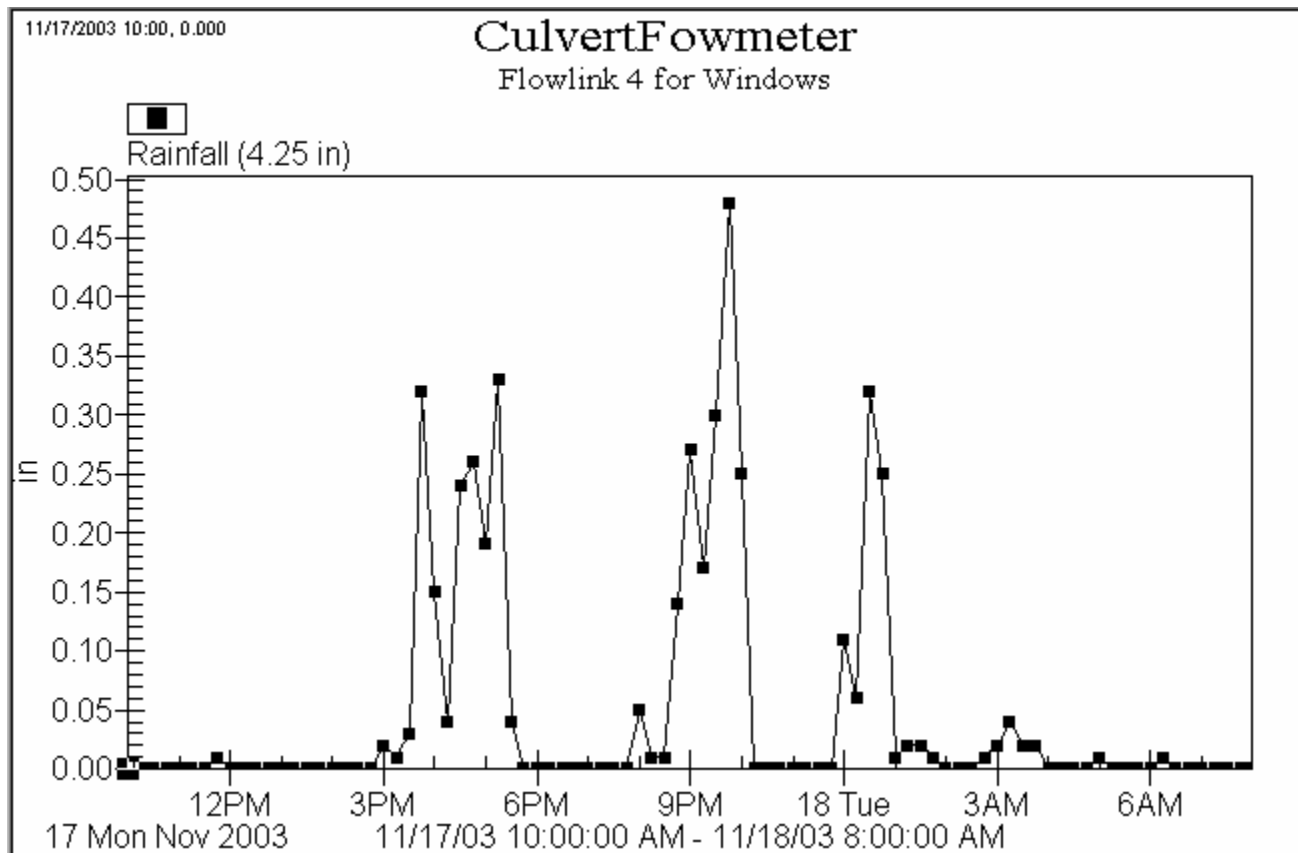
The following types of data were collected: rainfall data, level (stage) data, flow / discharge data, and concentration data.

#### **5.1.1 Rainfall data**

Rainfall data acquisition provided a good visual of approximately when and how much rainfall fell in units of inches. The rain fall events were grouped by months. An example is shown in Figure 5-1 which shows all the rainfall events which occurred during the month of October. The 2 peaks represent the 2 rainfall events which occurred on the 9<sup>th</sup> and the 26<sup>th</sup> of the months. Details of the storm events can also be obtained as shown in Figure 5-2. It should also be noted that not all the rainfall events during the project produced enough runoff for samples to be taken. This was either due to short duration of the rain fall period or the amount of rainfall. These data are available for each of the months during the project and will be displayed in Appendix B.



**FIG. 5-1. Sample rainfall data**



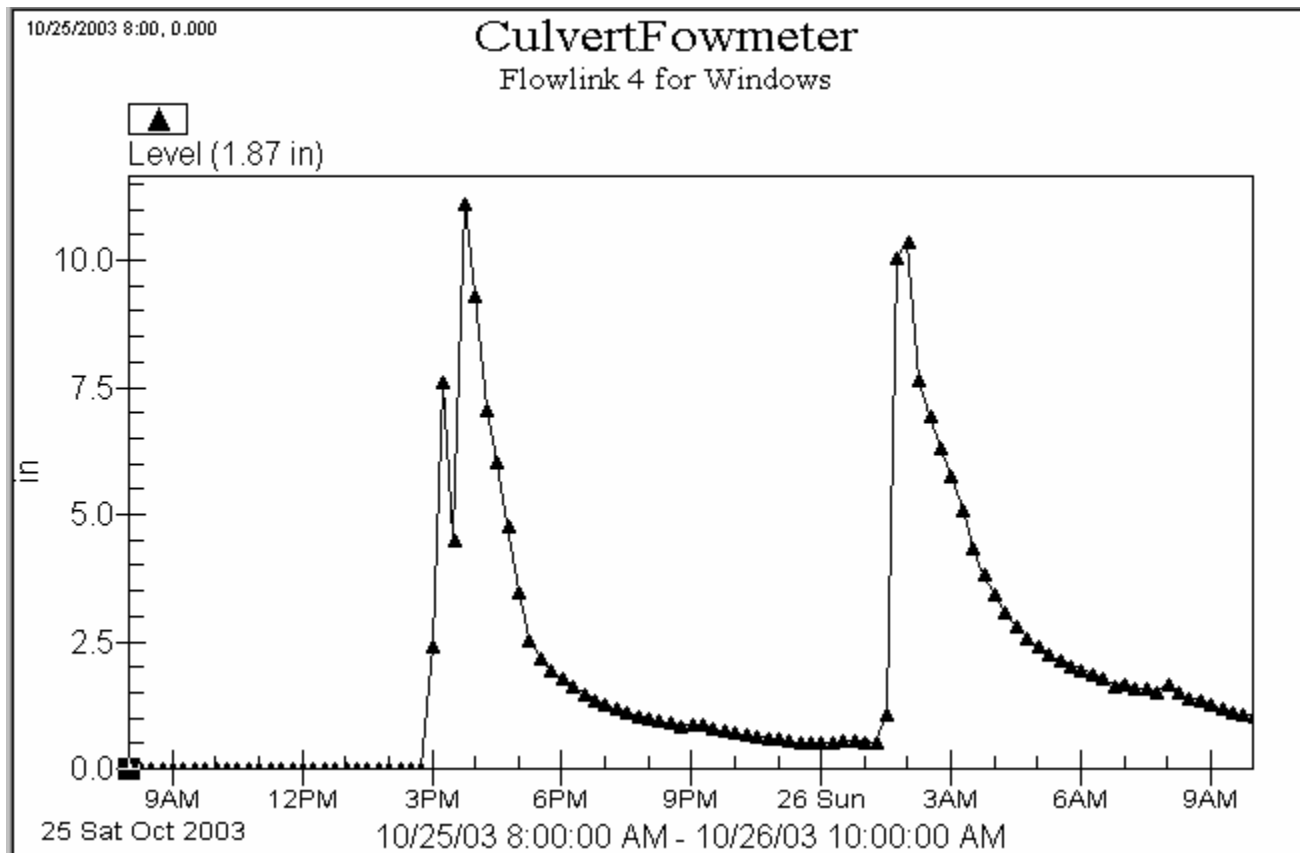
**FIG. 5-2. An example rainfall event details during hours of storm event**

### **5.1.2 Level (stage) data**

Level data was described in an event-to-event basis. Level data are measurements taken by the flow meters of the culvert and the flume. An example of these data is represented graphically in Figure 5-3 by the flow Level VS time graphs for an October event. For each rainfall event that occurred there will be level versus time graphs for the flows, which occurred in the flume and the culvert. This type of level data is useful in the determination of the total volume of rainfall for the event. These data are displayed in Appendix C.

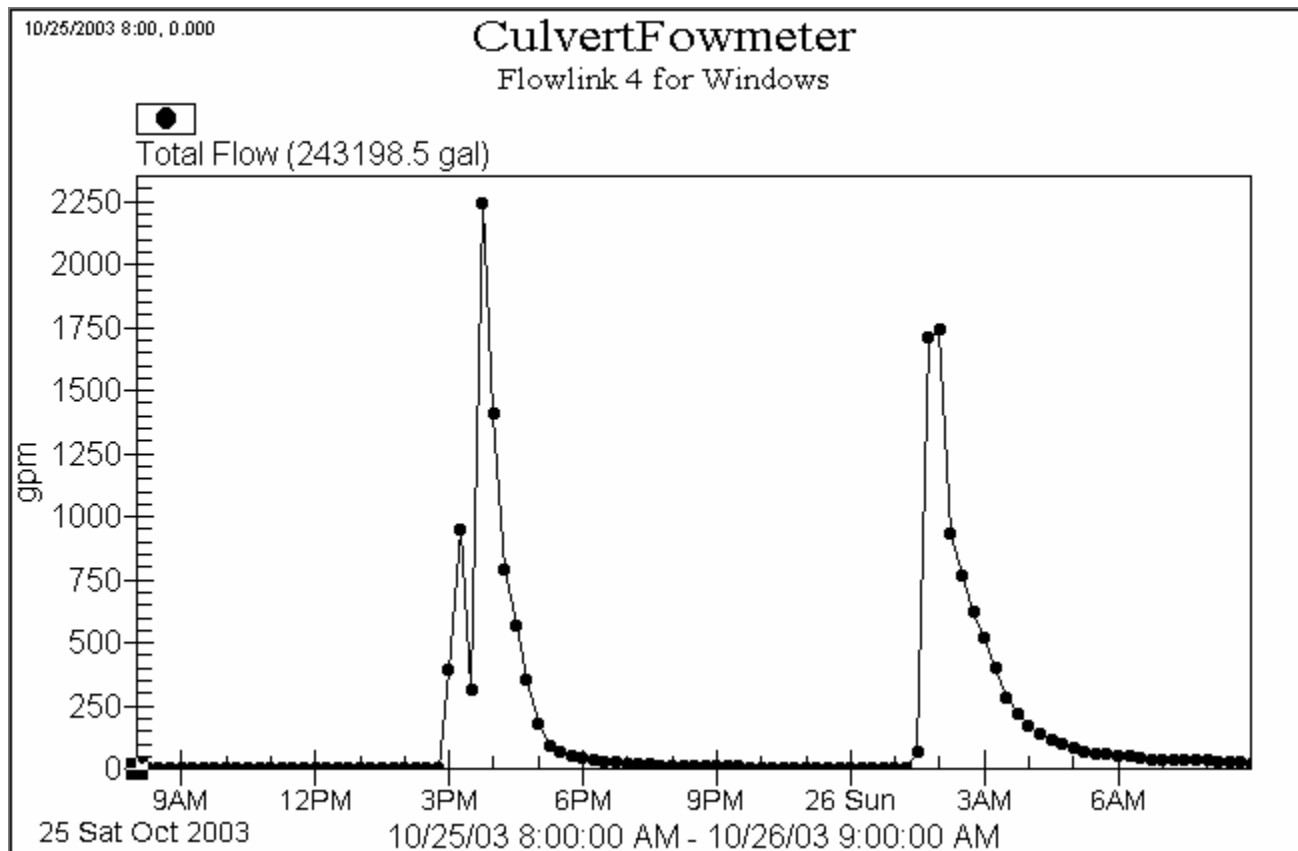
### **5.1.3 Flow data**

Flow data was also described in an event-to-event basis. The flow data was produced by the flow meter which measured the amount of flow in gpm (gallons per minute) through the culvert and the flume at given intervals of time during the rainfall event. This data is critical in the calculation of the constituent loadings because the volume of the event will be used in equation 2 mentioned earlier. A sample of this data is represented in Figure 5-4 in the flow versus time graph. There will also flow versus time graphs for the flume and culvert for each rain fall event. This data will also be presented in Appendix C.



**FIG. 5-3.** An example culvert level data for rainfall event 10/25/03 to 10/26/03



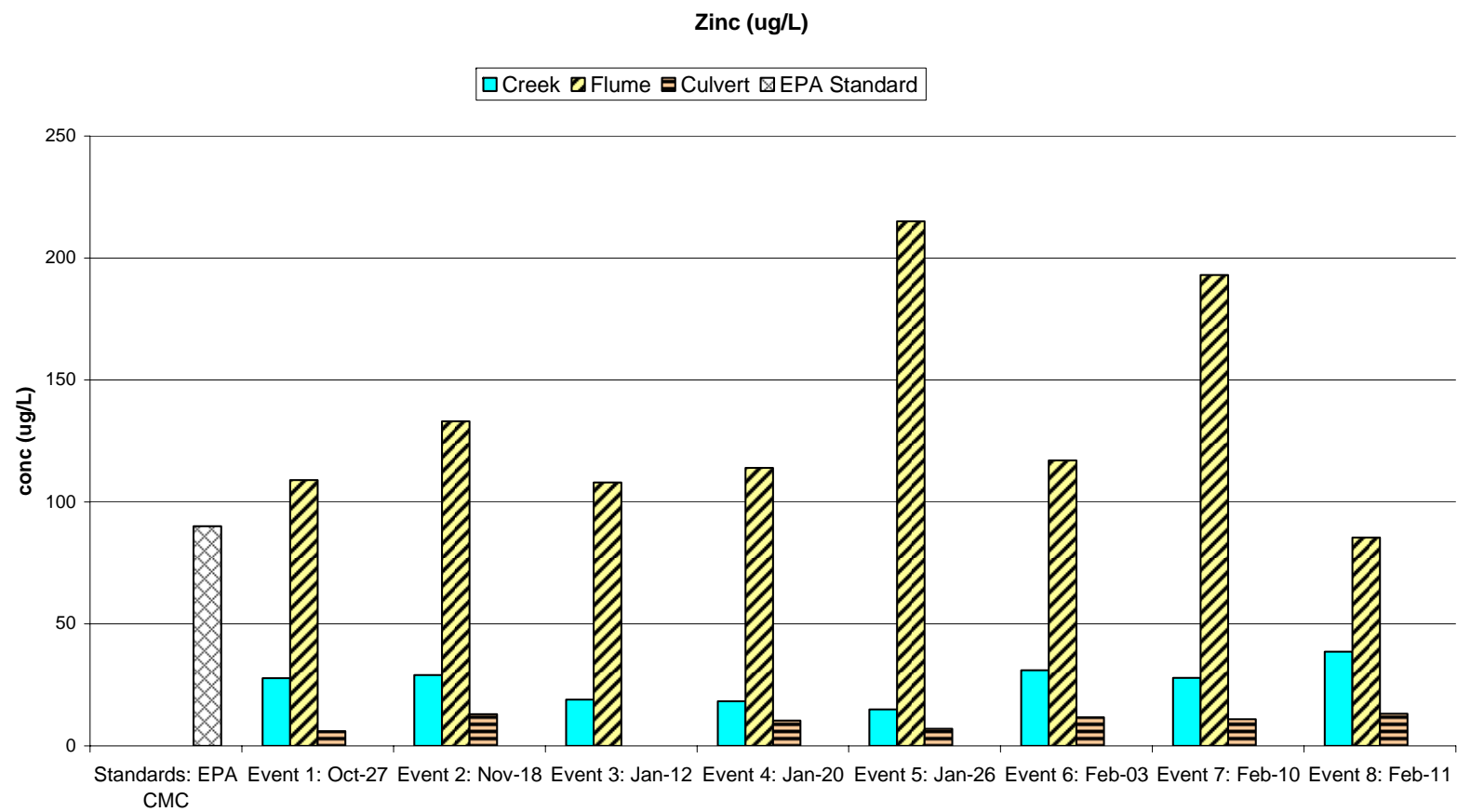


**FIG. 5-4.** An example culvert flow (discharge) data for rainfall event 10/25/03 to 10/26/03

#### **5.1.4 Concentration data**

From the results produced when the samples were sent to the lab and analyzed after each rainfall event the contaminant concentration data was produced. The culvert, bridge, and creek were all sampled simultaneously during each event. This simultaneous sampling was important since the concentration of all the different constituents (mentioned earlier) coming from all 3 different areas can be compared.

Additionally, by knowing the different constituent concentrations in the samples from the rainfall event and the rainfall volume, the constituent loading can be calculated using equation 2. A sample of the concentration data and comparisons of a constituent from the 3 different sampling points is shown in Figure 5-5. The constituent loadings for each rainfall event were calculated and are displayed in a summary table which is shown in Table 5-1. These data are all shown in Appendix D for each rain fall event.



**FIG. 5-5. An example constituent concentration comparison**

**TABLE 5-1. Storm event calculated constituent mass loadings**

CULVERT														
Rainfall Events (1)	Runoff Volume (gal) (2)	Cu (g) (3)	Pb (g) (4)	Zn (g) (5)	D-Cu (g) (6)	D-Pb (g) (7)	D-Zn (g) (8)	N (g) (9)	D-P (g) (10)	T-P (g) (11)	TKN (g) (12)	TSS (g) (13)	COD mg/L (14)	VSS mg/L (15)
1	243198.5	6.2	0.2	5.6	4.6	0.1	6.1	407.8	64.4	92.1	559.7	2761.8	0.1	2761.8
2	3528882.0	140.3	13.4	173.7	84.8	0.0	54.5	15094.8	2805.2	2805.2	20037.3	213731.7	0.2	106865.8
3	220059.5	5.8	0.0	0.0	5.3	0.0	7.3	349.9	58.3	58.3	320.7	0.0	-1.0	0.0
4	1575390.0	41.1	7.9	62.0	29.8	0.0	75.7	3941.9	417.4	417.4	4090.9	65598.3	0.3	35780.9
5	258375.0	10.0	0.0	6.8	6.6	0.0	5.8	231.8	68.5	68.5	431.3	9780.5	0.3	7824.4
6	847767.7	10.2	5.8	37.5	6.7	0.5	19.1	261.9	128.4	353.0	3016.6	83437.6	0.8	28882.3
7	450512.3	5.7	2.3	18.6	4.0	0.0	33.3	260.9	153.5	187.6	1331.9	28991.3	0.6	13643.0
8	953509.7	0.0	3.8	47.6	4.9	0.0	26.6	353.7	72.2	180.5	2378.6	28875.3	0.6	14437.7
9	71900.4	1.4	0.5	3.3	0.8	0.0	4.1	157.9	0.0	8.2	105.6	6804.3	1.3	3266.1
10	121259.6	5.1	2.2	15.1	3.3	0.0	6.8	459.0	41.3	55.1	546.2	16983.6	1.3	5508.2
11	378292.2	10.9	4.6	34.8	8.9	1.5	76.8	1718.4	243.4	229.1	829.1	38663.7	1.2	11455.9

**TABLE 5-1 (Continued)**

<b>BRIDGE</b>														
Rainfall Events (1)	Runoff Volume (gal) (2)	Cu (g) (3)	Pb (g) (4)	Zn (g) (5)	D-Cu (g) (6)	D-Pb (g) (7)	D-Zn (g) (8)	N (g) (9)	D-P (g) (10)	T-P (g) (11)	TKN (g) (12)	TSS (g) (13)	COD mg/L (14)	VSS mg/L (15)
1	977.00	0.057	0.046	0.403	0.038	0.008	0.282	1.010	0.370	0.481	3.920	210.805	0.012	62.872
2	787.70	0.041	0.027	0.397	0.021	0.000	0.078	1.240	0.119	0.119	2.022	68.580	0.004	23.854
3	1,125.00	0.066	0.014	0.460	0.051	0.006	0.464	0.000	0.256	0.256	4.054	34.069	0.002	34.069
4	977.00	0.088	0.005	0.422	0.070	0.000	0.407	12.463	0.148	0.148	6.620	33.285	0.003	29.587
5	977.00	0.079	0.023	0.795	0.052	0.000	0.377	2.792	0.222	0.222	4.586	170.123	0.014	44.380
6	264.30	0.008	0.006	0.117	0.004	0.000	0.064	0.385	0.020	0.050	0.332	27.013	0.001	10.005
7	1,086.50	0.066	0.012	0.794	0.055	0.000	0.679	3.755	0.000	0.123	4.565	65.805	0.004	16.451
8	1,382.50	0.027	0.024	0.447	0.018	0.000	0.309	1.413	0.000	0.000	1.434	20.933	0.000	0.000
9	1,216.00	0.042	0.010	0.363	0.028	0.000	0.222	1.427	0.000	0.000	0.506	46.030	0.002	59.840
10	9762.7	1.123	0.098	2.986	0.950	0.000	2.055	34.738	1.109	1.848	76.498	813.026	0.094	480.424
11	235.3	0.015	0.004	0.076	0.012	0.000	0.063	1.808	0.000	0.000	0.868	18.705	0.001	7.126

## 6. SUMMARY, RESULTS, AND CONCLUSIONS

### 6.1 RESULTS

A main objective of the project was to examine the effect of the selected FM 528 bridge deck runoff on the receiving Clear Creek water course. Samples were collected concurrently with rainfall, flow, and level data using state-of-the-art sampling and data acquisition equipment for multiple storm events. Collected samples were sent to the designated lab for analysis of selected contaminants immediately after each rain fall event. These results from the analysis were compared to current EPA standards shown in Table 6-1. The EPA currently is engaged in a program (the National Pollutant Discharge Elimination System (NPDES)) which regulates storm water runoff from construction, industrial activities and storm sewer systems.

**TABLE 6-1. EPA recommended criteria for water quality standards**

Constituent of concern analyzed for (1)	EPA Standards		Salt water	
	Fresh water			
	Fesh water: CMC (µg/L) (2)	Fresh water: CCC (µg/L) (3)	Salt water: CMC (µg/L) (4)	Salt water: CCC (µg/L) (3)
Copper	13	9	4.8	3.1
Lead	65	2.5	210	8.1
Zinc	120	120	90	81
Arsenic	340	150	69	36
Mecury	1.4	0.77	1.8	0.94
Chlorine	19	11	13	7.5

Constituent of concern analyzed for (1)	EPA standard (mg/l) (2)
Total phosphorus	0.128
Total Nitrogen	0.76
TKN	0.71

**TABLE 6-2. Summary tables of details from storm event sample lab analysis**

Rainfall Events (1)	BRIDGE												
	Cu µg/L (3)	Pb µg/L (4)	Zn µg/L (5)	D-Cu µg/L (6)	D-Pb µg/L (7)	D-Zn µg/L (8)	N mg/L (9)	D-P mg/L (10)	T-P mg/L (11)	TKN mg/L (12)	TSS mg/L (13)	COD mg/L (14)	VSS mg/L (15)
1	15.500	12.500	109.000	10.400	2.160	76.300	0.273	0.100	0.130	1.060	57.000	24.000	17.000
2	13.900	8.950	133.000	7.000	ND	26.200	0.416	0.040	0.040	0.678	23.000	26.000	8.000
3	15.400	3.210	108.000	12.000	1.420	109.000	ND	0.060	0.060	0.952	8.000	57.000	8.000
4	23.700	1.390	114.000	19.000	ND	110.000	3.370	0.040	0.040	1.790	9.000	64.000	8.000
5	21.400	6.170	215.000	14.000	ND	102.000	0.755	0.060	0.060	1.240	46.000	46.000	12.000
6	7.920	6.190	117.000	4.110	0.410	64.100	0.385	0.020	0.050	0.332	27.000	15.000	10.000
7	16.100	2.840	193.000	13.300	ND	165.000	0.913	ND	0.030	1.110	16.000	45.000	4.000
8	5.200	4.640	85.400	3.450	ND	59.000	0.270	ND	ND	0.274	4.000	27.000	ND
9	9.080	2.200	78.800	6.150	ND	48.300	0.310	ND	ND	0.110	10.000	20.000	13.000
10	30.400	2.650	80.800	25.700	ND	55.600	0.940	0.030	0.050	2.070	22.000	81.000	13.000
11	17.200	4.100	85.400	13.800	ND	70.900	2.030	ND	ND	0.975	21.000	49.000	8.000
Mean	15.982	4.985	119.945	11.719	1.330	80.582	0.966	0.050	0.058	0.963	22.091	41.273	10.100
Median	15.500	4.100	109.000	12.000	1.420	70.900	0.586	0.040	0.050	0.975	21.000	45.000	9.000

**TABLE 6-2 continued**

CREEK													
Rainfall Events (1)	Cu µg/L (3)	Pb µg/L (4)	Zn µg/L (5)	D-Cu µg/L (6)	D-Pb µg/L (7)	D-Zn µg/L (8)	N mg/L (9)	D-P mg/L (10)	T-P mg/L (11)	TKN mg/L (12)	TSS mg/L (13)	COD mg/L (14)	VSS mg/L (15)
1	8.120	5.610	27.8	8.120	0.250	9.710	0.552	0.200	0.240	0.651	3.000	18.000	ND
2	6.950	2.840	29	6.950	ND	16.300	1.880	0.640	0.640	1.140	23.000	21.000	8.000
3	5.210	1.730	19	5.210	ND	13.500	1.730	0.360	0.360	0.593	45.000	16.000	8.000
4	4.810	1.870	18.3	4.810	ND	13.100	2.060	0.340	0.340	0.894	43.000	17.000	10.000
5	4.300	2.240	15	4.300	ND	6.760	1.300	0.310	0.310	0.821	43.000	22.000	13.000
6	6.340	5.170	31	6.340	0.440	19.500	0.310	0.150	0.270	0.913	160.000	32.000	28.000
7	8.000	3.210	27.9	8.000	ND	9.190	0.748	0.190	0.260	1.390	79.000	27.000	21.000
8	6.940	5.840	38.6	6.940	ND	11.600	0.207	0.140	0.230	1.050	130.000	33.000	16.000
9	6.590	4.400	24.3	6.590	ND	10.900	0.180	0.110	0.140	0.203	122.000	25.000	9.000
10	4.060	2.200	16.2	4.060	ND	7.170	1.460	0.220	0.240	0.735	48.000	21.000	9.000
11	4.570	1.360	14.9	4.570	ND	14.600	2.890	0.510	0.510	0.940	31.000	17.000	7.000
Mean	5.990	3.315	23.818	5.990	0.345	12.030	1.211	0.288	0.322	0.848	66.091	22.636	12.900
Median	6.340	2.840	24.300	6.340	0.345	11.600	1.300	0.220	0.270	0.894	45.000	21.000	9.500



**TABLE 6-2 continued**

<b>CULVERT</b>													
Rainfall Events (1)	Cu µg/L (3)	Pb µg/L (4)	Zn µg/L (5)	D-Cu µg/L (6)	D-Pb µg/L (7)	D-Zn µg/L (8)	N mg/L (9)	D-P mg/L (10)	T-P mg/L (11)	TKN mg/L (12)	TSS mg/L (13)	COD mg/L (14)	VSS mg/L (15)
1	6.710	0.210	6.100	4.990	0.098	6.680	0.443	0.070	0.100	0.608	3.000	26.000	3.000
2	10.500	1.000	13.000	6.350	ND	4.080	1.130	0.210	0.210	1.500	16.000	20.000	8.000
3	6.990	ND	ND	6.400	ND	8.810	0.420	0.070	0.070	0.385	ND	15.000	ND
4	6.900	1.320	10.400	4.990	ND	12.700	0.661	0.070	0.070	0.686	11.000	22.000	6.000
5	10.200	ND	6.990	6.730	ND	5.970	0.237	0.070	0.070	0.441	10.000	16.000	8.000
6	3.180	1.810	11.700	2.080	0.160	5.960	0.082	0.040	0.110	0.940	26.000	37.000	9.000
7	3.360	1.340	10.900	2.340	ND	19.500	0.153	0.090	0.110	0.781	17.000	21.000	8.000
8	ND	1.060	13.200	1.350	ND	7.370	0.098	0.020	0.050	0.659	8.000	20.000	4.000
9	5.250	1.690	12.200	2.990	ND	14.900	0.580	ND	0.030	0.388	25.000	37.000	12.000
10	11.100	4.890	32.800	7.200	ND	14.900	1.000	0.090	0.120	1.190	37.000	35.000	12.000
11	7.580	3.210	24.300	6.200	1.050	53.600	1.200	0.170	0.160	0.579	27.000	30.000	8.000
Mean	7.177	1.837	14.159	4.693	0.436	14.043	0.546	0.090	0.100	0.742	18.000	25.364	7.800
Median	6.945	1.340	11.950	4.990	0.160	8.810	0.443	0.070	0.100	0.659	16.500	22.000	8.000

The event mean concentrations were also calculated and will be used in comparisons to prior data (this is also shown in Table 6-2). The U.S. EPA also currently publishes water quality criteria for 157 pollutants of concern, which provides guidance for tribes and states on water quality standards. (U.S. EPA, 2001). Table 6-1 shows criteria available for some of the constituents analyzed in this study and is utilized for comparison. Table 6-1 also depicts some EPA recommended CMC (Criteria Maximum Concentration) and CCC (Criteria Continuous Concentration) water quality criteria for some toxic metals and constituents in freshwater and salt water, which was obtained from the EPA's federal registry (U.S. EPA, 1998). The CMC criteria set by the EPA protects against acute effects that are short term while the CCC protects against chronic effects, which occur from long-term exposure. The details of the results from these comparisons for each of the storm events can be seen more clearly in the graphical form located in Appendix D.

## **6.2 COMPARISON AND CONCLUSIONS**

### **6.2.1 Prior data**

#### *Nationwide data*

Concentration data for water quality constituents collected from a nationwide highway studies done by the Federal Highway Administration in the 1990s (Driscoll et al. 1990).

*University of Texas Highway runoff data*

Data collected by the Center for Research in Water Resources at The University of Texas at Austin form a highway study done on a major Texas highway also in the 1990s (Irish et al. 1995).

*University of North Carolina Charlotte highway runoff assessment data*

In a related study done by Wu et al. (1998) at the University of North Carolina at Charlotte, 3 sites were chosen on a highway segment which were representative of an urban, a semi urban, and a rural setting. The 3 sites which were a bridge deck (urban setting), a pervious roadside shoulder (semi urban), and a non urban highway (rural setting) were monitored for different runoff constituent concentrations and loadings (Wu et al. 1998). The major findings of this study done by Wu et al. (1998) were the following;

- The TSS (Total Suspended Solids) EMCs (Event Mean Concentrations) and loadings of the bridge deck were highest among the 3 sites
- The TSS Event Mean Concentrations doubled the nationwide data (the Texas data and the nationwide data were both used for comparison purposes).
- The Event Mean Concentrations for all the metals were lower than the reported data in the nationwide data.
- The Event Mean Concentrations for the Nitrates and Phosphates were within the ranges of the nationwide data.

The data obtained by Wu et al. (1998) from the bridge deck site in the runoff study, the nationwide data set (Driscoll et al. 1990), and The University of Texas

highway data (Irish et al. 1995) will be used for comparison purposes only for the data obtained during this runoff study. Conclusions will be drawn from these comparisons. Table 6-3 list the event mean concentrations (EMCs) from the nationwide data set, The University of Texas at Austin highway runoff data set, the data obtained by Wu et al. 1998 from the bridge deck runoff and the Event Mean Concentrations from the results obtained from this runoff study for comparison purposes.

The constituents that were analyzed for included the following categories

- Metals (total and dissolved)
- Chemical oxygen demand
- Phosphates (dissolved and total)
- Nitrates (nitrogen and TKN)
- Suspended solids (total and volatile)

It should also be noted that a wider range of parameters were analyzed in this study when making comparisons to prior studies.

#### **6.2.2 ICPMS metals (total and dissolved)**

The analysis of the metals which included copper, zinc, and lead both in the dissolved and total forms presented some interesting yet varied results. However, these trends were consistent from event to event (this can be seen in Appendix D Figures D-3 and D-11). The most notable effect was that the zinc concentrations from the bridge deck were always consistently approximately ten times greater than the concentrations from the culvert and the creek. Also, the dissolved zinc concentrations were approximately 8

times larger than the zinc concentrations from the culvert and the creek. The zinc concentrations were consistently higher than Federal EPA standards (shown in Table 6-1) in about 9 of the 11 events sampled.

The copper concentrations were several magnitudes less than the zinc concentrations. However, the dissolved copper concentrations were significantly higher than the EPA standards in about 8 of the 11 events sampled and the total copper concentrations were also significantly higher than the EPA standards in all the events sampled (this is shown in Appendix D Figures D-1 and D-10). Additionally, in the EMC (Event Mean Concentration), the copper EMC concentration values are significantly less in comparison to the prior data shown in lines 9 and 10 of Table 6-3.

Finally, the lead concentration in the total and dissolved forms were not only magnitudes less than the EPA standards but also magnitudes less in comparison to the prior data shown in lines 13 and 14 of Table 6-3 . Some rainfall events exhibited non-detectable dissolved lead concentrations as shown in Appendix D Figures D-2 and D-9. (Driscoll et al. 1990, Irish et al. 1995, Wu et al. 1998)

**TABLE 6-3. Comparisons of the bridge deck runoff EMCs with prior bridge deck and highway runoff data**

Water quality parameter (1)	Nationwide Data <sup>a</sup>		Univ. of Texas <sup>b</sup> , Austin Highway data (4)	Charlotte <sup>c</sup> Highway Bridge deck site data (5)	Project runoff data		
	Urban highway (2)	Rural highway (3)			Bridge deck (6)	Culvert (7)	Creek (8)
ADT (vehicles/day)	>30,000	>30,000	16,090 - 811,060	25,000	15,000	0.00	0.00
TSS (mg/L)	142	41	67 - 291	215	22.09	18.00	66.09
VSS (mg/L)					10.10	7.80	12.90
COD (mg/L)	114	49	24 - 142	48	41.27	25.36	22.64
N (mg/L)	0.76	0.46	0.56 - 1.0	0.38	0.97	0.55	1.21
TKN (mg/L)	1.87	0.87		1	0.96	0.74	0.85
D-P (mg/L)	0.4	0.16		0.08	0.05	0.09	0.29
T-P (mg/L)			0.08 -0.41	0.2	0.06	0.10	0.32
Cu (µg/L)	54	22	6.0 - 49	15	15.98	7.18	5.99
D-Cu (µg/L)					11.72	4.69	5.99
Zn (µg/L)					119.95	14.16	23.82
D-Zn (µg/L)					80.58	14.04	12.03
Pb (µg/L)	400	80	16 - 123	15	4.99	1.84	3.32
D-Pb (µg/L)					1.33	0.44	0.35

<sup>a</sup>Driscoll et al. (1990).

<sup>b</sup>Irish et al. (1995).

<sup>c</sup>Wu et al. (1998).

### **6.2.3 Chemical oxygen demand (COD)**

The highest COD concentrations were exhibited in only 5 of the 11 rainfall events (this can be seen Appendix D Figure D-5). Additionally, the highest COD concentrations were from the bridge deck runoff and were more than twice the magnitude compared to the culvert and creek COD concentrations.

The event mean concentrations revealed that the bridge deck COD concentrations were significantly higher than the culvert and creek COD concentrations as shown in line 4 of Table 6-3. Additionally, in comparison to the prior data, the bridge deck COD event mean concentration alone was within the range of the University of Texas highway data but significantly less than the nationwide data. The culvert and the creek chemical oxygen demand event mean concentration data were significantly less in comparison to all the prior data. (Driscoll et al. 1990, Irish et al. 1995, Wu et al. 1998).

### **6.2.4 Phosphates (dissolved and total)**

The data obtained from the analysis for the phosphates, both total and dissolved exhibited almost identical and similar trends as can be seen in Appendix D Figures D-6 and D12. The creek phosphate concentrations were significantly higher than the phosphate concentrations of the bridge and the culvert. The bridge deck phosphate concentrations, however, was the lowest of the 3. It was also noted that the Phosphate concentrations were also significantly higher in magnitude to the EPA standards. Additionally, the EMC concentration of the creek was significantly higher than the University of Texas and Charlotte highway bridge deck data and within the range of the

nationwide data shown in lines 7 and 8 of Table 6-3. (Driscoll et al. 1990, Irish et al. 1995, Wu et al. 1998).

#### **6.2.5 Nitrates (total nitrogen and TKN)**

While no significant consistency or noticeable trend were exhibited by the total nitrogen or TKN data, several concentrations were noticeably above the EPA standards. The total nitrogen concentrations also exceeded EPA standards as shown in Appendix D Figures D-4 and D-7. Additionally, the nitrogen event mean concentration was within the range of the nationwide data and exceeded (but not substantially) the prior University of Texas and Charlotte highway data shown in lines 5 and 6 of Table 6-3. The TKN event mean concentration was significantly lower than the nationwide data but also lower than the Charlotte highway bridge deck data. (Driscoll et al. 1990, Irish et al. 1995, Wu et al. 1998).

#### **6.2.6 Suspended solids (total and volatile)**

From the analysis data obtained for the total suspended solids (TSS) and the volatile suspended solids (VSS), there were no consistency or noticeable trends exhibited as can be seen in Appendix D Figures D-8 and D-13. However, in the examination of the event mean concentrations, the volatile suspended solid (VSS) event mean concentration was highest in the creek but not significantly higher than the bridge deck or the culvert event mean concentration. As shown in lines 2 and 3 of Table 6-3, the total suspended solid (TSS) event mean concentration was also highest in the creek, however it was significantly higher than the bridge deck and the culvert TSS event mean



concentrations. Additionally, all 3 TSS concentrations were all very low in comparison to the prior data. (Driscoll et al. 1990, Irish et al. 1995, Wu et al. 1998).

### **6.3 SUMMARY**

From the highlights of this research study, it can be surmised that the chosen bridge deck exhibited relatively low total suspended solids and volatile suspended solids concentrations. Some of the metal concentrations (zinc in particular) were high and exceeded EPA standards. However, the lead concentrations from the bridge deck were extremely low and even non-detect in some events. Additionally, the phosphates exhibited the highest concentration in the creek and far exceeded EPA standards and the lowest phosphates concentrations were found in the bridge deck runoff. Finally, several nitrates concentration were noticeably above EPA standards but low in comparison to the prior and nationwide data set.

It can be concluded that bridge decks can be considered a non point source that produce noticeable amounts of constituent concentrations and loadings on receiving waters, which are sometimes more than those from highway roads.

## **7. PROJECT ACCOMPLISHMENTS AND RECOMMENDATIONS FOR FUTURE WORK**

The main accomplishments of this runoff assessment project were the following:

1. Acquisition of real time updated flow and level data using current data acquisition methods for the southeast Texas region,
2. Rainfall data collection for the southeast Texas region,
3. Analysis and characterization of the quantity and quality of runoff for chosen priority constituents on a bridge deck located in fresh and brackish water coastal margin interface, and
4. Better understanding of effects of bridge decks on receiving water quality.

However, the main opportunity for future work that was determined lies in the fact that the main sources of the elevated total and dissolved metal concentrations were not totally determined. It was, however, postulated that the old galvanized metal railings were the main sources of these concentrations. Therefore, future work recommendations might include the isolation of the metal railing of the bridge deck as a sole source (to determine if it is a source) and the determination of a reason behind the relatively high suspended solid and other constituent loadings by continued progressive runoff sampling.

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## **APPENDIX A**

### **PROGRAMMING PROCEDURES**

Note: The options underlined were chosen for the operation

## A-1: Culvert Flow Meter Programming Steps

### CUVERT: FLOWMETER #1

programming sheet

#### PROGRAM-

- LEVEL UNITS OF MEASUREMENT- FT...IN...M...MM...NOT MEASURED
- FLOW RATE UNITS OF MEASURE- GPS...GPM...GPH...MDG...CFS...CFM  
...CFH...CFD...LPS...M3S...M3M...M3H  
...AFD...NOT MEASURED
- TOTALIZED VOLUME UNITS OF MEASURE- GAL...MGAL...CF...L...M3...AF
- RAINFALL UNITS OF MEASURE- INCHES...MM...CF...L...M3...AF
- pH UNITS OF MEASURE- pH...NOT MEASURED
- D.O. UNITS- MG/L...PPM...NOT MEASURED
- TEMPERATURE UNITS- DEG F...DEG C...NOT MEASURED
- YSI 600 CONNECTED- YES...NO
- YSI 600 pH UNITS OF MEASURE- pH...NOT MEASURED
- YSI 600 DO UNITS OF MEASURE- MG/L...NOT MEASURED
- YSI 600 CONDUCTIVITY PARAMETERS- YSI SPCOND...YSI SALINITY...YSI  
CONDUCTIVITY...YSI TDS...  
NOT MEASURED
- TEMPERATURE COEFFICIENT- \_\_\_\_%
- TDS SCALE FACTOR- \_\_\_\_
- YSI 600 TEMPERATURE UNITS- <sup>0</sup>F...<sup>0</sup>C...NOT MEASURED
- Q-
- FLOW CONVERSION TYPE- WIER/FLUME...EQUATION...MANNING  
...DATAPOINTS...METERING INSERTS
- TYPE OF DEVICE-
  - WIER/FLUME-
    - WIER-
      - V-NOTCH-
        - SELECT V-NOTCH WEIR ANGLE (IN DEGREES)-  
22.5...30...45...60...90...120
      - RECTANGULAR-
        - END CORRECTIONS- YES...NO
        - ENTER CREST LENGTH-\_\_\_\_.\_\_\_\_ FT/M
      - CIPOLLETTI-
        - ENTER CREST LENGTH-\_\_\_\_:\_\_\_\_ FT/M
    - FLUME-
      - PARSHALL  
1"...2"...3"...6"...9"...1.0'...1.5'...2.0'...3'...4'...5'...6'...8'...  
10'...12'
      - PALMER-BOWLUS- 4"...6"...8"...9"...10"...12"...15"...18"...  
21"...24"...27"...30"...48"
      - LEOPOLD-LAGCO- 4"...6"...8"...10"...12"...15"...18"...21"...  
24"...30"
      - HS- 0.4'...0.5'...0.6'...0.8'...1.0'
      - H- 0.5'...0.75'...1'...2'...2.5'...3'...4.5'
      - HL- 2.0'...2.5'...3.0'...3.5'...4.0'
      - TRAPEZOIDAL- LG60V...2"45WSC...12"45SRCRC
  - EQUATION-
    - ENTER EQUATION UNITS-  $Q = \text{____} H^{\text{____}} + \text{____} H^{\text{____}}$
  - MANNING FORMULA CHANNEL SHAPE- ROUND PIPE...U-  
CHANNEL...RECTANGLE...  
TRAPEZOIDAL
    - ROUND PIPE-
      - SLOPE = 0.00010 ROUGH = 0.0050
      - DIAMETER = 4.00 FEET/METERS
    - U-CHANNEL-
      - SLOPE = \_\_\_\_ ROUGH = \_\_\_\_
      - WIDTH = \_\_\_\_ FEET/METERS
    - RECTANGULAR-
      - SLOPE = \_\_\_\_ ROUGH = \_\_\_\_

- WIDTH = . . . FEET/METERS
- TRAPEZOIDAL-
  - SLOPE = . . . ROUGH = . . .
  - TOP WIDTH = . . . FEET/METERS
  - BOTTOM WIDTH = . . . FEET/METERS
- DATA POINTS-
  - MAX HEAD- 4.00 FT
  - FLOW RATE AT MAX HEAD- 37.45 CFS
  - DATA TYPE FOR EXT ANALOG OUTPUT- LEVEL
    - EXTERNAL ANALOG OUTPUT-
      - 4 MA = 0.100 FT
      - 20 MA = 3.280 FT
  - PARAMETER TO ADJUST- NONE
  - FLOW TOTALIZER: 0001876920 CF  
PRESS 'ENTER'
  - RESET FLOW TOTALIZER- YES...NO
  - ENABLE TOTALIZER: 0001876880 CF  
PRESS 'ENTER'
  - RESET SAMPLE ENABLE TOTALIZER- YES...NO
  - SAMPLER PACING- ENABLE...DISABLE
  - SAMPLER ENABLE MODE- ENABLE...DISABLE
    - CONDITION LEVEL...FLOWRATE...RAINFALL
    - LEVEL GREATER THAN...LESS THAN...  
RATE OF CHANGE
  - 0.1000 FT
  - OPERATOR OR...AND...DONE
    - CONDITION TRUE PACING INTERVAL 15 MIN (0-120 MIN)
    - CONDITION FALSE PACING INTERVAL 120 MIN (0-120 MIN)
    - WHEN ENABLE CONDITION IS NO LONGER MET DISABLE SAMPLER...KEEP  
ENABLED
    - ENABLE CURRENTLY LATCHED, RESET? YES...NO
    - PLOTTER ON/OFF WITH ENABLE? YES...NO
  - PLOTTER SPEED- OFF...1/2"/HR...1"/HR...2"/HR...4"/HR
  - REPORT GENERATOR A- ON...OFF  
HOURS...DAYS...MONTHS
    - REPORT A DURATION TO BE IN-
    - REPORT A DURATION 30 DAYS
    - PRINT FIRST REPORT A AT-  
YR: \_\_\_\_ MONTH: \_\_\_\_ DAY: \_\_\_\_ HR: \_\_\_\_ MIN: \_\_\_\_
  - REPORT GENERATOR B- ON...OFF  
HOURS...DAYS...MONTHS
    - REPORT A DURATION TO BE IN-
    - REPORT A DURATION \_ DAYS
    - PRINT FIRST REPORT A AT-  
YR: \_\_\_\_ MONTH: \_\_\_\_ DAY: \_\_\_\_ HR: \_\_\_\_ MIN: \_\_\_\_
  - PRINT FLOW METER HISTORY- YES...NO
  - CLEAR HISTORY- YES...NO
- SETUP-
  - SET CLOCK-
    - \_\_\_\_-\_\_\_\_-\_\_\_\_ :\_\_\_\_ (YYYY-MM-DD HH:MM)
  - SITE ID-
    - 013 (\_\_\_\_)
  - MEASUREMENT SETUP-
    - LEVEL READING INTERVAL-
    - DO/PH READING INTERVAL-
    - YSI 600 READING INTERVAL-
    - PURGE INTERVAL-
      - PURGE INTERVAL- 5MIN...10MIN...15MIN...30MIN...1HR
      - PURGE DURATION- 1/2SEC...1SEC...2SEC...3SEC
    - SUPERBUBBLER MODE- ON...OFF
  - STATUS-
    - MODEL 4230 ID 1052403296
    - HW REV: B0 SW REV 02.24
    - SUPPLY VOLTAGE: 12.219
    - PUMP DUTY CYCLE: 6.3 %
  - ENABLE/ALARM HYSTERESIS-

- LEVEL ENABLE/ALARM HYSTERESIS- 0.1000 FT
  - FLOW ENABLE/ALARM HYSTERESIS- 0.9360 CFS
  - TEMPERATURE HYSTERESIS-
  - pH HYSTERESIS-
  - DO HYSTERESIS-
- OPTIONAL OUTPUTS-
  - ANALOG OUTPUT-
    - EXTERNAL 4-20MA...RANGE...  
SMOOTHING...MANUAL CONTROL
    - EXTERNAL 4-20MA-
    - RANGE-
    - SMOOTHING-
      - ANALOG OUTPUT SMOOTHING OFF...15SEC...30SEC...1MIN
    - MANUAL CONTROL-
  - SERIAL OUTPUT-
  - ALARM BOX-
- REPORT SETUP-
  - REPORT A-
    - FLOW-
      - LEVEL IN REPORT- YES...NO
      - FLOW RATE IN REPORT- YES...NO
      - RAINFALL IN REPORT- YES...NO
    - DO/pH-
      - pH OR DO IN REPORT- YES...NO
      - TEMPERATURE IN REPORT- YES...NO
    - YSI 600-
      - YSI DATA IN REPORT- YES...NO
    - SAMPLE HISTORY-
      - SAMPLE HISTORY IN REPORT- YES...NO
    - FLOW METER HISTORY-
      - FLOW METER HISTORY IN REPORT- YES...NO
  - REPORT B-
    - FLOW-
      - LEVEL IN REPORT- YES...NO
      - FLOW RATE IN REPORT- YES...NO
      - RAINFALL IN REPORT- YES...NO
    - DO/pH-
      - pH OR DO IN REPORT- YES...NO
      - TEMPERATURE IN REPORT- YES...NO
    - YSI 600-
      - YSI DATA IN REPORT- YES...NO
    - SAMPLE HISTORY-
      - SAMPLE HISTORY IN REPORT- YES...NO
    - FLOW METER HISTORY-
      - FLOW METER HISTORY IN REPORT- YES...NO
- LCD BACKLIGHT- KEYPRESS TIMEOUT...CONTINUOUS...OFF
- LANGUAGE- ENGLISH...SECOND LANGUAGE
- PROGRAM LOCK- ON...OFF
- PROGRAM-



## A-2: Bridge / Flume Flow Meter Programming Steps

### FLUME: FLOWMETER #2

### programming sheet

#### PROGRAM-

- LEVEL UNITS OF MEASUREMENT- FT...IN...M...MM...NOT MEASURED
- FLOW RATE UNITS OF MEASURE- GPS...GPM...GPH...MDG...CFS...CFM  
...CFH...CFD...LPS...M3S...M3M...M3H  
...AFD...NOT MEASURED
- TOTALIZED VOLUME UNITS OF MEASURE- GAL...MGAL...CF...L...M3...AF
- RAINFALL UNITS OF MEASURE- INCHES...MM...CF...L...M3...AF...  
NOT MEASURED
- pH UNITS OF MEASURE- pH...NOT MEASURED
- D.O. UNITS- MG/L...PPM...NOT MEASURED
- TEMPERATURE UNITS- DEG F...DEG C...NOT MEASURED
- YSI 600 CONNECTED- YES...NO
- YSI 600 pH UNITS OF MEASURE- pH...NOT MEASURED
- YSI 600 DO UNITS OF MEASURE- MG/L...NOT MEASURED
- YSI 600 CONDUCTIVITY PARAMETERS- YSI SPCOND...YSI SALINITY...YSI  
CONDUCTIVITY...YSI TDS...  
NOT MEASURED  
\_\_\_\_%
- TEMPERATURE COEFFICIENT- \_\_\_\_\_
- TDS SCALE FACTOR- \_\_\_\_\_
- YSI 600 TEMPERATURE UNITS- \_\_\_\_\_
- Q- \_\_\_\_\_
- FLOW CONVERSION TYPE- WIER/FLUME...EQUATION...MANNING  
...DATAPOINTS...METERING INSERTS
- TYPE OF DEVICE-
  - WIER/FLUME-
    - WIER-
      - V-NOTCH-
        - SELECT V-NOTCH WEIR ANGLE (IN DEGREES)-  
22.5...30...45...60...90...120
      - RECTANGULAR-
        - END CORRECTIONS- YES...NO
        - ENTER CREST LENGTH-  
\_\_\_\_ FT/M
      - CIPOLLETTI-
        - ENTER CREST LENGTH-  
\_\_\_\_:\_\_\_\_ FT/M
    - FLUME-
      - PARSHALL- PARSHALL...PALMER-BOWLUS...  
LEOPOLD-LAGCO...HS...H...HL...  
TRAPEZOIDAL  
1"...2"...3"...6"...9"...1.0'...1.5'...2.0'...  
3'...4'...5'...6'...8'...10'...12'
      - PALMER-BOWLUS- 4"...6"...8"...9"...10"...12"...15"...18"...  
21"...24"...27"...30"...48"
      - LEOPOLD-LAGCO- 4"...6"...8"...10"...12"...15"...18"...21"...  
24"...30"
      - HS- 0.4'...0.5'...0.6'...0.8'...1.0'
      - H- 0.5'...0.75'...1'...2'...2.5'...3'...4.5'
      - HL- 2.0'...2.5'...3.0'...3.5'...4.0'
      - TRAPEZOIDAL- LG60V...2"45WSC...12"45SRCRC
  - EQUATION-
    - ENTER EQUATION UNITS-  $Q = \frac{1.49}{n} A R^{2/3} S^{1/2}$
  - MANNING FORMULA CHANNEL SHAPE- ROUND PIPE...U-CHANNEL...  
RECTANGLE...TRAPEZOIDAL
    - ROUND PIPE-
      - SLOPE = \_\_\_\_\_ ROUGH = \_\_\_\_\_
      - DIAMETER = \_\_\_\_\_ FEET/METERS
    - U-CHANNEL-
      - SLOPE = \_\_\_\_\_ ROUGH = \_\_\_\_\_

- WIDTH =      FEET/METERS
  - RECTANGULAR-
    - SLOPE =      ROUGH =
    - WIDTH =      FEET/METERS
  - TRAPEZOIDAL-
    - SLOPE =      ROUGH =
    - TOP WIDTH =      FEET/METERS
    - BOTTOM WIDTH =      FEET/METERS
  - DATA POINTS-
- MAX HEAD- 0.5000 FT
- FLOW RATE AT MAX HEAD- 0.3473 CFS
- DATA TYPE FOR EXT ANALOG OUTPUT- LEVEL
  - EXTERNAL ANALOG OUTPUT-
    - 4 MA = 0.100 FT
    - 20 MA = 3.280 FT
- PARAMETER TO ADJUST- NONE
- FLOW TOTALIZER: 0001876920 CF  
PRESS 'ENTER'
- RESET FLOW TOTALIZER- YES...NO
- ENABLE TOTALIZER: 0001876880 CF  
PRESS 'ENTER'
- RESET SAMPLE ENABLE TOTALIZER- YES...NO
- SAMPLER PACING- ENABLE...DISABLE
- SAMPLER ENABLE MODE- ENABLE...DISABLE
  - CONDITION LEVEL...FLOWRATE...RAINFALL
  - LEVEL GREATER THAN...LESS
  - THAN...
- 0.0200 FT
  - OPERATOR
  - CONDITION TRUE PACING INTERVAL
  - CONDITION FALSE PACING INTERVAL
  - WHEN ENABLE CONDITION IS NO LONGER MET  
ENABLED
  - ENABLE CURRENTLY LATCHED, RESET?
  - PLOTTER ON/OFF WITH ENABLE?
- PLOTTER SPEED- OFF...1/2"/HR...1"/HR...2"/HR...4"/HR
- REPORT GENERATOR A- ON...OFF
  - REPORT A DURATION TO BE IN-
  - REPORT A DURATION 30 DAYS
  - PRINT FIRST REPORT A AT-  
YR:      MONTH:      DAY:      HR:      MIN:
- REPORT GENERATOR B- ON...OFF
  - REPORT A DURATION TO BE IN-
  - REPORT A DURATION 30 DAYS
  - PRINT FIRST REPORT A AT-  
YR:      MONTH:      DAY:      HR:      MIN:
- PRINT FLOW METER HISTORY- YES...NO
- CLEAR HISTORY- YES...NO
- SETUP-
  - SET CLOCK-
    - -    -         :     (YYYY-MM-DD HH:MM)
  - SITE ID- ( )
    - ?
  - MEASUREMENT SETUP-
    - LEVEL READING INTERVAL-
    - DO/PH READING INTERVAL-
    - YSI 600 READING INTERVAL-
    - PURGE INTERVAL-
      - PURGE INTERVAL- 5MIN...10MIN...15MIN...30MIN...1HR
      - PURGE DURATION- 1/2SEC...1SEC...2SEC...3SEC
    - SUPERBUBBLER MODE- ON...OFF
  - STATUS-
    - MODEL 4230 ID 3687578656

- HW REV: B0 SW REV 02.24
  - SUPPLY VOLTAGE: 13.056
  - PUMP DUTY CYCLE: 1.3%
- ENABLE/ALARM HYSTERESIS-
  - LEVEL ENABLE/ALARM HYSTERESIS- 0.0200 FT
  - FLOW ENABLE/ALARM HYSTERESIS- 0.01390 CFS
  - TEMPERATURE HYSTERESIS-
  - pH HYSTERESIS-
  - DO HYSTERESIS-
- OPTIONAL OUTPUTS-
  - ANALOG OUTPUT-
    - EXTERNAL 4-20MA...RANGE...  
SMOOTHING...MANUAL CONTROL
    - EXTERNAL 4-20MA-
      - RANGE-
      - SMOOTHING-
        - ANALOG OUTPUT SMOOTHING OFF...15SEC...30SEC...1MIN
      - MANUAL CONTROL-
    - SERIAL OUTPUT-
    - ALARM BOX-
- REPORT SETUP-
  - REPORT A-
    - FLOW-
      - LEVEL IN REPORT- YES...NO
      - FLOW RATE IN REPORT- YES...NO
      - RAINFALL IN REPORT- YES...NO
    - DO/pH-
      - pH OR DO IN REPORT- YES...NO
      - TEMPERATURE IN REPORT- YES...NO
    - YSI 600-
      - YSI DATA IN REPORT- YES...NO
    - SAMPLE HISTORY-
      - SAMPLE HISTORY IN REPORT- YES...NO
    - FLOW METER HISTORY-
      - FLOW METER HISTORY IN REPORT- YES...NO
  - REPORT B-
    - FLOW-
      - LEVEL IN REPORT- YES...NO
      - FLOW RATE IN REPORT- YES...NO
      - RAINFALL IN REPORT- YES...NO
    - DO/pH-
      - pH OR DO IN REPORT- YES...NO
      - TEMPERATURE IN REPORT- YES...NO
    - YSI 600-
      - YSI DATA IN REPORT- YES...NO
    - SAMPLE HISTORY-
      - SAMPLE HISTORY IN REPORT- YES...NO
    - FLOW METER HISTORY-
      - FLOW METER HISTORY IN REPORT- YES...NO
- LCD BACKLIGHT- KEYPRESS
- TIMEOUT...CONTINUOUS...OFF
- LANGUAGE- ENGLISH...SECOND LANGUAGE
- PROGRAM LOCK- ON...OFF
- PROGRAM-

### A-3: Bridge / Flume Sampler Programming Steps

#### FLUME SAMPLER ID#1

#### programming sheet

##### PROGRAM-

- PACED SAMPLING- ( TIME, FLOW)
  - TIME-
    - SAMPLE EVERY \_ HRS \_ MINS
    - \_ COMPOSITE SAMPLES (0-500)
    - SAMPLE VOLUME OF \_ ML (10-100)
    - CALIBERATE SAMPLE VOLUME? ( YES, NO )
      - PRESS MANUAL SAMPLE KEY WHEN READY...
      - ...MANUAL SAMPLE...
      - ...RINSING... 0 OF 1
      - ...MANUAL SAMPLE...
      - PUMPING100ml
      - 100 ml VOLUME DELIVERED
    - CALIBERATE SAMPLE VOLUME? ( YES, NO )
    - ENTER START TIME? ( YES, NO )
    - \_ : \_ : \_ ( HH:MM DD:MM MON )
    - \_ STOP OR RESUME TIME ( 0-24 )
  - FLOW-
    - SAMPLE EVERY 1 PULSES (1-9999 )
    - 100 COMPOSITE SAMPLES (0-500)
    - SAMPLE VOLUME OF 100 ML (10-100)
    - CALIBERATE SAMPLE VOLUME? ( YES, NO )
      - PRESS MANUAL SAMPLE KEY WHEN READY...
      - ...MANUAL SAMPLE...
      - ...RINSING... 0 OF 1
      - ...MANUAL SAMPLE...
      - PUMPING100ml
      - 100 ml VOLUME DELIVERED
    - CALIBERATE SAMPLE VOLUME? ( YES, NO )
    - ENTER START TIME? ( YES, NO )
    - \_ : \_ : \_ ( HH:MM DD:MM MON )
    - 0 STOP OR RESUME TIME ( 0-24 )
- PROGRAMING SEQUENCE COMPLETE

##### CONFIGURE-

(SELECT OPTIONS↔ )

- SET CLOCK-
  - HH:MM DD-MM-YY
- BOTTLES AND SIZES-
  - SAMPLER ( PORTABLE, REFRIG.)
  - BOTTLES- [ 1,4,12,24 ]
  - BOTTLE VOLUME IS 10000 ML ( \_ )
  - 10000 ML! ... ARE YOU SURE? ( YES, NO )
- SUCTION LINE-
  - SUCTION LINE ID IS 3/8 [ 1/4, 3/8 ]
  - SUCTION LINE IS TEFLON [ VINYL, TEFLON ]
  - SUCTION LINE LENGTH IS 49 ( 3-99 )
- LIQUID DETECTOR-
  - LIQUID DETECTOR ( ENABLE, DISABLE )
  - 0 RINSE CYCLES ( 0-3 )
  - ENTER HEAD MANUALLY? ( YES, NO )
  - RETRY UPTO 1 TIMES WHEN SAMPLING ( 0-3 )
- PROGRAMMING MODE- ( BASIC, EXTENDED )
  - BASIC-
    - CALIBERATE SAMPLE- ( ENABLE, DISABLE )
      - CALIBERATE SAMPLER
      - 1 MINUTE DELAY TO START (0-9999)
    - START TIME DELAY
  - EXTENDED-

- LOAD STORED PROGRAM-
    - LOAD PROGRAM [ #1, #2, #3, NONE]
  - SAVE CURRENT PROGRAM-
    - SAVE PROGRAM AS [ #1, #2, #3, NONE]
  - FLOW MODE SAMPLING-
    - TAKE SAMPLE AT START TIME? ( YES, NO)
  - NONUNIFORM TIME-
    - ENTER INTERVALS IN ( CLOCK TIME, MINUTES)
  - SAMPLING STOP RESUME- ( ENABLE, DISABLE)
    - SAMPLE AT STOP? ( YES, NO)
    - SAMPLE AT RESUME? ( YES, NO)
  - ENABLE PIN-
    - MASTER/SLAVE MODE? ( YES, NO)
    - SAMPLE UPON DISABLE? ( YES, NO)
    - SAMPLE UPON ENABLE? ( YES, NO)
    - RESET SAMPLE INTERVAL? ( YES, NO)
    - INHIBIT COUNTDOWN? ( YES, NO)
  - EVENT MARK-
    - EVENT MARK- (CONTINUOUS SIGNAL, PULSE )
    - AT THE BEGINNING OF- ( PURGE, FWD PUMPING)
  - PURGE COUNTS-
    - 200 PRE-SAMPLE COUNTS (0-9999)
    - 200 POST-SAMPLE COUNTS (0-9999)
  - TUBING LIFE-
    - 0 PUMP COUNTS WARNING AT 9000000
    - RESET PUMP COUNTER? ( YES, NO)
    - 9000000 PUMP COUNTS TO WARNING
  - PROGRAM LOCK-
    - PROGRAM LOCK (ENABLE, DISABLE)
  - SAMPLER ID-
    - SAMPLER ID IS 0000000001 ( \_\_\_\_\_ )
  - RUN DIAGNOSTICS-
    - SOFTWARE REVISION #4.5
    - TESTING 'RAM'
    - 'RAM' PASSED TEST
    - TESTING 'ROM'
    - 'ROM' PASSED TEST
    - ABCDEFGHIJKLMNOPQRST
    - UVWXYZ[Y]^\_ 'abcdefgh
    - PUMP COUNT TEST... OFF/ON = 105
  - TEST DISTRIBUTOR-
    - REINITIALIZE?- ( YES/NO )
  - EXIT CONFIGURATION- ( YES/NO )
- START SAMPLING-

## A-4: Creek Sampler Programming Steps

### CREEK SAMPLER ID#2

### programming sheet

#### PROGRAM-

- PACED SAMPLING- ( TIME, FLOW)
  - TIME-
    - SAMPLE EVERY \_ HRS \_ MINS
    - \_ COMPOSITE SAMPLES (0-500)
    - SAMPLE VOLUME OF \_ ML (10-100)
    - CALIBERATE SAMPLE VOLUME? ( YES, NO )
      - PRESS MANUAL SAMPLE KEY WHEN READY...
      - ...MANUAL SAMPLE...
      - ...RINSING... 0 OF 1
      - ...MANUAL SAMPLE...
      - PUMPING100ml
      - 100 ml VOLUME DELIVERED
    - CALIBERATE SAMPLE VOLUME? ( YES, NO )
    - ENTER START TIME? ( YES, NO )
    - \_ : \_ : \_ ( HH:MM DD:MM MON )
    - \_ STOP OR RESUME TIME ( 0-24 )
  - FLOW-
    - SAMPLE EVERY 1 PULSES (1-9999 )
    - 100 COMPOSITE SAMPLES (0-500)
    - SAMPLE VOLUME OF 100 ML (10-100)
    - CALIBERATE SAMPLE VOLUME? ( YES, NO )
      - PRESS MANUAL SAMPLE KEY WHEN READY...
      - ...MANUAL SAMPLE...
      - ...RINSING... 0 OF 1
      - ...MANUAL SAMPLE...
      - PUMPING100ml
      - 100 ml VOLUME DELIVERED
    - CALIBERATE SAMPLE VOLUME? ( YES, NO )
    - ENTER START TIME? ( YES, NO )
    - \_ : \_ : \_ ( HH:MM DD:MM MON )
    - 0 STOP OR RESUME TIME ( 0-24 )
- PROGRAMING SEQUENCE COMPLETE

#### CONFIGURE-

- SET CLOCK- (SELECT OPTIONS↔ )
  - HH:MM DD-MM-YY
- BOTTLES AND SIZES-
  - SAMPLER (PORTABLE, REFRIG.)
  - BOTTLES- [ 1,4,12,24 ]
  - BOTTLE VOLUME IS 10000 ML ( \_\_\_\_\_ )
  - 10000 ML! ... ARE YOU SURE? ( YES, NO )
- SUCTION LINE-
  - SUCTION LINE ID IS 3/8 [ 1/4, 3/8 ]
  - SUCTION LINE IS TEFLON [ VINYL, TEFLON ]
  - SUCTION LINE LENGTH IS 14 ( 3-99 )
- LIQUID DETECTOR-
  - LIQUID DETECTOR ( ENABLE, DISABLE )
  - 0 RINSE CYCLES ( 0-3 )
  - ENTER HEAD MANUALLY? ( YES, NO )
  - RETRY UPTO 1 TIMES WHEN SAMPLING ( 0-3 )
- PROGRAMMING MODE- ( BASIC, EXTENDED )
  - BASIC-
    - CALIBERATE SAMPLE- ( ENABLE, DISABLE )
      - CALIBERATE SAMPLER
      - 1 MINUTE DELAY TO START (0-9999)
    - START TIME DELAY

- EXTENDED-
      - LOAD STORED PROGRAM-
        - LOAD PROGRAM [ #1, #2, #3, NONE]
      - SAVE CURRENT PROGRAM-
        - SAVE PROGRAM AS [ #1, #2, #3, NONE]
      - FLOW MODE SAMPLING-
        - TAKE SAMPLE AT START TIME? ( YES, NO)
      - NONUNIFORM TIME-
        - ENTER INTERVALS IN ( CLOCK TIME, MINUTES)
      - SAMPLING STOP RESUME-
        - SAMPLE AT STOP? ( ENABLE, DISABLE)
        - SAMPLE AT RESUME? ( YES, NO)
  - ENABLE PIN-
    - MASTER/SLAVE MODE? ( YES, NO)
    - SAMPLE UPON DISABLE? ( YES, NO)
    - SAMPLE UPON ENABLE? ( YES, NO)
    - RESET SAMPLE INTERVAL? ( YES, NO)
    - INHIBIT COUNTDOWN? ( YES, NO)
  - EVENT MARK-
    - EVENT MARK- (CONTINUOUS SIGNAL, PULSE)
    - AT THE BEGINNING OF- ( PURGE, FWD PUMPING)
  - PURGE COUNTS-
    - 200 PRE-SAMPLE COUNTS (0-9999)
    - 200 POST-SAMPLE COUNTS (0-9999)
  - TUBING LIFE-
    - 0 PUMP COUNTS WARNING AT 9000000
    - RESET PUMP COUNTER? ( YES, NO)
    - 9000000 PUMP COUNTS TO WARNING
  - PROGRAM LOCK-
    - PROGRAM LOCK (ENABLE, DISABLE)
  - SAMPLER ID-
    - SAMPLER ID IS 0000000002 ( \_\_\_\_\_ )
  - RUN DIAGNOSTICS-
    - SOFTWARE REVISION #4.5
    - TESTING 'RAM'
    - 'RAM' PASSED TEST
    - TESTING 'ROM'
    - 'ROM' PASSED TEST
    - ABCDEFGHIJKLMNOPQRST
    - UVWXYZ[Y]^\_'abcdefgh
    - PUMP COUNT TEST... OFF/ON = 105
  - TEST DISTRIBUTOR-
    - REINITIALIZE?- ( YES/NO )
  - EXIT CONFIGURATION-
    - REINITIALIZE?- ( YES/NO )
- START SAMPLING-

## A-5: Culvert Sampler Programming Steps

### CULVERT SAMPLER: ID#3

### programming sheet

#### PROGRAM-

- PACED SAMPLING- ( TIME, FLOW)
  - TIME-
    - SAMPLE EVERY \_ HRS \_ MINS
    - \_ COMPOSITE SAMPLES (0-500)
    - SAMPLE VOLUME OF \_ ML (10-100)
    - CALIBERATE SAMPLE VOLUME? ( YES, NO )
      - PRESS MANUAL SAMPLE KEY WHEN READY...
      - ...MANUAL SAMPLE...
      - ...RINSING... 0 OF 1
      - ...MANUAL SAMPLE...
      - PUMPING 100ml
      - 100 ml VOLUME DELIVERED
    - CALIBERATE SAMPLE VOLUME? ( YES, NO )
    - ENTER START TIME? ( YES, NO )
    - \_ : \_ : \_ ( HH:MM DD:MM MON )
    - \_ STOP OR RESUME TIME (0-24)
  - FLOW-
    - SAMPLE EVERY 1 PULSES (1-9999)
    - 100 COMPOSITE SAMPLES (0-500)
    - SAMPLE VOLUME OF 100 ML (10-100)
    - CALIBERATE SAMPLE VOLUME? ( YES, NO )
      - PRESS MANUAL SAMPLE KEY WHEN READY...
      - ...MANUAL SAMPLE...
      - ...RINSING... 0 OF 1
      - ...MANUAL SAMPLE...
      - PUMPING 100ml
      - 100 ml VOLUME DELIVERED
    - CALIBERATE SAMPLE VOLUME? ( YES, NO )
    - ENTER START TIME? ( YES, NO )
    - \_ : \_ : \_ ( HH:MM DD:MM MON )
    - 0 STOP OR RESUME TIME (0-24)
- PROGRAMING SEQUENCE COMPLETE

#### CONFIGURE-

(SELECT OPTIONS↔→)

- SET CLOCK-
  - HH:MM DD-MM-YY
- BOTTLES AND SIZES-
  - SAMPLER ( PORTABLE, REFRIG.)
  - BOTTLES- [ 1, 4, 12, 24 ]
  - BOTTLE VOLUME IS 10000 ML ( \_\_\_\_\_ )
  - 10000 ML! ... ARE YOU SURE? ( YES, NO )
- SUCTION LINE-
  - SUCTION LINE ID IS 3/8 [ 1/4, 3/8 ]
  - SUCTION LINE IS TEFLON [ VINYL, TEFLON ]
  - SUCTION LINE LENGTH IS 38 ( 3-99 )
- LIQUID DETECTOR-
  - LIQUID DETECTOR ( ENABLE, DISABLE )
  - 0 RINSE CYCLES (0-3)
  - ENTER HEAD MANUALLY? ( YES, NO )
  - RETRY UPTO 1 TIMES WHEN SAMPLING (0-3)
- PROGRAMMING MODE- ( BASIC, EXTENDED )
  - BASIC-
    - CALIBERATE SAMPLE- ( ENABLE, DISABLE )
      - CALIBERATE SAMPLER
      - 1 MINUTE DELAY TO START (0-9999)
    - START TIME DELAY



- EXTENDED-
    - LOAD STORED PROGRAM-
      - LOAD PROGRAM [ #1, #2, #3, NONE]
    - SAVE CURRENT PROGRAM-
      - SAVE PROGRAM AS [ #1, #2, #3, NONE]
    - FLOW MODE SAMPLING-
      - TAKE SAMPLE AT START TIME? ( YES, NO)
    - NONUNIFORM TIME-
      - ENTER INTERVALS IN ( CLOCK TIME, MINUTES)
    - SAMPLING STOP RESUME-
      - SAMPLE AT STOP? ( YES, NO)
      - SAMPLE AT RESUME? ( YES, NO)
- ENABLE PIN-
  - MASTER/SLAVE MODE? ( YES, NO)
  - SAMPLE UPON DISABLE? ( YES, NO)
  - SAMPLE UPON ENABLE? ( YES, NO)
  - RESET SAMPLE INTERVAL? ( YES, NO)
  - INHIBIT COUNTDOWN? ( YES, NO)
- EVENT MARK-
  - EVENT MARK- (CONTINUOUS SIGNAL, PULSE )
  - AT THE BEGINNING OF- ( PURGE, FWD PUMPING)
- PURGE COUNTS-
  - 200 PRE-SAMPLE COUNTS (0-9999)
  - 200 POST-SAMPLE COUNTS (0-9999)
- TUBING LIFE-
  - 0 PUMP COUNTS WARNING AT 9000000
  - RESET PUMP COUNTER? ( YES, NO)
  - 9000000 PUMP COUNTS TO WARNING
- PROGRAM LOCK-
  - PROGRAM LOCK (ENABLE, DISABLE)
- SAMPLER ID-
  - SAMPLER ID IS 0000000003 ( \_\_\_\_\_ )
- RUN DIAGNOSTICS-
  - SOFTWARE REVISION #4.5
  - TESTING 'RAM'
  - 'RAM' PASSED TEST
  - TESTING 'ROM'
  - 'ROM' PASSED TEST
  - ABCDEFGHIJKLMNOPQRST
  - UVWXYZ[Y]^\_ 'abcdefgh
  - PUMP COUNT TEST... OFF/ON = 105
- TEST DISTRIBUTOR-
  - REINITIALIZE?- ( YES/NO )
- EXIT CONFIGURATION-
  - REINITIALIZE?- ( YES/NO )

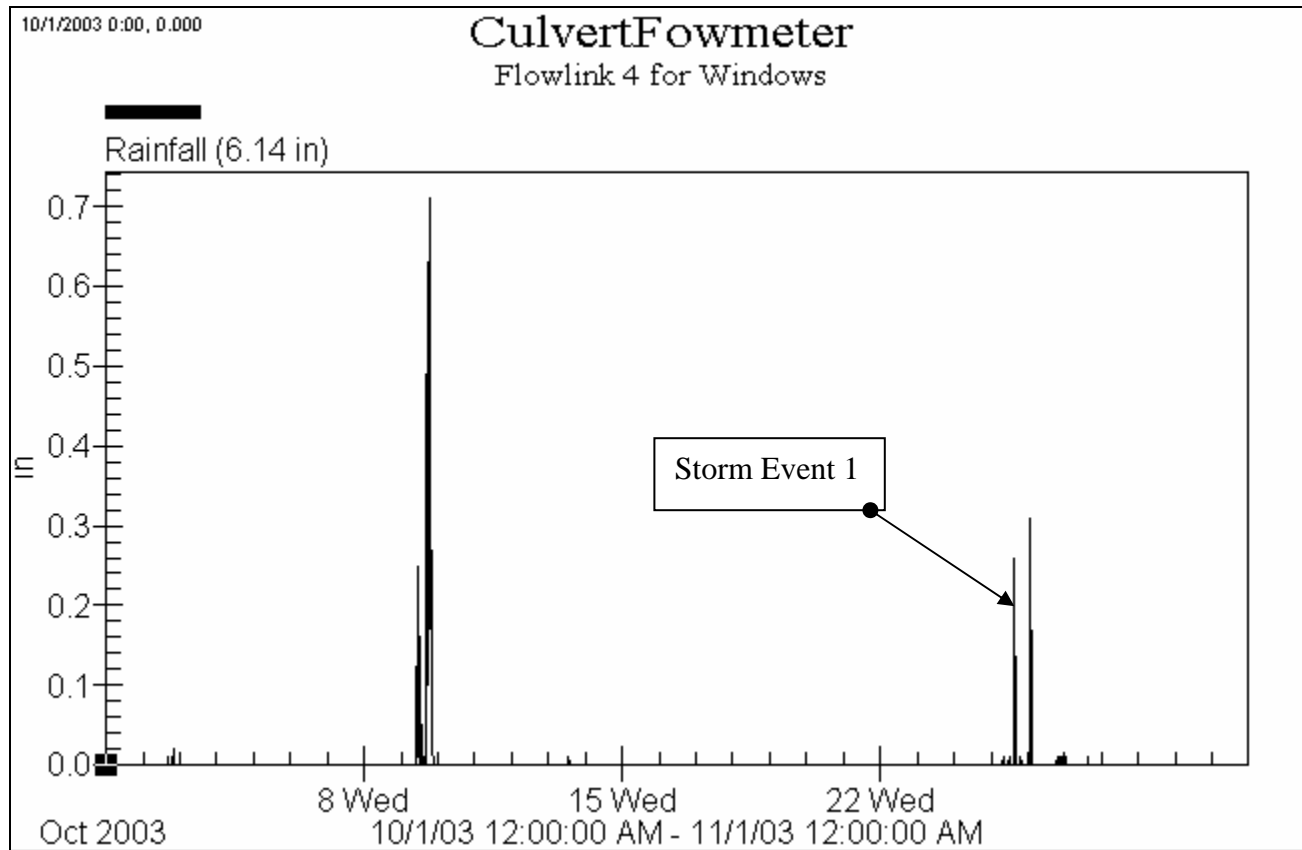
START SAMPLING-

## **APPENDIX B**

### **MONTHLY RAINFALL DATA**

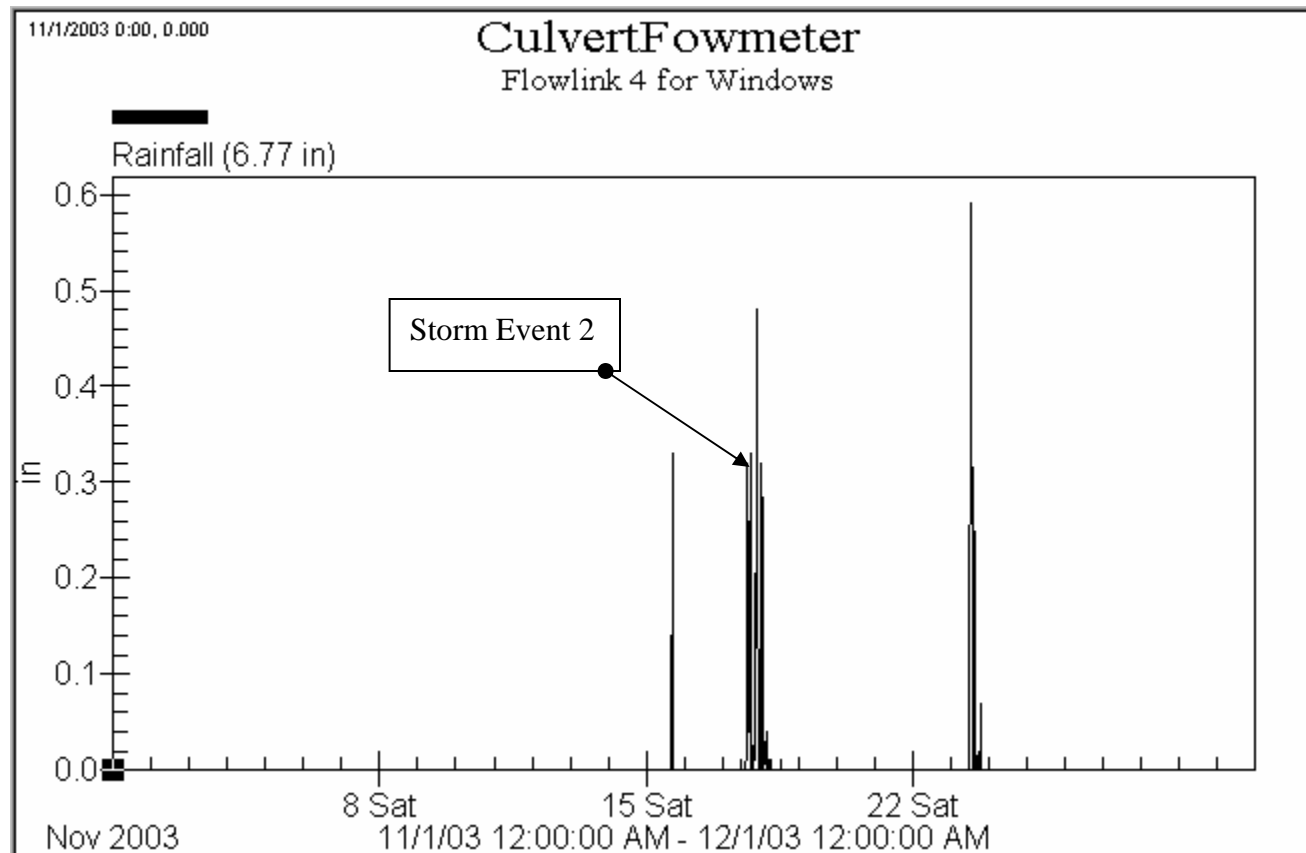
Note: Only the peaks labeled are sampling events

**B-1: October 203 rainfall data**



**FIG. B-1. October 2003 rainfall data**

**B-2: November 203 rainfall data**



**FIG. B-2. November 2003 rainfall data**

B-3: January 2004 rainfall data

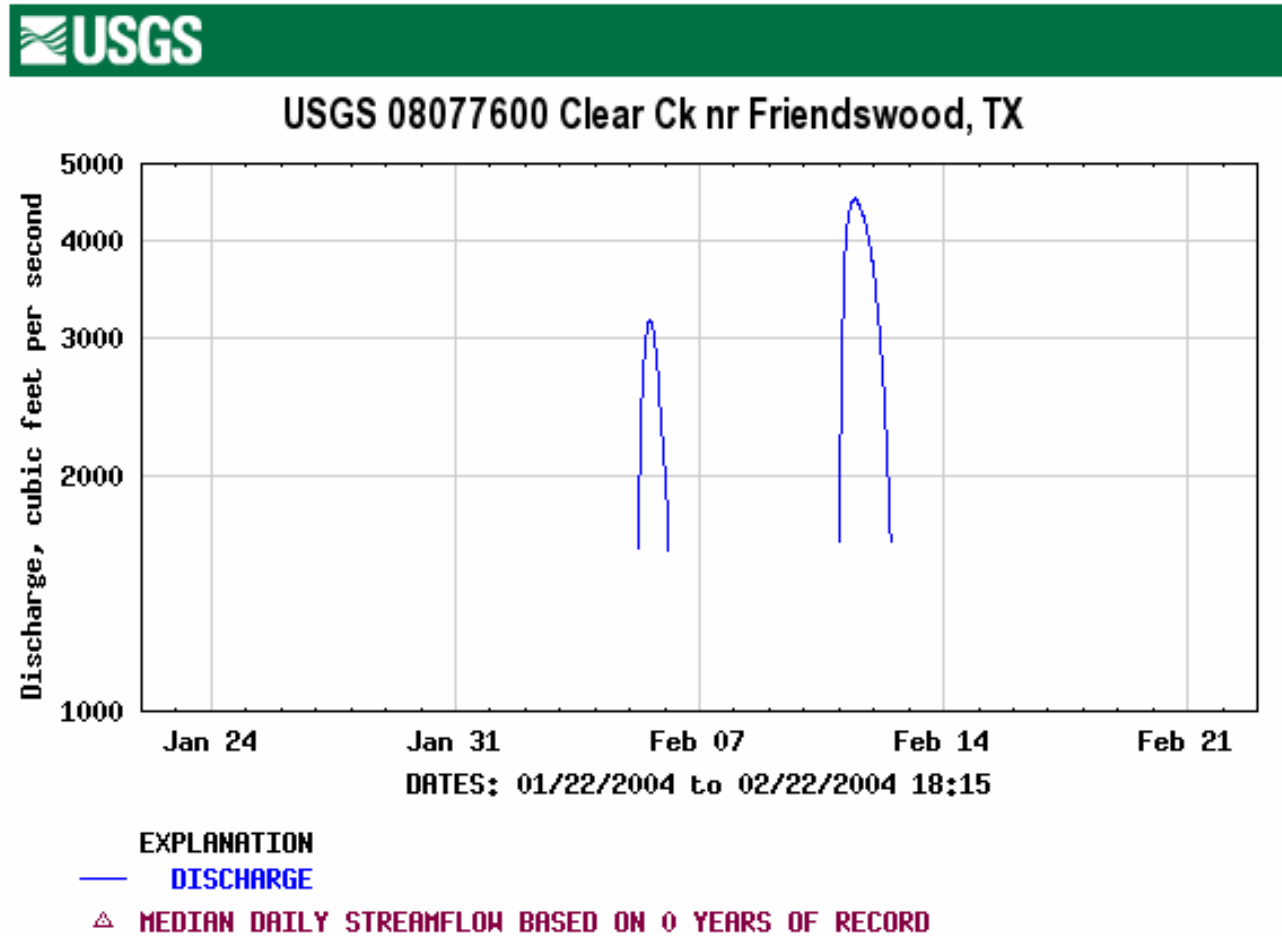
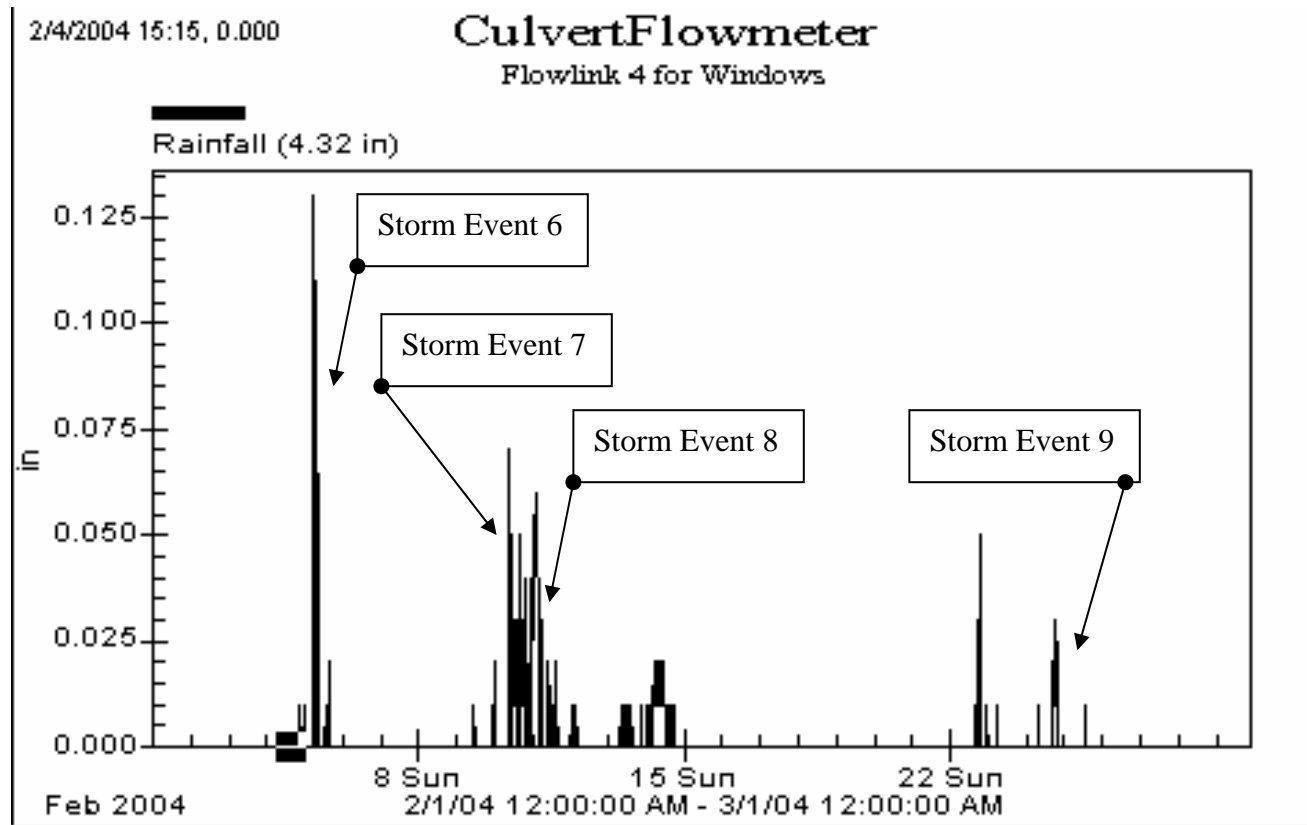


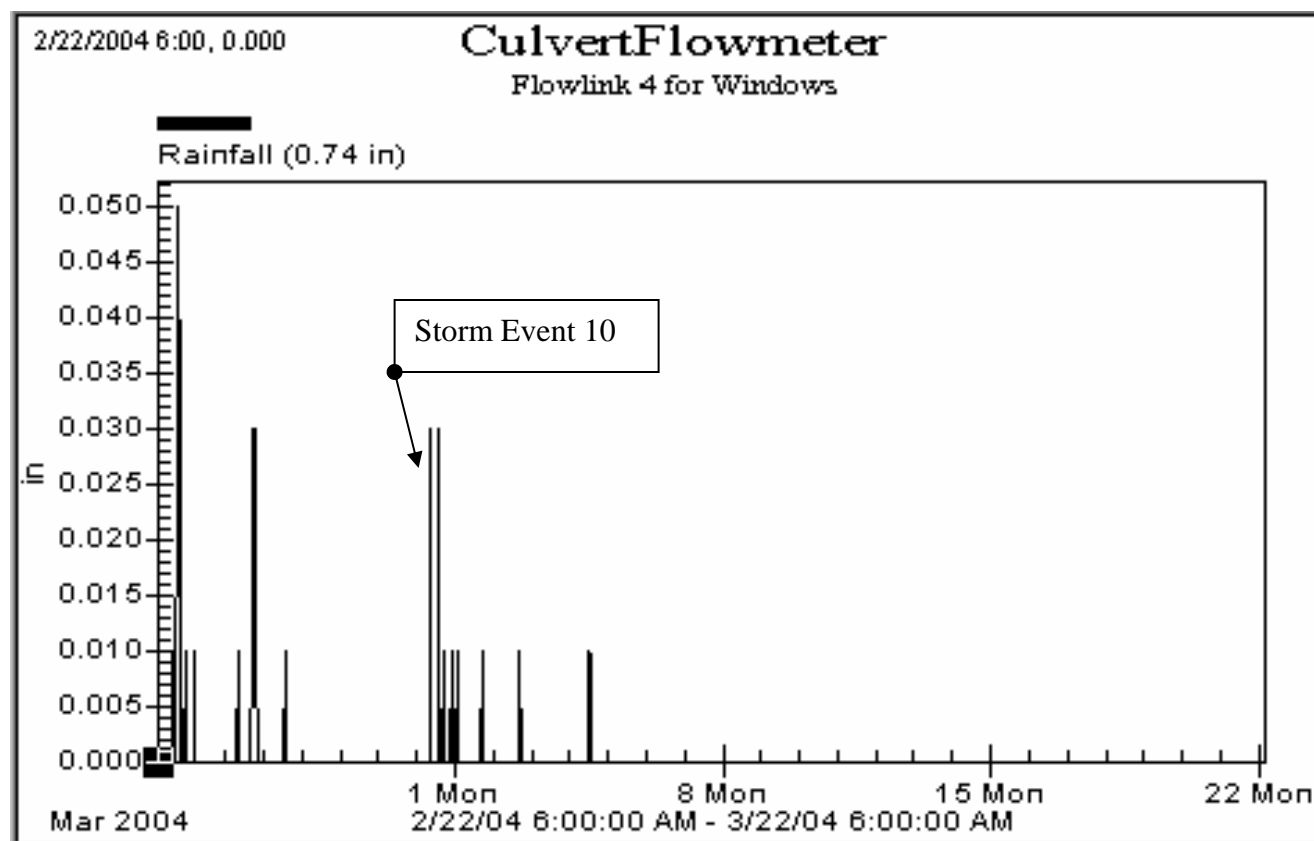
FIG. B-3. January 2004 rainfall data

**B-4: February 2004 rainfall data**



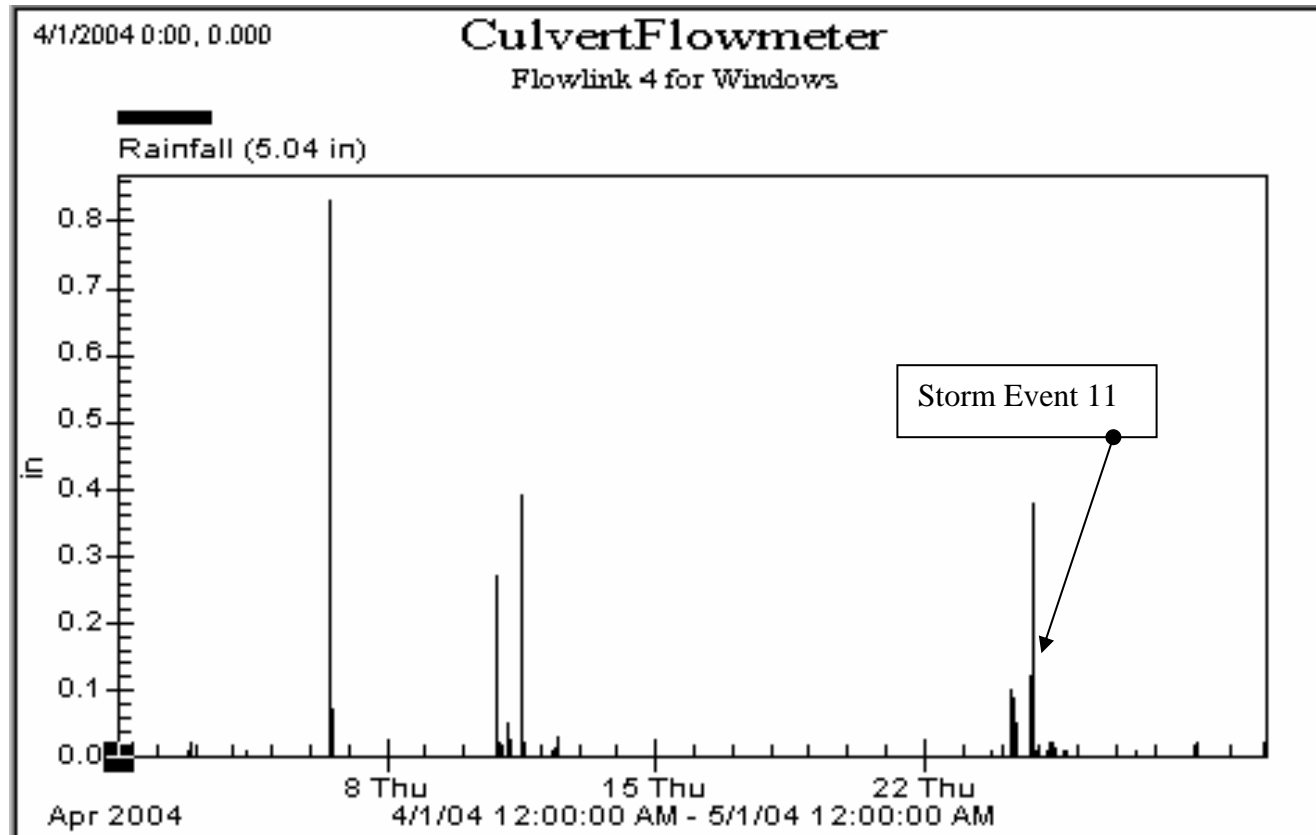
**FIG. B-4. February 2004 rainfall data**

**B-5: March 2004 rainfall data**



**FIG. B-5. March 2004 rainfall data**

**B-6: April 2004 rainfall data**



**FIG. B-6. April 2004 rainfall data**



**APPENDIX C**

**SAMPLED STORM EVENTS (RAINFALL, FLOW, AND LEVEL  
DATA)**

**STORM EVENT 1****Oct 25- 7:00am thru Oct 26- 12:00pm**

## RAINFALL DETAILS

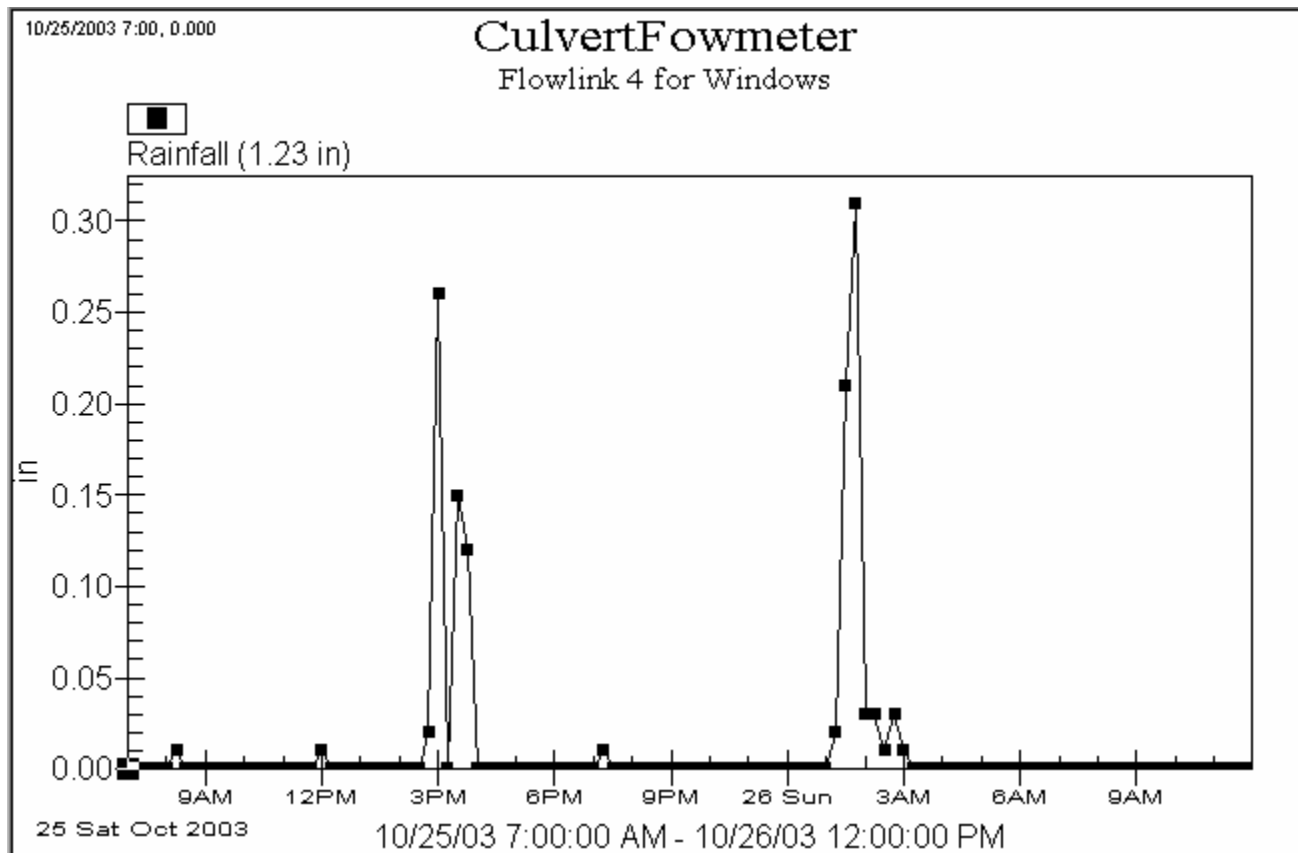
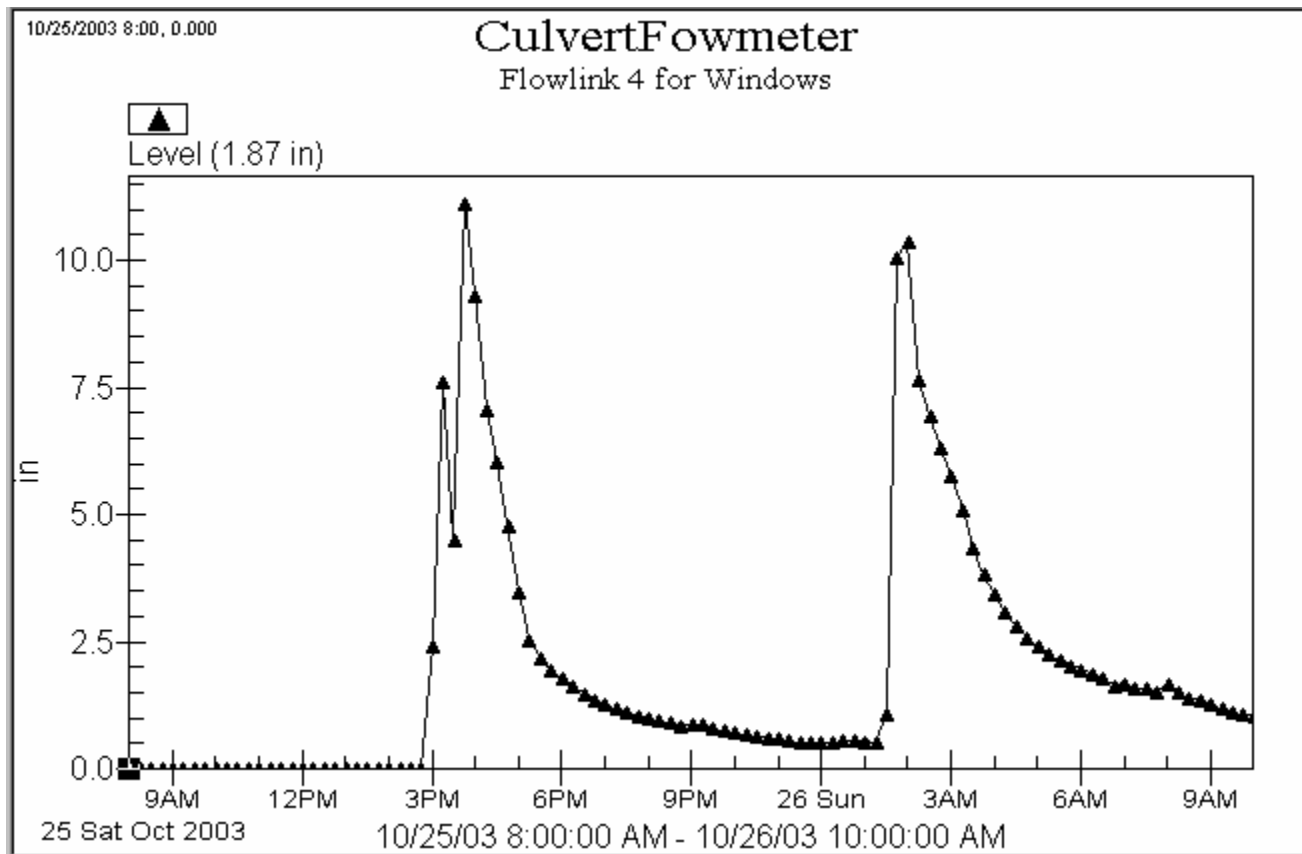


FIG. C-1. Storm event 1 detail: Oct 25 7:00am through Oct 26 12:00pm

### LEVEL DATA (CULVERT)



**FIG. C-2. Storm event 1: Culvert flow level vs. time (Oct 25 2003)**

### LEVEL DATA (BRIDGE)

This data might be considered inconclusive due to errors during the data acquisition

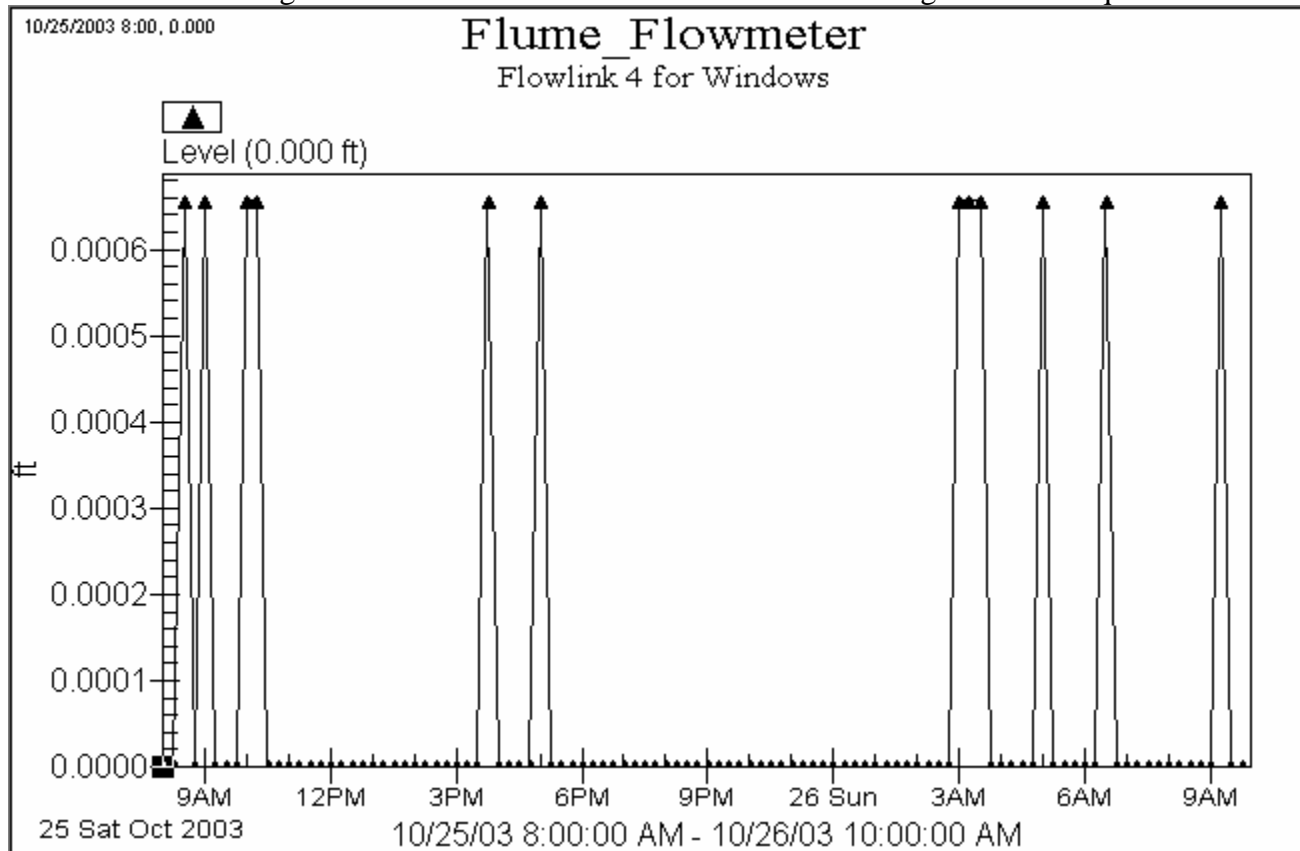


FIG. C-3. Storm event 1: Bridge and flume flow level vs. time (Oct 25 2003)

### FLOW DATA (CULVERT)

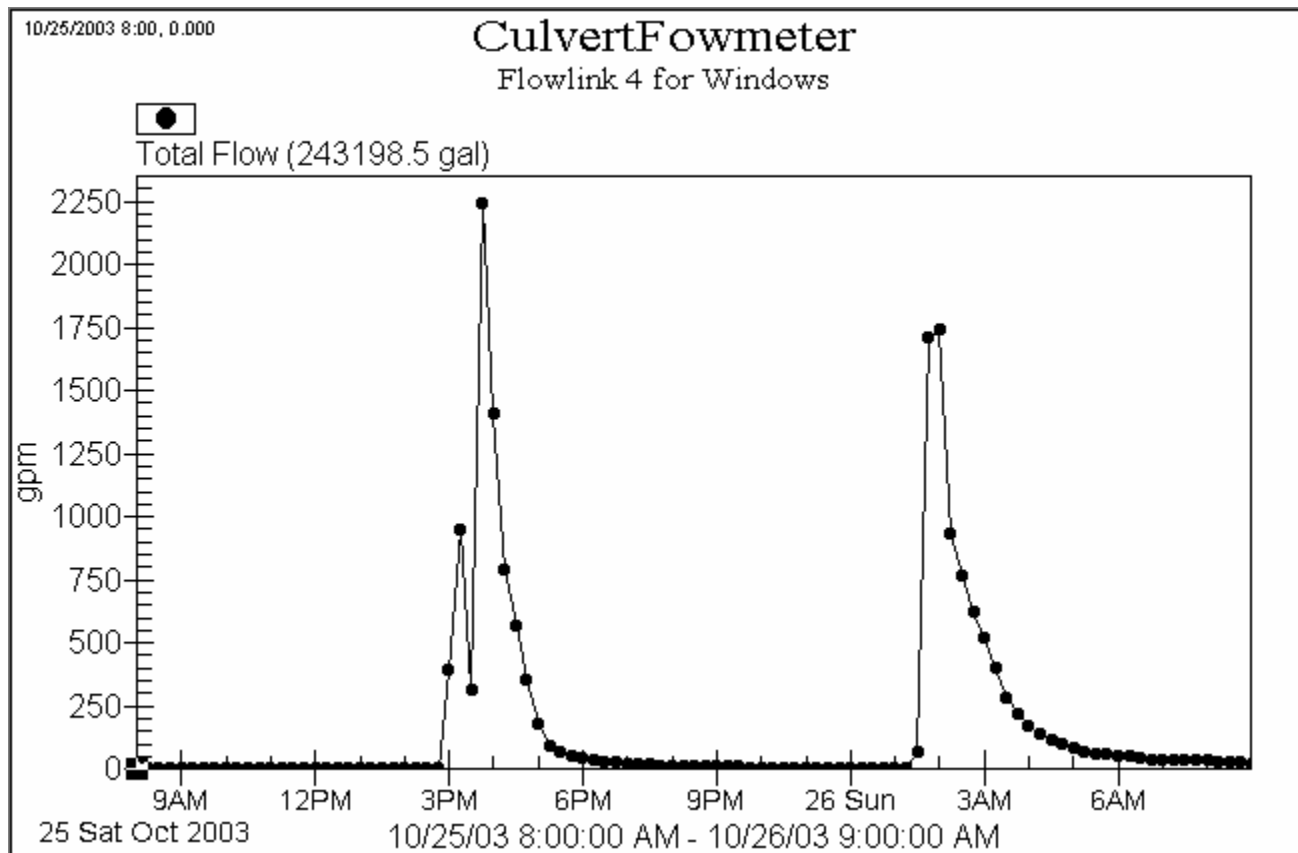


FIG. C-4. Storm event 1: Culvert flow vs. time

### FLOW DATA (BRIDGE)

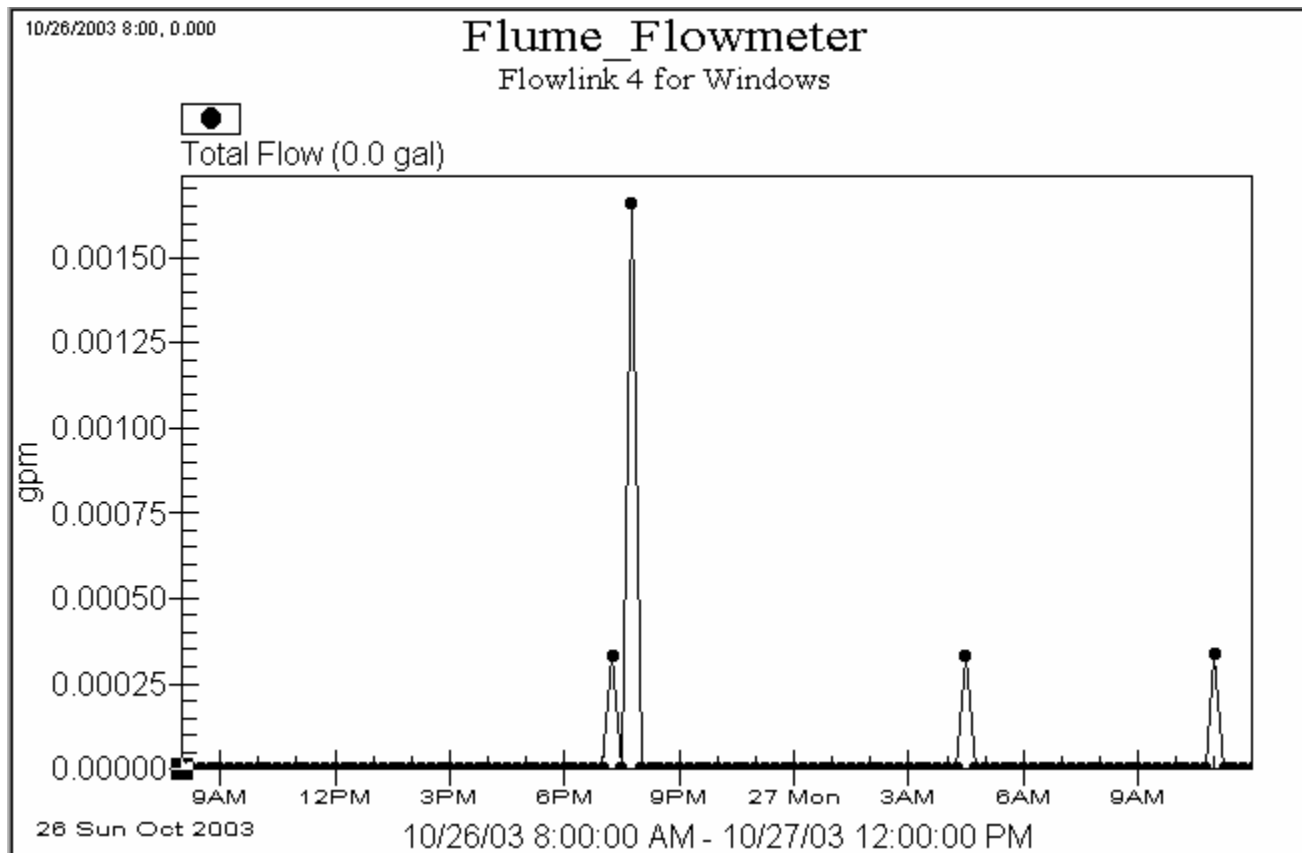


FIG. C-5 Storm event 1: Bridge and flume flow vs. time

**STORM EVENT 2****Nov 17- 12:00am thru Nov 18- 6:00am**



## RAINFALL DETAILS

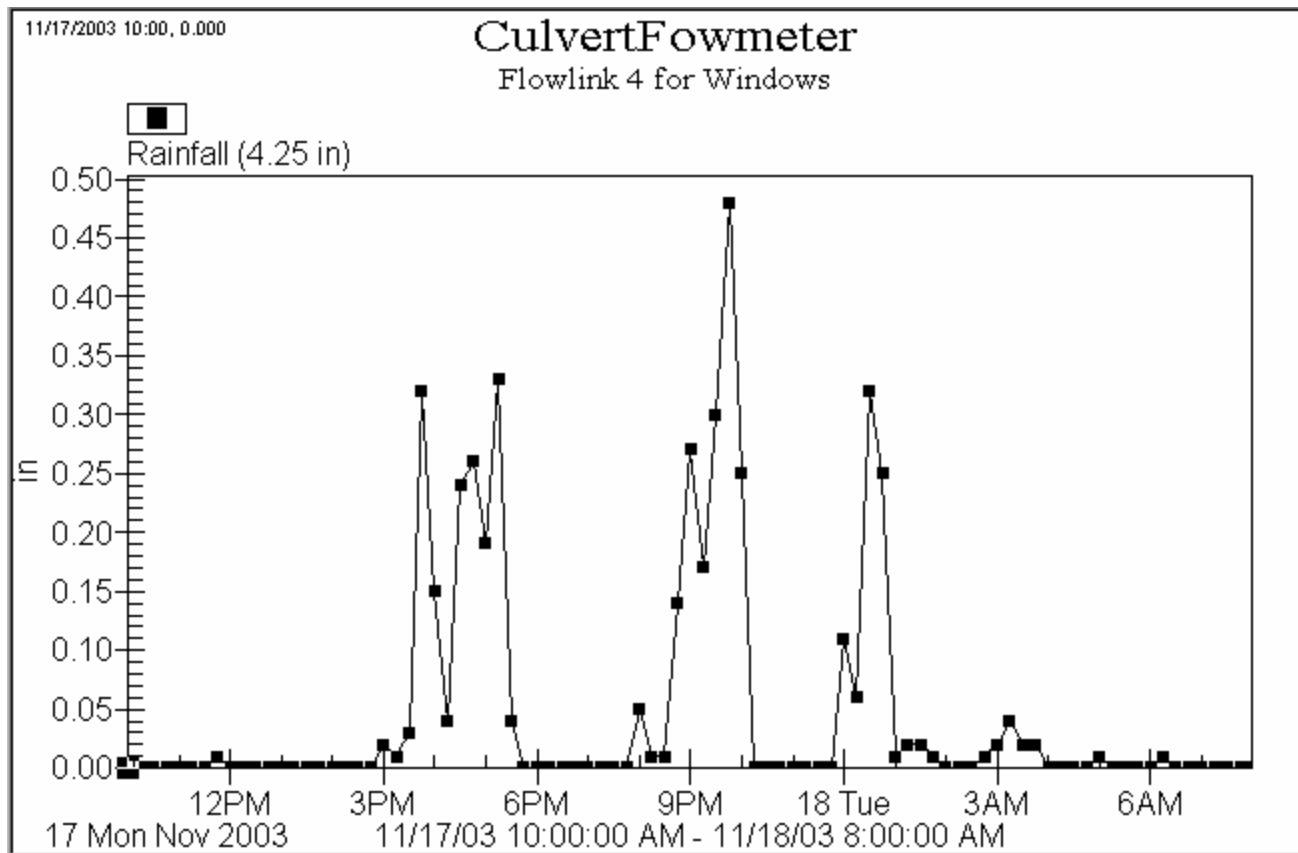


FIG. C-6. Storm event 2 Nov 17- 12:00 pm through Nov 18 6:00am

### LEVEL DATA (CULVERT)

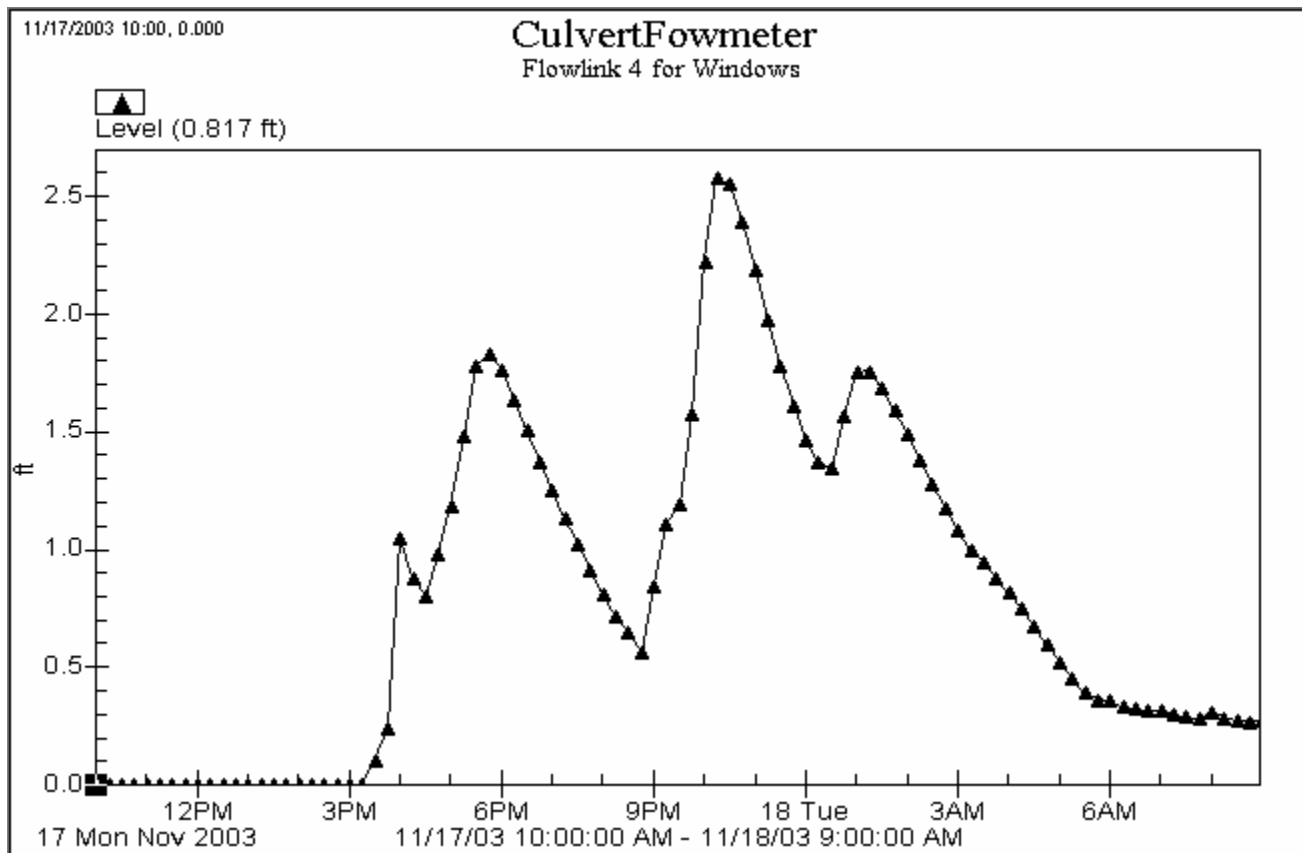


FIG. C-7. Storm event 2: Culvert flow level vs. time (Nov 17 2003)

### LEVEL DATA (BRIDGE)

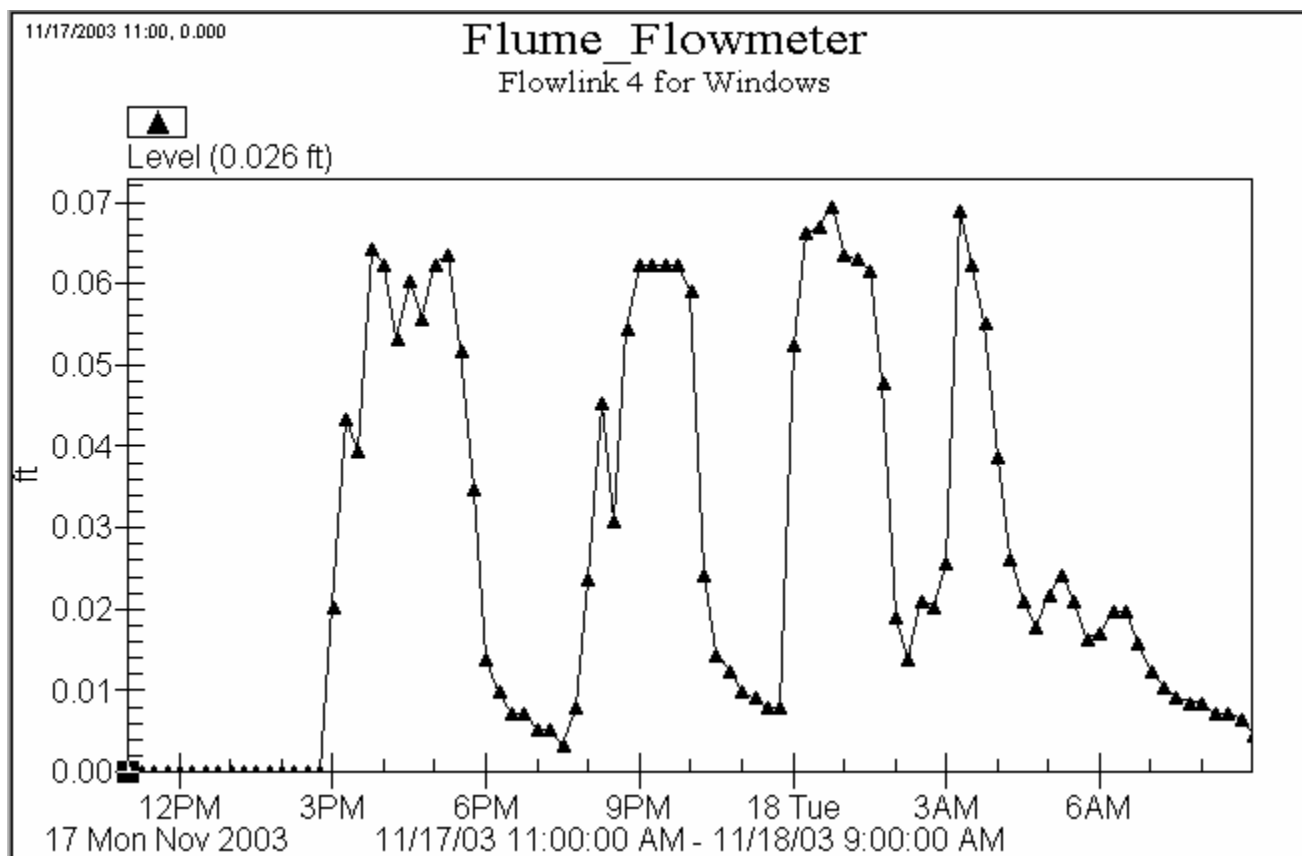


FIG. C-8. Storm event 2: Flume flow level vs. time (Nov 17 2003)

### FLOW DATA (CULVERT)

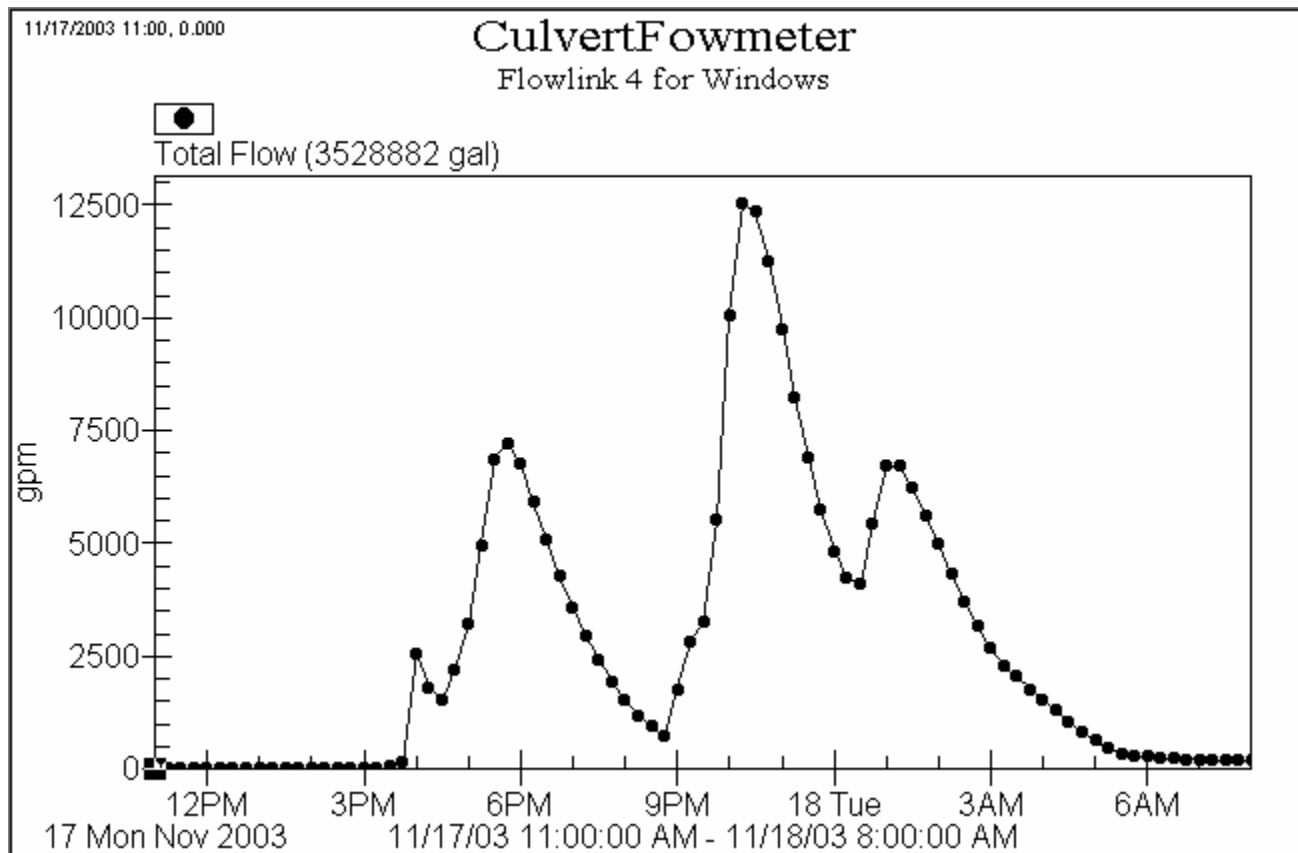
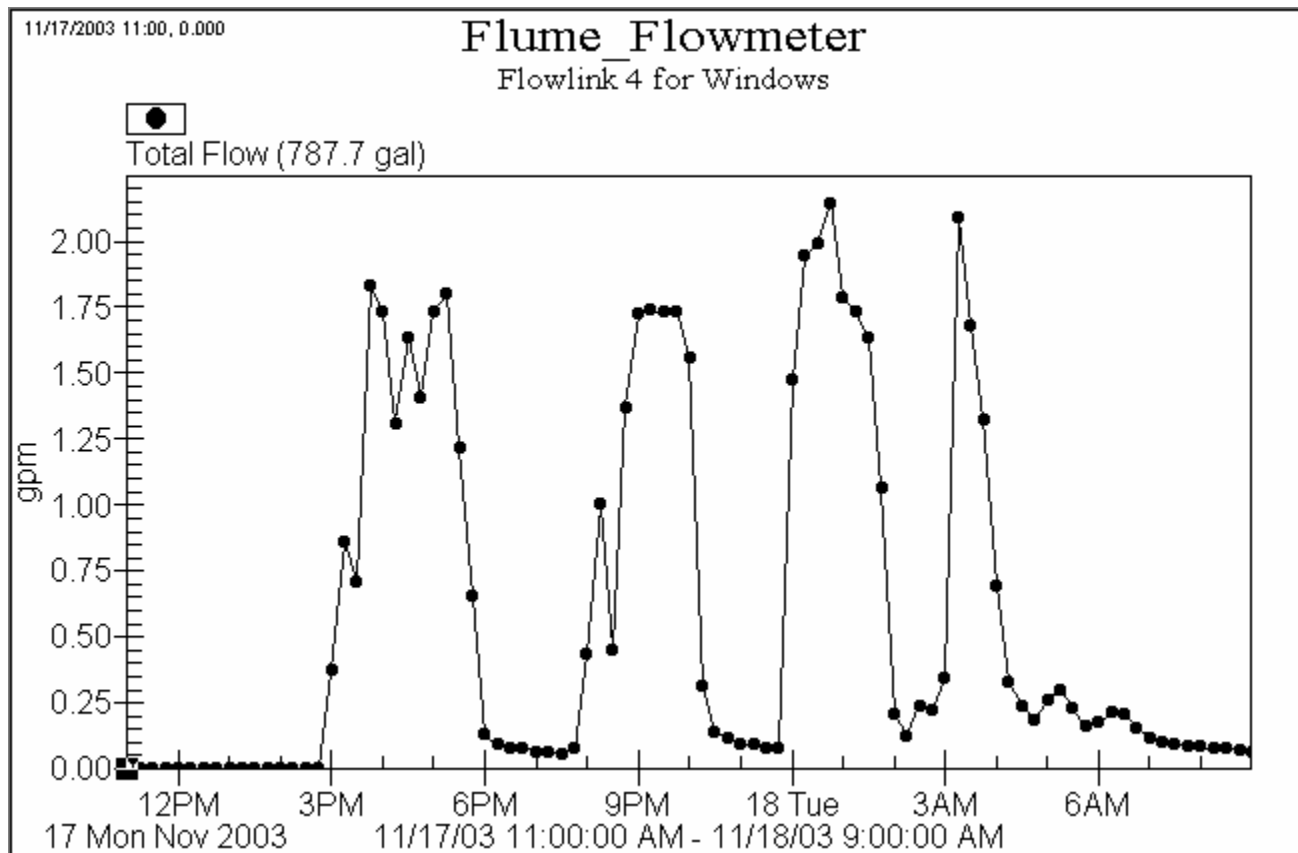


FIG. C-9. Storm event 2: Culvert flow vs. time

### FLOW DATA (LEVEL)



**FIG. C-10. Storm event 2: Bridge and flume flow vs. time**

**STORM EVENT 3****Jan 8- 2:00 am thru Jan 8- 9:00pm**

### LEVEL DATA (CULVERT)

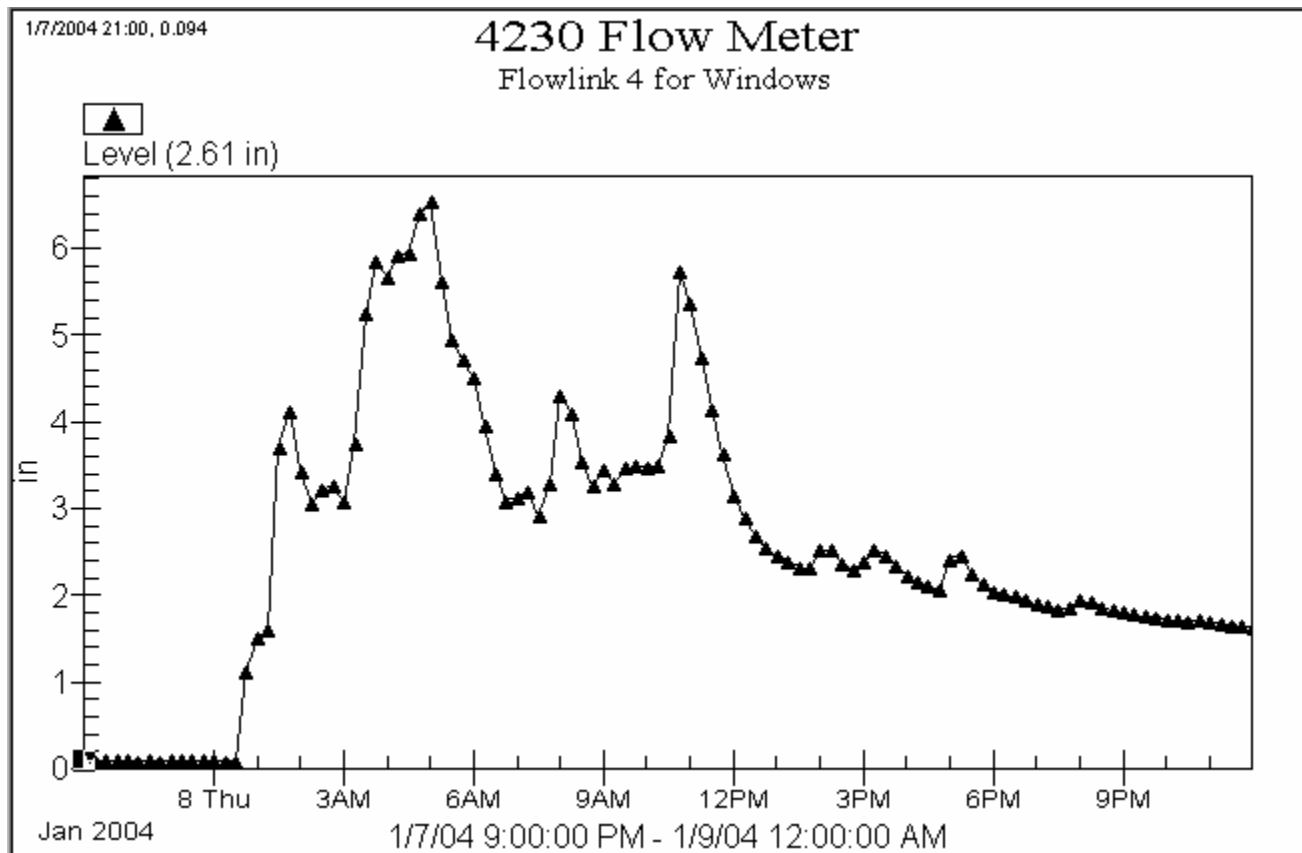


FIG. C-11. Storm event 3: Culvert flow level vs. time (Jan 12 2004)

### LEVEL DATA (BRIDGE)

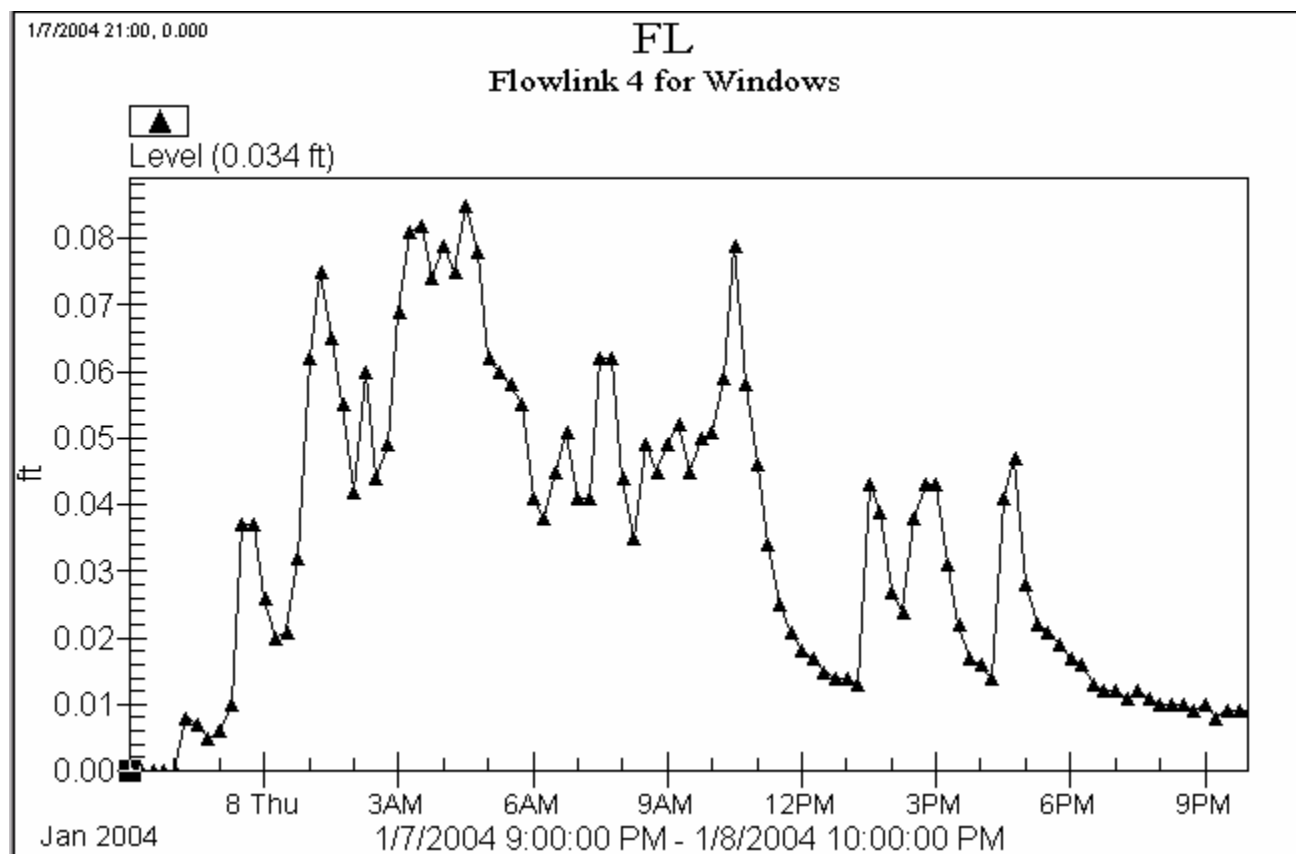


FIG. C-12. Storm event 3: Bridge and flume flow level vs. time (Jan 12 2004)



### FLOW DATA (CULVERT)

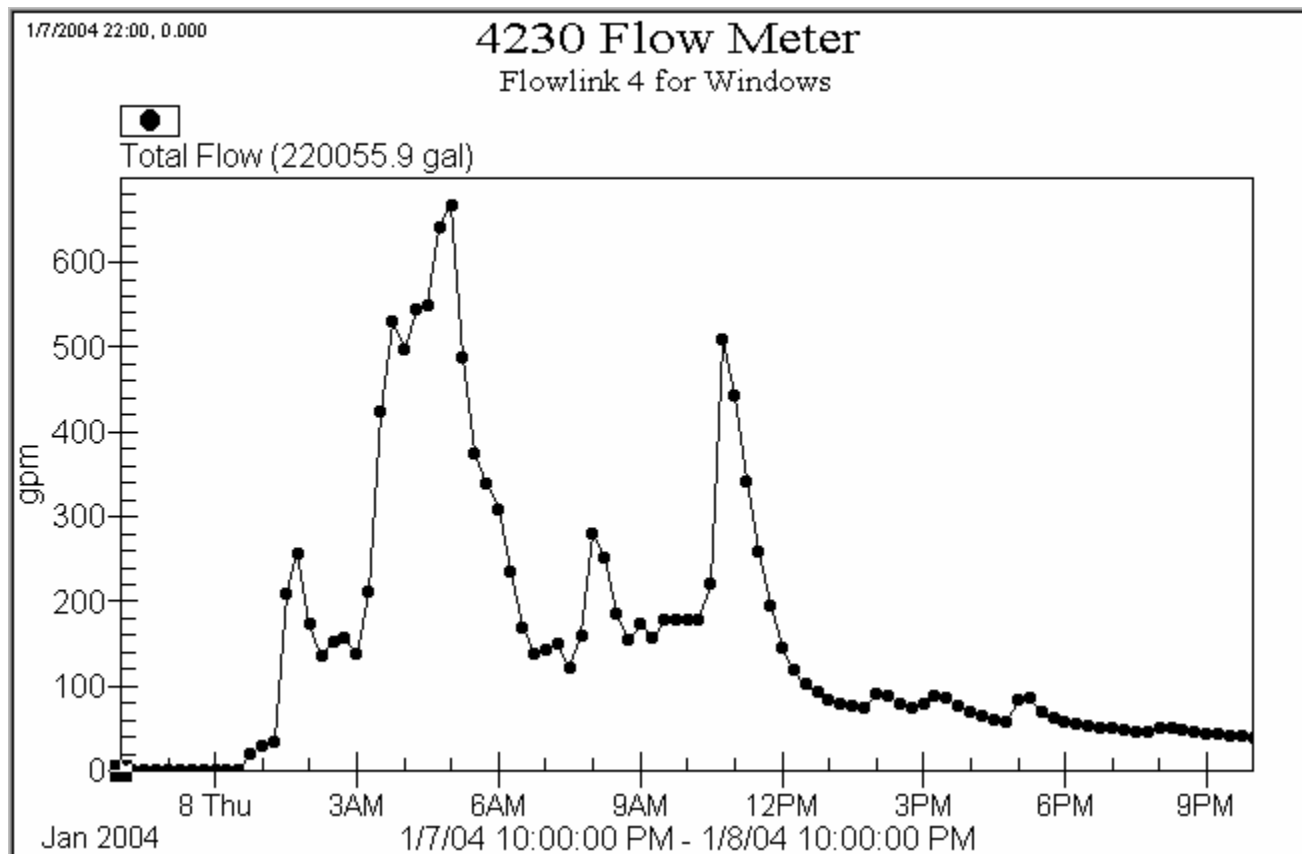


FIG. C-13. Storm event 3: Culvert flow vs. time

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Flowlink 4 for Windows



**STORM EVENT 4****Jan 16- 5:00 pm thru Jan 17- 2:00pm**

## RAINFALL DETAILS

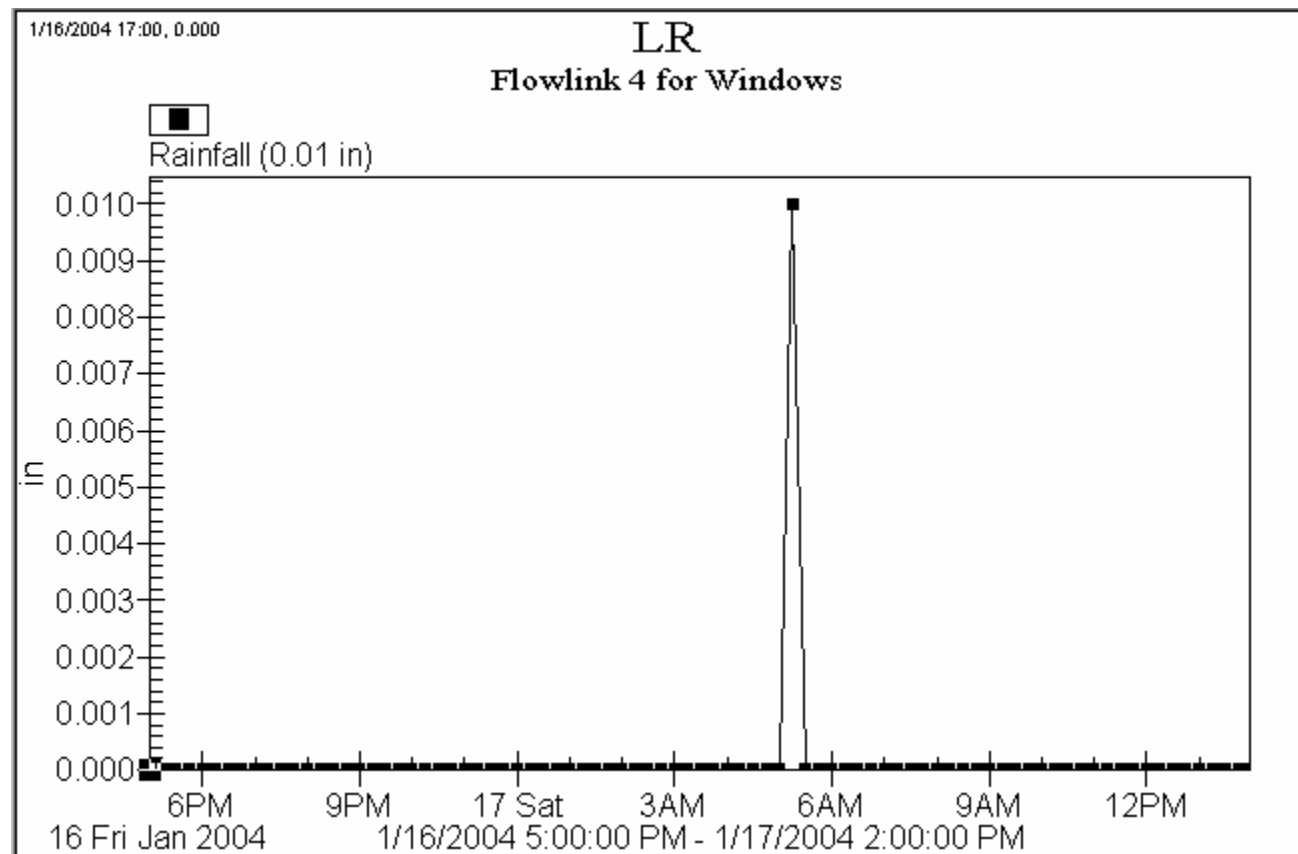


FIG. C-15. Storm event 4 Jan 20 through Jan 21

### LEVEL DATA (CULVERT)

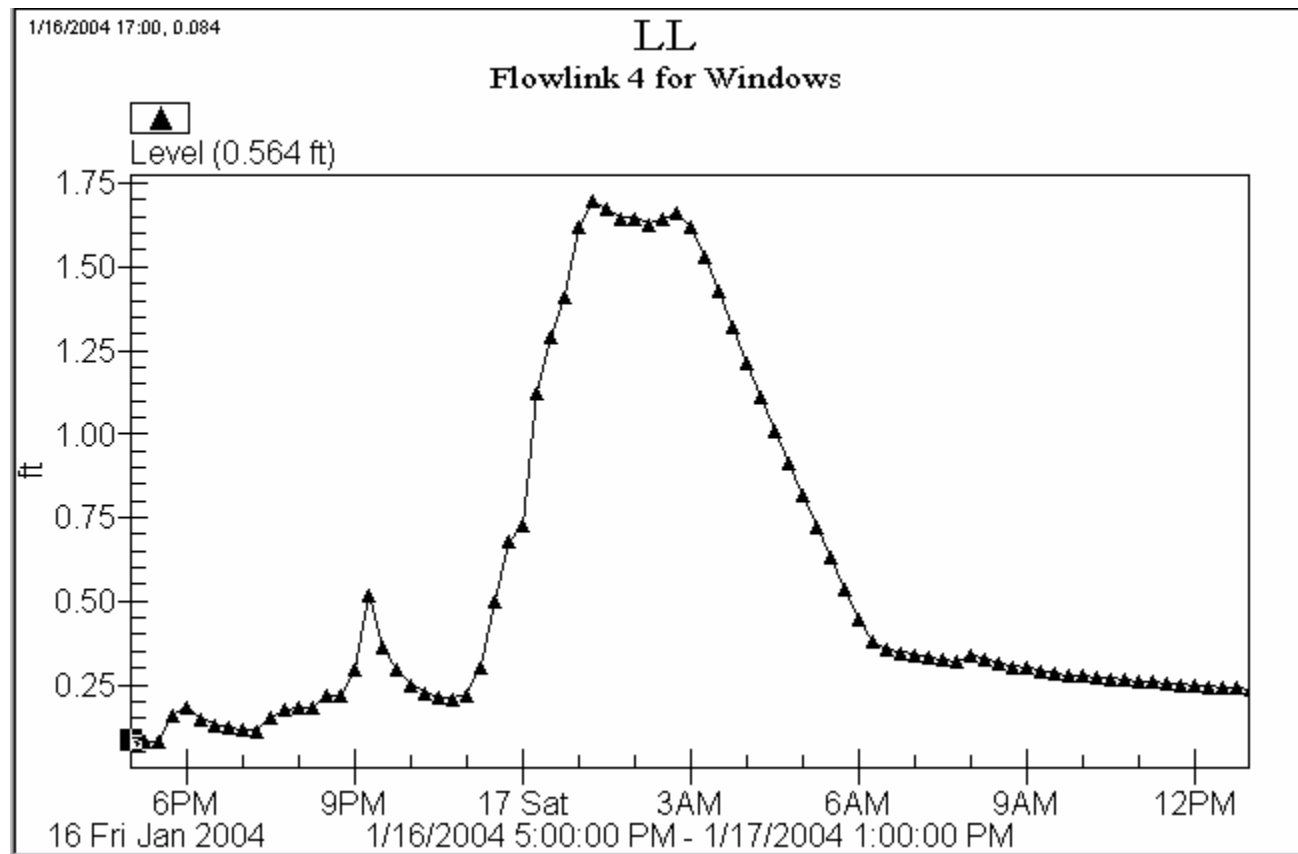
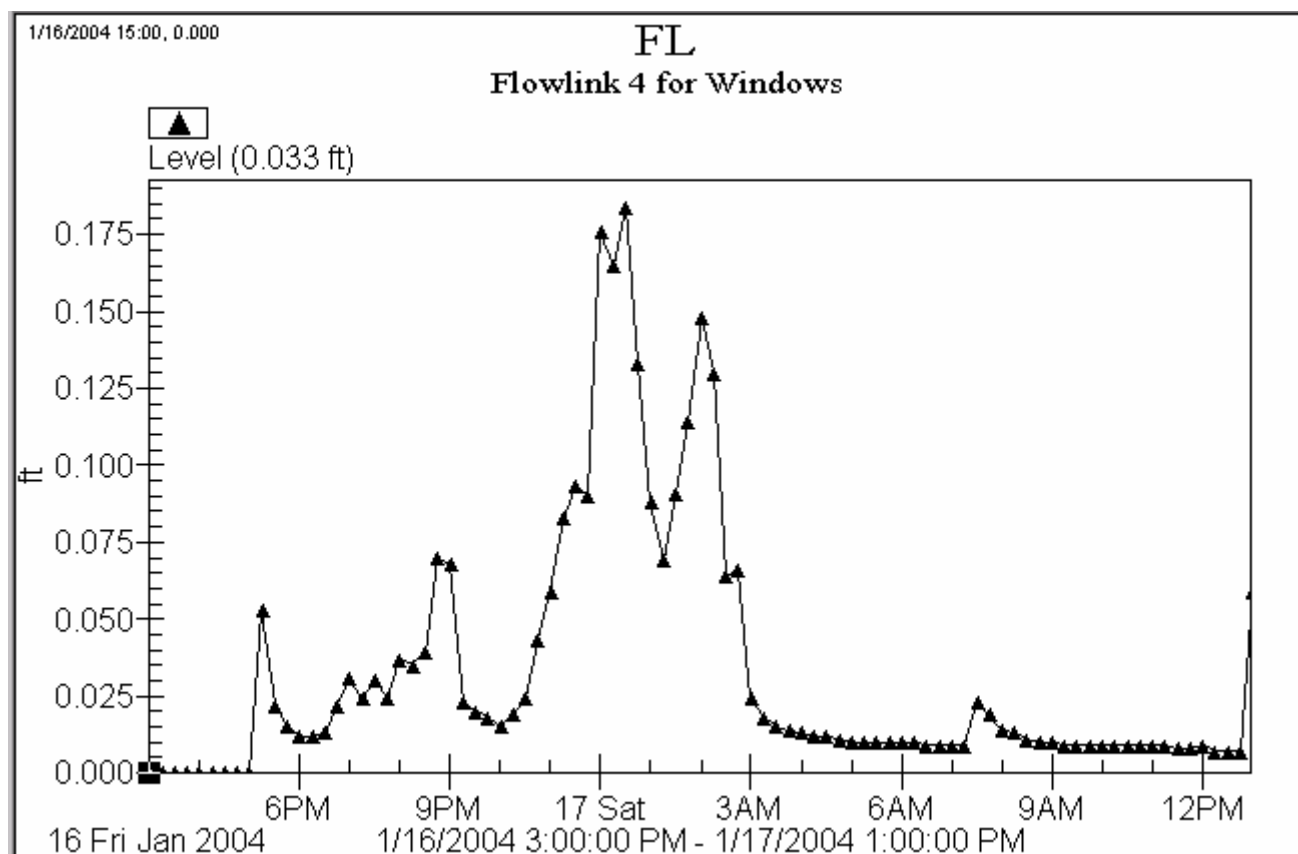


FIG. C-16. Storm event 4: Culvert flow level vs. time (Jan 20 2004)

# **LEVEL DATA (BRIDGE)**



## FLOW DATA (CULVERT)

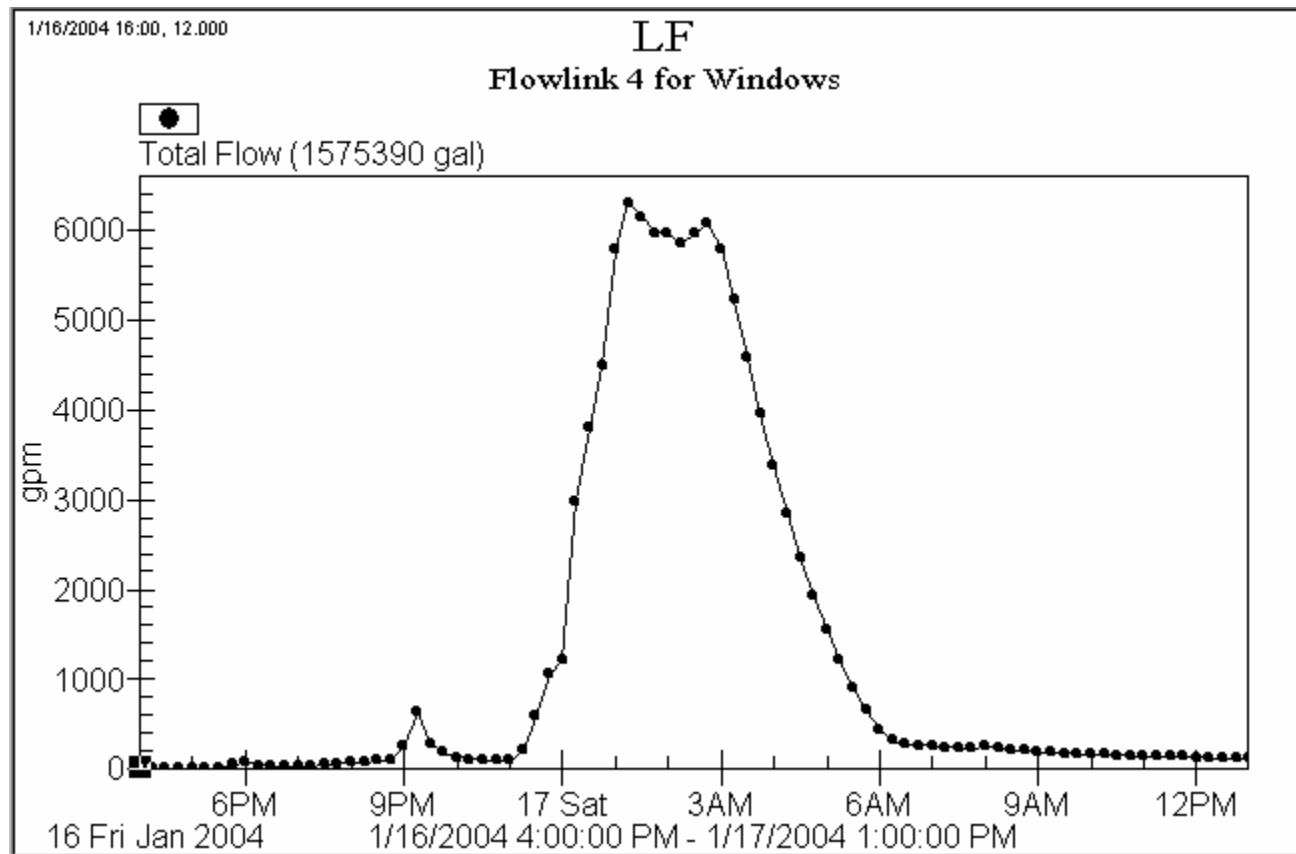


FIG. C-18. Storm event 4: Culvert flow vs. time

**STORM EVENT 5****Jan 25- 9:00 pm thru Jan 25- 9:00am**



## RAINFALL DETAILS

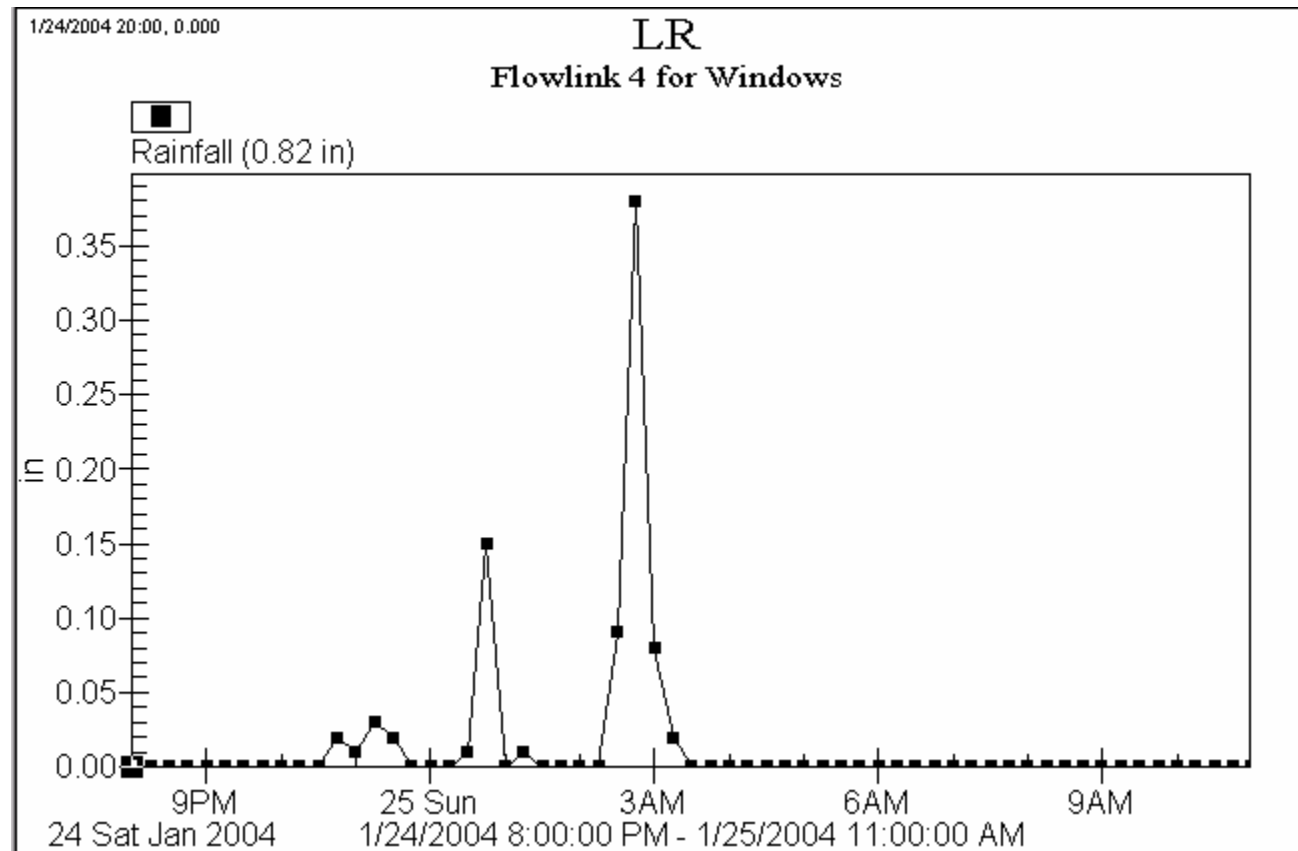


FIG. C-20. Storm event 5 Jan 24<sup>rd</sup> through Jan 25 2004

### LEVEL DATA (CULVERT)

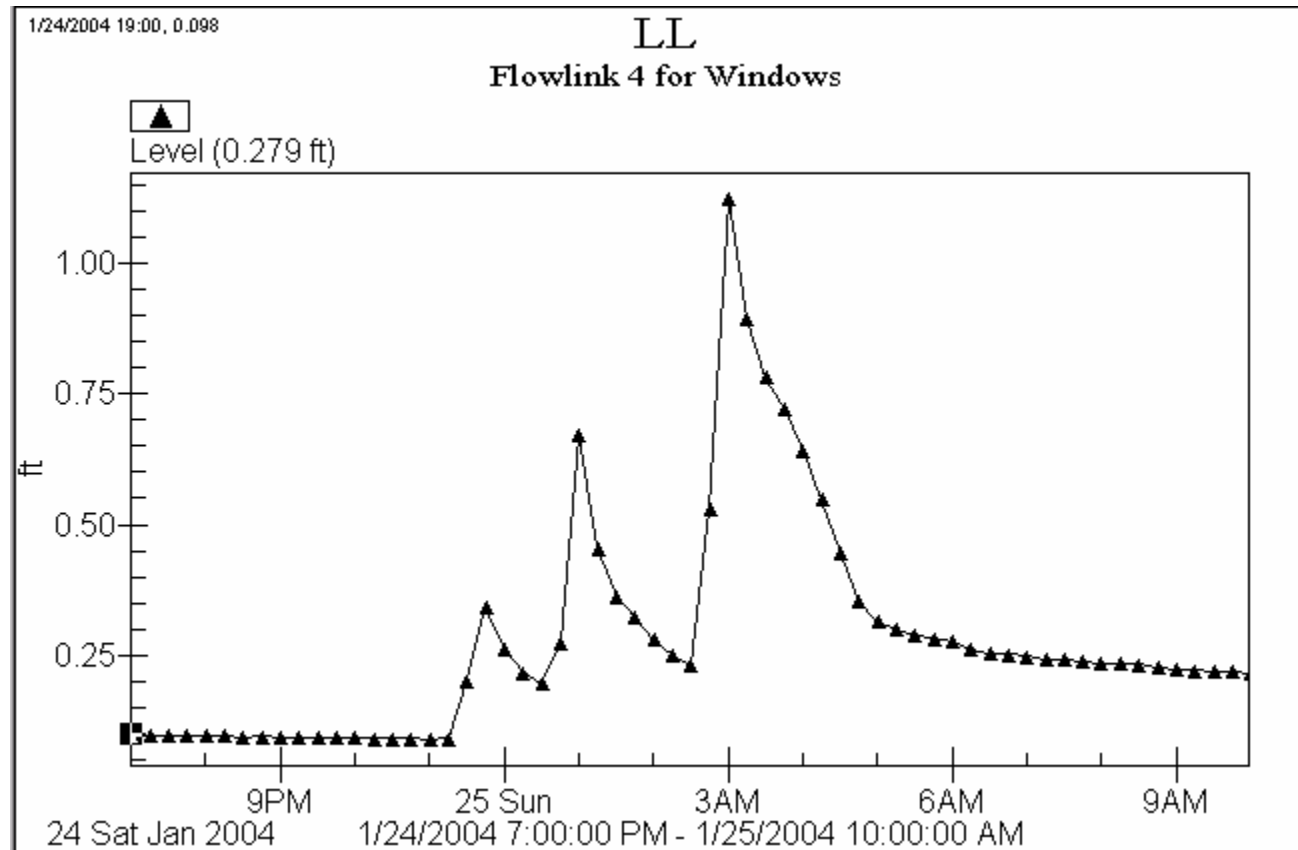


FIG. C-21. Storm event 5: Culvert flow level vs. time (Jan 25 2004)

### LEVEL DATA (BRIDGE)

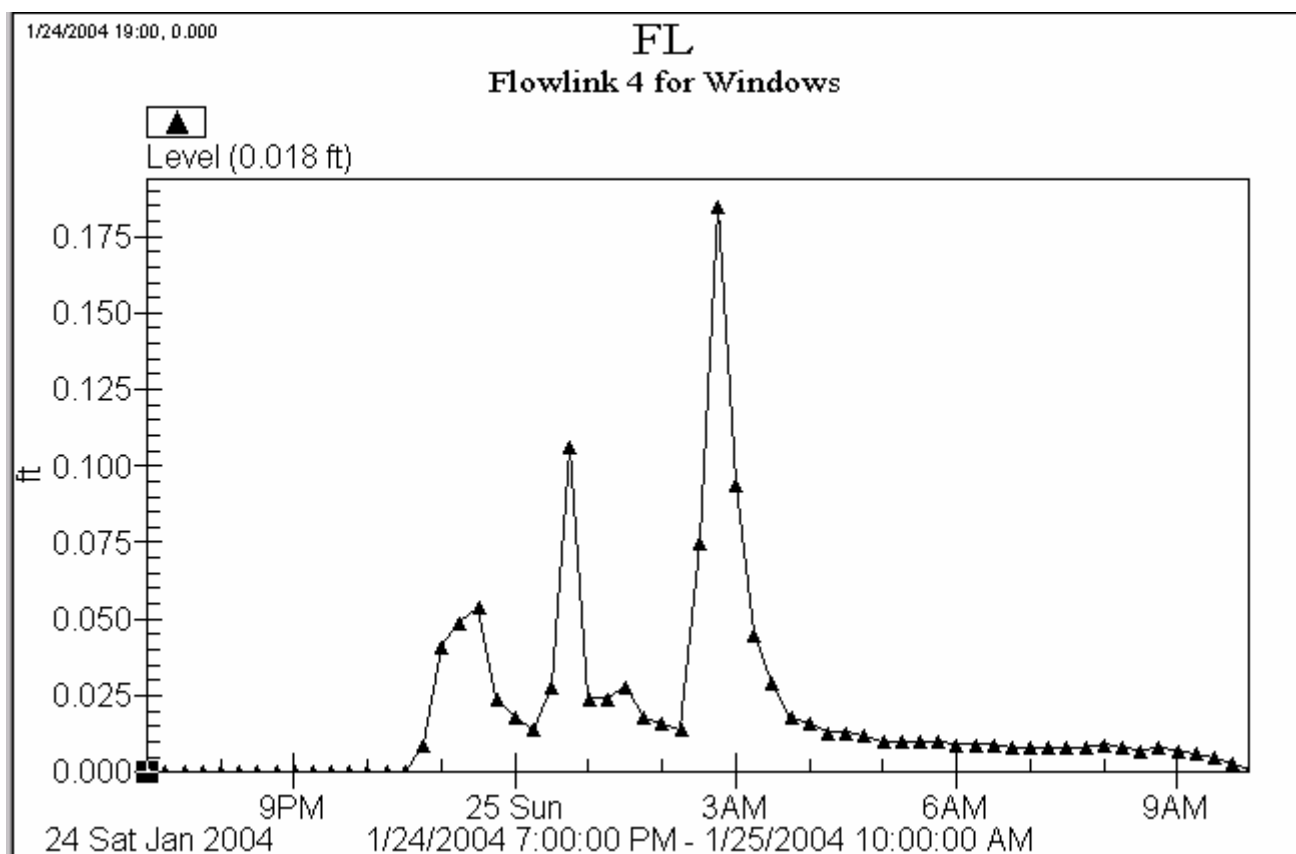


FIG. C-22. Storm event 5: Bridge and flume flow level vs. time (Jan 25 2004)

### FLOW DATA (CULVERT)

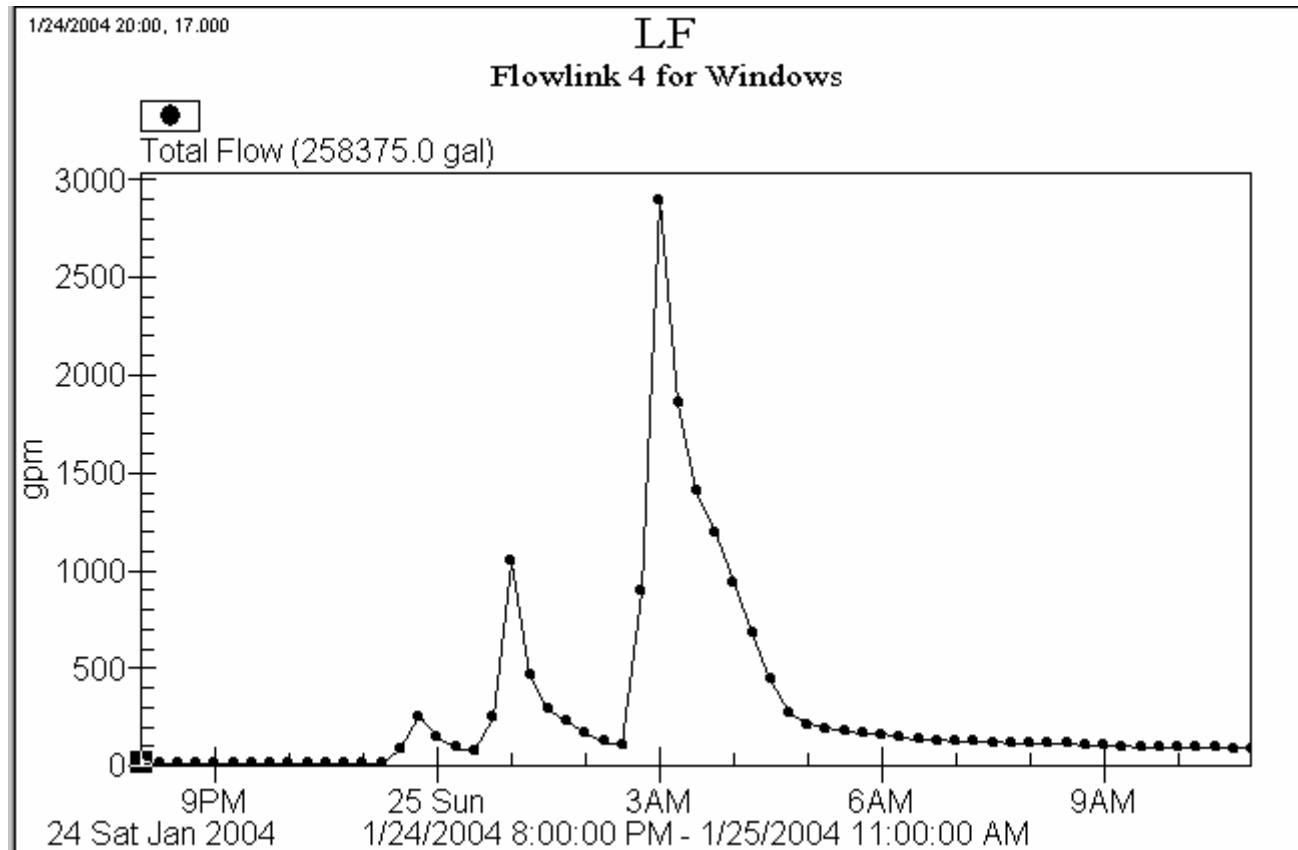


FIG. C-23. Storm event 5: Culvert flow vs. time

**STORM EVENT 6****Feb 3- 3:00 pm thru Feb 4- 5:00pm**

## RAINFALL DETAILS

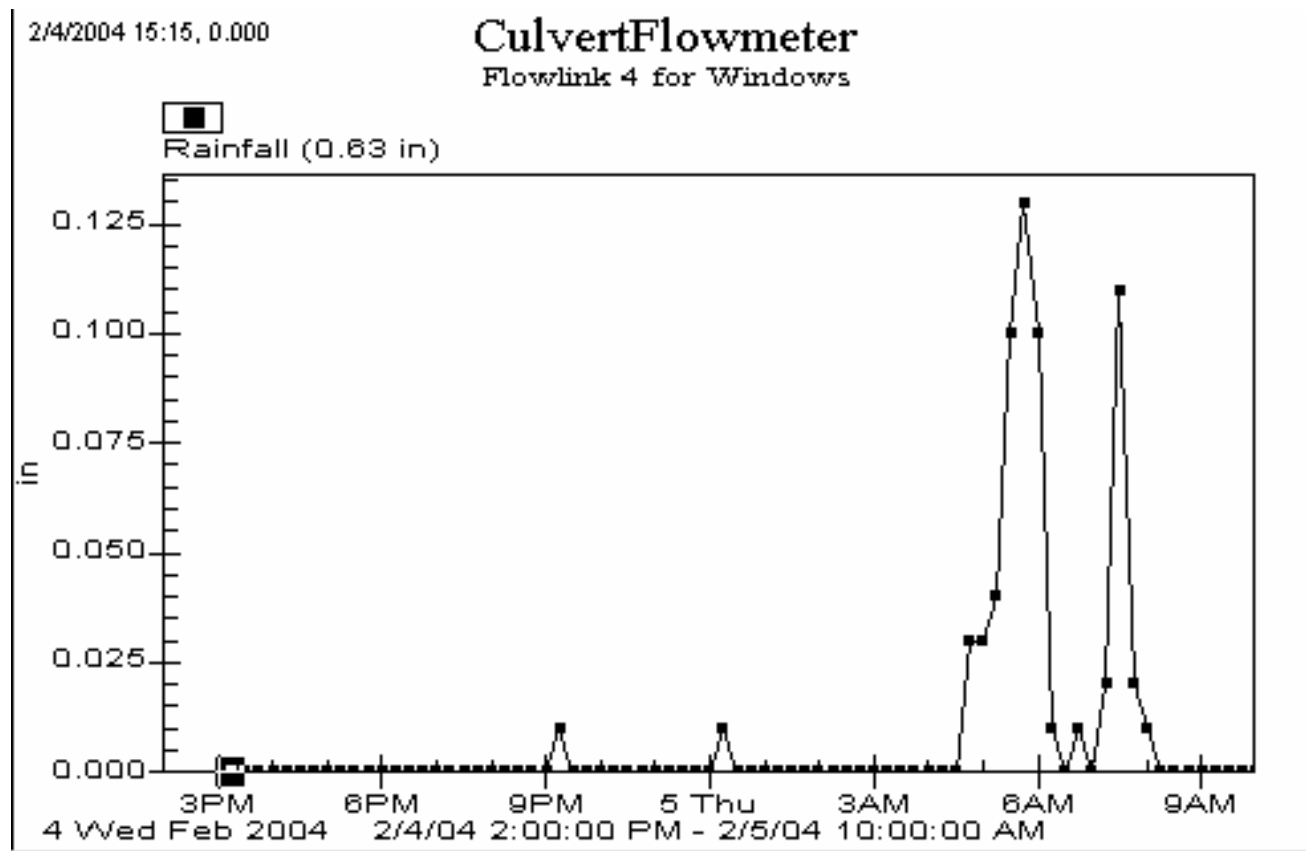


FIG. C-24. Storm event 6 Feb 3 through Jan 4

### LEVEL DATA (CULVERT)

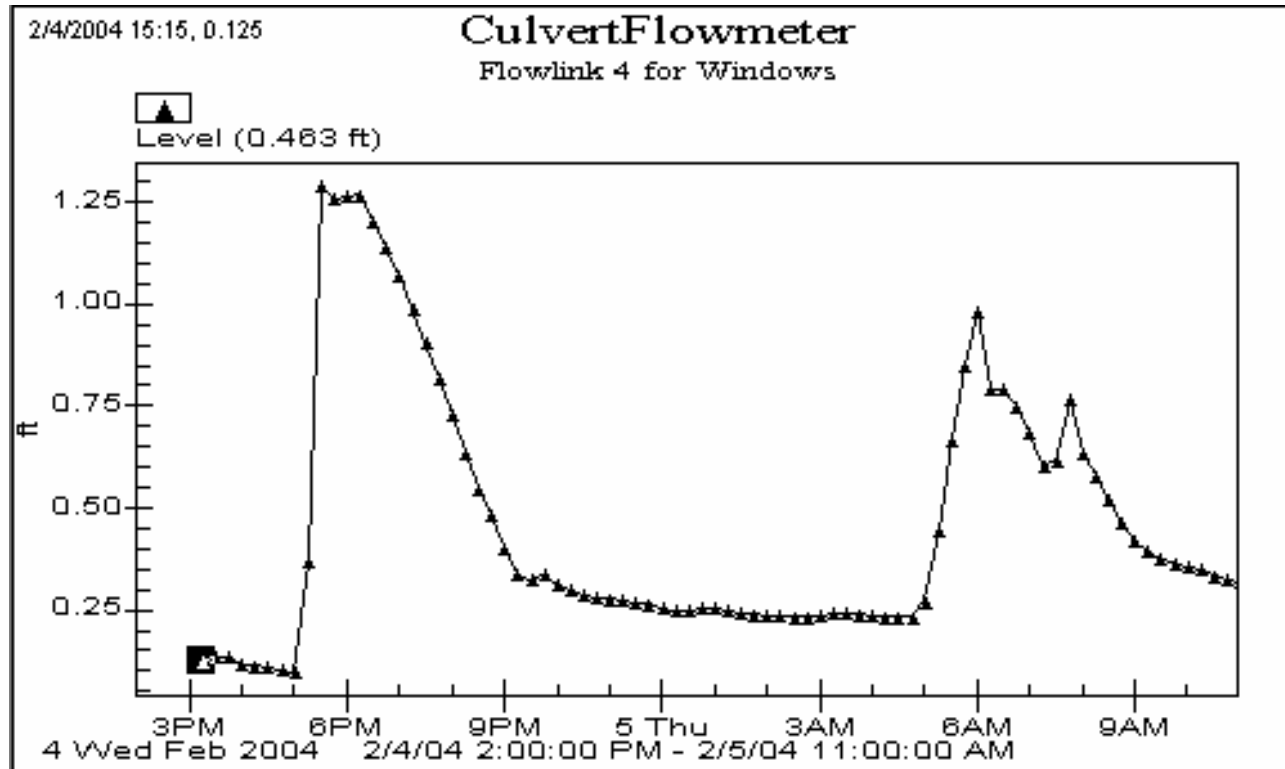


FIG. C-25. Storm event 6: Culvert flow level vs. time (Feb 3 2004)

# LEVEL DATA (BRIDGE)

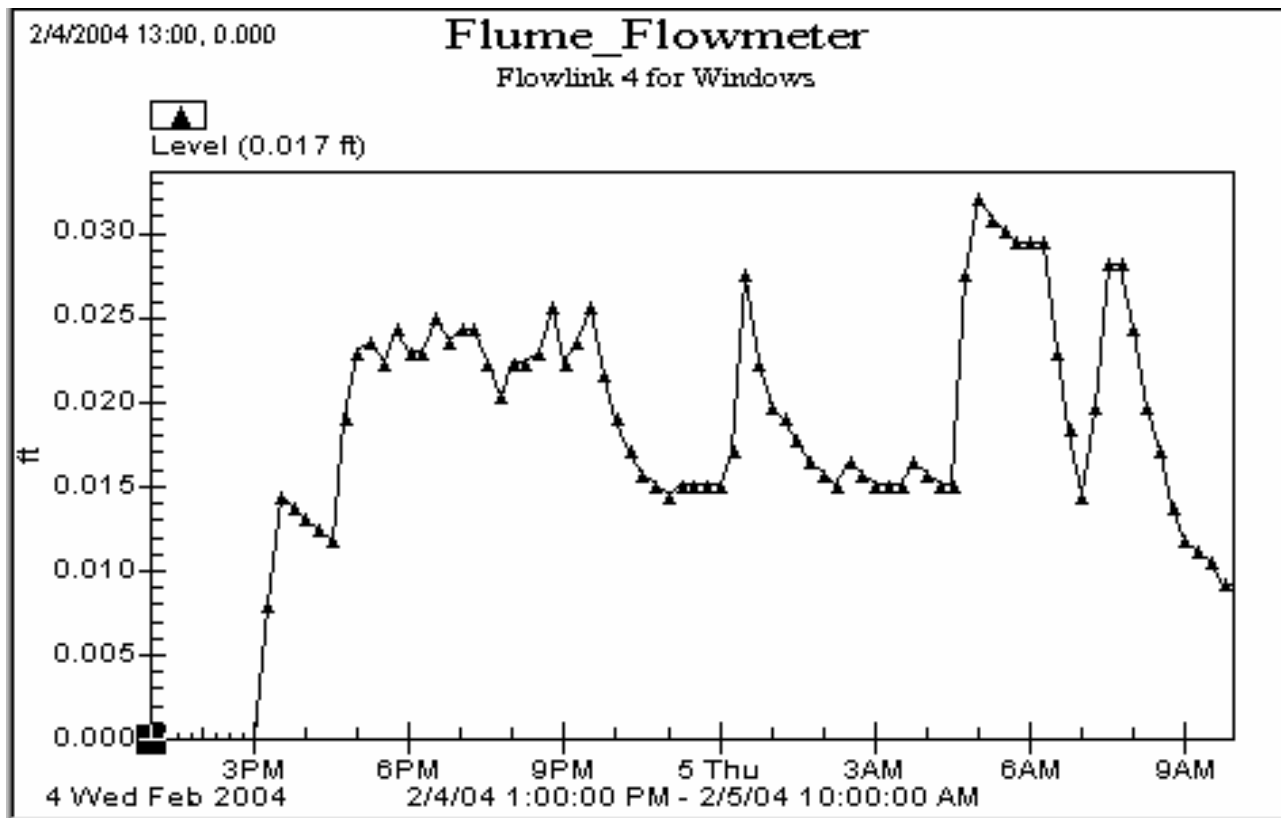


FIG. C-26. Storm event 6: Bridge and flume flow level vs. time (Feb 3 2004)



### FLOW DATA (CULVERT)

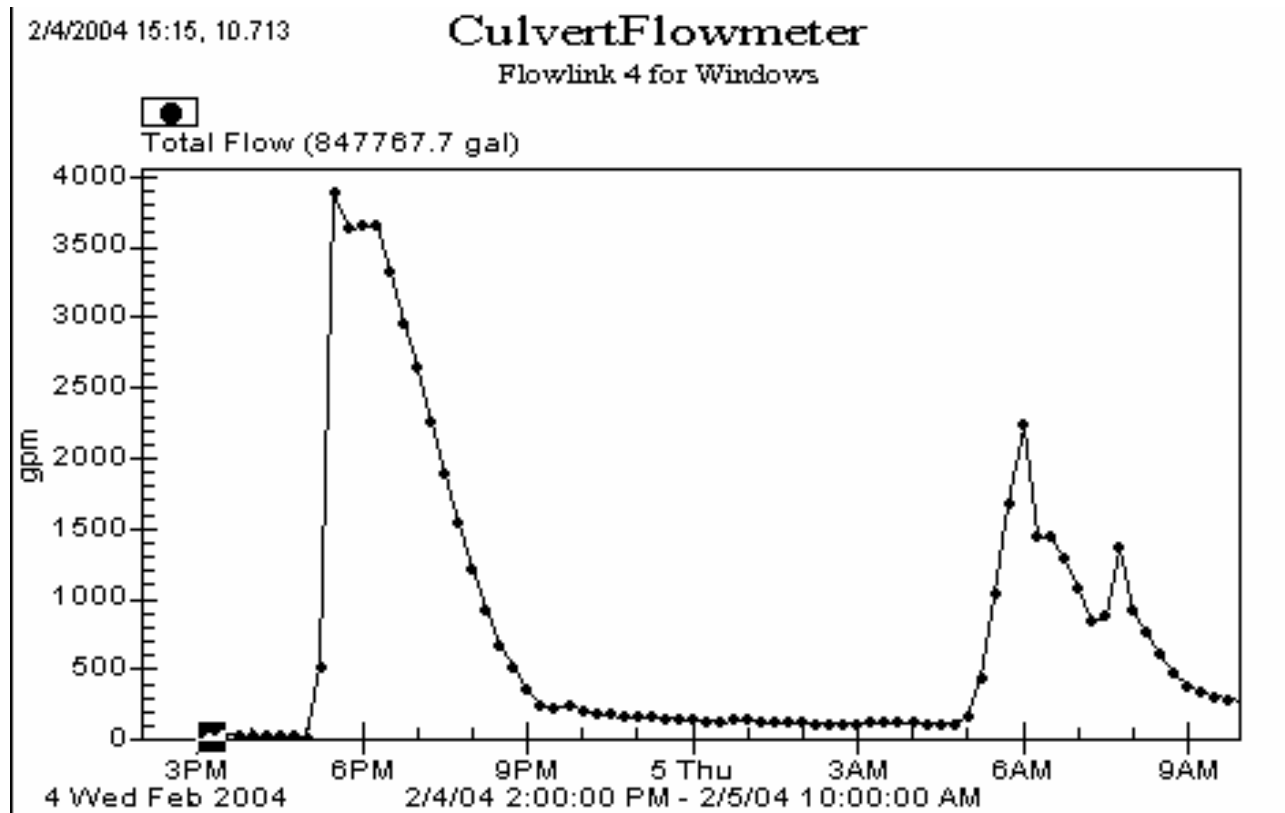


FIG. C-27. Storm event 6: Culvert flow vs. time

### FLOW DATA (BRIDGE)

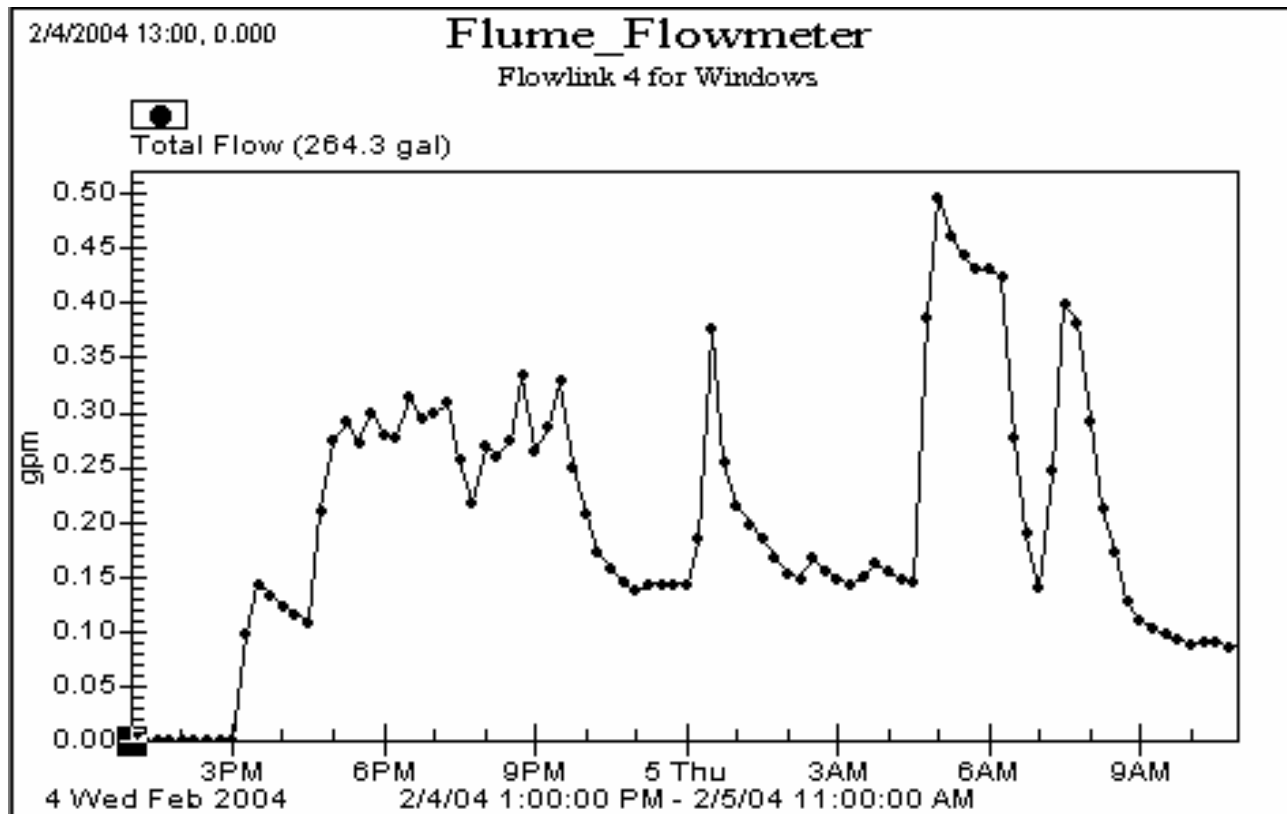


FIG. C-28. Storm event 6: Bridge and flume flow vs. time

**STORM EVENT 7****Feb 10- 6:00 am thru Feb 10- 11:00pm**

## RAINFALL DETAILS

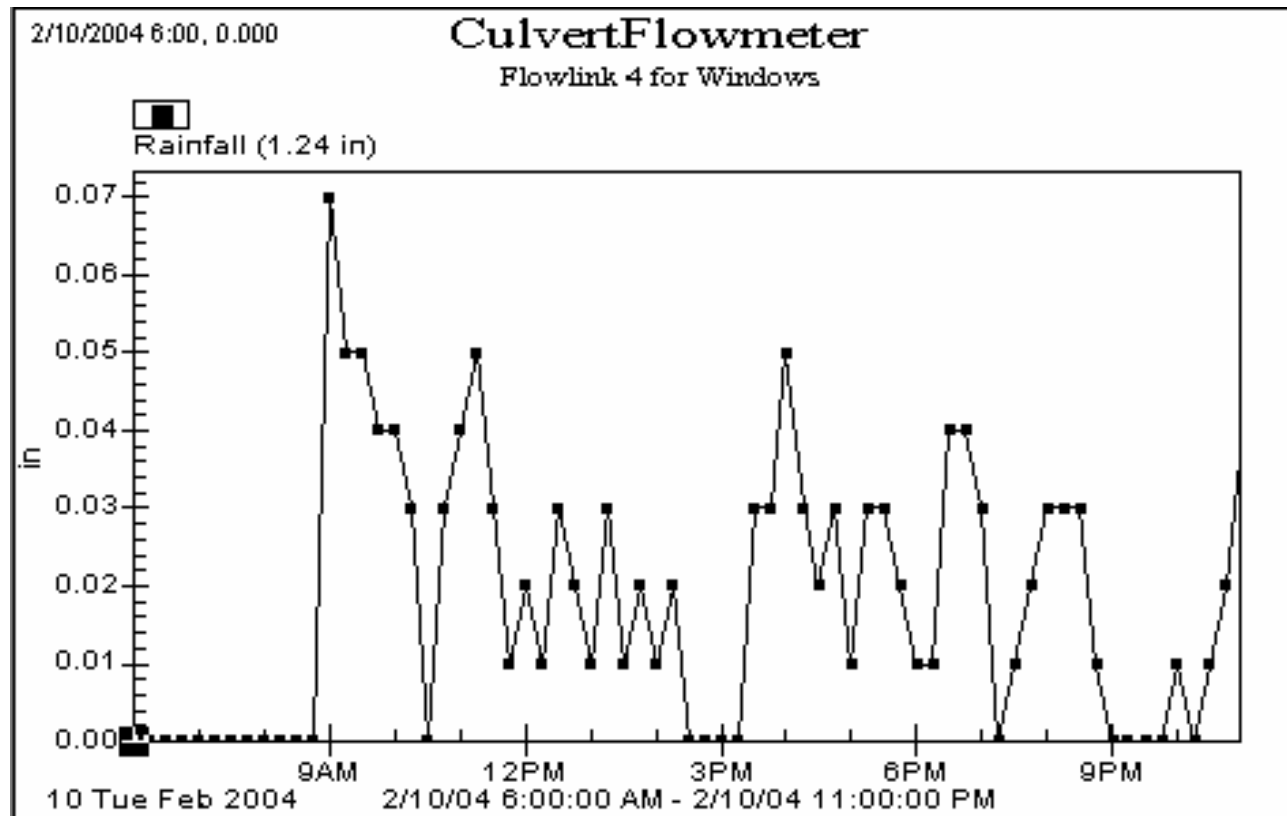


FIG. C-29. Storm event 7 Feb 10 2004

### LEVEL DATA (CULVERT)

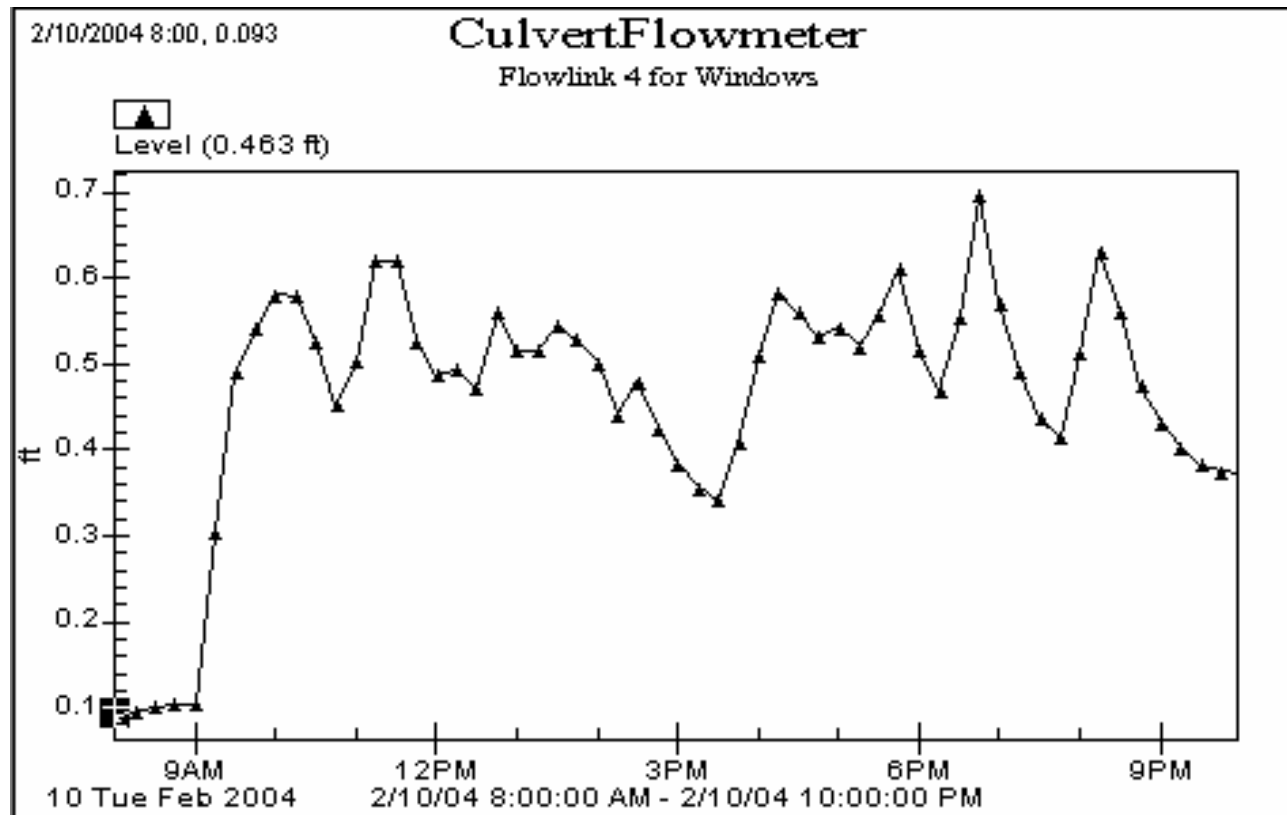


FIG. C-30. Storm event 7: Culvert flow level vs. time (Feb 10 2004)

### LEVEL DATA (BRIDGE)

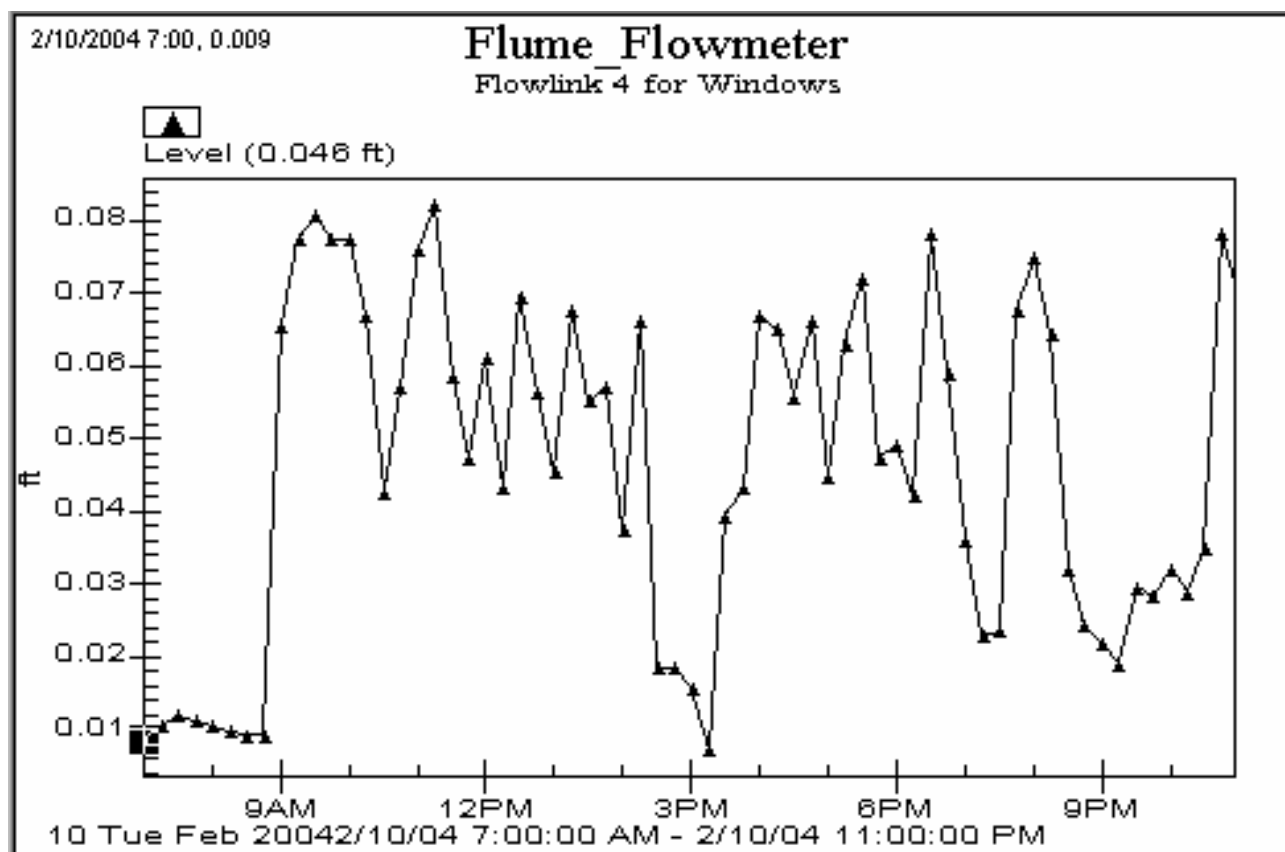


FIG. C-31. Storm event 7: Bridge and flume flow level vs. time (Feb 10 2004)

### FLOW DATA (CULVERT)

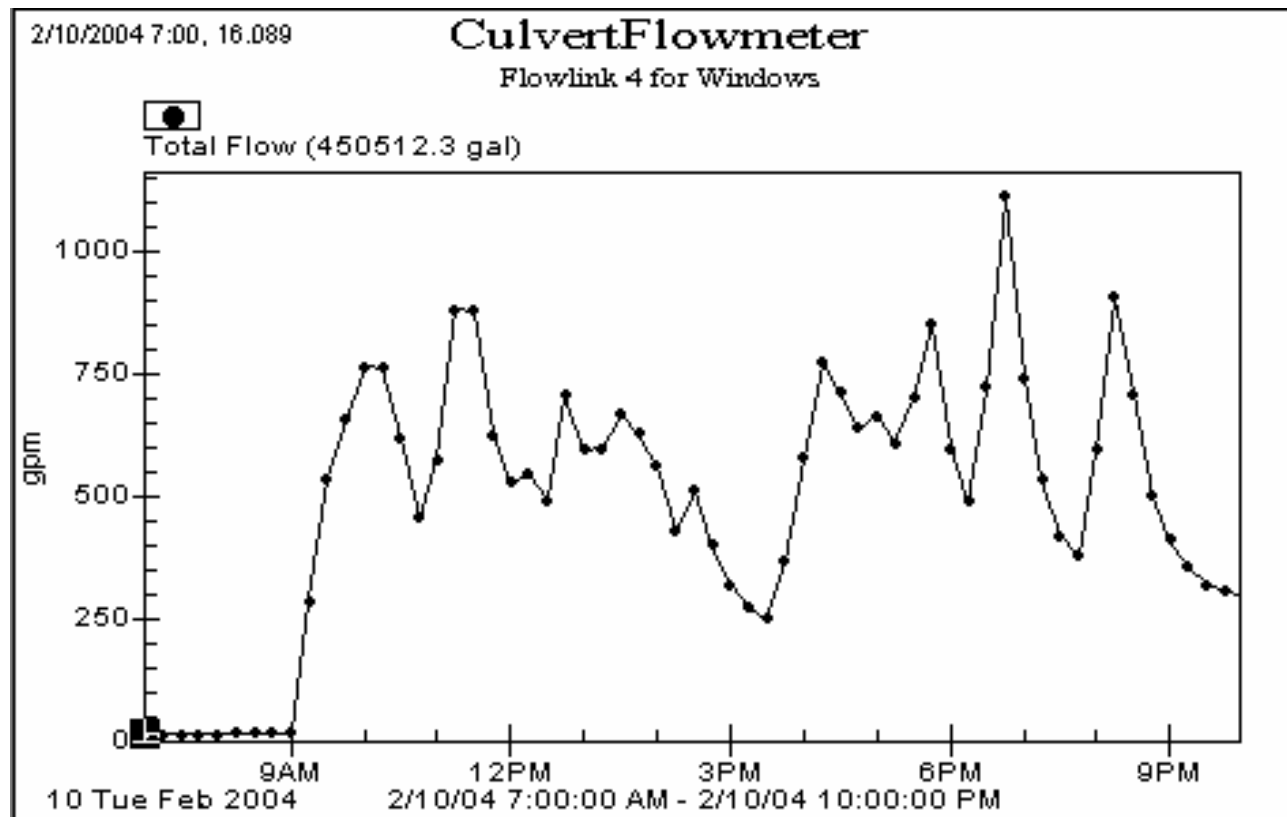


FIG. C-32. Storm event 7: Culvert flow vs. time

### FLOW DATA (BRIDGE)

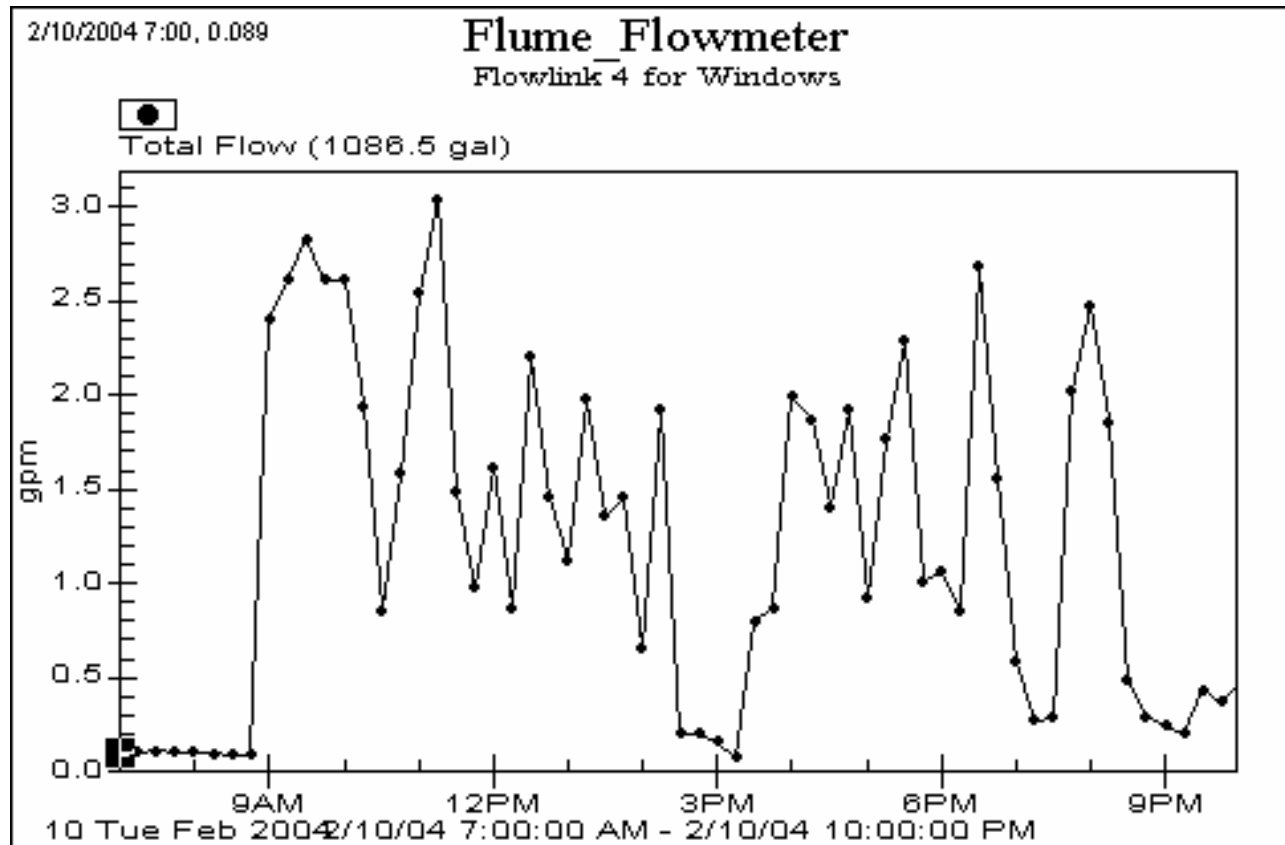


FIG. C-33. Storm event 7: Bridge and flume flow vs. time



**STORM EVENT 8****Feb 11- 7:00 am thru Jan 25- 10:00pm**

## RAINFALL DETAILS

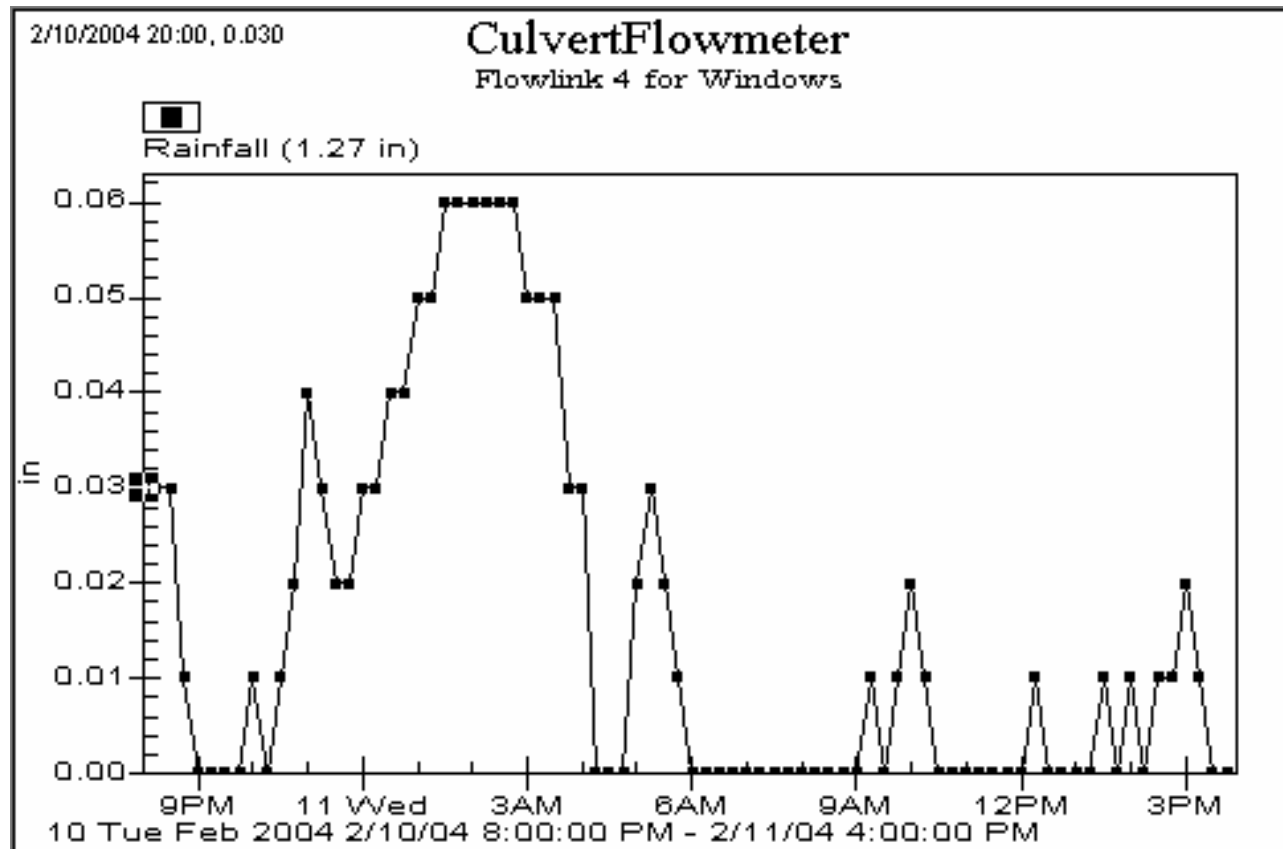


FIG. C-34. Storm event 8 Feb 11 2004

### LEVEL DATA (CULVERT)

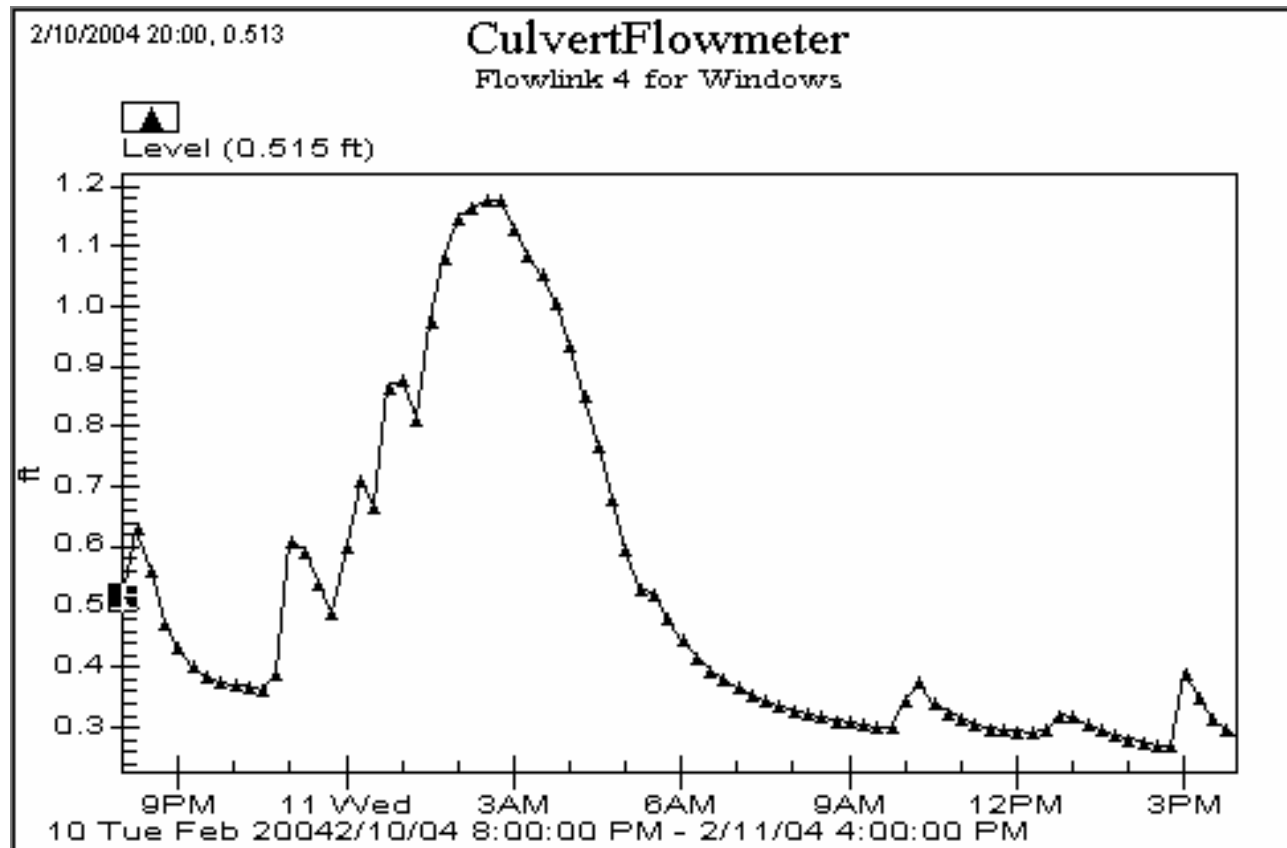


FIG. C-35. Storm event 8: Culvert flow level vs. time (Feb 11 2004)

### LEVEL DATA (BRIDGE)

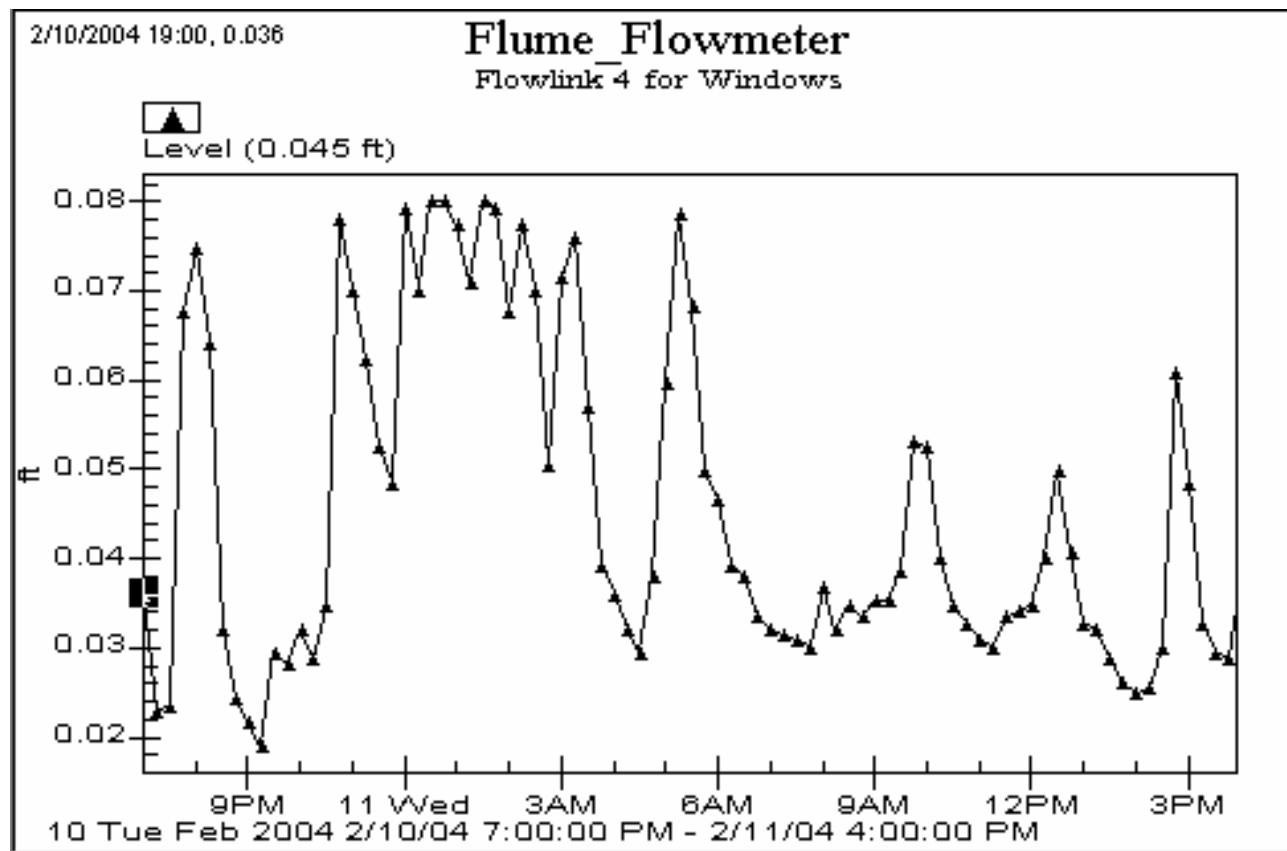


FIG. C-36. Storm event 8: Bridge and flume flow level vs. time (Feb 11 2004)

# CulvertFlowmeter

## Flowlink 4 for Windows



### FLOW DATA (BRIDGE)

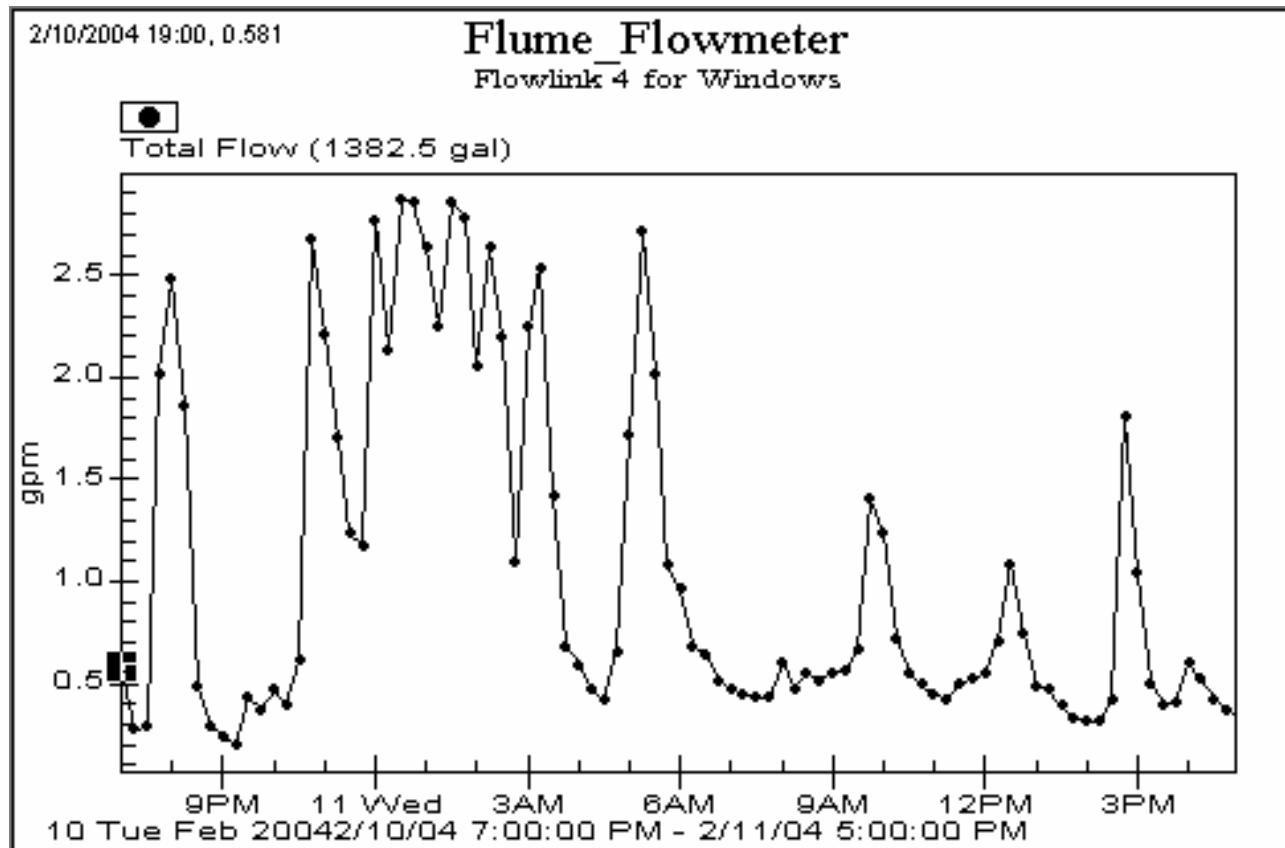


FIG. C-38. Storm event 8: Bridge and flume flow vs. time

**STORM EVENT 9****Feb 24- 10:00 am thru Feb 25- 3:00am**

## RAINFALL DETAILS

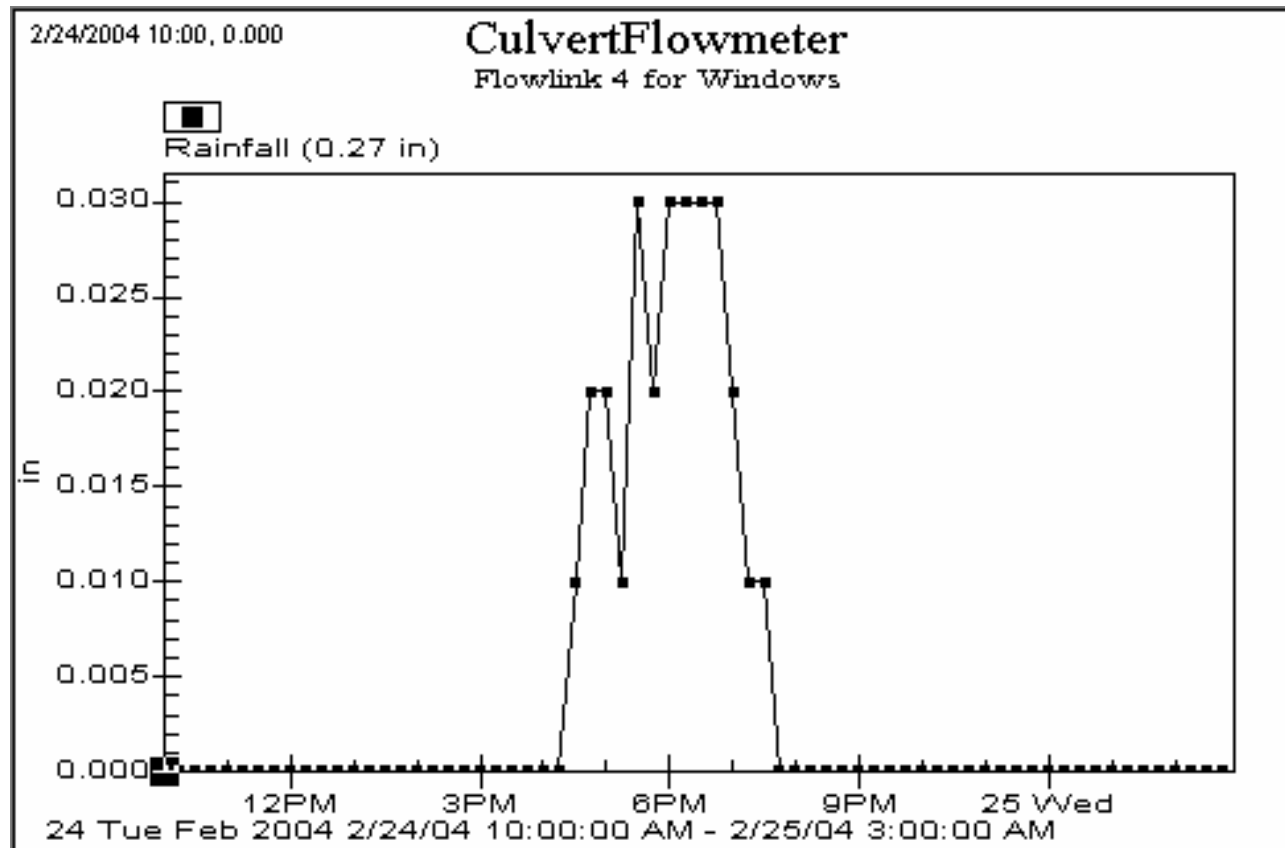


FIG. C-34. Storm event 9 Feb 25 2004



### LEVEL DATA (CULVERT)

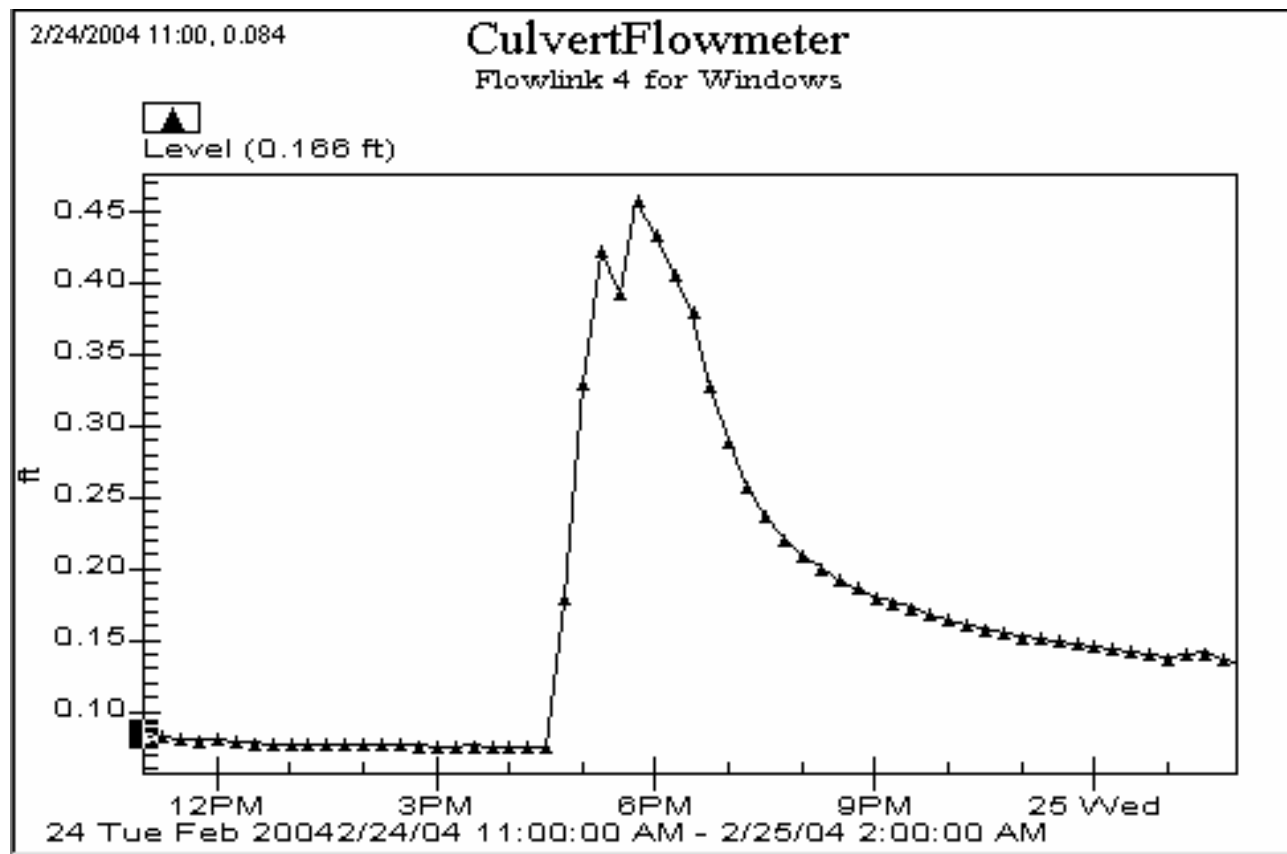


FIG. C-35. Storm event 9: Culvert flow level vs. time (Feb 25 2004)

# LEVEL DATA (BRIDGE)

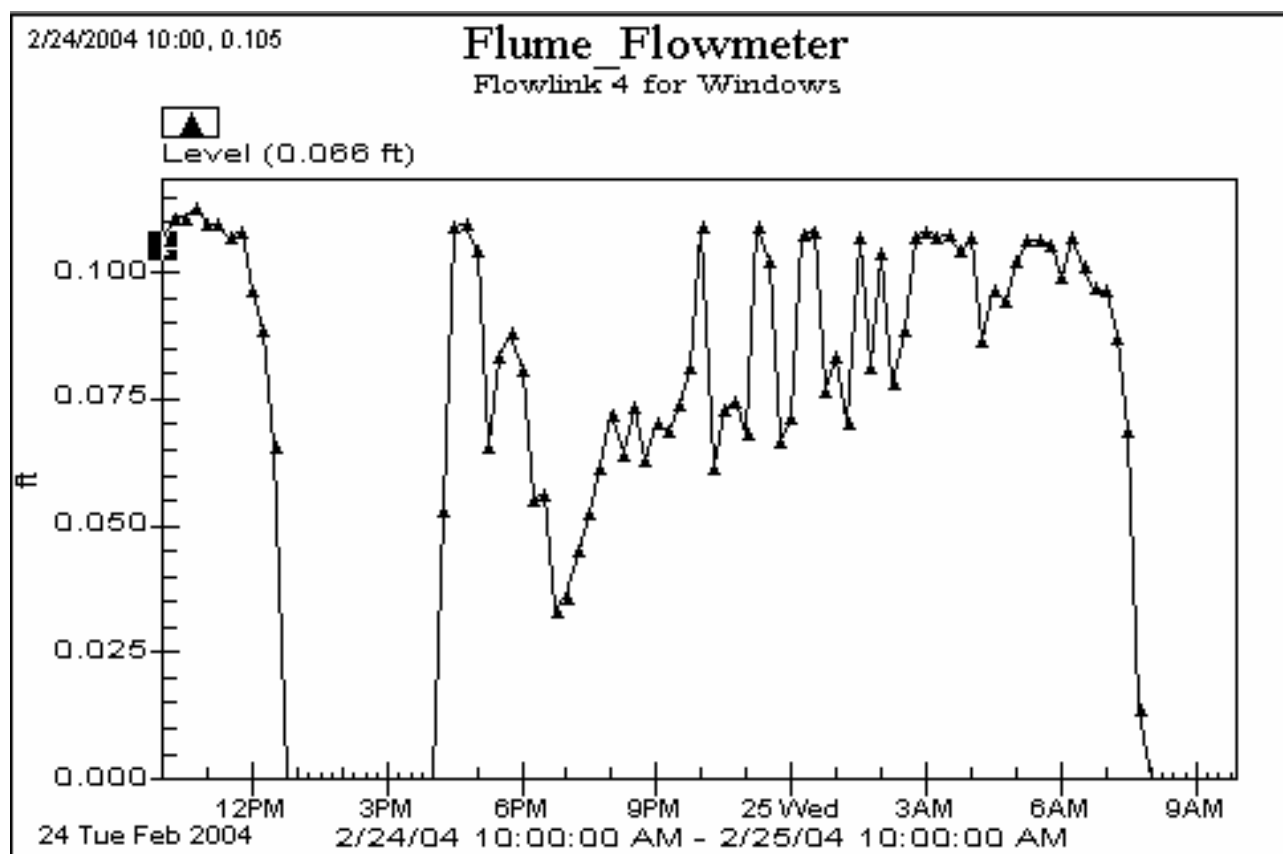


FIG. C-36. Storm event 9: Bridge and flume flow level vs. time (Feb 25 2004)

### FLOW DATA (CULVERT)

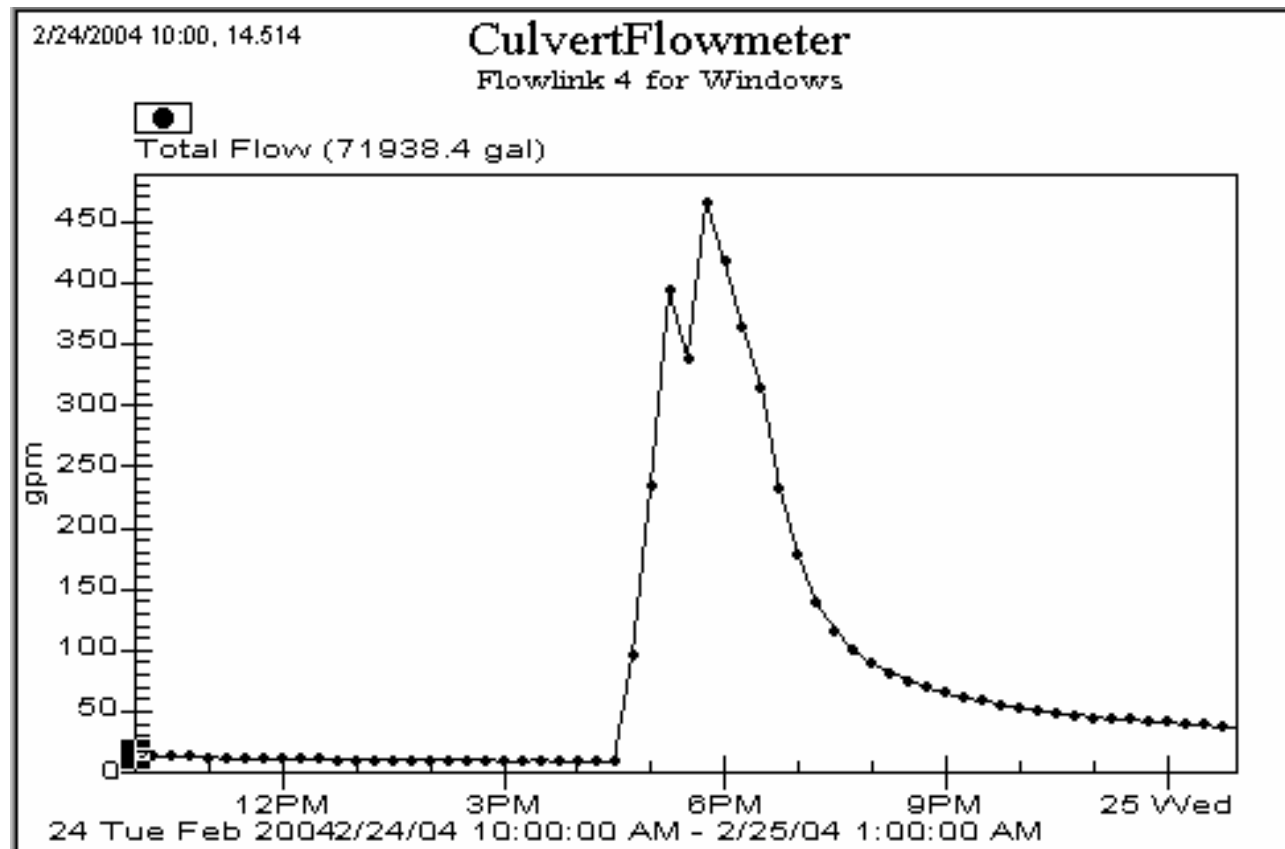


FIG. C-37. Storm event 9: Culvert flow vs. time

### FLOW DATA (BRIDGE)

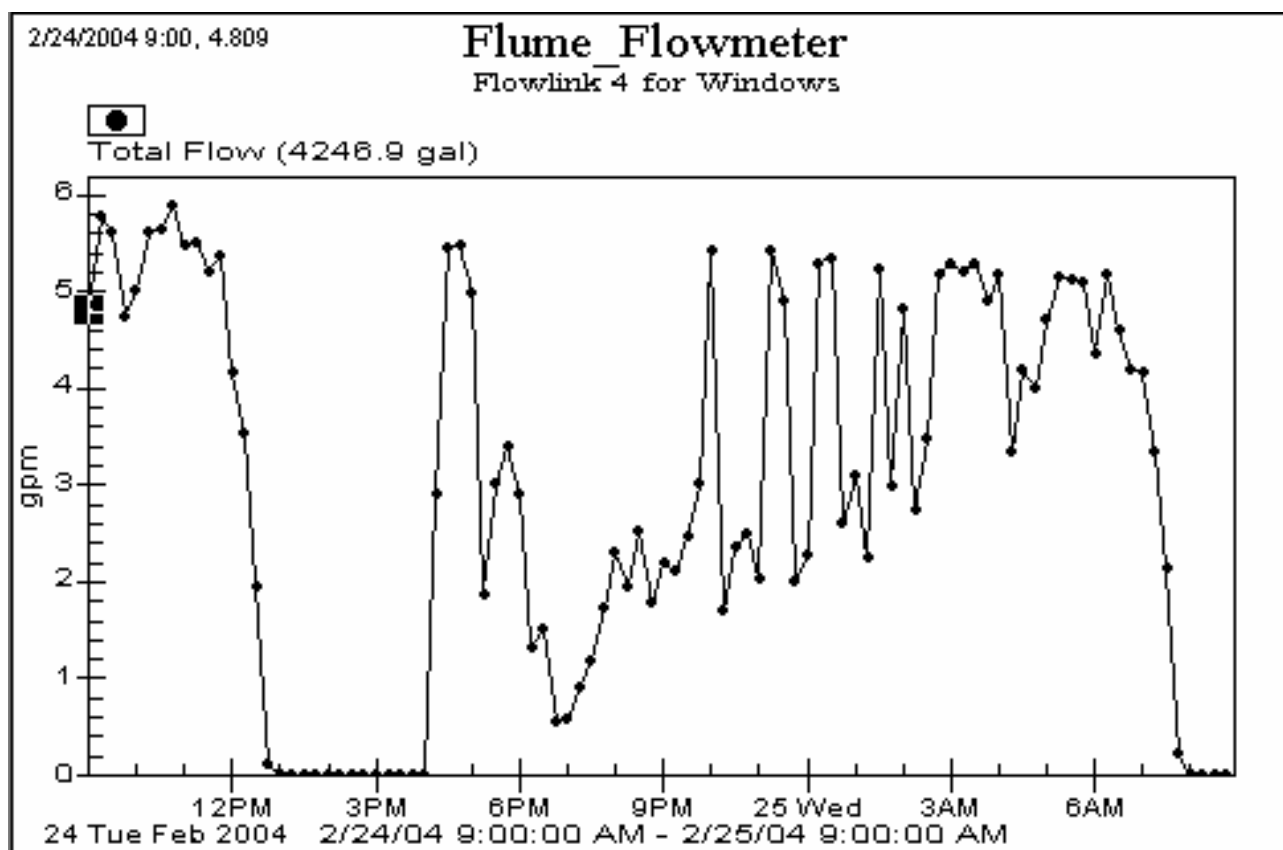
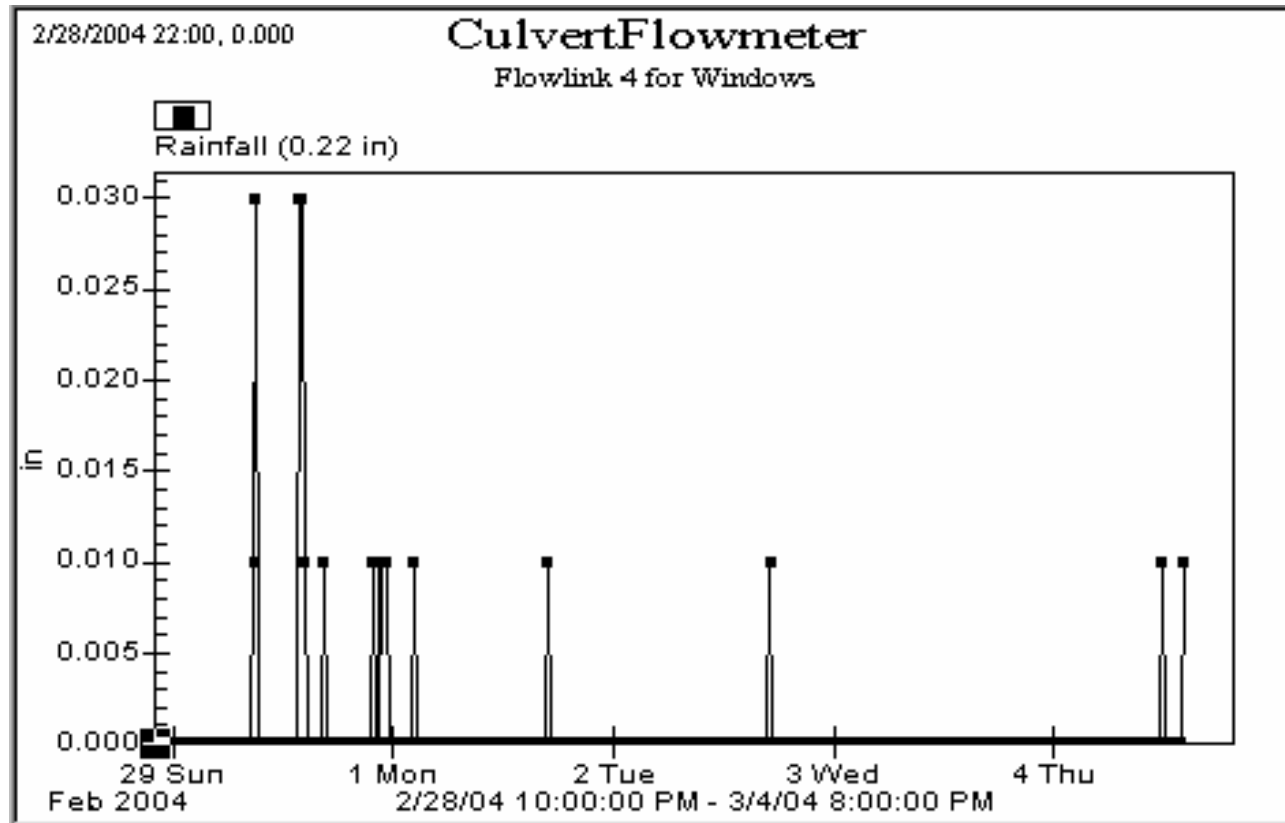


FIG. C-38. Storm event 9: Bridge and flume flow vs. time

**STORM EVENT 10****Feb 28- 10:00 pm thru Mar 4- 8:00pm**

## RAINFALL DETAILS



**FIG. C-39. Storm event 10 Feb 28 -Mar 4**

### LEVEL DATA (CULVERT)

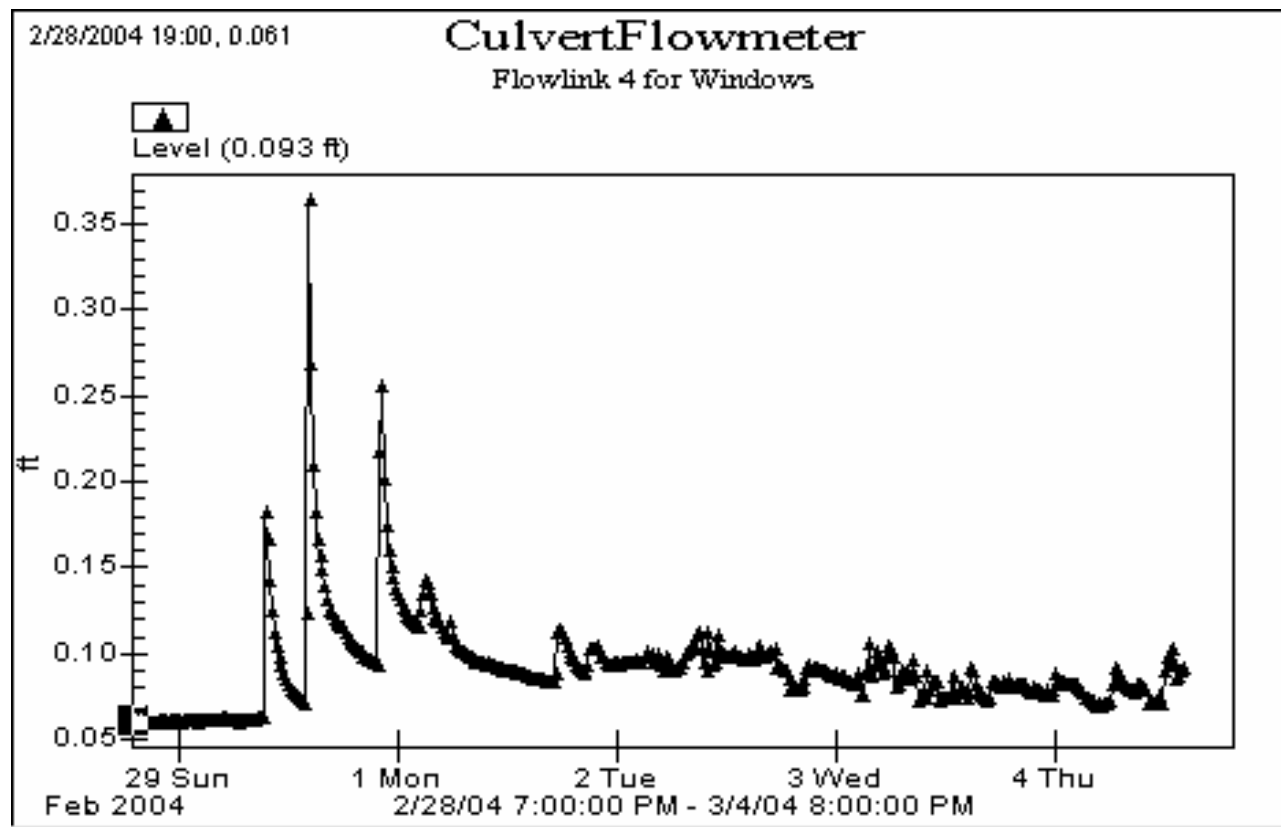


FIG. C-40. Storm event 10: Culvert flow level vs. time

### LEVEL DATA (BRIDGE)

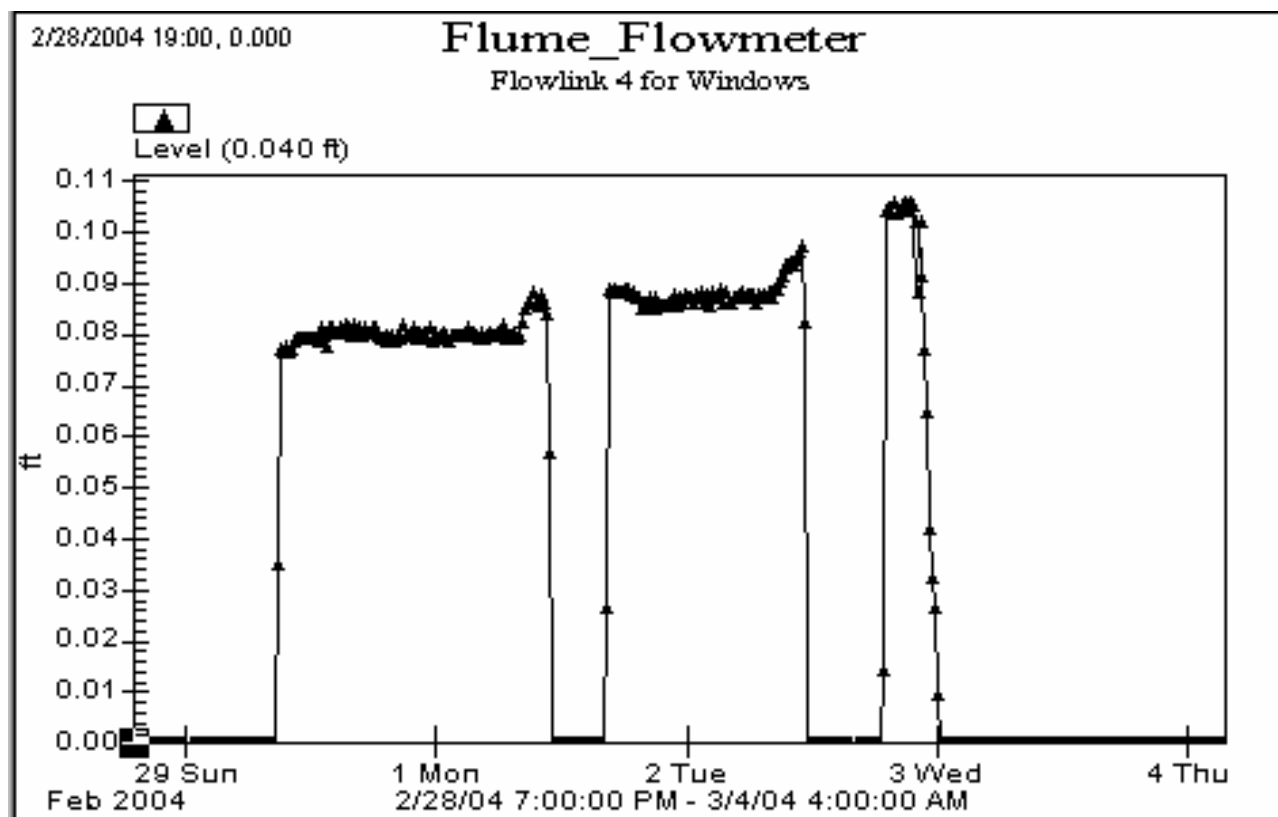


FIG. C-41. Storm event 10: Bridge and flume flow level vs. time



## FLOW DATA (CULVERT)

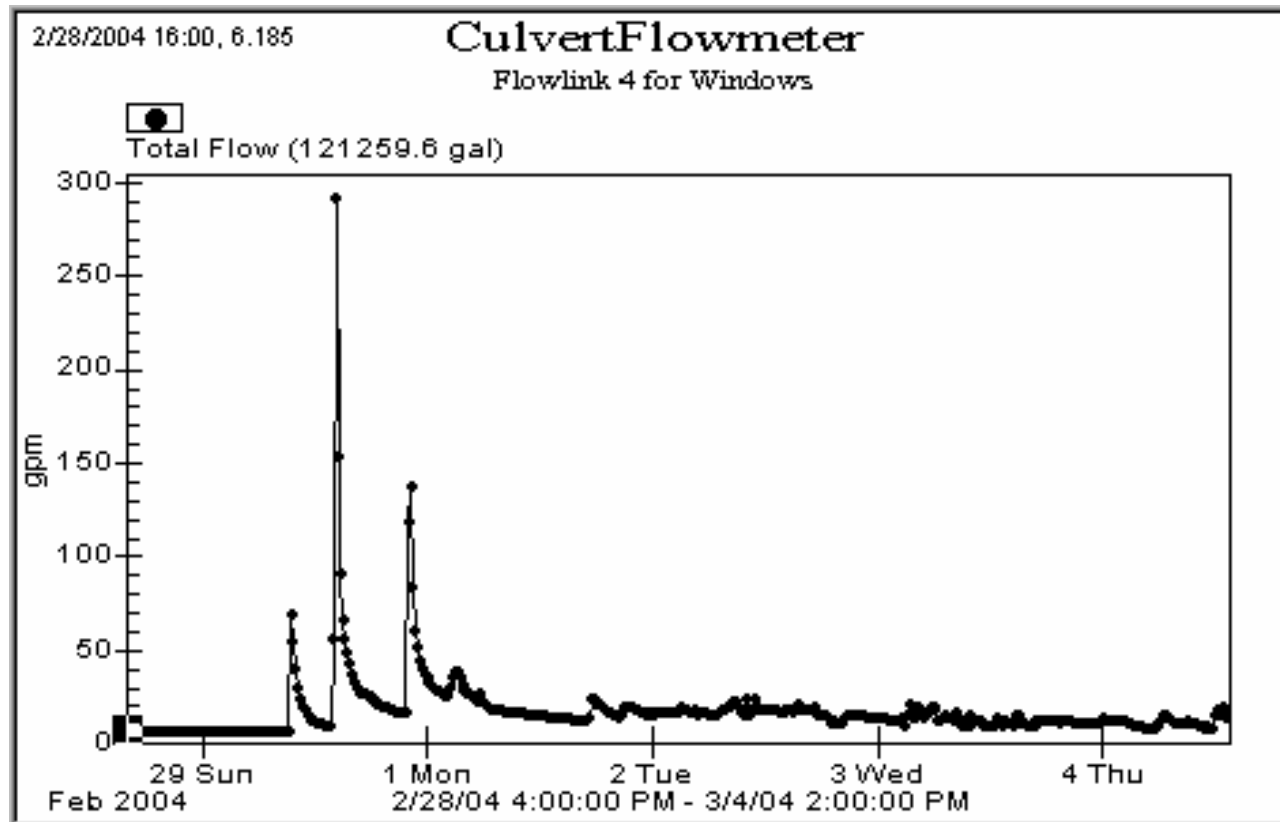


FIG. C-42. Storm event 10: Culvert flow vs. time

### FLOW DATA (BRIDGE)

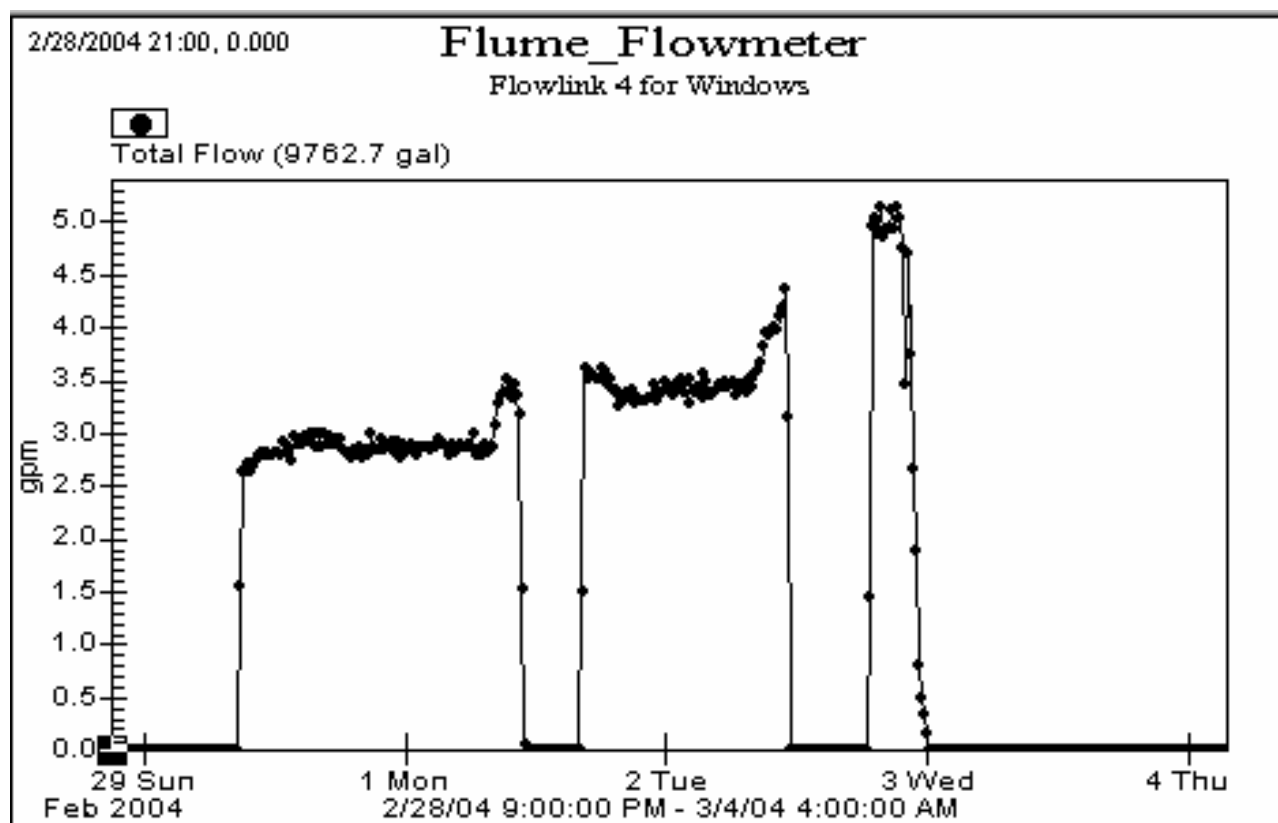


FIG. C-43. Storm event 10: Bridge and flume flow vs. time

**STORM EVENT 11****Apr 24- 3:00 am thru Apr 25- 1:00am**

## RAINFALL DETAILS

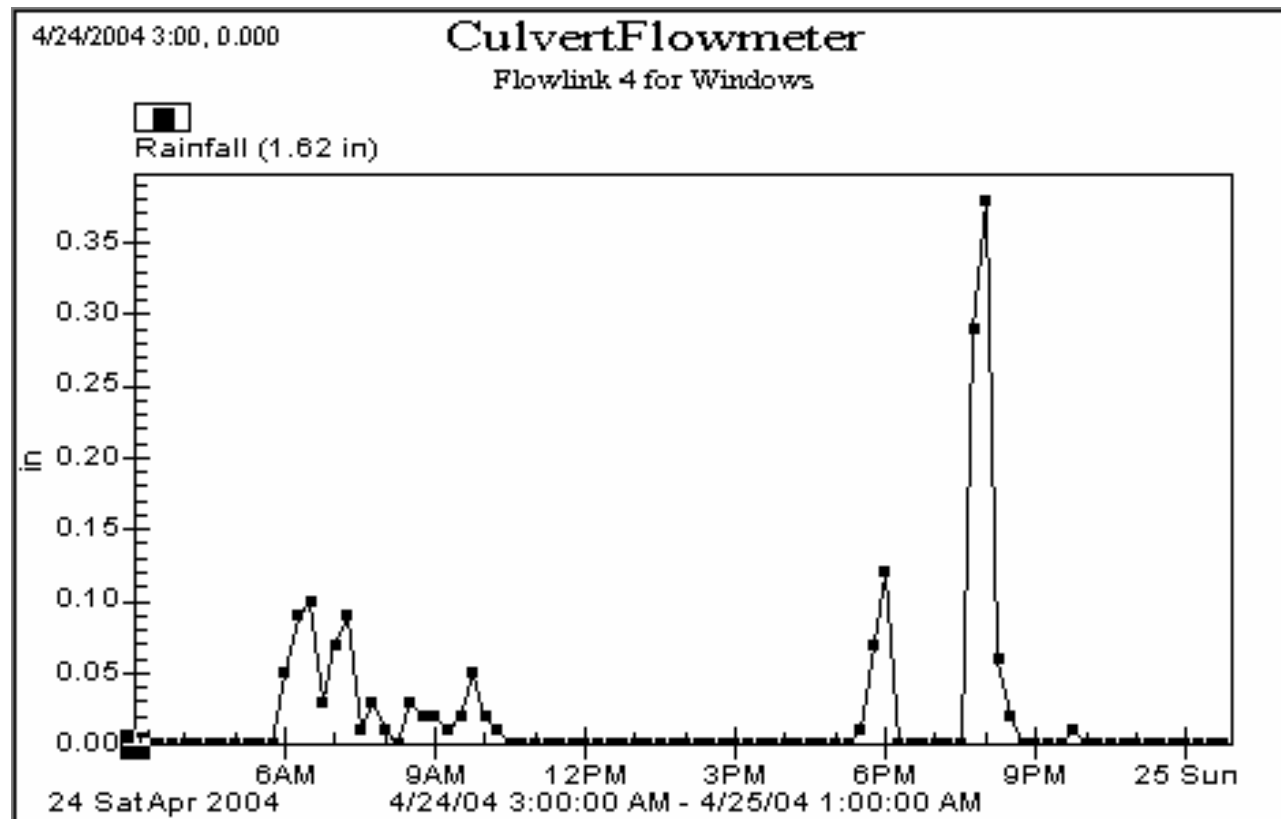


FIG. C-44. Storm event 11 Apr 24 2004

### LEVEL DATA (CULVERT)

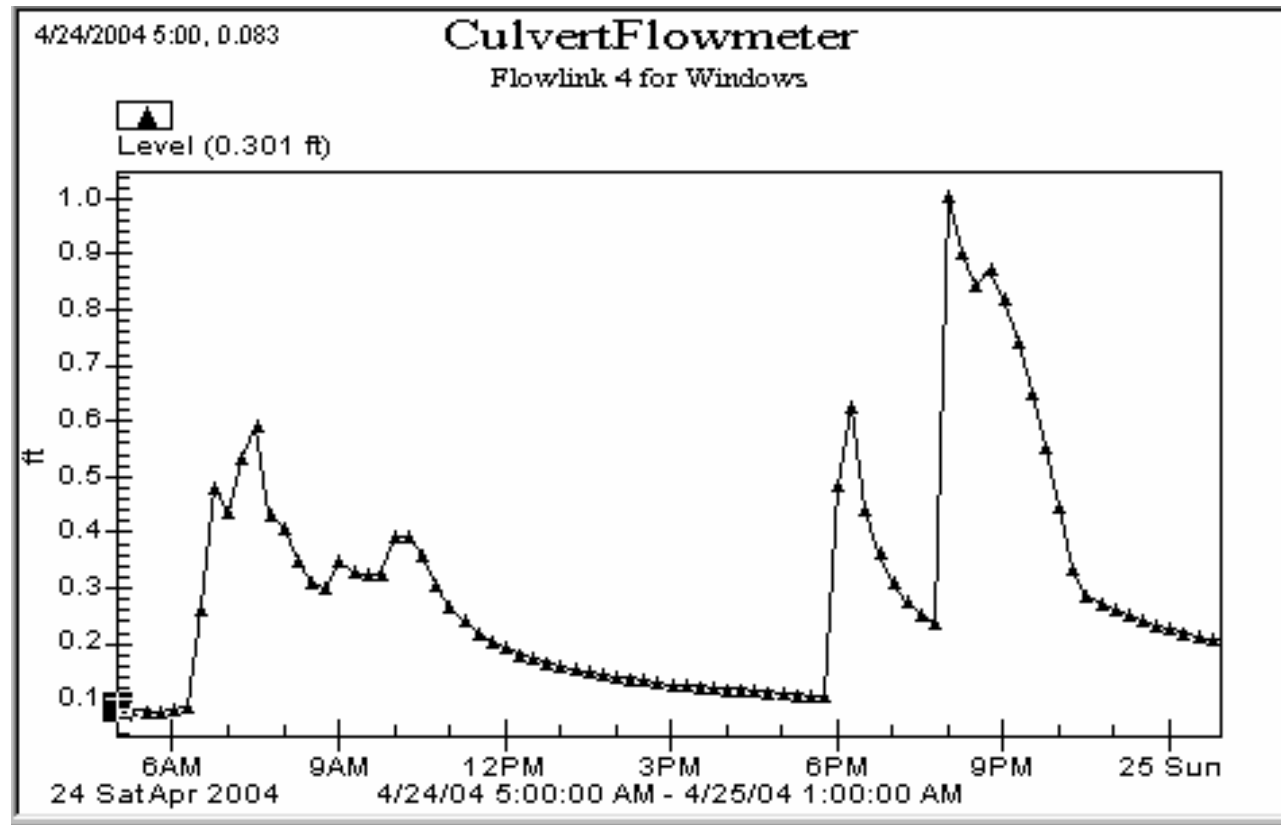


FIG. C-45. Storm event 11: Culvert flow level vs. time

# LEVEL DATA (BRIDGE)

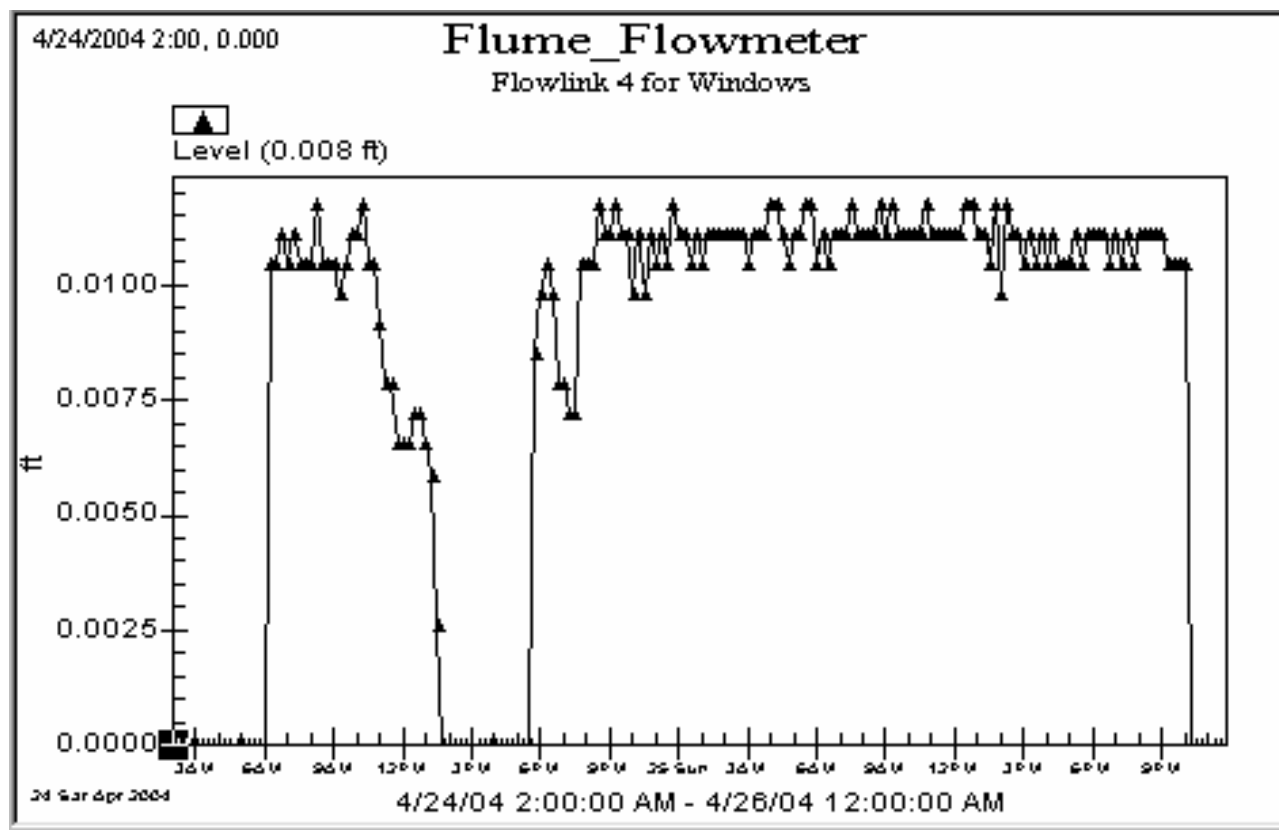


FIG. C-46. Storm event 11: Bridge and flume flow level vs. time

### FLOW DATA (CULVERT)

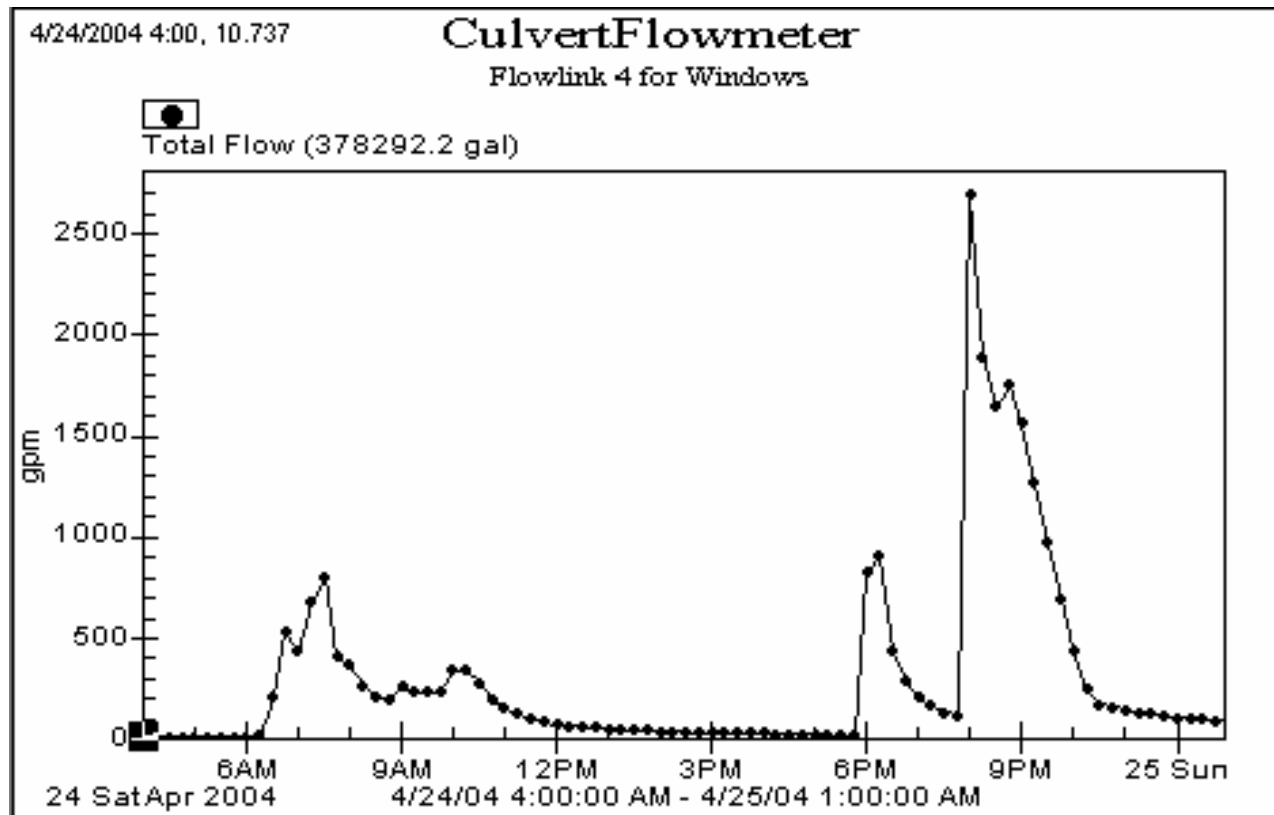


FIG. C-47. Storm event 11: Culvert flow vs. time

### FLOW DATA (BRIDGE)

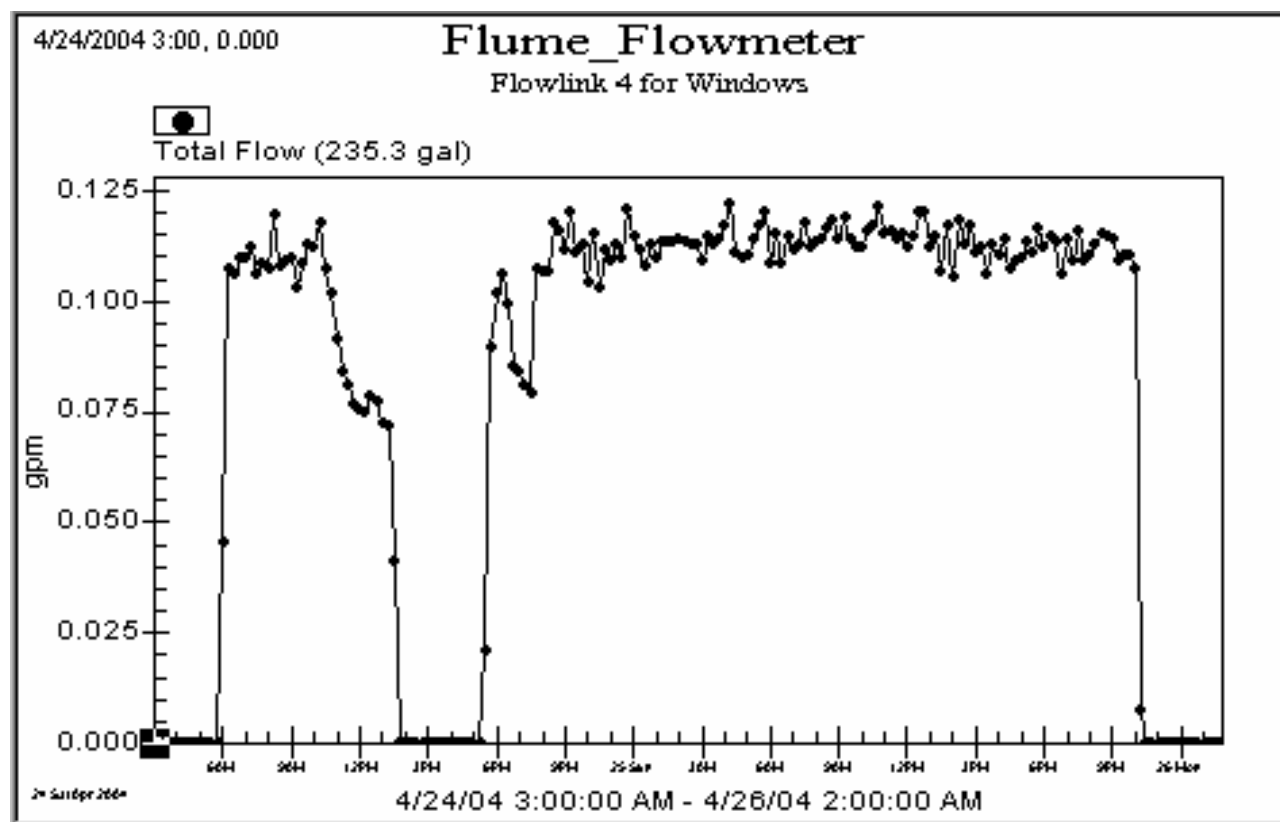


FIG. C-48. Storm event 11: Bridge and flume flow vs. time



**APPENDIX D**

**CONSTITUENT DETAILED COMPARISONS DURING**

**DIFFERENT EVENTS**

# D-1: Copper concentrations

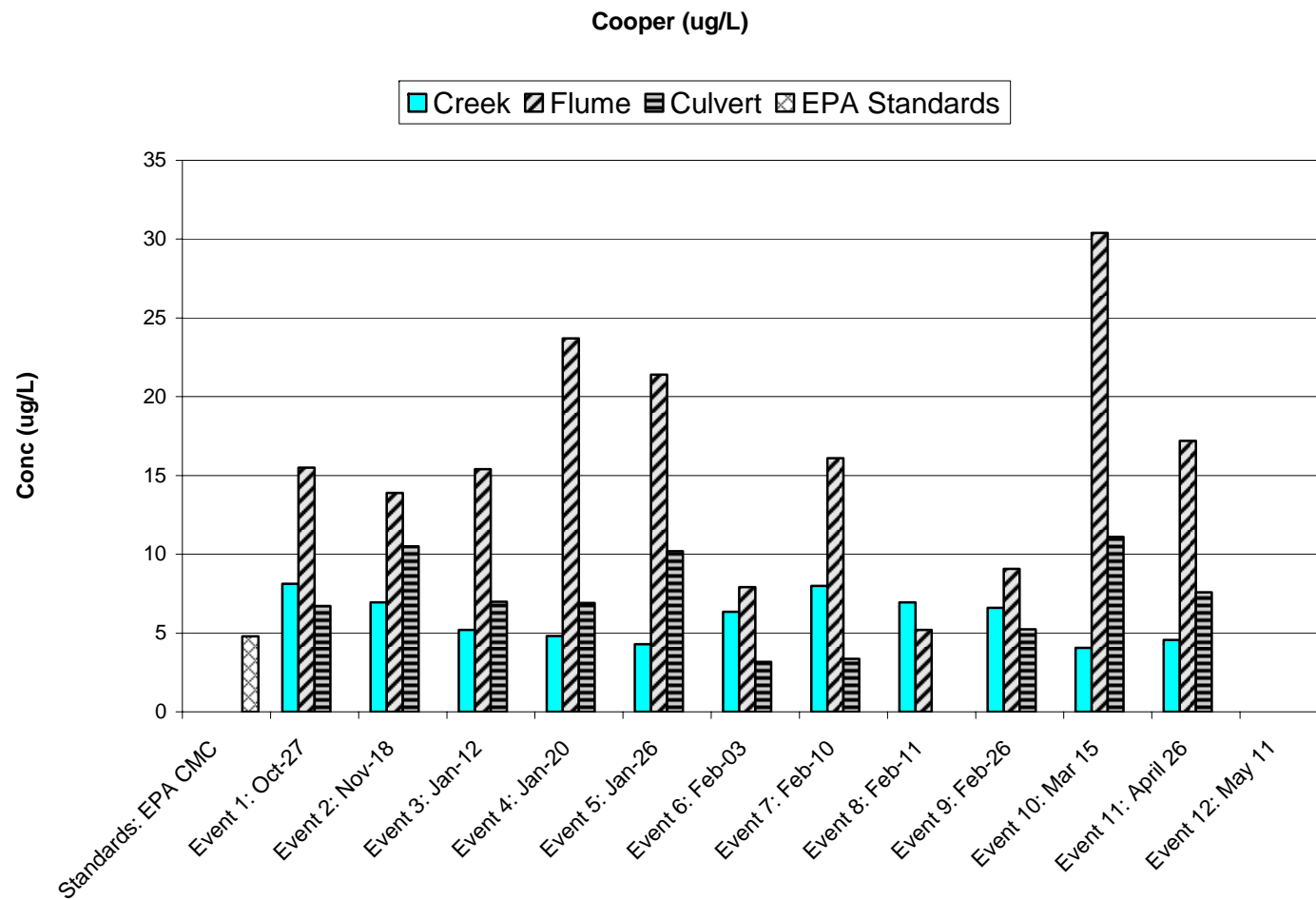


FIG. D-1. Storm events copper concentration comparison

## D-2: Lead concentrations

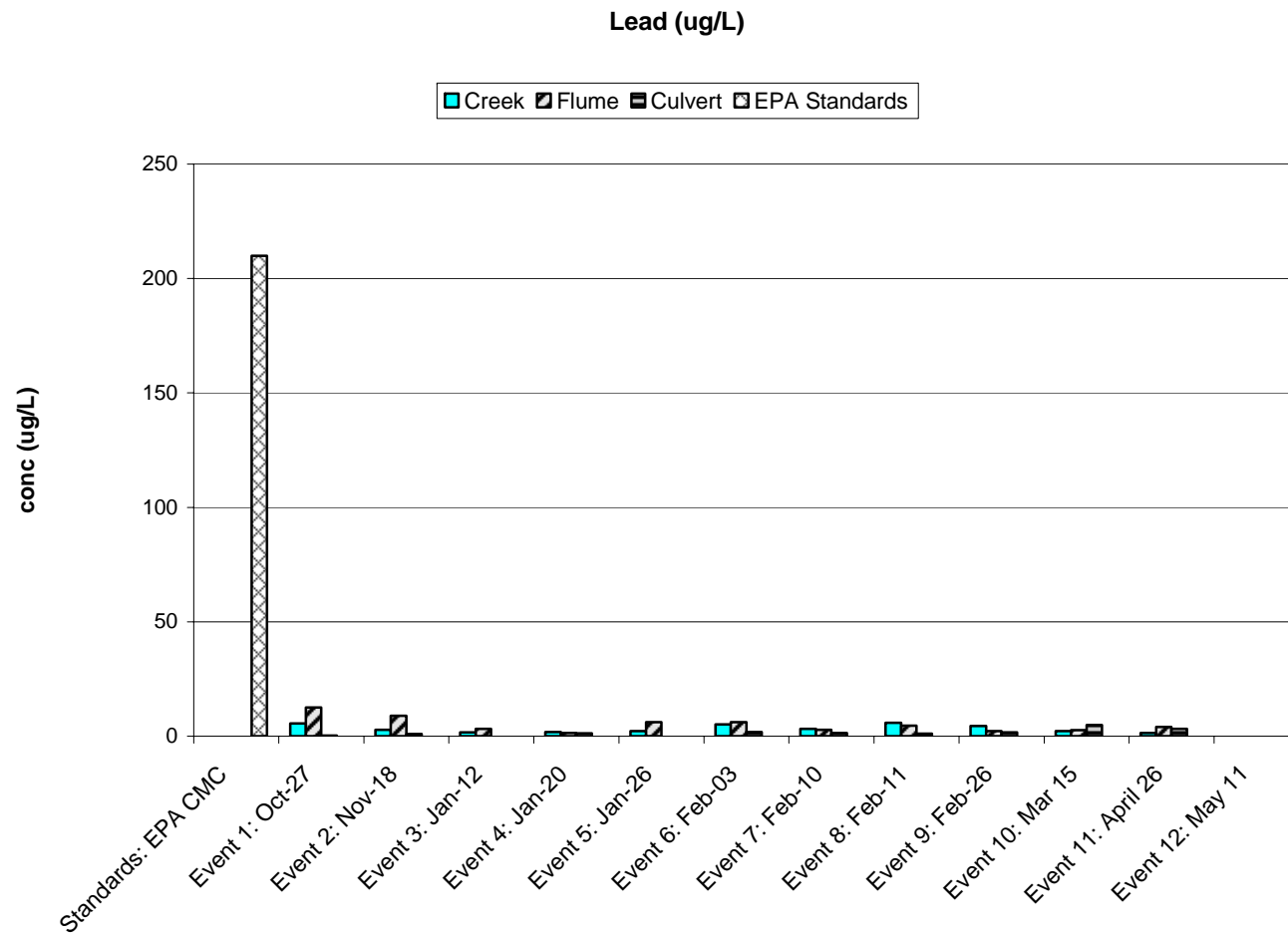
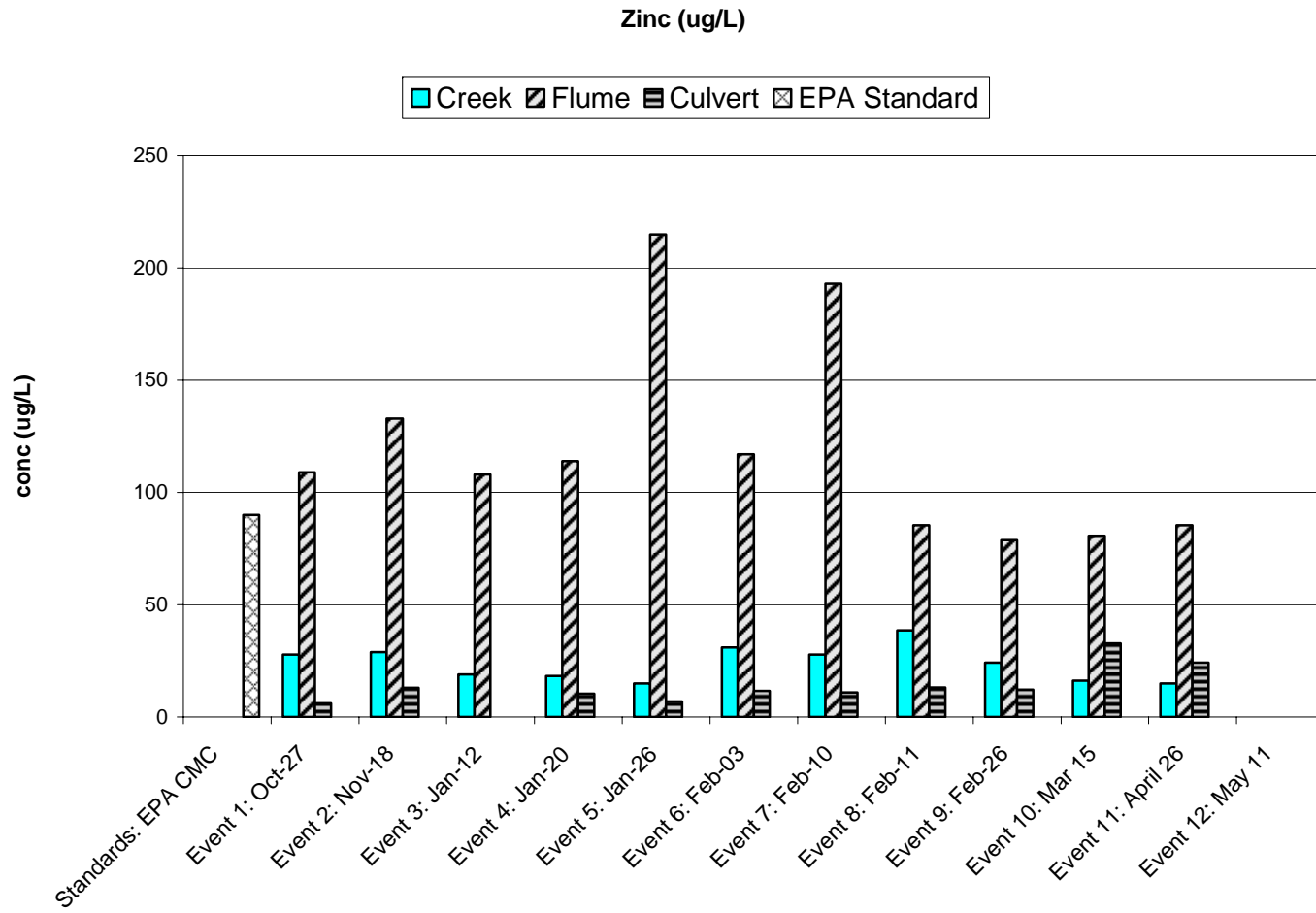


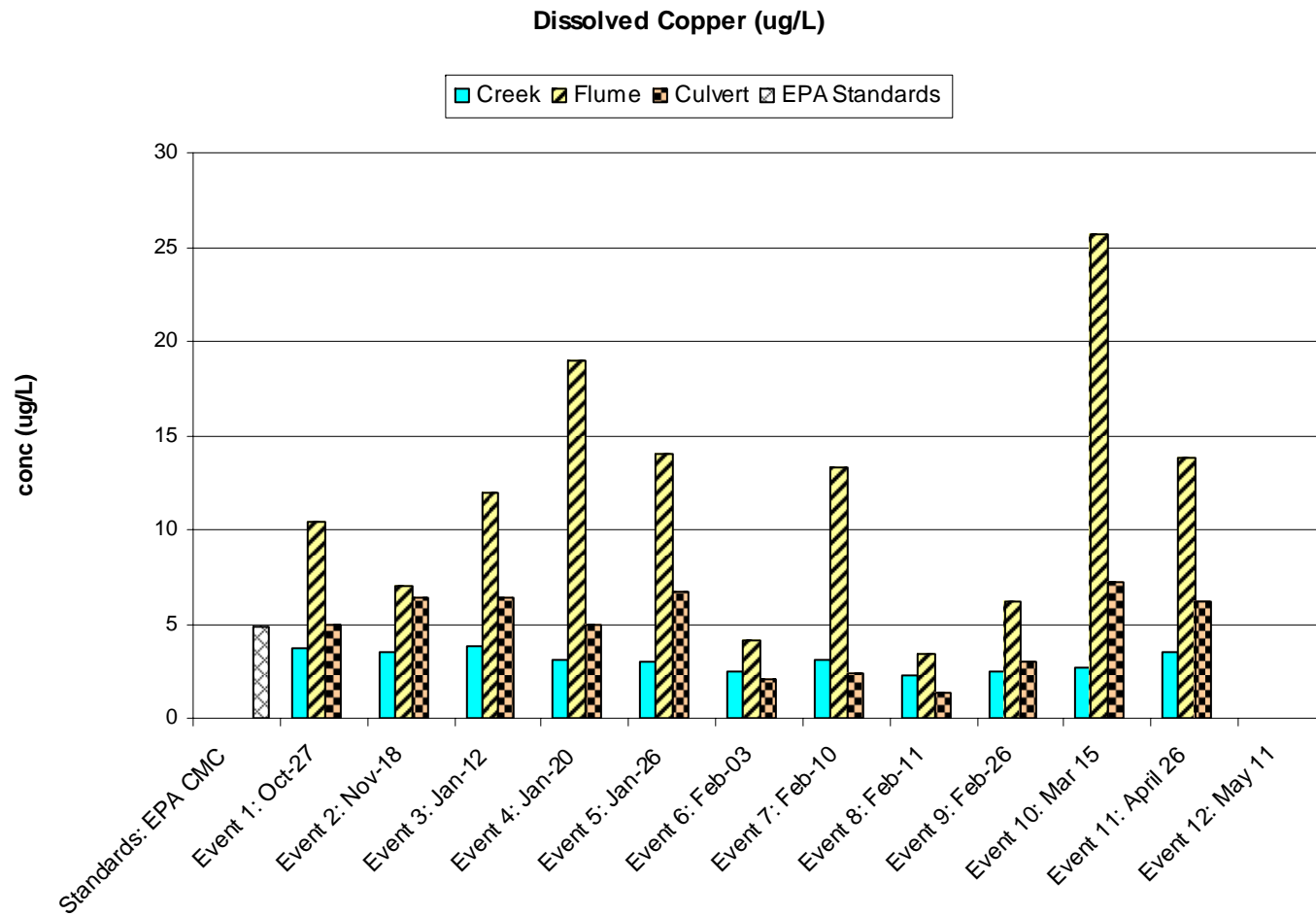
FIG. D-2. Storm events lead concentration comparison

### D-3: Zinc concentrations

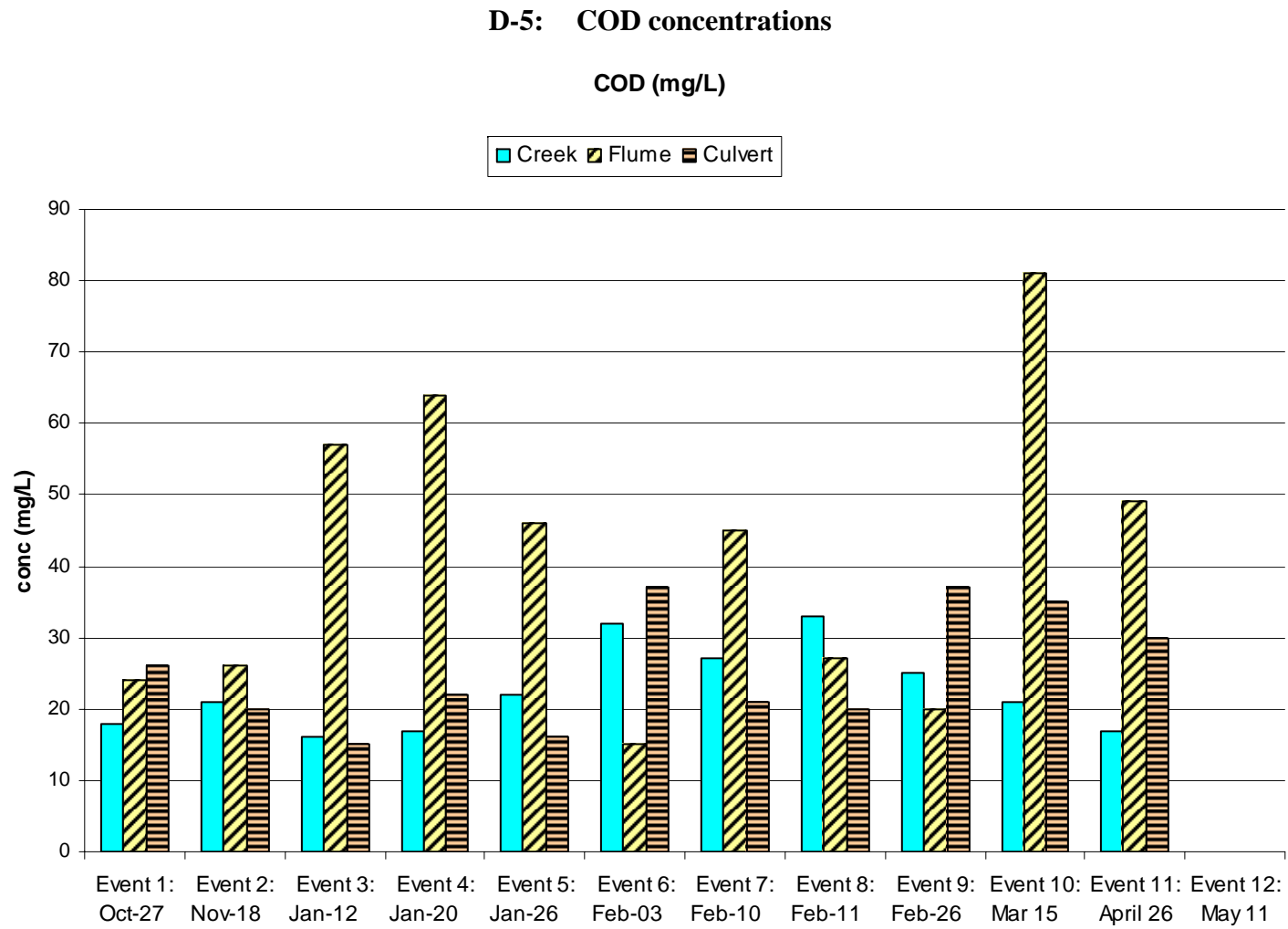


**FIG. D-3. Storm events zinc concentration comparison**

#### D-4: Nitrogen concentrations

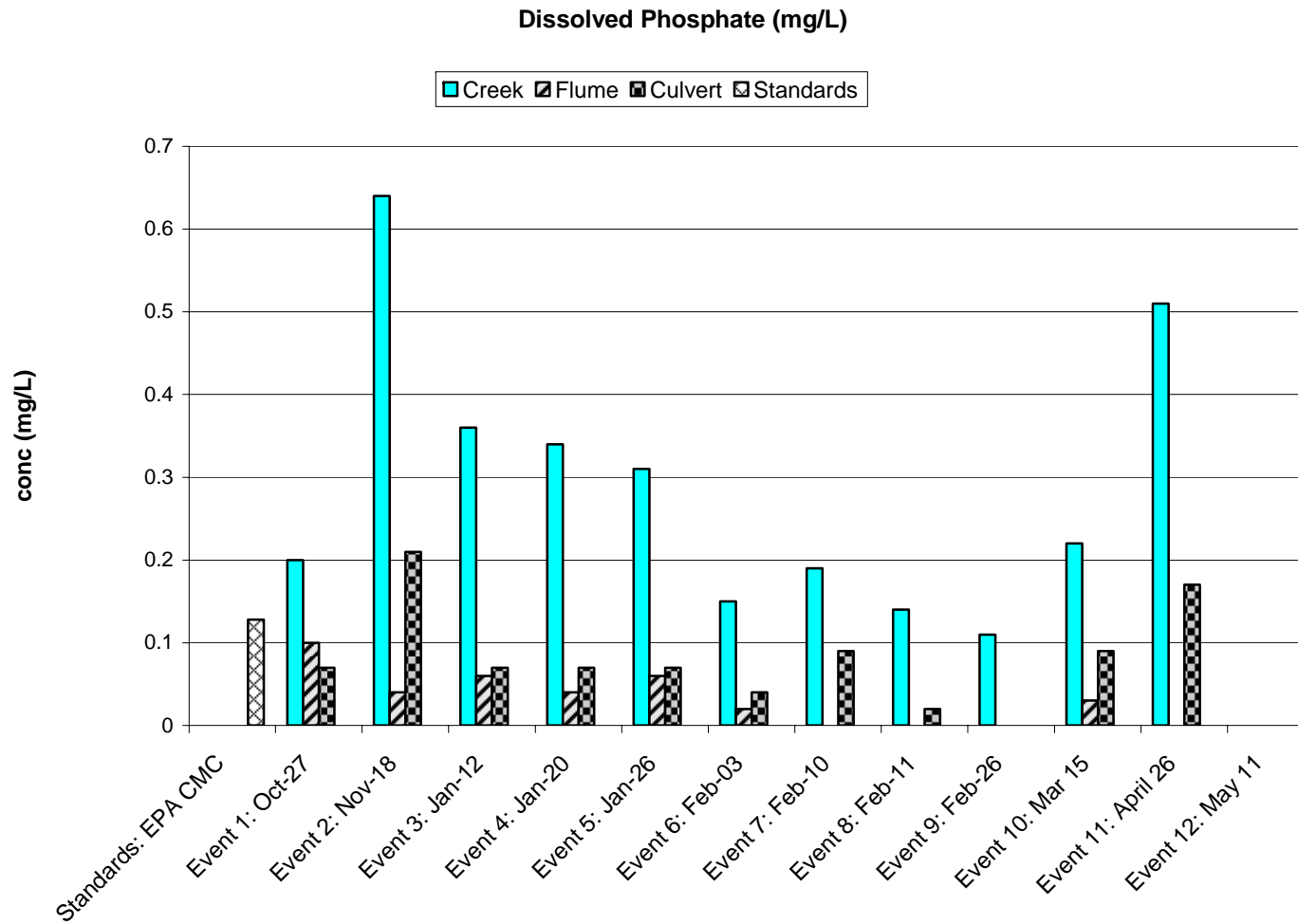


**FIG. D-4. Storm events nitrogen concentration comparison**



**FIG. D-5. Storm events chemical oxygen demand (COD) concentration comparison**

## D-6: Dissolved phosphate concentrations



**FIG. D-6. Storm events dissolved phosphate concentration comparison**

### D-7: TKN concentrations

Total Kjeldahl Nitrogen (mg/L)

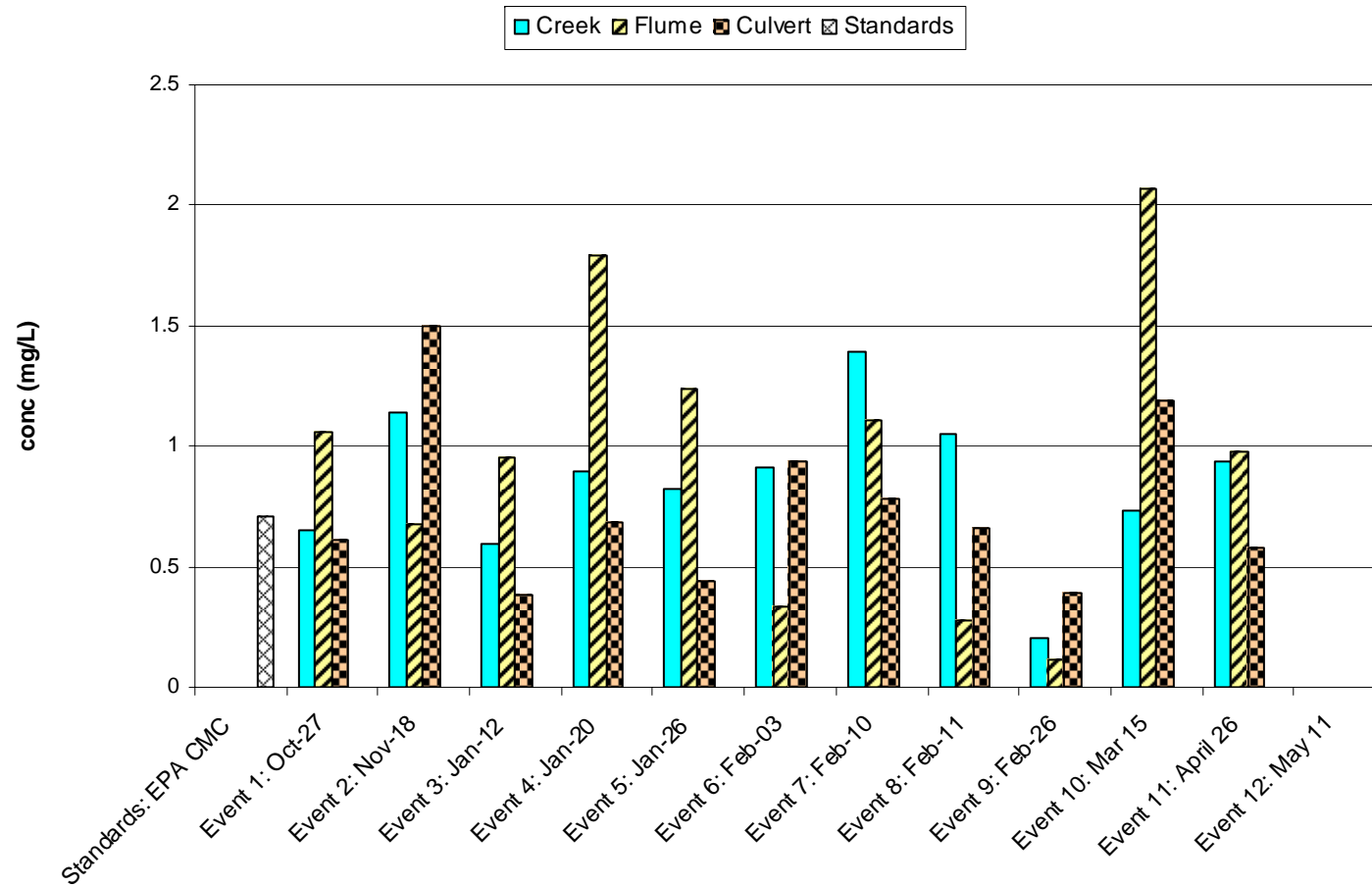
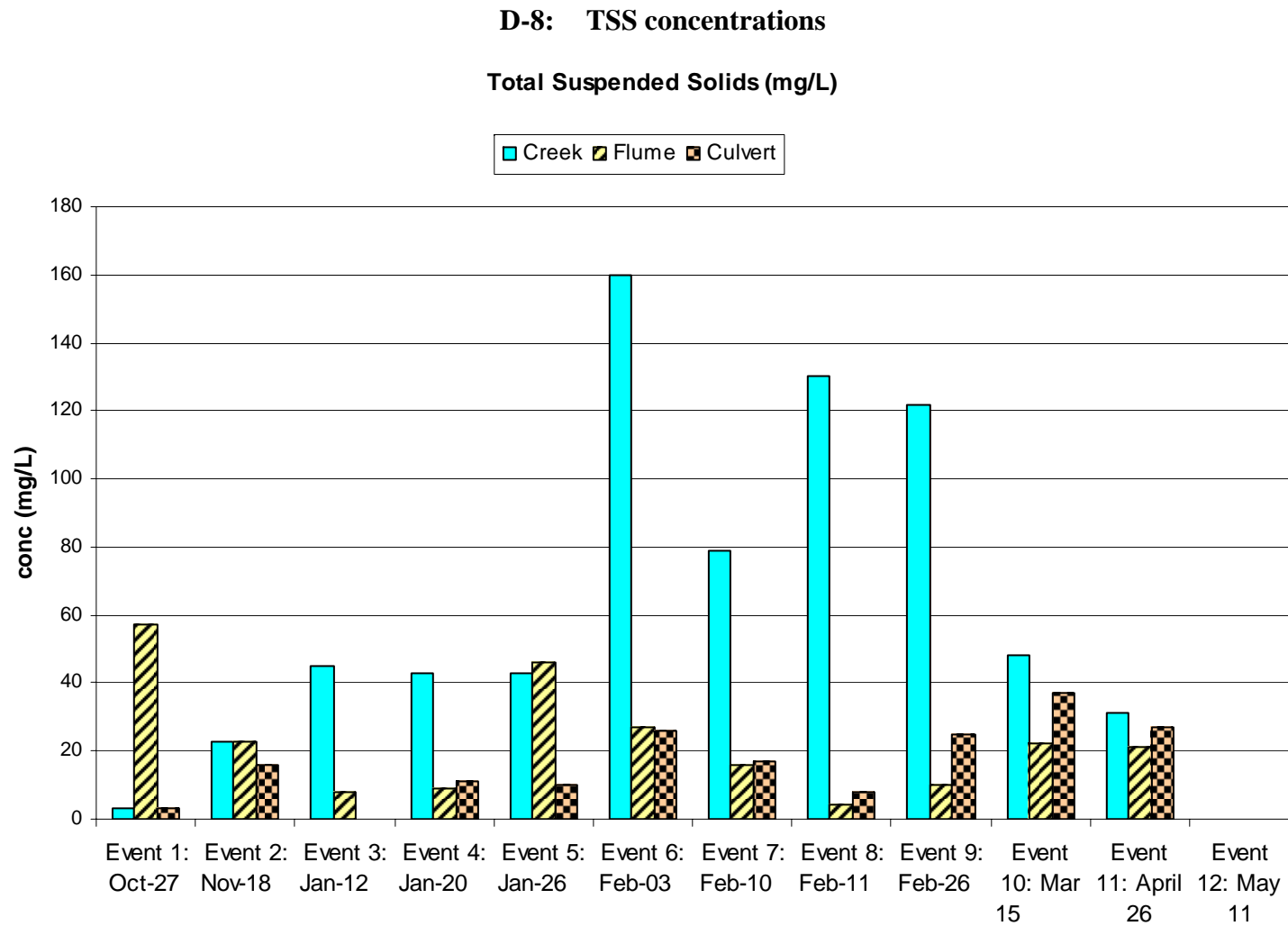


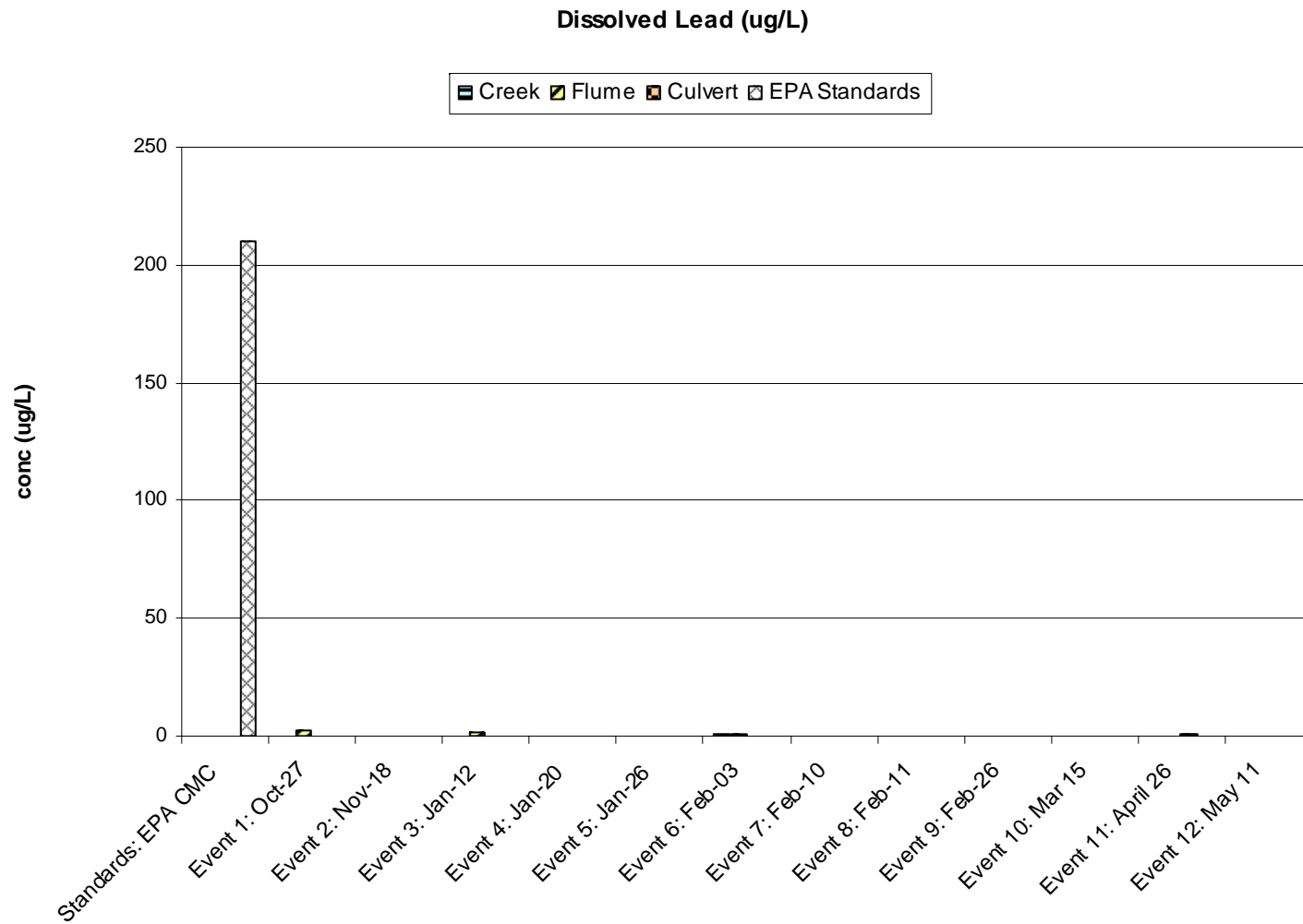
FIG. D-7. Storm events total kjeldhal nitrogen (TKN) concentration comparison





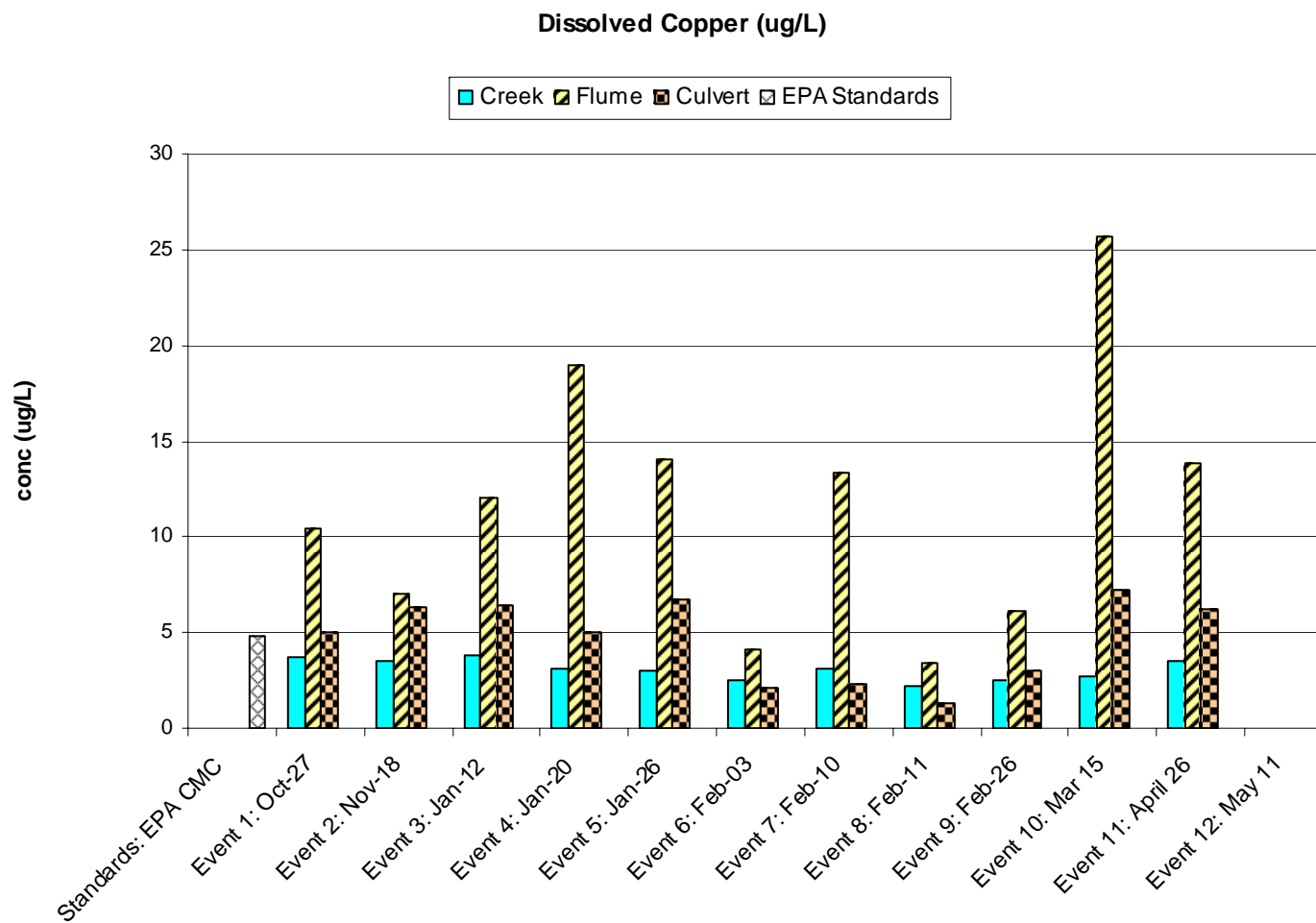
**FIG. D-8. Storm events total suspended solids (TSS) concentration comparison**

### D-9: Dissolved lead concentrations



**FIG. D-9. Storm events dissolved lead concentration comparison**

## D-10: Dissolved copper concentrations



**FIG. D-10. Storm events dissolved copper concentration comparison**

### D-11: Dissolved zinc concentrations

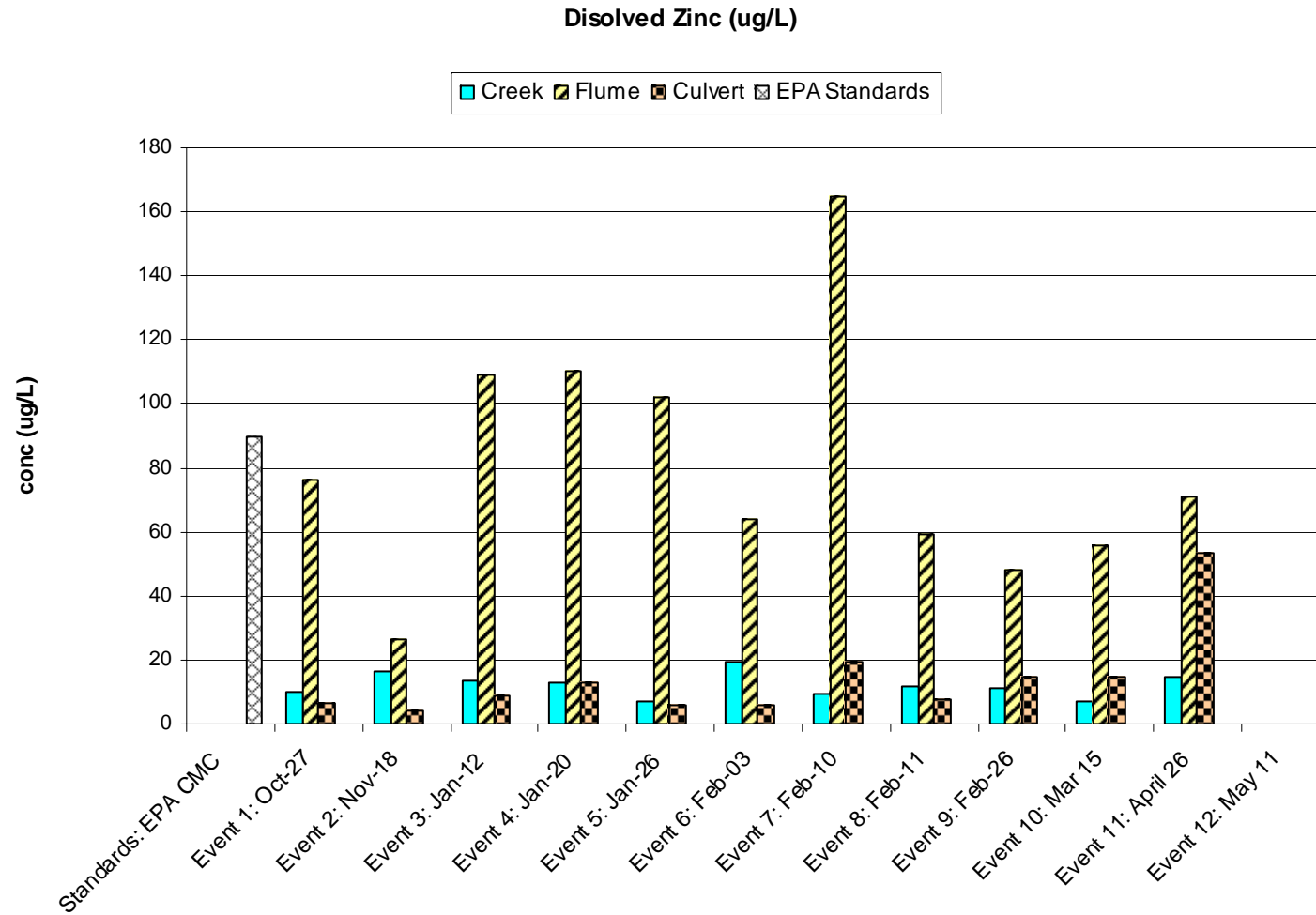


FIG. D-11. Storm events dissolved zinc concentration comparison

D-12: Total phosphate concentrations

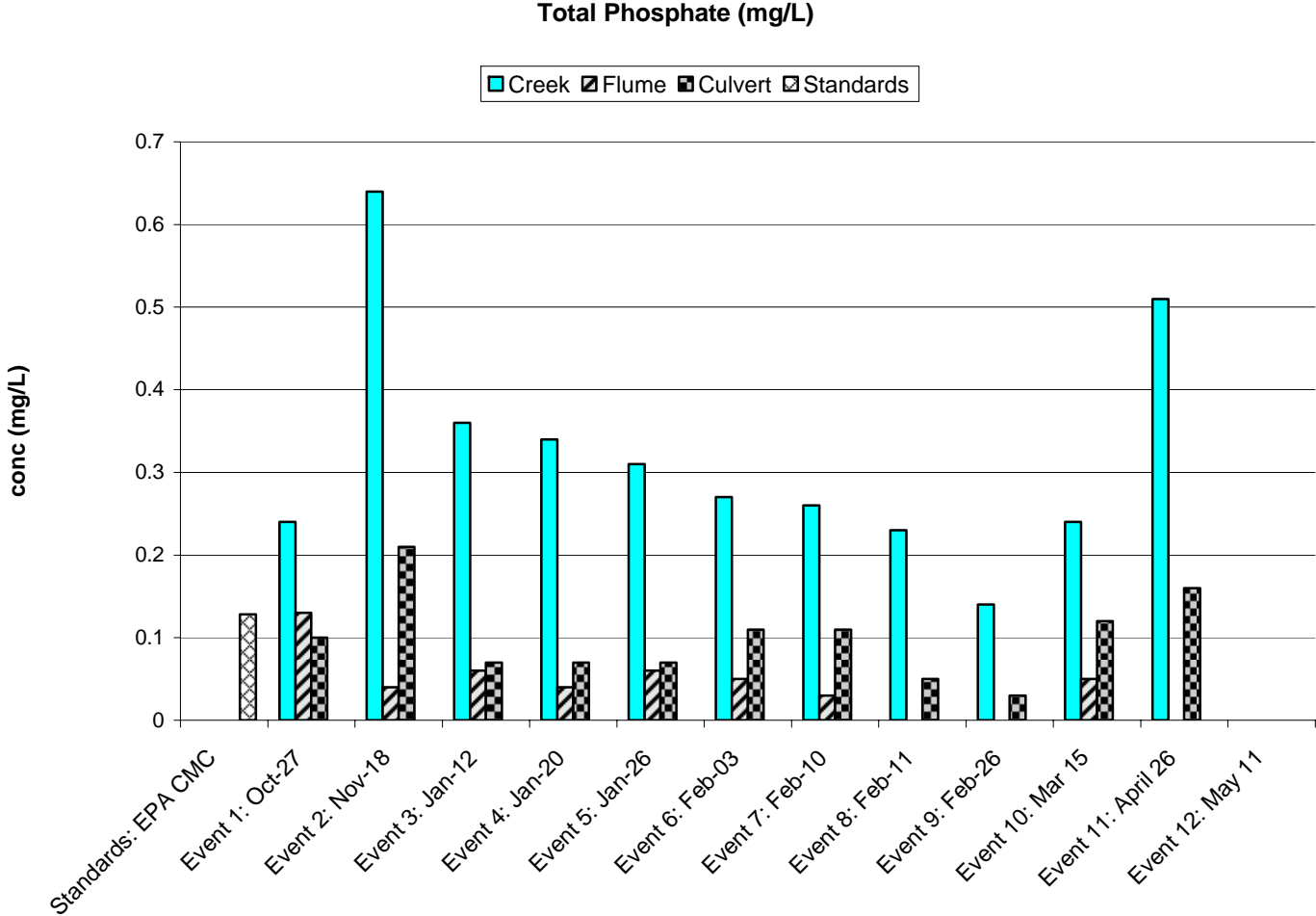
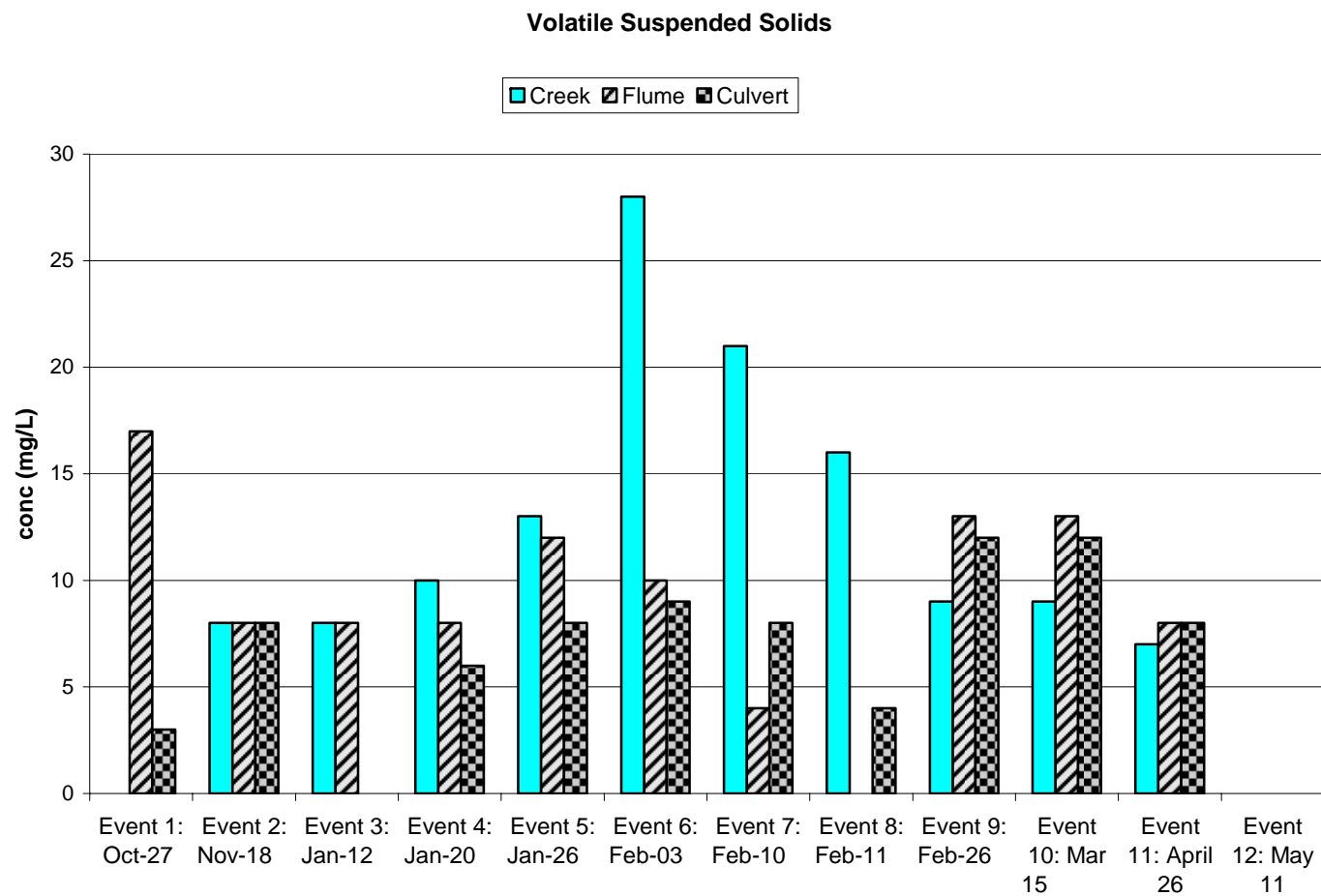


FIG. D-12. Storm events total phosphorus concentration comparison

### D-13: Volatile suspended solids (VSS) concentrations



**FIG. D-13. Storm events volatile suspended solids (VSS) concentration comparison**

## VITA OKE NWANESHIUDU

### PERMANENT ADDRESS

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### EDUCATIONAL BACKGROUND

Texas A&M University,	College station, TX
Master of Science in Civil Engineering	Graduation: Dec 2004
Temple University,	Philadelphia, PA
Bachelor of Science in Civil Engineering	Graduation: May 2002

### EXPERIENCE

**Shell Oil Products, U.S. (SH&E S&E)** Houston, TX  
(SH&E S&E- Safety Health and Environmental, Science and Engineering Division)

*May 2003 - Aug 2003      Engineering Intern*

- Performed tasks on issues related to environmental liability reserving and budgeting.

**Shell Oil Products, U.S. (SH&E S&E)** Cherry Hill, NJ  
(SH&E S&E- Safety Health and Environmental, Science and Engineering Division)

*May 2002 - Aug 2002      Engineering Intern (Inroads Program)*

- Responsible for assisting in due diligence activities in divestment of 2 company sites

**Old Castle Precast** Morrisville, PA  
(Building systems division)

*Nov 2001 - April 2002      Engineering Intern (QC Assoc.)*

- Overseeing fabrication of building components

**Shell Oil Products, U.S. (SH&E S&E)** Cherry Hill, NJ

*May 2001 - Aug 2001      Engineering Intern (Inroads Program)*

- During project: Assisted in project management of site assessments for 6 sites

**Consulting Structural Engineers** Philadelphia, PA

*Sept 2000 - May 2001      Engineering Intern*

- Performed revisions and additions to drawings.

**Shell Oil Products, U.S. (SH&E S&E)** Cherry Hill, NJ

*June 2000 - Aug 2000      Engineering Intern (Inroads Program)*

- Reviewed remedial action reports, soils and ground water data.

**American Geotech, Inc** Reading, PA

*Oct. 1999 - Jan 2000      Engineering Intern*

- Observed and oversaw different trades and construction accuracy.