

ASSESSING URBAN NON-POINT SOURCE POLLUTANTS
AT THE VIRGINIA TECH EXTENDED DRY DETENTION POND

by

Kimberly Jean Hodges

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APPROVED:

D.F. Kibler, Chairman

G.V. Loganathan

S. Mostaghimi

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Abstract

With a growing concern for the environment and increasing urbanization of rural areas, understanding the characteristics of urban non-point source pollution has become a focus for water quality investigators. Once thought to be a small contributor to the pollution problem, urban non-point sources are now responsible for transporting over 50% of all pollutants into natural waterways. Assessing non-point source pollution is the key to future water quality improvements in natural receiving waters.

The purpose of this research was to investigate the water quality of an urbanized watershed, analyze current prediction methods and to investigate the effectiveness of an extended dry detention basin as a pollutant removal management practice on a 21.68-acre urban watershed on the Virginia Tech Campus. This research included extensive stormwater monitoring and sampling to characterize the runoff and water quality from an urban watershed. The resulting analysis included comparing well-known desktop prediction methods with pollutant removal rates using an extended dry detention basin and comparison with different literature values. Finally, the study team calibrated the PSRM-QUAL model for watershed prediction of non-point source runoff and pollution.

The results of the stormwater monitoring process show that water quality prediction methods are not very successful on a storm by storm basis, but can be fairly accurate over longer periods of time with little or no storm water quality sampling. The extended dry detention basin is a simple yet effective management practice for the removal of sediments and sediment bound pollutants.

Dedication

I would like to dedicate the many hours of hard work that went into this thesis to my husband and best friend, Clayton Hodges. Without his help and support, this work may never have seen the light of day. His hard work and commitment to every endeavor he attempts and his drive to be the best at all he does inspires me every day. His unfailing faith and love have given me the desire and momentum to complete my degree requirements. I will always appreciate his dedication to help me, especially during those cold and rainy sampling events. He is my biggest strength and my greatest fan and to me he is the greatest man alive. I love you, Clay. Thanks.

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Chapter 1

Introduction

As increasing urban development takes place, it is becoming quite evident that the changes affect not only the landscape, but also the environment. It is well known that improving the hydraulic efficiency of a watershed through urbanization produces increased runoff volumes and stormwater control problems. However, only since the late 1960's has the quality of uncontrolled urban runoff been assessed. Consequently stormwater pollution problems are widespread and significant in both the urban and rural environments. Initially, it was assumed that controlling the major point source discharges, such as wastewater discharges and sewage could address most water quality concerns. Although this approach improved water quality, the desired reductions were not attained. Further research indicated that seemingly insignificant non-point sources (NPS) of water pollution, such as urban stormwater runoff, can be large contributors to the water quality problem. Over 50% of all water pollution problems can be attributed to non-point sources (Novotny & Chesters, 1981). However, due to the unpredictable nature of these inputs, their impact is difficult to assess and control.

In 1978, Congress determined that not enough information was known about non-point source pollution and authorized the first comprehensive study of non-point source pollution in the United States. This study, the Nationwide Urban Runoff Program (NURP), focused on obtaining a national understanding of the NPS water quality problem. It was to be used for providing basic information to planners aimed at

determining amounts and types of pollutants found in stormwater runoff. This project provided a strong background for further research in the water quality field with much of its data being used as the basis for water quality modeling parameters and guidelines.

In addition to the NURP studies, many researchers began investigating important pollutant removal options, while regulations to decrease non-point source pollutants were created using the NURP data. Such options included porous asphalt pavement, grass filter strips, infiltration trenches, detentions ponds--including wet ponds, dry ponds, and extended dry detention ponds--and many more. Most of these projects were focused on the removal of non-point pollutants from the urban environment and quantity control.

The main goal of this study was to establish an outdoor laboratory to serve as a basic building block in an urban watershed for the study the pollutants commonly found in urban non-point source pollution. To achieve this goal, the four main objectives of this project are:

1. Determine the amount of runoff on a highly urbanized surface.
2. Use water quality samples to determine the amount and type of pollutants on a highly urbanized surface.
3. Evaluate the performance of an extended dry detention basin as a pollutant removal basin at the downstream end of the watershed.
4. Test the Penn State Runoff Model (PSRM-QUAL) in its ability to predict pollutant loadings on a highly urbanized watershed surface.

It is expected that the conclusions of this study will help modelers understand the benefits and drawbacks of the water quality prediction and modeling processes.

Chapter 2

Literature Review

2.1 General

There are many characteristics of non-point source pollution that make it very difficult to identify, categorize, control, and prevent. According to Novotny and Chesters, 1981, the following general characteristics describe non-point source pollution:

- Non-point sources are related closely to meteorological events, enter surface waters intermittently and diffusely.
- The pollution is accumulated over a large area of land.
- They cannot be monitored at any point of origin and their exact source is nearly impossible to find.
- NPS pollutants cannot be measured or regulated in terms of effluent limitations.
- Since the extent of the NPS problem is climate related, it varies significantly from place to place and year to year.

All of the above characteristics indicate that not only is NPS pollution difficult to control, it is difficult to identify who, if anyone, would be responsible for its prevention, unlike point source pollution which is easily identified, controlled and regulated. There are many laws, regulations and studies that were instrumental in the improvement of water quality throughout the years and their focus was on reduction of both point and non-point pollution. In addition, as urbanization increased, certain aspects of non-point source pollution studies focused on the more hazardous water quality impacts imparted by urban environments. This chapter reviews the major steps in pollution abatement

through history and is not by any means a complete listing of research in the water quality field. It is a summary of the efforts that the research team feels are the most important works relating to this project.

2.2 Background of Legislative Water Pollution Controls

The first law to regulate pollution in the United States was the Rivers and Harbors Act of 1899. This act banned the disposal of any objects into a waterway that would create a hazard to navigation. Surprisingly, it remained the only consequential environmental law until the 1950's (Wentz, 1989). From the 1950's onward, as concerns over the environment grew many more legislative acts were signed into existence. This section will focus on the environmental actions that significantly affected water quality.

On the first of January 1970, President Nixon signed the National Environmental Policy Act (NEPA) into law (Wentz, 1989). NEPA applies to the federal government and its policy makes agencies use "all practicable means to administer federal programs in the most environmentally sound fashion" (Findley, 1991). It also requires the completion of an Environmental Impact Statement (EIS) assessing environmental impacts of all projects before approval. Many states have implemented their own laws similar to NEPA to cover state projects. This legislation helped to protect some waters, especially wetlands, but did not address water quality control as a specific issue.

Before 1972, there was very little water quality regulation and most of it was state developed and enforced, with enforcement becoming quite difficult as more and more dischargers emerged (Findley, 1991). There was little legislation that touched on the issue of non-point source pollution. Due to the fact that non-point source pollution is

frequently associated with rainfall, a series of floodplain management laws were introduced beginning in the 1930's to regulate development on the floodplain, thereby decreasing flooding effects and reducing pollution (Novotny and Chesters, 1981). In 1935, the creation of the U.S. Department of Agriculture's Soil Conservation Service (SCS), now the Natural Resource Conservation Service (NRCS), helped rural areas to limit NPS pollution by teaching soil conservation practices. In addition, the Rural Development Act of 1972 authorizes the assistance to farmers to install pollution controls (Novotny and Chesters, 1981).

In 1972 Congress put into law the Federal Water Pollution Control Act (FWPCA) which was the first major piece of legislation to deal with non-point source as well as point source pollution (Novotny and Chesters, 1981). The goal was to "restore and maintain the chemical, physical, and biological integrity of the waters of the United States", returning them to "fishable and swimmable" conditions (Wentz, 1989). The FWPCA was amended in 1977 and 1987 and is now referred to as the Clean Water Act (CWA). The CWA amendment included a new Section, 402, which created the National Pollutant Discharge Elimination System (NPDES), requiring a five-year renewable permit to discharge pollutants into waterways. It also included an amendment which forbids "backsliding", meaning that new permits are not allowed to be less stringent than previous permits for the same facility (Findley, 1991). The NPDES program did make a large impact on water quality by limiting the point source discharges into water bodies, but there is still a long way to go in water pollution prevention. To help with the problems on non-point source pollution, the Clean Water Act did include a goal to

“provide incentives to major research and demonstration efforts to develop new technology necessary for eliminating the discharge of pollutants into navigable waters” (Novotny and Chesters, 1981). The specific sections of the CWA that cover non-point source pollution include sections 208 and 319. Section 208 requires a regional plan reviewed by the state governor to identify treatment works and sources of non-point pollution and determine a feasible procedure of controlling pollution over a 20-year period (Novotny and Chesters, 1981). Though local governments monitor these programs, the Secretary of Agriculture, through NRCS, can impose a Best Management Practice (BMP) program. A BMP is defined by Novotny and Chesters, 1981, as:

“Best Management Practice means a practice or combination of practices that is determined by a state or designated area-wide planning agency) after problem assessment, examination of alternative practices, and appropriate public participation to be the most effective practicable (including technological, economic, and institutional considerations) means if preventing or reducing the amount of pollution generated by non-point sources to a level compatible with water quality goals.”

Section 319 requires states to develop management programs for any water body in which water quality standards cannot be met by point source controls alone. This includes an implementation schedule and BMP's and must be approved by EPA to be eligible for federal appropriations (Findley, 1991). This act is still the major source of legislation covering water quality today.

2.3 Street Surface Contaminants

The first landmark study in the field of urban non-point source pollution was the *Water Pollution Aspects of Street Surface Contaminants* study completed in 1972 by James Sartor and Gail Boyd. The goal was to provide a knowledge base of urban

pollutants as they relate to particles found on a typical street surface, how the pollutants are transported, and to analyze pollution reduction techniques. This is a very important aspect of non-point source pollution since many models correlate amounts of pollutants directly to fractions of total suspended solids in urban runoff. From the study Sartor and Boyd drew the following conclusions:

- Street surface runoff is most often highly contaminated, so much so that it can be compared to that of sanitary sewage.
- The largest portions of street surface pollutants were typically found to be inorganic and mineral-like.
- The amount of materials available was directly related to the length of time elapsed since the last street cleaning, whether manual or natural. The material amounts are dependent on land use type and from this, corresponding curves and equations to determine solids build-up were developed.
- The quantity of contaminants averaged 1400 lb/curb mile, but varied greatly depending on land use and other factors.
- A large portion of the overall pollution problem is associated with the finer fraction of particles, usually found along the curblines, though the percentage of fines is a small part of the total load.
- Surface contaminants are not spread uniformly across a street section; nearly 80% of the loading is located within 6 inches of the curb.
- Current street sweeping practices have a very low removal rate of the dust and dirt particles associated with pollution.
- The dislodging of the particles during a rainfall event is dependent on the street characteristics, the rainfall intensity and the particle size, where the wash-off can be described by the following equation:

$$N_c = N_o(1 - e^{-krt}) \quad 2-1$$

Here N_c is the weight of material of a given particle size washed off in time t , N_o is the initial loading, t is the minutes of rainfall, r is the intensity in in/hr, and k is a proportionality constant dependent on street surface characteristics.

2.4 The Nationwide Urban Runoff Program

With the passing of the Federal Water Pollution Control Act in 1972, it was recognized that non-point source pollution was indeed important to control. It was also recognized that there were many uncertainties that made it hard to identify, predict and prevent. It was because of these uncertainties and the lack of knowledge of NPS effects that Congress made separate storm sewers ineligible for Federal funds in the 1977 amendments (NURP, Vol. 1, 1983). To gather information to resolve these problems, the Environmental Protection Agency established a five-year program called the Nationwide Urban Runoff Program (NURP) in 1978 to investigate the following issues, as stated from the 1983 NURP Volume 1 final report:

- The quality characteristics of urban runoff, and similarities or differences at different urban locations;
- The extent to which urban runoff is a significant contributor to water quality problems across the nation; and
- The performance characteristics and the overall effectiveness and utility of management practices for the control of pollutant loads from urban runoff.

For the purpose of future urban planning, the goal of the NURP study was to characterize urban runoff, both by flows and by pollutant loadings. Twenty-eight sites across the country representing different regional climates, land uses, slopes and soil conditions were chosen to study a variety of pollutants to find significant patterns (NURP Exec.

Summary, 1983). Findings of the NURP study are reported as an event mean concentration (EMC), which weights discrete concentrations with flow volumes as shown in Equation 2-2.

$$EMC = \frac{\text{Total Mass}}{\text{Total Flow}} = \frac{\sum Q_i C_i}{Q_t} \quad 2-2$$

Where Q_i = discrete flow ordinates, C_i = discrete concentrations on the pollutograph and Q_t = total flow of the storm event. The conclusions of the NURP study paved the way for the future of water quality analysis. Many of the conclusions from the NURP executive summary are described in the following paragraphs.

Some of the constituents tested that were of high concern were the heavy metals, including all 13 on the EPA priority list. All 13 were found in the NURP study, but the three most widely detected metals were copper, zinc and lead. These three were detected in over 91% of all samples. The concentrations frequently exceeded water quality criteria established by EPA. The NURP data set yields a site median EMC for copper, lead, and zinc as 34 $\mu\text{g/l}$, 144 $\mu\text{g/l}$ and 160 $\mu\text{g/l}$ respectively and suggests that these levels be used for urban planning purposes.

According to the NURP study, nutrients were usually found to be contained in the urban runoff, but not at significantly high levels. Data for total phosphorous, soluble phosphorous, total kjeldahl nitrogen (TKN), and nitrate-nitrite were analyzed. Median concentration of median sites yielded EMCs as follows: TP = 0.33 mg/l, SP = 0.12 mg/l, TKN = 1.5 mg/l and $\text{NO}_2+\text{NO}_3-\text{N}$ = 0.68 mg/l. Another constituent commonly identified in

urban stormwater runoff is total suspended solids (TSS); however, there is no formal water quality criterion for this constituent.

Other pollutants that were identified by NURP to be in urban runoff include 63 of a possible 106 organic priority pollutants with the most common being bis-(2-ethylhexyl)-phthalate, a plasticizer. In addition, coliform bacteria were found in high levels in urban stormwater runoff and often exceeded EPA criteria. Also, oxygen-demanding substances at nearly the same concentrations as secondary water treatment plants were found. NURP data shows site median EMC values of 9 mg/l Biological Oxygen Demand (BOD5) and 65 mg/l Chemical Oxygen Demand (COD).

In addition to identifying priority pollutants in urban stormwater, the NURP program also assessed the effectiveness of certain control measures in decreasing pollutant loads to receiving streams. The study analyzed the effects of detention, retention, street sweeping, wetlands, and infiltration swales. The NURP findings indicate that of all types of detention, wet ponds perform the best by settling suspended particles while biological processes aid in reducing soluble pollutant fractions. Dry basins do not seem to have a large effect on pollutant loadings. Though there was little NURP data on extended dry detention ponds, it was found that they can be nearly as efficient as wet ponds in the removal of suspended loads, but lack the biological processes necessary to decrease the soluble load fraction.

Street sweeping seems to be insignificant in removal of pollutants and serves only as an aesthetic cleanup in the urban environment. This is attributed to the poor removal of small particle size distribution responsible for carrying most of the pollutant load.

Pollutant removal through wetlands seems to be a possibility in the future, but more research needs to be done in this area to determine actual effectiveness. Grass swales could also be used to provide some minimal decrease in some pollutant loadings, but again future research was recommended.

In conclusion, the NURP study was a monumental attempt to characterize urban runoff and identify control measures to reduce pollution. Though the study revealed no pattern of urban runoff pollution by geographical region there was variability of EMC concentrations at different sites. However, it was determined that similarities suggest that there is enough consistency in data to be able to use the NURP results to estimate loadings on sites that are not monitored. Pollutant loadings among different land use groups have been addressed by dividing the NURP data sets into three distinct categories - residential, commercial, and industrial. The results of the NURP findings have since been used for urban planning and pollutant modeling throughout the United States.

2.5 Urban Water Quality Modeling

After the completion of the NURP study in 1983, the focus of urban pollutant studies shifted from field measurements to modeling techniques. In-depth field monitoring is quite expensive and time consuming. By creating working models of the urban non-point source pollution problems, investigators have been able to estimate both runoff quantity and quality with less cost and effort. Though a large number of site specific monitoring projects have been undertaken to help develop, verify, and enhance water quality modeling, the runoff pollutant fundamentals of most models still lie mainly in the work of Sartor and Boyd and the NURP study. However, some other notable

names in the field of water quality modeling include: Wayne Huber, Steven Nix, James Heaney, as well as James Sartor, Gail Boyd and many more. It would take many full volumes to completely summarize all of the work done in this field. Table 2-1 briefly describes the sponsors and the capabilities of many of the available models as summarized by ASCE Manuals and Reports of Engineering Practice No. 77 (1992).

2.6 Extended Dry Detention Basin Design

Another aspect of urban stormwater management that is extremely important to this study is the research done in the field of extended dry detention basins. A wet detention basin was not feasible at this site and dry basins have been found ineffective in removing urban pollutants from stormwater (Novotny and Olem, 1994). Many different studies have focused on the design and water quality benefits of the extended detention basin and this report does not attempt to cover them all. Many people have played a significant role in the study of detention basins including Thomas Grizzard, Ben Urbonas, Clifford Randall, William Whipple and many more. The principle behind extended dry basins is that since many of the urban pollutants are associated with particles, settling is the primary removal technique. There are many design objectives that can be implemented to aid in the settling process. This brief list by Randall (1982) covers some of the major design objectives:

- Utilize long narrow pond configuration, such as width to length ratios of 2:1 to 3:1.
- Install inlet and outlet structures at opposite ends of the basin.
- Construct ponds in series or in two stages.

Table 2-1. Comparison of Water Quality Models (Source: ASCE, 1992)

	DR3M-QUAL	HSPF	STORM	SWMM	PSRM-QUAL^a
Sponsoring agency	USGS	EPA	HEC	EPA	City of Phil.
Simulation Type ^b	C,SE	C,SE	C	C,SE	C,SE
No. of Pollutants	4	10	6	10	12
Rainfall/Runoff Analysis	Y	Y	Y	Y	Y
Sewer system flow routing	Y	Y	N	Y	Y
Full, dynamic flow routing equations	N	N	N	Y ^c	N
Surcharge	Y ^d	N	N	Y ^c	Y
Regulators, overflow structures	N	N	Y	Y	N
Special solids routines	Y	Y	N	Y	Y
Storage analysis	Y	Y	Y	Y	Y
Treatment analysis	Y	Y	Y	Y	Y
Suitable for planning (P), or design (D)	P,D	P,D	P	P,D	P,D
Data and personnel Requirements ^e	Medium	High	Low	High	Medium
Overall model complexity ^f	Medium	High	Medium	High	Medium
Available on PC	N	Y	N	Y	Y

^a Model updated to include quality routines since publishing of ASCE manual, therefore this column varies from what is found in the cited source.

^b Y = yes, N = no, C = continuous simulation, SE = single event simulation

^c Full dynamic equations and surcharge calculations only in the EXTRAN Block of SWMM.

^d Surcharge simulated by storing excess inflow at upstream end of pipe. Pressure flow not simulated.

^e General requirements for model installation, familiarization, data requirements, etc. To be interpreted only very generally.

^f Reflection of general size and overall model capabilities. Note that complex models may still be used to simulate very simple systems with minimal data requirements.

NOTE:

DR3M -QUAL = Distributed Routing Rainfall Runoff Model with Quality routines

HSPF = Hydrologic Simulation Program - Fortran

STORM = Storage, Treatment, Overflow, Runoff Model

SWMM = Storm Water Management Model

PSRM-QUAL = Penn State Runoff Model with Quality routines

- Use baffles or flow retarders to decrease flow velocities.
- Develop grass cover on the floor of the basin.

2.7 Extended Dry Detention Basin Observed Removal Rates

A study completed by Grizzard (1986) that shows that for a detention pond to achieve the same removal settling rates as a water column, the water in the pond needs to be detained for 24 hours to remove the equivalent amount of solids as a water column settling for only 6 hours. Thus, it is recommended both by Grizzard (1986) and Urbonas (1993) that a basin be designed to drain in no less than 40 hours. Based on additional field studies by Grizzard et. al (1986) the following removal rates can be expected over the long-term in an extended dry detention basin, as shown in Table 2-2.

Table 2-2. Removal Rates for Extended Dry Detention Basins by Grizzard (1986)

TSS	50% - 70%	Lead	75% - 90%
TP	10% - 20%	Zinc	30% - 60%
Nitrogen	10% - 20%	Hydrocarbons	50% - 70%
Organics	20% to 40%	Bacteria	50% - 90%

Another study done in New York by Zarriello and Sherwood in 1993 tested the removal rates of a typical detention pond and then retrofitted the pond to act as an extended dry detention basin and re-tested the removal rates. The study was done over a three-year period and measured the trap efficiency of the basin for 22 different constituents. The study watershed was a 26.9-acre site of moderate residential density with a basin designed to hold a volume of 0.43 inches of runoff over the watershed. The

basin originally had a drawdown time of 45 minutes. The basin was then modified to have a drawdown time of 1.5 hours and was then finally modified to a drawdown time of 11 hours. Table 2-3 shows the removal rates they found for three different basin configurations reported as EMC average efficiencies.

Table 2-3. Extended Dry Detention EMC Removal Rates by Zarriello et. al. (1993)

Constituent	45 Minute Drawdown	1.5 Hour Drawdown	11 Hour Drawdown
TSS	-13.9	78.6	83.8
TOC	-15	30.6	47.4
NH4	-23.2	18.9	21.5
NO3N	19.8	14.8	35.2
TP	-2.6	11.5	32
FTP	0	22.2	11.1
Pb	35.4	60.8	37.6
Zn	42.3	53.7	66.1

Another study reported by the Federal Highway Administration in their new publication *Evaluation and Management of Highway Runoff Water Quality*, 1996, summarizes current best management practices for pollutant removal including extended dry detention basins. The study results showed the gradual improvements in water quality with increased detention time. The results indicate that up to 90% of particulates can be removed with detention time of 2 days or more; however, only slight reductions are made in soluble contaminants such as phosphorus and nitrogen. Based on field measurements with various detention times, the removal rates shown in Table 2-4 were found.

Table 2-4. FHWA Removal Rates for Extended Dry Detention Basins (1996)

Pollutant	½ day (%)	1 day (%)	1 ½ day (%)	2 day (%)	Total range (%)
TSS	68	75	82	90	68-90
Lead	68	75	82	90	68-90
Zinc/Copper	42	45	47	50	42-50
Phosphorus	42	45	47	50	42-50
Nitrogen	28	32	36	40	28-40
COD	42	45	47	50	42-50

2.8 Pollutant Prediction Methods

Several recent methods/models are described here, with application to the test watershed in Chapter 5.

2.8.1 Regression Model

Another important technique in water quality determination was developed by Gary Tasker and Nancy Driver in a 1988 report entitled *Nationwide Regression Model for Predicting Urban Runoff Water Quality at Unmonitored Sites*. The goal of the study was to use the enormous database of water quality samples obtained by the NURP study into a simple set of regression equations. The regression equations can be used to make early estimates of water quality mean seasonal or annual loads (Tasker and Driver, 1988). This saves much time, effort, and money by providing a reasonable average load estimate for an area without having to undertake a large sampling or data collecting effort.

Depending on the amount of data collected, there are two sets of regression curves available. For both sets of curves, the country is divided into three regions based on mean annual rainfall amounts. The first set of curves, which is more complex, requires the following data:

Climatic:

- Total Rainfall (H_r , inches)
- Storm Duration (t_R , minutes)
- Maximum 2-year, 24-hour rainfall (inches)
- Mean annual Rainfall (H_{MAR} , inches)
- Nitrogen load in precipitation (T_j , °F)

Physical:

- Drainage Area (A , mi^2)
- Impervious percentage of the watershed (I , % of A)
- Population density (PD , people/km)
- % residential, industrial, commercial and non-urban areas (% of A)

Using different combinations of the above variables, regression values were determined to calculate pollutant loads. There are ten constituents that can be determined using this method, including chemical oxygen demand (COD), suspended solids (SS), dissolved solids (DS), total nitrogen (TN), total ammonia plus nitrogen (AN), total phosphorus (TP), dissolved phosphorous (SP), total copper (CU), total lead (PB) and total zinc (ZN).

For the more simplified equation, only total rainfall, watershed area and impervious fraction are required as input, but the accuracy of the results is affected by the decrease in parameters modeled. Both of these methods yield good results for rough pollutant load estimates.

2.8.2 The Simple Method

In 1987, Schueler introduced easy empirical equations for urban pollutant load prediction. These equations were based on the NURP data results and are designed for use on watershed less than 2 km². Like the simplified regression equations, this method trades off some accuracy for simplicity in the data gathering process. The generalized equation is as follows:

$$L_p = \frac{[Hr \cdot Pj \cdot Rv] \cdot [C] \cdot [A]}{98.6} \quad 2-3$$

where Hr = total rainfall (mm), Pj = percent of rainfall that contributes to runoff (equal to 1 for individual storm events), Rv = runoff coefficient estimated as 0.05+0.009* (impervious percentage), C = a flow-weighted pollutant mean concentration in mg/L, A = watershed area (ha), and 98.6= unit conversion factor.

2.9 Typical Water Quality Constituents Studied

Because they are representative priority pollutants in urban runoff, the following contaminants have been frequently monitored in water quality studies: total suspended solids (TSS), nitrogen in the forms of total kjeldahl nitrogen (TKN), filtered TKN (FTKN), ammonia (NH₄) and nitrite plus nitrate (NO₃-N), phosphorus in the forms of phosphate (PO₄), total phosphorus (TP), and soluble phosphorus (FTP), the heavy metals total cadmium, total chromium, total zinc and total lead, and total organic carbon (TOC). The following paragraphs briefly describe each of the constituents and the risks they pose to the environment and to human life.

2.9.1 Total Suspended Solids

Most of the suspended solid loads are dependent on local geographic conditions. For urban surfaces the condition of the roadway is also very important. Particles originate from erosion of soils and pavements and are also transported by air. According to the NURP study in 1983, there is no formal water quality criterion for TSS relating to human health or aquatic life. The NURP study also reported that the nature of suspended solids in urban runoff is different from those in treatment plants, being higher in mineral and man made products (e.g. tire and street surface wear particles) and somewhat lower in organic pollutants. They are also more likely to have pollutants associated with them. Most of the solids associated with urban runoff are in the coarser size fraction, such as gravels and sands. This size fraction, referred to as the 'dust and dirt' sizes, can originate from the breakdown of larger litter, such as leaves (Novotny & Chesters, 1981). This size fraction can be removed fairly well from waters by simply holding the water for a long enough period of time for the particles to settle out. However, most pollutants are associated with the fine size particles that do not settle easily. For example, according to Novotny & Chesters (1981), 51.3% of heavy metals and 92.2% of phosphates adsorb to particles less than 246 μm . Table 2-5 is from the study of Sartor & Boyd (1972) and depicts the fraction of pollutants associated with different particle sizes.

Table 2-5. Fraction of Pollutant Associated With Each Particle Size (% by Weight)

	Particle Size(μ)					
	>2,000	840-2,000	246-840	104-246	43-104	<43
Total Solids	24.4	7.6	24.6	27.8	9.7	5.9
TKN	9.9	11.6	20.0	20.2	19.6	18.7
Nitrates	8.6	6.5	7.9	16.7	28.4	31.9
Phosphates	0	0.9	6.9	6.4	29.6	56.2
Chromium	26.1	13.6	16.3	16.3	27.7	
Copper	22.5	20.0	16.5	19.0	22.0	
Zinc	4.9	25.9	16.0	26.6	26.6	
Lead	1.7	2.6	8.7	42.5	44.5	

2.9.2 Heavy Metals

The NURP study reports that heavy metals are by far the most prevalent priority pollutant constituent found in urban runoff. The study found that freshwater chronic exceedences were common for lead, copper, zinc and chromium. Each of these four metals also has a common use in the urban environment as shown below in Table 2-6

Table 2-6. Traffic Related Sources of Pollution (Novotny & Chesters, 1981):

Copper	Thrust bearings, bushings, and brake linings
Chromium	Metal plating, rocker arms, crankshafts, rings, brake linings & pavement
Lead	Motor oil, transmission babbit metal bearings, formerly in gasoline
Zinc	Motor oils and tires

Other sources of these metals as reported by Novotny (1994) include copper, zinc and chromium from metal corrosion, zinc in tires and road salts, and lead in batteries. Lead, cadmium and zinc are all transported by particulate matter in the atmosphere, though lead levels have dropped rapidly since the banning of leaded gasoline in the US. Many nations, however, still do not restrict lead in their gasoline. Copper, lead and zinc according to the NURP study, appear to pose a significant threat to aquatic life, especially in the south and southeast sections of the country. For aquatic life, copper is the most

significant threat. According to Harrison (1990), chromium is undoubtedly a human carcinogen and cadmium is a highly probable carcinogen.

2.9.3 Nutrients

Nutrients are essential to the environment for plant growth, but only nitrogen and phosphorus are considered to be growth limiting. On the average, about 50% of phosphorus and an even greater proportion of nitrogen originates from nonpoint sources such as uncontrolled urban runoff (Novotny & Chesters, 1981).

2.9.4 Phosphorus

Phosphorus, as stated above, is most commonly bound to fine sediments, making its removal from the water column very difficult. Dissolved particles can be removed through vegetative uptake; however, its concentration can also increase within a basin through the dissolution of solids. One large source of phosphorus can be tree leaves since they are 90-95% organic and contain significant amounts of phosphorus (Novotny & Chesters, 1981). Phosphorus is a necessary nutrient to plants, though it, like nitrogen, can cause algae blooms. Phosphorus is usually the limiting nutrient, and many water quality management strategies commonly control phosphorus instead of nitrogen since phosphorus is less prevalent in the environment (Hem, 1970).

2.9.5 Nitrogen

Nitrogen sources include decomposing organic matter that is introduced to the soil by nitrogen-fixing plants and bacteria, animal and human wastes, fertilizers (both organic and inorganic), and through atmospheric deposition (Zarriello & Sherwood, 1993). As stated above, nitrogen is important to plant growth and can contribute to algae blooms.

2.9.6 Total Organic Carbon

The measure of total organic carbon (TOC) was used to estimate the amount of oil and grease coming from the impervious surfaces in the watershed. TOC was selected as an indicator for oil and grease because of the difficult assay techniques required for petroleum hydrocarbons. Total organic carbon levels can be greatly influenced by the decomposition of organic matter such as grass clippings. According to the Federal Highway Administration (1981), oil and grease and related petroleum compounds found in highway runoff result from spills or leaks of motor vehicle lubricants, antifreeze and hydraulic fluid. Some oil and grease may be contributed by roadbed leachate if the surface is made of paved asphalt.

Chapter 3

Site Characterization

In order to understand the hydraulics of the watershed in this study and the choice of sampling locations, the site itself has to be understood. This chapter includes a description of the site and the layout of the watershed. It describes the watershed topography and its role in determining the site subdivision for input into the models. The extended detention pond characteristics and its outlet design are also detailed. In addition a discussion of the two monitoring locations is provided.

3.1 Site Description and Layout

The site is a 21.68-acre newly paved parking lot used by commuters to the University. Previously, the parking lot had a gravel surface to allow infiltration of stormwater entering the watershed. In the summer of 1993 the lot was paved and a small extended dry detention pond was designed to reduce the post-development hydrograph peaks and remove entering pollutants. As part of the landscaping, many small islands of grassy areas were constructed throughout the parking lot. These areas aid in entrapment and reduction of drainage as well as to beautify the watershed. Figure 3-1 shows the basic parking lot layout and the surrounding areas. A system of underlying drainage pipes was installed to carry the excess runoff from the parking lot to the new extended detention basin as shown in Figure 3-2. The basin receives input from the parking lot only, with other adjoining parts of the watershed diverted around the detention basin into the Duck Pond. Table 3-1 details the properties of each pipe.

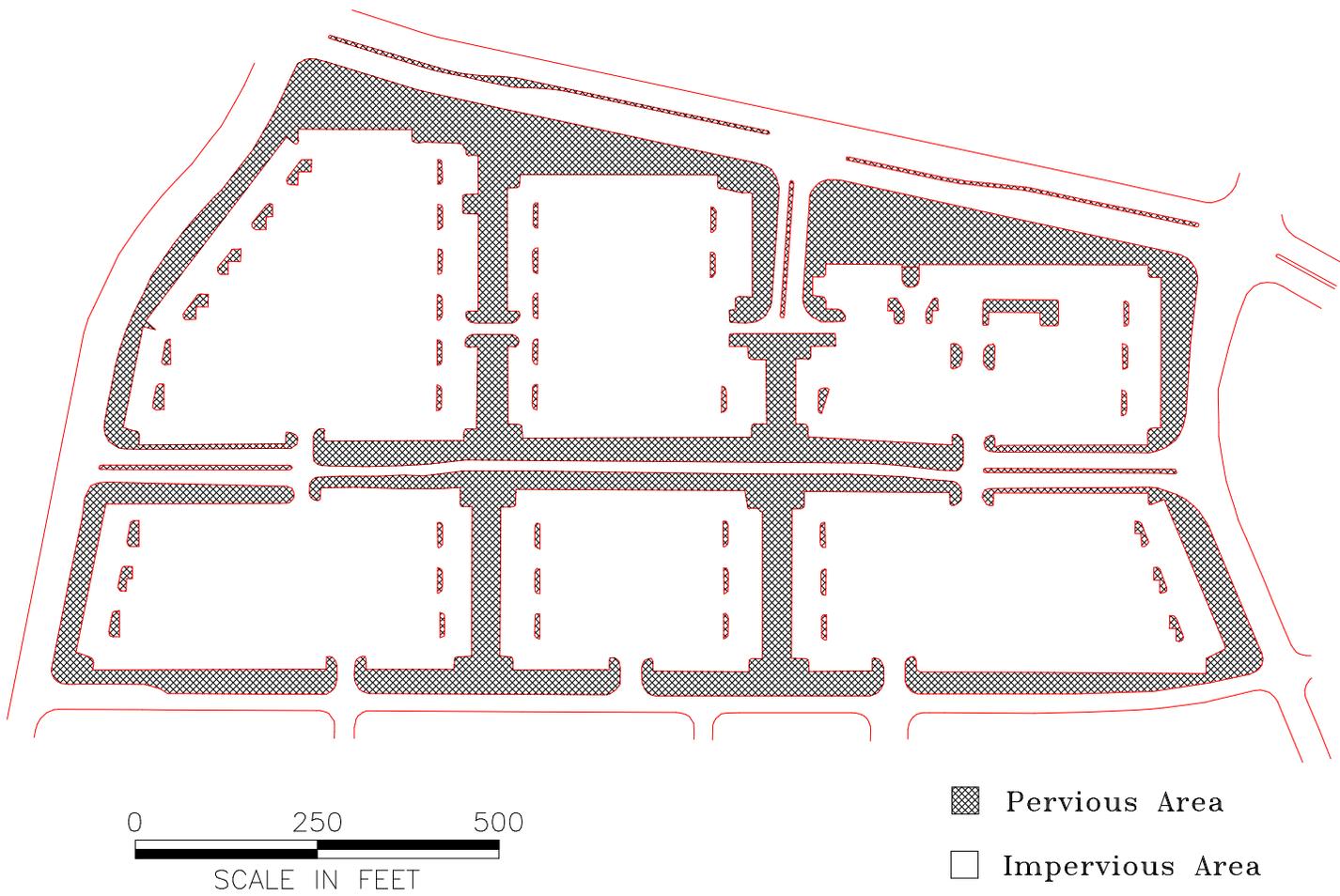


Figure 3-1. Schematic of the Parking Lot

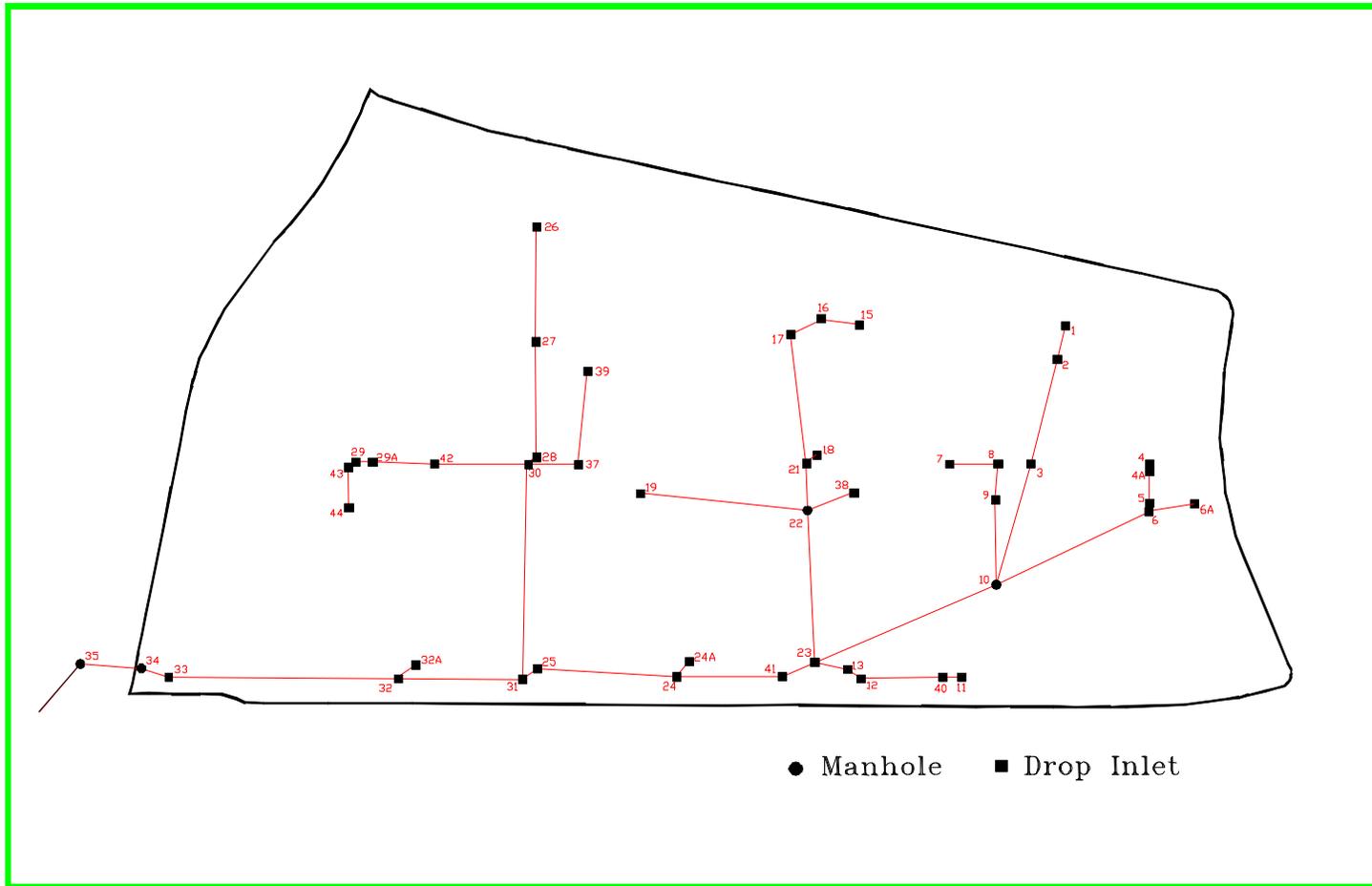


Figure 3-2. Storm Sewer Layout with Nodes and Numbers

Table 3-1. Summary of Storm Sewer Characteristics

Inlet Number	Invert Top	Invert In	Invert Out	Height (feet)	Structure Length (feet)	Pipe Size (inches)	Pipe Length (feet)	To Inlet Number
1	48.70	37.75	37.50	10.95	8	15	50.0	2
2	48.50	37.40	36.65	11.10	---	18	150.0	3
3	48.00	36.55	35.50	11.45	4	18	175.0	10
4	45.95	37.35	37.30	8.60	16	21	10.0	4A
4A	48.85	37.19	36.95	8.64	8	21	48.0	5
5	45.85	36.85	36.80	9.00	8	21	10.0	6
6	45.50	36.67	35.50	8.63	16	24	235.0	10
7	50.20	36.90	36.56	13.30	6	15	68.0	8
8	49.00	36.46	36.19	12.54	6	15	54.0	9
9	49.80	36.09	35.50	13.71	4	15	118.0	10
10	48.80	35.40	34.00	13.40	---	30	282.0	23
11	44.80	41.10	40.97	3.70	10	18	25.0	40
12	44.10	40.20	40.10	3.90	8	21	18.0	13
13	44.00	40.00	39.60	4.00	8	21	48.0	23
15	57.10	51.50	51.20	5.60	4	15	56.0	16
6A	45.10	40.93	40.50	4.15	4	15	60.0	6
16	57.10	51.10	50.80	6.00	4	15	45.0	17
17	52.25	47.75	47.65	4.50	10	15	15.0	21
18	52.20	47.00	45.00	5.20	10	15	70.0	22
19	43.20	33.81	33.53	9.39	8	36	55.0	41
20	43.30	32.60	31.60	10.70	10	42	195.0	25
21	70.10	66.20	59.10	3.90	4	15	158.0	27
22	63.00	59.00	52.60	4.00	8	15	15.0	28
23	56.50	52.50	52.10	4.00	12	15	22.0	30
24	59.50	53.40	53.10	6.10	10	15	155.0	29A
29A	59.00	53.00	51.15	6.00	---	15		42
30	56.10	45.70	36.70	10.40	10	24	295.0	31
17	43.50	31.30	30.40	12.20	8	48	178.0	32
18	44.75	40.05	39.87	4.70	---	15	26.0	32
32A	44.25	30.30	28.60	13.95	6	48	330.0	33
33	44.00	28.50	28.20	15.50	12	48	40.0	34

Note: All elevations refer to elevation 2000' MSL

Table 3-1. Summary of Storm Sewer Characteristics (Cont'd)

Inlet Number	Invert Top	Invert In	Invert Out	Height (feet)	Structure Length (feet)	Pipe Size (inches)	Pipe Length (feet)	To Inlet Number
34	47.00			18.90	---			existing
35	46.00	27.50	26.50	18.50	---	60	85.0	existing
37	55.00	51.20	49.80	3.80	16	18	70.0	30
38	51.50	47.50	47.00	4.00	6	15	73.0	22
39	59.75	53.95	51.45	5.80	---	15	125.0	37
40	45.50	40.87	40.29	4.63	---	18	115.0	12
41	43.20	33.48	32.70	9.72	10	42	145.0	24
42	57.50	51.05	49.25	6.45	8	18	135.0	30
43	59.50	53.60	53.50	5.90	6	15	12.0	29
44	58.00	54.00	53.70	4.00	6	15	54.0	43

3.2 Subarea Division

In order to represent the variability within the site during the modeling process, the modeler should subdivide the watershed into subareas. The purpose of the subdivision is to better characterize the watershed's flow characteristics, such as slope, overland length, and Manning's n values. By dividing the watershed into subareas, modelers can be more effective in matching observed conditions. Many watersheds are divided based on land-use characteristics and their storm sewer inlet points (Kibler, 1982). The parking lot has the same land-use category throughout; therefore, it was divided into subareas based on inlet locations. The construction and paving of the lot was done in well-defined sections and the six subareas are easily delineated. Each subarea has its own values for overland slope and length, however, due to the uniform land usage, the Manning's n values and other calibration factors to be mentioned later are constant for the watershed. Table 3-2 lists the major characteristics of each subarea.

Table 3-2. Major Subarea Characteristics

Subarea	Area (acres)	Length (feet)	Width (feet)	Slope (ft/ft)	Percent Impervious
1	3.31	486	297	0.015	76.13
2	2.72	500	237	0.037	90.37
3	3.04	511	259	0.050	87.06
4	3.72	350	463	0.035	82.48
5	4.92	540	397	0.050	83.61
6	3.97	375	461	0.045	83.71

3.3 Extended Dry Detention Pond Characteristics

As mentioned above, when the parking lot was paved, a structure to detain peak flows and control water quality was needed. There are many different types of structures in practice that can be designed to control peak flows only; however, it was decided that this project would address water quality issues as well as peak reduction. Since the watershed has no other water source other than precipitation (such as a spring), a wet detention pond with a permanent pool was not feasible at this site. It was decided that an extended dry detention basin would be designed to reduce the peak flows and also to remove pollutants transported from the parking lot.

An extended dry detention basin removes pollutants by simple physical settling, allowing enough time for sediment borne pollutants to settle out of the water column. Approximately 80% of the pollutants that are associated with suspended solids are attached to the silt and clay fraction, leading to the need for very long detention times. To attain this settling, extended detention basins are usually designed for a holding time of 24-48 hours. The study basin maximizes this time to increase removal rates. In an extended basin, portions of the suspended solids are removed while only a very small

fraction of the dissolved pollutants are removed. Because of the very large volumes of runoff generated in an extended storm, the detention basins are frequently designed with a smaller water quality pool to catch the first 0.5 to 1 inch of rain, thereby retaining and treating only the first flush of runoff. The overflow structure is designed to pass larger storms without significant storage.

The extended detention basin at the campus parking lot test site is designed to capture the first one-half inch of rainfall and detain it for 40 to 50 hours. The pond is approximately four feet deep and contains a bottom clay liner to limit infiltration. The two-stage outlet structure consists of a three-inch orifice with the invert at the bottom of the pond riser box and a 3' x 5.67' grate inlet at the top of the four-foot water quality pool at elevation 2026. The flow is conveyed from the riser box in two 36" concrete pipes directly into the receiving stream. Figure 3-3 depicts the designed storage-elevation curve. Pond maintenance is fairly simple, consisting of trash and grass clipping removal and clearing the trash rack over the orifice after each storm to prevent blockage. The inflow to the pond is a 60" concrete pipe conveying all of the flow from the parking lot. Large riprap is located around the opening to dissipate the flow velocity. The pond was designed to contain the 100-year flood, so an emergency spillway is not necessary. The location of the pond is across the street from the parking lot adjacent to the University golf course. A close-up schematic of the pond area is shown in Figure 3-4. Photographs of the pond and its surroundings are shown in Figures 3-5 to 3-11.

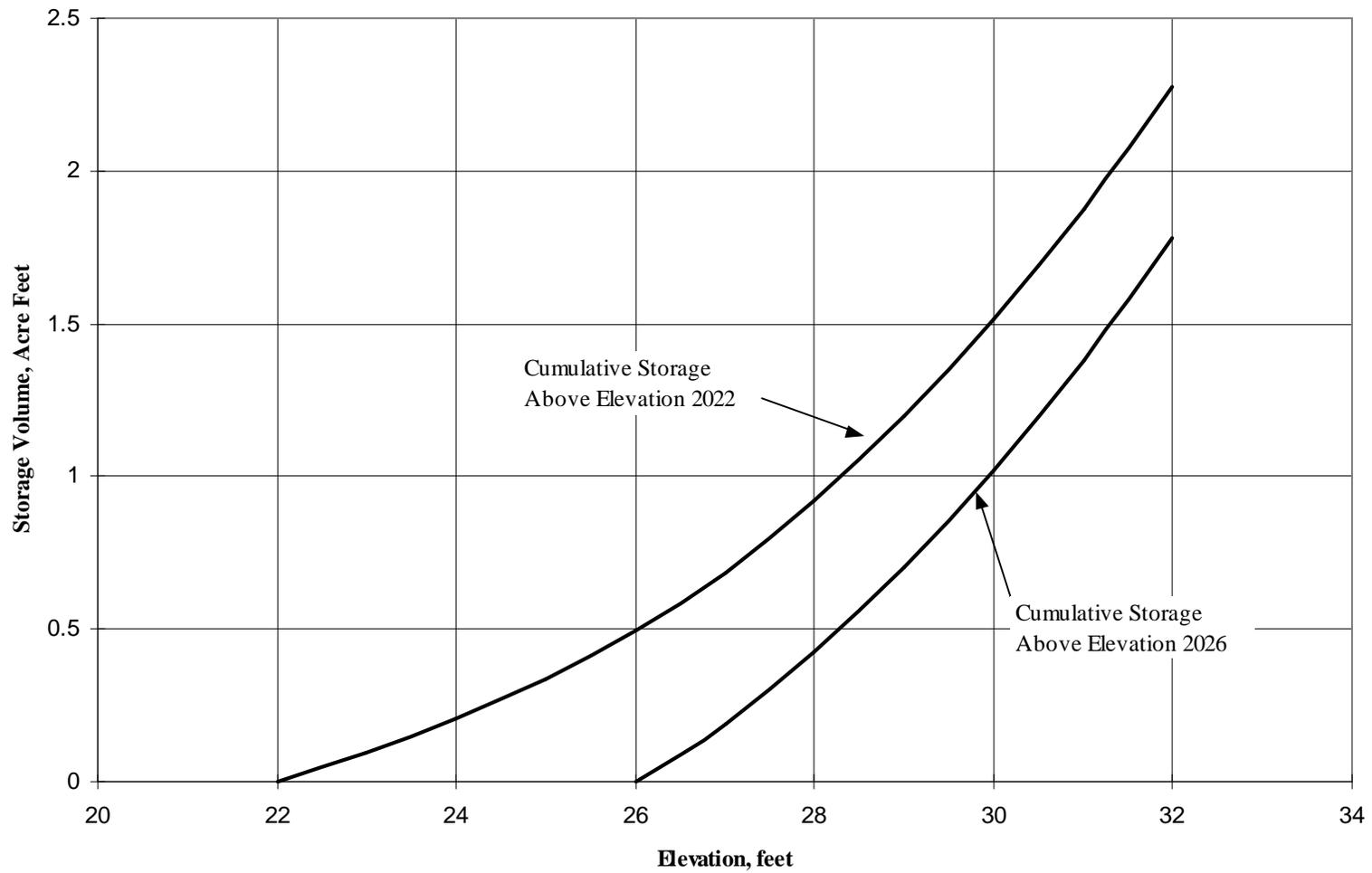


Figure 3-3. Pond Storage Elevation Curves

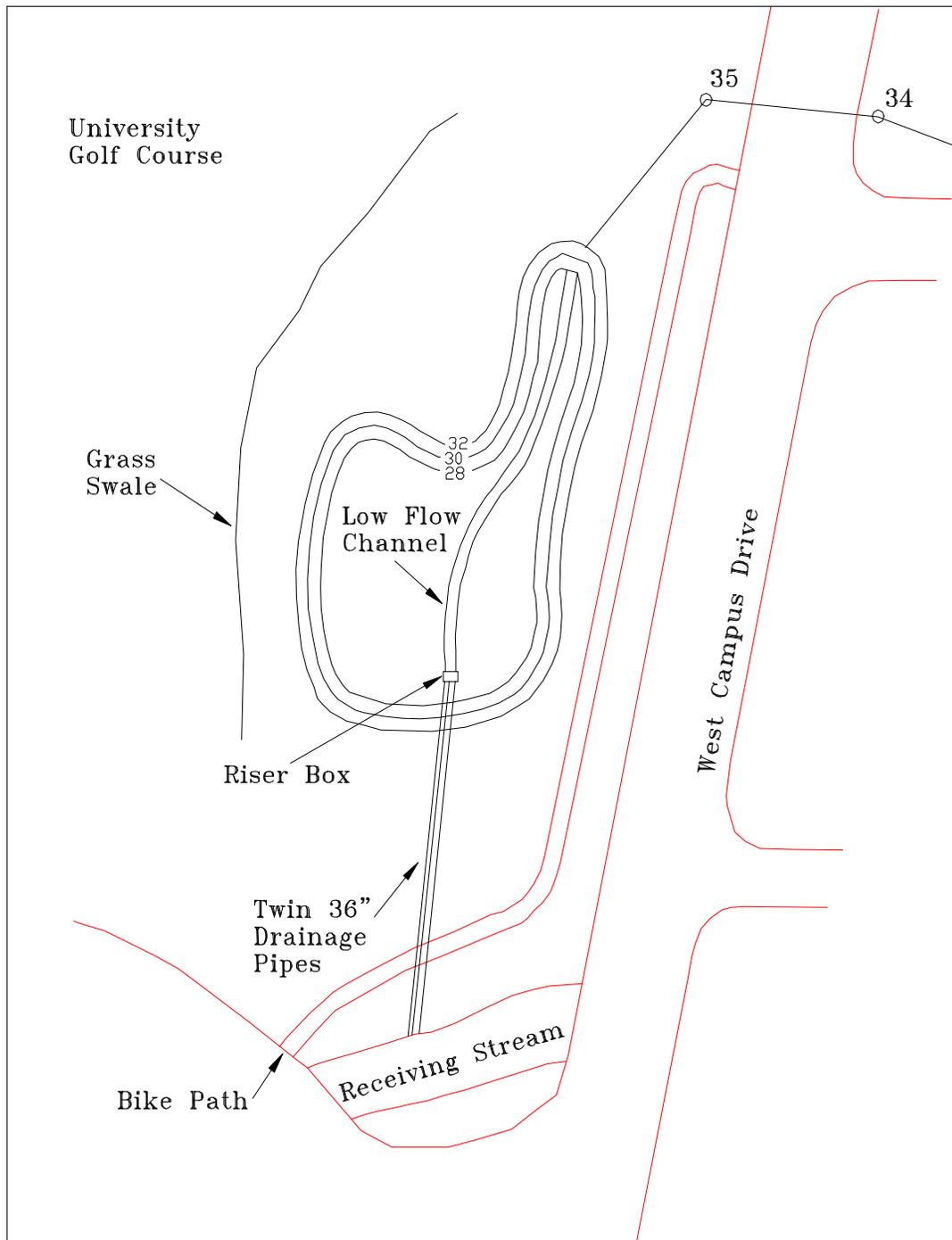


Figure 3-4. Close-Up Schematic of the Pond Area



Figure 3-5. Extended Dry Detention Pond and Surrounding Areas.



Figure 3-6. Golf Course and Detention Pond



Figure 3-7. Pond with Grass Cover and Low Flow Channel



Figure 3-8. Full Pond Depth Looking at Inlet Pipe



Figure 3-9. Top of Riser Box During an Overflow Storm Event



Figure 3-10. Water Depth Inside of Riser Box During an Overflow Storm Event



Figure 3-11. Outlet Structure After a Storm Event

3.4 Sampling Locations

To monitor water quality and assess how well the extended basin removes pollutants; water quality samples were taken in two places - at the pond entrance and at the pond outlet. Discrete samples were taken at each site by an automatic sampler as described in Chapter 4.

3.4.1 Sampling Site DL1 (Pond inlet)

Sampling site Data Logger 1 (DL1) is the sampling site upstream of the pond in the entering storm sewer. To make the sample as representative as possible, the water

was drawn from the drainage sewer pipe after all of the inflow points were contributing and before the flow reached to the pond. Because of the need for maintenance access, a junction with a manhole entrance was chosen for the site. Unfortunately, because of backwater extending from the pond into the storm sewer it was impossible to place the sampling equipment at the first manhole junction upstream from the pond. The 60" pipe into the pond is set at a 0.5% slope and consequently there is a significant backwater from the pond at the first manhole. This backwater affects both the discharge rating and the water quality analysis. Therefore, the next manhole upstream was chosen as the monitoring site, leaving a small portion of the drainage area out of the sampling stream at this point. Because of the uniformity of land-use in the watershed, this area exclusion was not considered a problem. The full inflow to the pond from the parking lot was obtained by multiplying the flow by the total area contributing to the pond divided by total area of the watershed above the gage site. Figure 3-12 shows the location of the sampling intake for DL1.

3.4.2 Sampling Site DL2 (Pond outlet)

The sampler at the pond outlet was positioned to capture the entire outflow regardless of whether it had come from the water quality pool or over the top of the grated inlet. It was important in this study to estimate removal rates from all storms, including those large events passing water through the system virtually untreated. To do this the sampler intake was located behind the riser box in one of the twin 36" culverts that lead to the receiving stream. The intake was placed as close to the riser box as

possible to avoid backflow problems in the pipe in the event the receiving stream would swell out of its normal banks. See Figure 3-12 for the location of sampling point DL2.

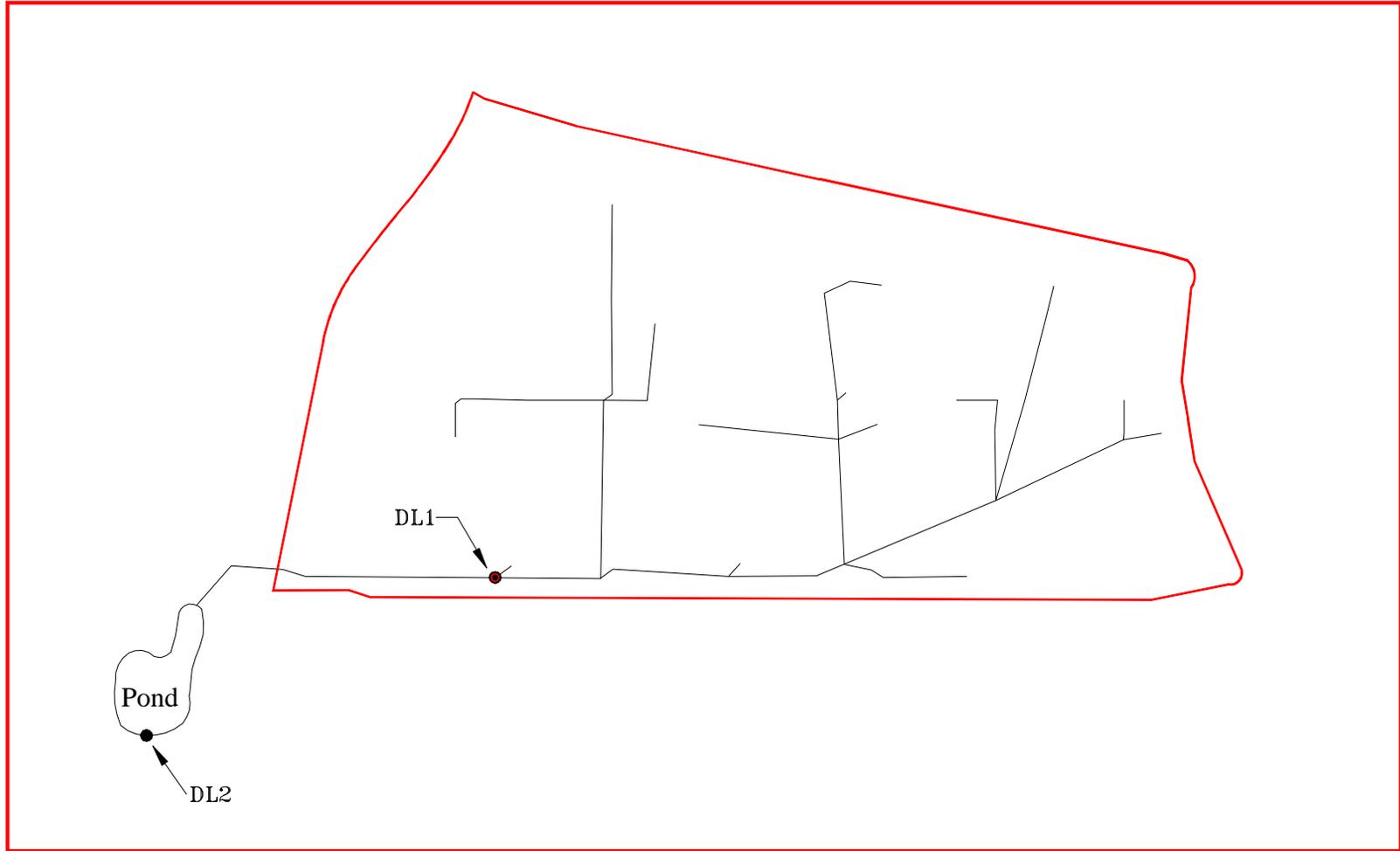


Figure 3-12. Sampling Locations

Chapter 4

Instrumentation and Data Collection

Efforts at measuring and sampling stormwater are often thwarted by the lack of manpower and technology. Along with advances in our understanding of non-point source pollution problems have come new technologies which simplify and automate the sampling process making it both more manageable and more reliable. Today, storms can be sampled automatically at all times, day or night, to obtain more representative and more accurate samples. The parking lot sampling site has been fully automated to insure accurate and representative flow and water quality measurements. This chapter describes the instruments used in the flow monitoring system at the inlet and outlet of the detention basin together with the procedures used in the stormwater quality sampling process.

4.1 Instrumentation

The site has two points of flow measurement, one just upstream of the detention pond to measure pond inflows, and one at the pond outlet to measure pond outflows. The two monitoring systems are slightly different because of the different data collection and sampling needs at each location.

4.2 DL1 Sampling Equipment

4.2.1 The Palmer-Bowlus Flume

The first point of measurement upstream of the detention pond (DL1) was placed at the second manhole upstream from the pond due to the low slope of the pipe and the need for easy pipe access for maintenance purposes. The pipe at the sampling point, which is

immediately downstream of the manhole entrance, is a 48-inch concrete pipe with invert about ten feet below ground elevation. A Palmer-Bowlus flume was installed in this 48-inch pipe segment to constrict the flow and provide for accurate flow-depth measurements. The flume is constructed of aluminum sheet metal to the dimensions specified in Figure 4-1. Calibration of the flume by the United States Geological Survey (Kilpatrick, 1985) revealed that the general discharge equation for all slopes (0 to 3%) and all pipe sizes (18-48 inches diameter) is:

$$\left(\frac{Q}{D}\right)^{5/2} = a\left(\frac{H}{D}\right)^b \quad 4-1$$

where H is the head in feet, a and b are calibration constants, D is the pipe diameter in feet, and Q is the flow rate in cfs. Two sets of a and b calibration constants were developed, one for H measured in the approach to the flume and the other for the H measured in the throat of the flume. In this study, H was measured in the approach to the flume, resulting in the following generalized equation and constants shown in Table 4-1:

Table 4-1. Summary of generalized equation coefficients.

Pipe Slope	"Visual" best fit		Linear Regression Equations		
	a	b	a	b	r ²
0%	3.536	2.055	3.533	2.059	0.9981
1 & 2%	3.685	1.868	3.349	1.718	0.9814
3%	3.969	1.922	4.176	1.988	0.9984

Table 4-1 shows that the same constants can be used for a 1 or 2% slope. The text of the study also states that this calibration will apply to most field calibrations with pipe slopes

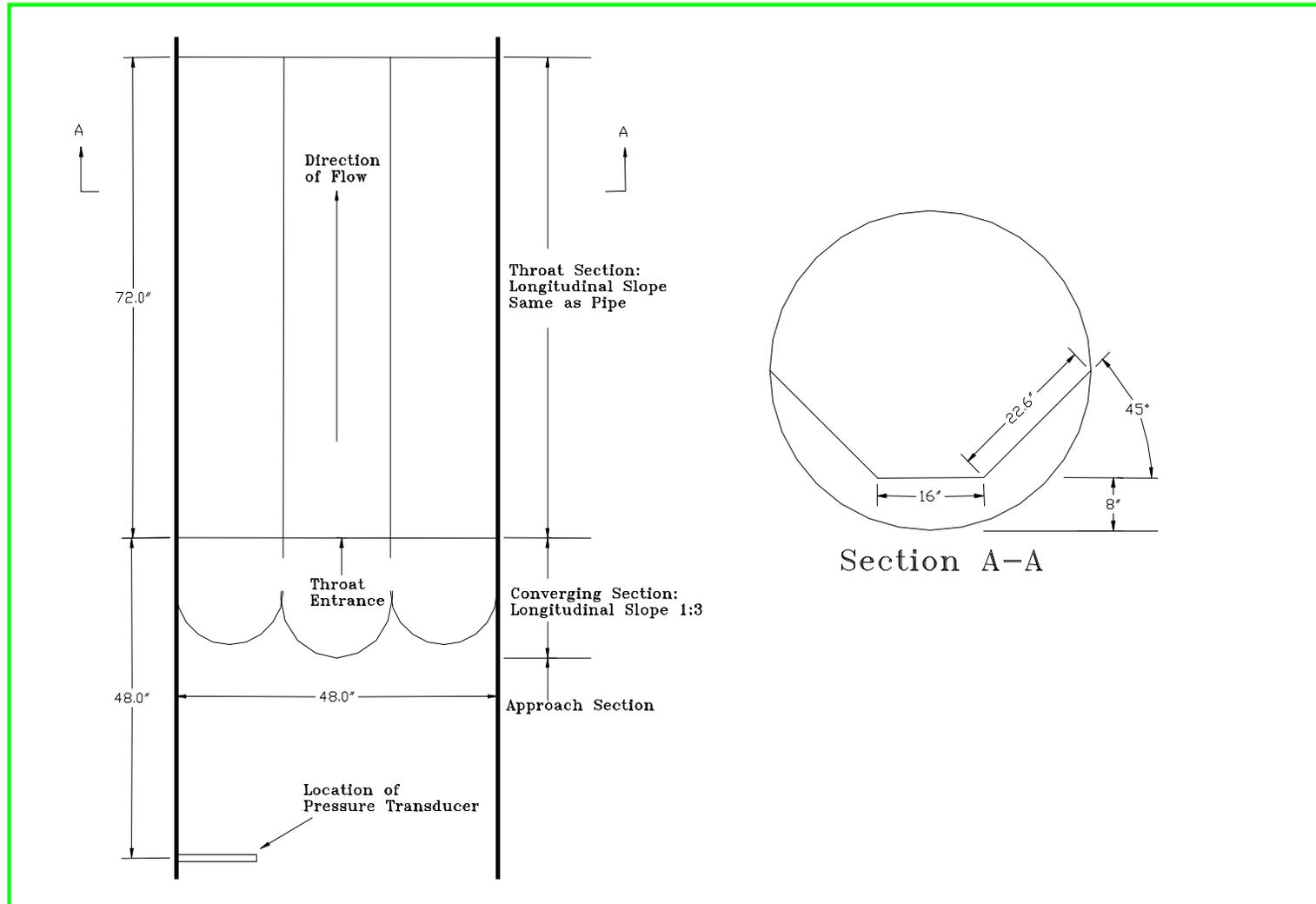


Figure 4-1. Schematic of the Palmer-Bowlus Flume.

from 0.5 to 2 % (Kilpatrick, 1985). The study section has a slope of 0.5%. Both the visual best fit and the linear regression equation yielded similar numbers and the visual best fit constants for a and b were chosen for flow calculations.

4.2.2 CR-10 Data Logger with Pressure Transducer

To record data at the sampling station, the research team installed a Campbell CR-10 data logger. The data logger is hooked to a 12-volt marine battery power supply and it records data measurements (see Figure 4-2).



Figure 4-2. Data Logger DL-1

The data is actually collected every minute by the logger and then averaged across the 5-minute time span to establish a recorded value. The data logger at site DL1 collects the following data: year, Julian day, time, millivolt depth reading, temperature of flow and air, and battery voltage. For simplicity of recording and keeping track of data, the research team

used a Julian calendar system where each day is numbered consecutively throughout the year (1-365 or 366). The weekly recording of the battery voltage was necessary to avoid a battery failure and power outage during a sampling event. A pressure transducer is installed in the pipe to send out a millivolt reading that is stored by the data logger. The millivolt reading is converted into a depth using a rating equation found by field calibration. The depth transformation equation at DL1 is:

$$2.716 \times 10^{-3} \cdot \text{millivolts} - 0.5366 = \text{depth}(ft) \quad 4-2$$

where a zero depth corresponds to the base elevation at the approach of the Palmer-Bowlus flume so that the depth of flow over the flume is being measured. It is this flow depth that is used in the Palmer-Bowlus rating curve equation to determine the flow in the pipe. The data logger must be downloaded with a laptop computer at least once a week to avoid any data losses.

4.2.3 The Starflow Ultrasonic Doppler

In addition to the data logger and the Palmer-Bowlus flume combination for measuring flow, a Starflow Ultrasonic Doppler Instrument was installed in the pipe to verify the flows being calculated for QA/QC purposes. The Starflow was mounted in the pipe invert one pipe diameter upstream of the Palmer-Bowlus flume. The unit sends out an ultrasonic sound and measures a Doppler shift in the reflected signal. It uses this measurement to calculate a velocity. See Figure 4-3.

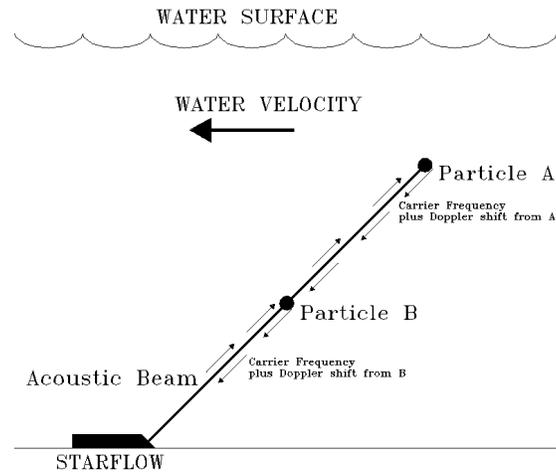


Figure 4-3. Diagram of Starflow Measurement Method (Source: User Manual)

The Starflow does not require field calibration and permits direct flow determination using the measured velocity and the pipe area. In a related Virginia Tech study by John Massey (1995), it was determined that the stagnant water pool caused by the Palmer-Bowlus flume interferes with the Starflow measurements during low flows; however, during larger flows the two calculated flows agree closely. Following completion of the Starflow study by Massey, the Palmer-Bowlus flume and pressure transducer measurement system was used as the primary measurement device for the duration of the study due to its easy maintenance and the consistency of depth/flow calculations.

4.3 DL2 Sampling Equipment

4.3.1 CR-10 Data Logger with Pressure Transducer

To record data at this sampling station a Campbell CR-10 data logger was used. This data logger operates the same as the logger at DL1, but collects different information. The investigators used a pressure transducer mounted in a stilling well to measure height of water in the pond at the outlet in terms of millivolts. The data logger at site DL2 collects the

following data: year, Julian day, time, millivolt depth reading in the pond, rainfall increments in 100^{ths} of an inch, temperature of pond and the air, and battery voltage. The depth transformation equation at DL2 is:

$$0.00512 \cdot \text{millivolts} - 1.6709 = \text{pond depth}(ft) \quad 4-3$$

where a zero depth corresponds to 0.24 feet below the bottom of the three-inch orifice which is the elevation of the floor of the basin. The flow out of the pond can be computed from the following orifice and weir equations:

For depths under 4.24 feet (orifice flow only):

$$Q = 0.6 \cdot A \cdot \left(\sqrt{2g(h - 0.24)} \right) \quad 4-4$$

For depths over 4.24 feet (orifice and weir flow):

$$Q = \left[0.6 \cdot A \cdot \left(\sqrt{2g(h - 0.24)} \right) \right] + \left[3 \cdot P \cdot (h - 0.24)^{1.5} \right] \quad 4-5$$

Here A is the area of the orifice in square feet, h is the head in feet above the orifice centerline, P is the perimeter of the grate inlet opening in feet, and Q is the flow in cfs. This data must also be downloaded from the logger once a week to avoid any data losses.

4.3.2 Tipping Bucket Rain Gage

The DL2 site was equipped with a tipping bucket rain gage to measure rainfall. The rain gage is wired to the data logger so that rainfall data is also collected in 5-minute increments. The buckets hold 0.01” of rain and a ‘tip’ completes the circuit sending an electrical pulse to the data logger. The logger counts the pulses in the 5-minute interval and records this number. The rain gage gives a simple but accurate measurement of the rainfall

on the watershed. A hyetograph of the rainfall distribution in time can be easily constructed from these measurements.

4.4 Water Sampling Procedures

Storm water samples were automatically collected with an ISCO 6700 automatic sampler. At station DL1, the sampler was initialized to begin sampling as soon as the water depth exceeded the base elevation at the approach of the Palmer-Bowlus flume. Sampling rates were set at one sample every fifteen minutes for the first two hours of the storm in order to catch the 'first flush', and then one sample every hour thereafter. In addition, if the data logger sensed a rise in the water level during the tail end of a hydrograph, indicating more rainfall or an increase in intensity of the storm, the sampler would return to its fifteen-minute cycle. Once the water level dropped below the level of the Palmer-Bowlus flume the data logger would stop its sampling routine. The sampler intake strainer is located in the discharge pipe at the manhole approximately two pipe diameters upstream of the flume and the sample is pumped up to ground level. The sampler intake was elevated above the pipe invert by approximately 6 inches to avoid capturing the sediment that begin to settle out of the water column in the pool behind the flume. After each storm event, the sediments that have settled in the pipe are collected and deposited downstream of the flume.

At the pond outflow site, DL2, the sampling scheme consists of taking a water quality sample for every 6-inch rise or fall of the pond elevation. This means that samples are usually taken quickly at the beginning of the storm as the basin fills with water and then more slowly as the basin is draining resulting in an even distribution of hydrograph points

for the inflow and outflow hydrographs. The sampler intake is located on the back-side of the riser box just inside one of the two 36" pipes.

4.5 Sample Storage and Preservation

Bottles used to hold the samples in the sampler were one-liter ISCO high-density polyethylene (HDPE) triangular bottles that had been cleaned and dipped into chloric acid. The water quality samples were removed from the samplers within 12 - 15 hours. Two laboratories were analyzing different properties of each sample. The first performed metal and TOC analysis, while the second analyzed all remaining constituents. Due to this, the sample was divided after removal from the sampler. The sample was thoroughly shaken and approximately 300 ml was poured from the sampler bottle into a smaller bottle for the metals analysis. The bottles used to hold the metal samples were 250 or 500-ml HDPE bottles that had been acid soaked for 48 hours. To preserve the metal samples, a 50% solution of nitric acid was used to lower the pH to approximately 2. The preserved samples can be stored for up to 6 months at room temperature in the acid soaked bottles. Figure 4-4 shows all of the different bottles used in the sampling process. The remaining sample used to test for the other constituents was refrigerated. TOC analysis was performed on the refrigerated sample as soon as possible, and the remaining portion of the sample was taken to the other laboratory for analysis of the remaining constituents. There, since nitric acid preservation would contaminate any nitrate analysis, a hydrochloric acid solution was used for preservation. The samples remained refrigerated until analysis was performed.

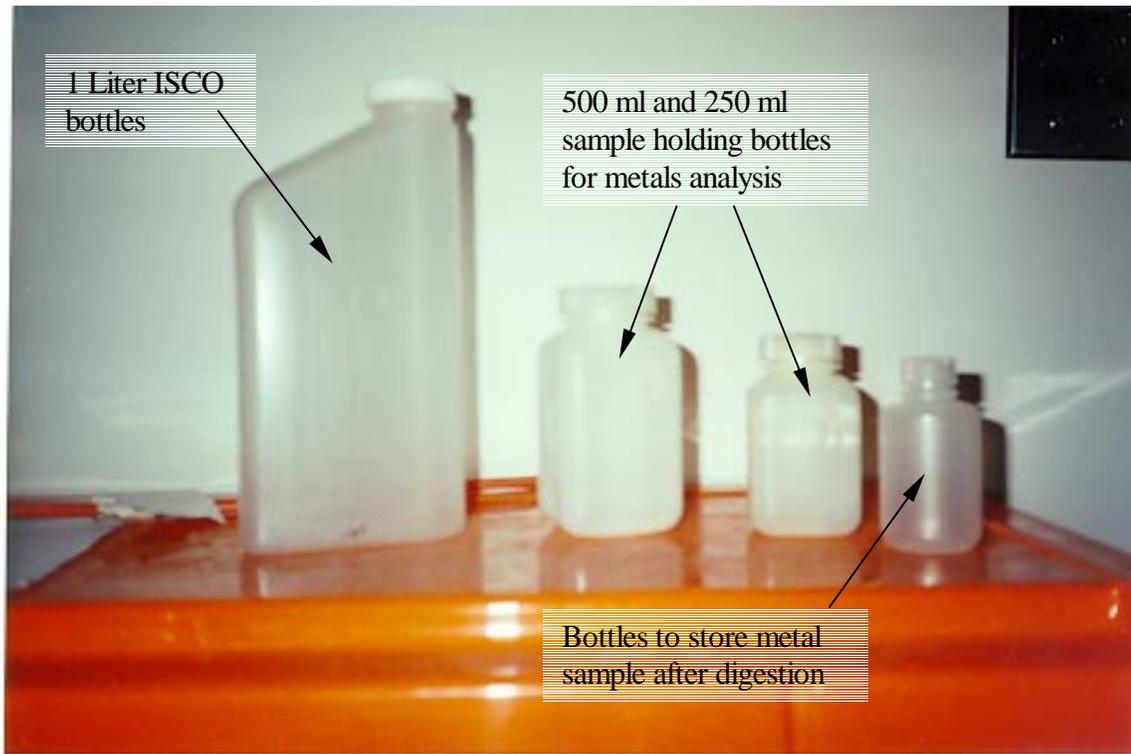


Figure 4-4. Bottles for Storage of Samples

4.6 Sample Analysis

All of the analysis for the constituents was done based on different approved variations of EPA methods and Standard Methods. A complete description of the analysis procedures can be found in Appendix A. Test methods for all constituents in both laboratories were completed using a rigorous QA/QC procedure, including duplicate and spiked samples for comparison. In addition proper preparation, preservation and handling techniques were used with all samples. More information on the QA/QC process can be obtained from the Virginia Tech Biological Department Water Quality Laboratory.

Chapter 5 Observed Field Results

This chapter describes the process of analyzing the field data and the lab results.

The first step was to generate inflow and outflow hydrographs, then to determine the pollutant loadings both into and out of the extended dry detention pond, and finally to determine the pollutant removal rates within the extended dry detention pond.

5.1 Hydrograph and Hyetograph Generation

The calculations for the inflow and outflow hydrographs, based on the rating curves in Chapter 4, were not difficult, but could be extremely time consuming. This is because a hydrograph point was generated every 5 minutes throughout the duration of each storm. A sample of the output from DL1 and DL2 is shown in Tables 5-1 and 5-2.

Table 5-1. Sample Data from DL1.

Data Code	Year	Julian Date	Military Time	Blank	Millivolt Reading	Depth (mm) over flume	T1 Temp.	T2 Temp.	T3 Temp.	Battery Voltage
111	1995	277	1115	999	203.3	4.742	18.22	19.05	18.3	10.93
111	1995	277	1120	999	250.8	44.03	18.15	19.23	18.24	10.93
111	1995	277	1125	999	283.1	70.8	18.11	19.28	18.19	10.92
240	1995	277	1129	999	309.5	92.6	----	----	----	----
111	1995	277	1130	999	306	89.7	18.09	19.23	18.14	10.93
111	1995	277	1135	999	323.4	104.1	18.07	19.27	18.1	10.93
111	1995	277	1140	999	340.2	118	18.03	19.3	18.04	10.93
240	1995	277	1144	999	356.9	131.9	----	----	----	----
111	1995	277	1145	999	353.1	128.7	18	19.34	18.01	10.93
111	1995	277	1150	999	361.5	135.6	17.98	19.4	17.96	10.93
111	1995	277	1155	999	359.9	134.3	17.97	19.43	17.94	10.93
240	1995	277	1159	999	364.9	138.5	----	----	----	----
111	1995	277	1200	999	363.1	137	17.97	19.48	17.91	10.93

T1 = air temperature in storm sewer

T2 = water temperature

T3 = air temperature at data logger.

Data code 240 indicates sample event time and no voltage or temperatures are recorded.

Temperatures are only recorded in 5-minute increments.

Table 5-2. Sample Data from DL2.

Data Code	Year	Julian Date	Military Time	Rainfall (1/100")	Millivolt Reading	Depth (ft) in pond	T1 Temp.	T2 Temp.	T3 Temp.	Battery Voltage
113	1995	277	1115	1	539.4	1.102	18.18	18.58	18.24	11.44
113	1995	277	1120	1	535.7	1.083	18.19	18.57	18.2	11.43
113	1995	277	1125	0	531.6	1.062	18.24	18.59	18.16	11.44
113	1995	277	1130	1	528.8	1.048	18.26	18.6	18.12	11.47
113	1995	277	1135	1	529.1	1.049	18.26	18.59	18.08	11.42
113	1995	277	1140	1	537.1	1.091	18.2	18.57	18.05	11.44
113	1995	277	1145	1	550.7	1.16	18.25	18.51	18	11.45
113	1995	277	1150	1	566.7	1.242	18.31	18.44	17.97	11.44
113	1995	277	1155	1	582.7	1.324	18.28	18.41	17.93	11.45
113	1995	277	1200	1	596.2	1.393	18.28	18.56	17.91	11.44
113	1995	277	1205	1	609	1.458	18.25	18.71	17.88	11.47
113	1995	277	1210	1	621.1	1.521	18.26	18.8	17.86	11.47

T1 = water temperature, T2 = culvert air temperature, T3 = air temperature at data logger panel

Data for the collection period was compiled into a continuous data bank for both the inflow and outflow measurements. A Microsoft Visual Basic program, Thesis Reduction Analysis Program, TRAP, was written to do the calculations directly from the raw data, including inflow and outflow hydrographs, inflow and outflow pollutant loadings, storm hyetographs and total daily rainfall for the sampling period. Program code for selected hydrographs and loading calculations are included in Appendix B.

To produce an inflow hydrograph, the program user only needs to input the Julian date of the storm. The program will search through the data files for DL1 until the correct Julian date is found. A hydrograph is the calculated beginning at time 0 for the entered day and extending until the raw data indicates that the water level in the pipe has dropped below the height of the flume. Flows for each time step are calculated using the Palmer-Bowlus rating curve equation discussed in Chapter 4. Date, time and flow values are recorded in five-minute increments into an output hydrograph file. In addition, the

program keeps a running total of flow and calculates incremental volumes. These volumes are added and recorded at the end of the output hydrograph file to yield the total storm volume in cubic feet. The TRAP input screen is shown in Figure 5-1.

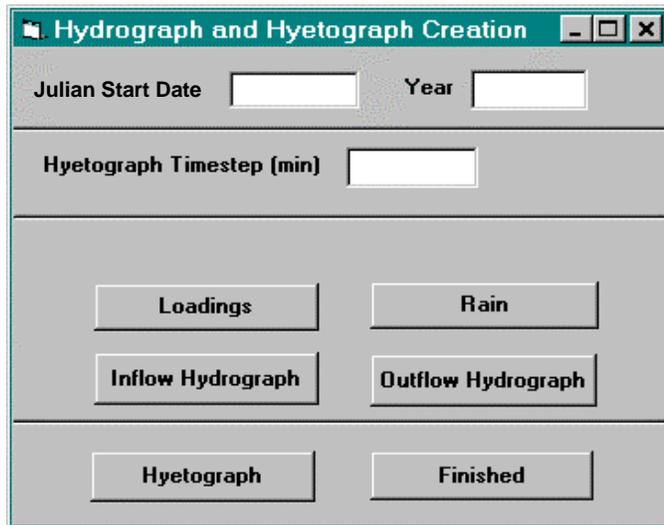


Figure 5-1. TRAP Input Screen

Outflow hydrographs are also created by inputting the Julian date of the storm; however, the supporting calculations are more difficult. Due to the irregularities of the natural pond bottom, an accurate drawdown time for each storm was difficult to determine. To account for these slight variations in the pond datum inside the stage recorder, an averaging routine was used to calculate the exact datum of the pond on the day of the rainfall event. At time zero on the Julian date of the storm, the computer would begin to sum the recorded bottom depths of the pond (shown in Table 5-2, Column 7) until rainfall began. At this point, the average bottom depth for that day was determined. The program would then calculate hydrograph points, using the orifice and weir discharge equations described in Chapter 4, until the water depth in the pond reached

within one percent of the average bottom depth before the event began. These hydrograph points and a total storm volume were written to an output file.

The program can also create hyetograph files. Given the Julian date when rainfall began and a desired timestep, TRAP will extract out the date, time, and rainfall amount and write the hyetograph data to a file. Since some storms had intermittent rainfall, the program continues to report rainfall amounts until six hours passes with no additional rainfall amounts. The program also calculates the total storm rainfall amount and records that number as the last line of each data file.

The program was run for each of the observed storm events to generate inflow and outflow hydrographs and a storm hyetograph. For some of the very small events, only a hyetograph and a pond inflow hydrograph could be obtained since the outflow was often too small to measure. As can be seen in Table 5-3, there is some loss in the total volumes of each of the storms between the storm hyetograph, inflow hydrograph, and outflow hydrographs. The differences between the hyetograph and inflow hydrograph are an indication of the losses in the system caused by initial abstraction and depression storage losses. The losses between the inflow and outflow hydrographs are indications of the infiltration and evaporation losses. In addition, there are losses due to system calibration, etc. that cannot be directly measured in the field. Overall, the results of the volume analysis were constant, and as expected the general pattern indicates that the percent volume difference caused by losses was greater in smaller storms and lower in larger storms. Figure 5-2 shows a graphical example of the flow comparison that can

Table 5-3. Observed Storm Volumes.

Julian Date	Dry Days Previous	Rainfall (Inches)	Hyetograph (Cu. Feet)	Inflow (Cu. Feet)	Outflow (Cu. Feet)	% Error	Initial Losses
198	(10)	1.38	102,495	79,173	70,615	10.8	22.8%
230	5	1.80	133,686	127,455	107,567	15.6	4.7%
239	8	0.52	38,620	30,545	27,017	11.6	20.9%
256	10	0.14	10,398	7,763			25.3%
259	2	1.13	83,925	77,551	55,012	29.1	7.6%
265	4	0.06	4,456	537			87.9%
267	0	0.08	5,942	381			93.6%
269	0	0.20	14,854	9,919	7,266	26.7	33.2%
277	5	1.59	117,346	107,266	84,640	21.1	8.6%
286	6	0.36	26,737	16,971	15,102	11.0	36.5%
293	5	0.67	49,761	46,471	32,393	30.3	6.6%
300	5	0.10	7,427	2,913			60.8%
304	2	0.07	5,199	1,457			72.0%
306	1	0.33	24,509	13,578	11,604	14.5	44.6%
311	3	0.89	66,100	57,756	45,439	21.3	12.6%
315	3	0.42	31,193	24,359	23,613	3.1	21.9%
<p>Notes: Inflow is the adjusted inflow calculated as Measured Inflow*(Total Area/Gaged Area) % Error is calculated as [(inflow-outflow)/inflow] *100 Initial losses are calculated as [(Hyetograph Volume - Inflow Volume)/Hyetograph Volume]*100 Blank Spaces indicate that the outflow was too small for measurement</p>							

Flow Comparison For Oct.4

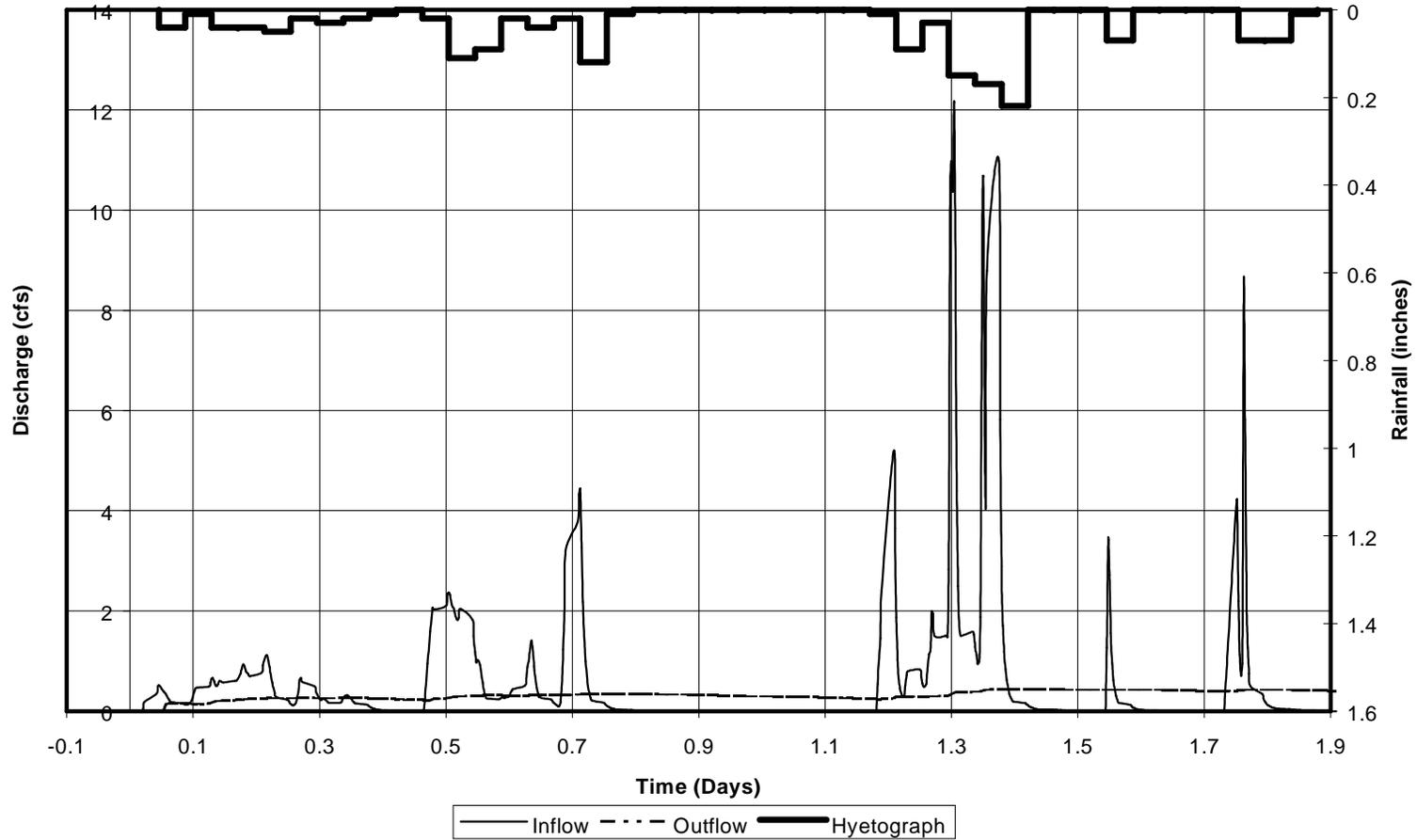


Figure 5-2. Sample Flow Comparison Graph.

be obtained for any storm by plotting the hyetograph, and the inflow and outflow hydrographs generated by the program.

5.2 Pollutant Loadings

Generation of the pollutant loadings for each storm after the sample constituent results were determined was performed by TRAP. Use of the program greatly decreased the time needed for calculation of constituent total loadings for each storm. Laboratory results of all of the constituents for each sample were saved in a database that the program can access. The program user inputs the Julian date of the storm and TRAP calculates the total load for each measured constituent for both the inflow and outflow samples. This data is then saved to disk.

The investigators had to consider the process of how to calculate total storm loads from continuous hydrographs and discrete samples. There are three basic methods of approaching the problem: forward calculation, backward calculation and average calculation. The forward calculation multiplies the discrete sample results for each constituent with the total flow volume under the hydrograph that occurs after that sample and before the next sample. The backwards method uses the same approach, but multiplies the constituent amounts with the flow volume between samples that occurred before the sample was taken. The average method multiplies the constituent results with the flow volume that occurs halfway between the sample before and the sample after. Each of these methods is shown graphically in Figure 5-3. After some initial analysis comparing the average and backward methods, the backward method was chosen as the basis of the TRAP program calculations.

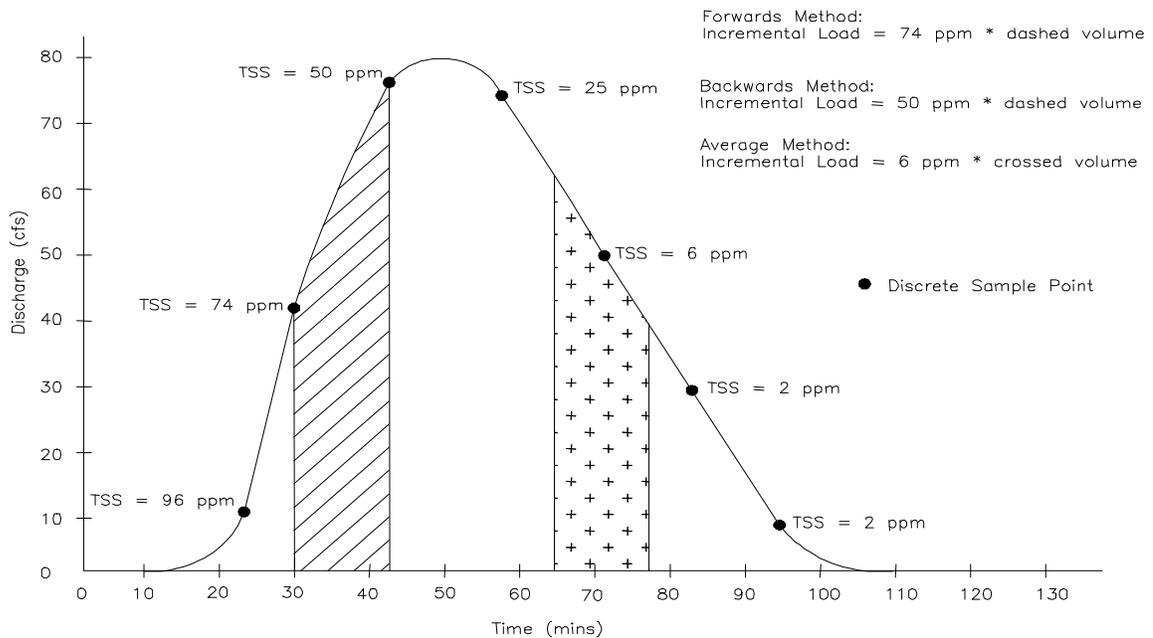


Figure 5-3. Load Calculation Methods.

The TRAP program was run on each of the observed storms to calculate the total pollutant loadings for each storm event and each measured constituent. The sample input screen is shown in Figure 5-4. As can be seen, only the Julian date is required as input.

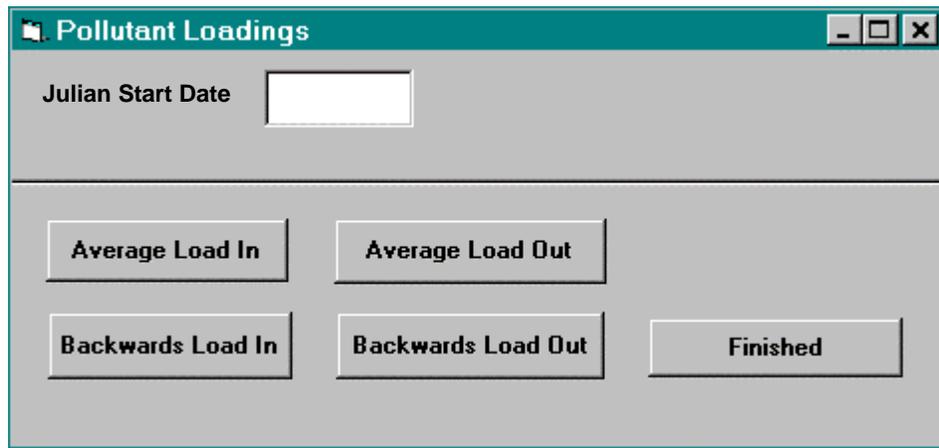


Figure 5-4. Sample Pollutant Loading Analysis Input Screen

For each storm that had a measured outflow hydrograph, the percent difference in the loads was calculated as $\% \text{ removal} = \frac{\text{Load In (g)} - \text{Load Out (g)}}{\text{Load In (g)}} \times 100$. The results showed inconsistencies in removal rates for individual storms as shown in Table 5-4 (a-h) where all constituent loads are in grams. The next step was to make the same comparisons based on EMC values instead of loadings. These results, shown in Table 5-5 (a-h) in $\mu\text{g/L}$ showed the same inconsistencies for individual storm events.

To try and account for the removal rate inconsistencies, the investigators looked at the total collection of storms as a single data set instead of a series of individual events. The total amounts of inflow for all storm events was added to get a total constituent inflow into the extended dry detention basin over the six month sampling period and the same was done for the outflows. Since some of the storms did not have measurable outflows, this method accounted for the removal rate of the entire input loading. Table 5-6 shows the total loading for inflows and outflows of all the storm events. Table 5-7 shows the removal rates as a percentage. The results shown in Table 5-7 are an indication of the removal rates that are possible with an extended dry detention pond. Unlike the sporadic results that were found analyzing the data on a storm by storm basis, the long term average showed that the extended dry detention pond performed consistently in removing of many of the sediments and the sediment-bound pollutants. As expected, the pond was not as effective in pollutant removal when it came to dissolved constituents. Appendix C gives the raw constituent concentrations for each of the data points.

Table 5-4. Removal Rates.

Table 5-4(a) - July 17-18 (Day 198)

	IN (g)	OUT (g)	%
NH4	135.0	0.0	100.00
FTKN	3432.5	1239.8	63.88
TKN	3148.3	1848.4	41.29
NO3N	1354.1	422.0	68.83
PO4	23.5	92.9	-294.75
FTP	0.0	153.7	
TP	145.3	191.8	-31.98
TSS	378797	35682	90.58
Cd	1.3	0.5	62.36
Cu	14.7	9.2	37.41
Pb	14.1	11.7	17.50
Zn	216.5	137.4	36.51
TOC	43179	12932	70.05

Table 5-4(b) - Sept.13 (Day 256)

	IN (g)	OUT (g)	%
NH4	59.0	2.4	95.93
FTKN	244.6	125.3	48.76
TKN	444.7	284.4	36.04
NO3N	362.3	67.7	81.30
PO4	0.0	0.0	
FTP	3.8	0.3	91.67
TP	23.3	31.1	-33.64
TSS	10325	1035	89.97
Cd	0.4	0.1	63.01
Cu	2.6	1.5	41.06
Pb	1.6	1.5	10.20
Zn	24.8	10.2	58.72
TOC	11075	6156	44.41

Table 5-4(c) - Sept. 16 (Day 259)

	IN (g)	OUT (g)	%
NH4	28.9	0.0	100.00
FTKN	176.6	84.8	51.95
TKN	791.9	548.2	30.77
NO3N	809.5	291.8	63.96
PO4	4.0	3.5	12.95
FTP	29.4	31.1	-5.96
TP	111.3	126.9	-14.00
TSS	16580	4032	75.68
Cd	1.8	1.4	23.76
Cu	11.2	9.2	17.99
Pb	24.4	18.0	26.51
Zn	120.4	106.9	11.26
TOC	16072	10372	35.46

Table 5-4(d) - Sept. 26 (Day 269)

	IN (g)	OUT (g)	%
NH4	22.1	0.0	100.00
FTKN	111.5	0.3	23.88
TKN	253.4	220.7	-116.38
NO3N	190.6	78.9	-53.05
PO4	0.0	0.0	
FTP	1.4	0.0	-2053.91
TP	23.5	10.3	-440.94
TSS	11213	2093	64.04
Cd	0.2	0.1	-570.58
Cu	2.5	1.2	-261.19
Pb	3.7	1.1	-381.59
Zn	37.1	8.7	-188.36
TOC	3470	2436	-198.87

Table 5-4 Removal Rates. (Cont'd)

Table 5-4(e) - Oct. 4 (Day 277)

	IN (g)	OUT (g)	%
NH4	27.6	8.4	69.76
FTKN	2291.3	1104.6	51.79
TKN	4029.7	2577.7	36.03
NO3N	679.5	247.5	63.58
PO4	33.6	23.8	29.29
FTP	45.6	19.0	58.43
TP	266.7	119.4	55.23
TSS	131126	42116	67.88
Cd	6.0	1.7	71.13
Cu	14.6	12.1	17.12
Pb	49.5	25.9	47.69
Zn	273.1	108.2	60.38
TOC	19637	16677	15.07

Table 5-4(f) - Oct. 13 (Day 286)

	IN (g)	OUT (g)	%
NH4	6.7	2.7	58.93
FTKN	47.9	103.4	-115.90
TKN	122.6	540.6	-340.75
NO3N	125.5	68.9	45.08
PO4	1.2	8.2	-599.98
FTP	3.7	0.0	100.00
TP	34.3	28.7	16.41
TSS	10025	4851	51.61
Cd	0.2	0.2	-10.78
Cu	2.5	3.2	-29.75
Pb	3.2	3.6	-11.71
Zn	29.7	23.7	20.15
TOC	4155	4451	-7.12

Table 5-4(g) - Oct. 20 (Day 293)

	IN (g)	OUT (g)	%
NH4	35.5	1.5	95.89
FTKN	41.6	163.0	-291.98
TKN	284.2	30.0	89.45
NO3N	456.2	215.2	52.83
PO4	0.0	7.6	
FTP	2.9	27.3	-827.78
TP	82.0	73.7	10.06
TSS	24234	7154	70.48
Cd	0.5	0.2	51.49
Cu	6.3	2.3	63.26
Pb	5.0	4.9	2.17
Zn	67.6	27.9	58.70
TOC	6673	5250	21.32

Table 5-4(h) - Nov. 2 (Day 306)

	IN (g)	OUT (g)	%
NH4	11.0	0.0	100.00
FTKN	21.1	26.4	-24.87
TKN	115.9	13.9	88.03
NO3N	72.9	36.8	49.51
PO4	2.4	10.2	-327.17
FTP	8.0	0.0	100.00
TP	27.4	32.4	-18.28
TSS	11351	2759	75.69
Cd	0.2	0.2	25.49
Cu	2.0	1.8	12.11
Pb	3.1	2.0	35.24
Zn	23.5	14.9	36.78
TOC	4137	3665	11.41

Table 5-4 Removal Rates. (Cont'd)

Table 5-4(g) - Nov. 7 (Day 311)

	IN (g)	OUT (g)	%
NH4	4.9	0.1	97.09
FTKN	874.7	95.0	89.14
TKN	690.6	180.3	73.90
NO3N	285.7	185.5	35.07
PO4	2.4	68.8	-2819.18
FTP	11.1	90.1	-713.37
TP	97.7	171.8	-75.86
TSS	26375	26743	-1.40
Cd	0.9	4.0	-374.83
Cu	5.5	5.7	-4.30
Pb	10.4	5.2	49.78
Zn	99.6	64.8	34.90
TOC	7974	7788	2.32

Table 5-4(h) - Nov. 11 (Day 315)

	IN (g)	OUT (g)	%
NH4	0.4	0.0	100.00
FTKN	314.9	272.5	13.46
TKN	772.6	892.2	-15.48
NO3N	87.5	35.9	59.02
PO4	10.1	2.2	77.93
FTP	4.3	79.7	-1765.25
TP	59.6	132.5	-122.28
TSS	47584	137049	-188.02
Cd	0.3	0.5	-58.05
Cu	4.2	8.6	-106.68
Pb	7.5	12.8	-70.79
Zn	44.5	109.7	-146.55
TOC	3615	5111	-41.37

Table 5-5. Event Mean Concentration Removal Rates.

Table 5-5(a) - July 17-18 (Day 198)

	IN (ug/L)	OUT(ug/L)	%
NH4	0.060	0.000	100.00
FTKN	1.520	0.620	59.23
TKN	1.395	0.924	33.72
NO3N	0.600	0.211	64.82
PO4	0.010	0.046	-345.61
FTP	0.000	0.077	
TP	0.064	0.096	-48.98
TSS	167.797	17.843	89.37
Cd	0.001	0.000	57.51
Cu	0.006	0.005	29.34
Pb	0.006	0.006	6.87
Zn	0.096	0.069	28.33
TOC	19.127	6.467	66.19

Table 5-5(b) - Sept.13 (Day 256)

	IN (ug/L)	OUT(ug/L)	%
NH4	200.205	10.904	94.55
FTKN	830.607	570.045	31.37
TKN	1510.347	1293.799	14.34
NO3N	1230.268	308.149	74.95
PO4	0.000	0.000	
FTP	12.913	1.440	88.85
TP	79.149	141.672	-78.99
TSS	35062.776	4708.613	86.57
Cd	1.219	0.604	50.46
Cu	8.879	7.010	21.05
Pb	5.589	6.722	-20.28
Zn	84.148	46.528	44.71
TOC	37609.346	28000.663	25.55

Table 5-5 Event Mean Concentration Removal Rates (Cont'd)

Table 5-5(c) - Sept. 16 (Day 259)

	IN (ug/L)	OUT(ug/L)	%
NH4	13.174	0.000	100.00
FTKN	80.394	54.462	32.26
TKN	360.565	351.878	2.41
NO3N	368.595	187.273	49.19
PO4	1.825	2.240	-22.72
FTP	13.386	19.994	-49.37
TP	50.695	81.473	-60.71
TSS	7549.203	2587.957	65.72
Cd	0.821	0.882	-7.48
Cu	5.110	5.907	-15.61
Pb	11.122	11.522	-3.60
Zn	54.832	68.595	-25.10
TOC	7317.981	6657.690	9.02

Table 5-5(d) - Sept. 26 (Day 269)

	IN (ug/L)	OUT(ug/L)	%
NH4	78.798	0.000	100.00
FTKN	396.823	1.238	99.69
TKN	901.914	1072.663	-18.93
NO3N	678.641	383.421	43.50
PO4	0.000	0.000	
FTP	5.148	0.000	100.00
TP	83.531	49.822	40.36
TSS	39917.514	10170.892	74.52
Cd	0.730	0.324	55.64
Cu	9.071	6.009	33.76
Pb	13.269	5.273	60.26
Zn	131.928	42.333	67.91
TOC	12354.621	11838.384	4.18

Table 5-5(e) - Oct. 4 (Day 277)

	IN (ug/L)	OUT(ug/L)	%
NH4	27.004	1.590	94.11
FTKN	31.604	177.722	-462.34
TKN	215.962	32.679	84.87
NO3N	346.637	234.562	32.33
PO4	0.000	8.282	
FTP	2.240	29.812	-1230.99
TP	62.298	80.384	-29.03
TSS	18413.787	7798.283	57.65
Cd	0.382	0.266	30.41
Cu	4.783	2.521	47.29
Pb	3.781	5.307	-40.34
Zn	51.368	30.434	40.75
TOC	5070.156	5723.146	-12.88

Table 5-5(f) - Oct. 13 (Day 286)

	IN (ug/L)	OUT(ug/L)	%
NH4	28.479	0.000	100.00
FTKN	54.932	80.260	-46.11
TKN	301.347	42.219	85.99
NO3N	189.594	112.020	40.92
PO4	6.239	31.186	-399.84
FTP	20.862	0.000	100.00
TP	71.205	98.548	-38.40
TSS	29518.620	8396.357	71.56
Cd	0.641	0.559	12.81
Cu	5.193	5.341	-2.85
Pb	8.125	6.157	24.22
Zn	61.109	45.206	26.02
TOC	10758.682	11151.879	-3.65

Table 5-5 Event Mean Concentration Removal Rates (Cont'd)

Table 5-5(g) - Oct. 20 (Day 293)

	IN (ug/L)	OUT(ug/L)	%
NH4	3.016	0.111	96.31
FTKN	534.759	73.836	86.19
TKN	422.246	140.095	66.82
NO3N	174.693	144.175	17.47
PO4	1.441	53.463	-3610.47
FTP	6.769	69.979	-933.85
TP	59.742	133.538	-123.52
TSS	16124.936	20782.388	-28.88
Cd	0.521	3.145	-503.54
Cu	3.340	4.428	-32.57
Pb	6.377	4.070	36.17
Zn	60.896	50.385	17.26
TOC	4874.905	6052.402	-24.15

Table 5-5(h) - Nov. 2 (Day 306)

	IN (ug/L)	OUT(ug/L)	%
NH4	0.520	0.000	100.00
FTKN	456.436	394.983	13.46
TKN	1119.921	1293.274	-15.48
NO3N	126.843	51.978	59.02
PO4	14.650	3.233	77.93
FTP	6.192	115.494	-1765.25
TP	86.396	192.038	-122.28
TSS	68978.064	198667.586	-188.02
Cd	0.464	0.734	-58.05
Cu	6.025	12.453	-106.68
Pb	10.854	18.537	-70.79
Zn	64.517	159.063	-146.55
TOC	5240.621	7408.680	-41.37

Table 5-5(g) - Nov. 7 (Day 311)

	IN (ug/L)	OUT (ug/L)	%
NH4	0.085	0.003	96.31
FTKN	15.144	2.091	86.19
TKN	11.958	3.968	66.82
NO3N	4.947	4.083	17.47
PO4	0.041	1.514	-3610.47
FTP	0.192	1.982	-933.85
TP	1.692	3.782	-123.52
TSS	456.658	588.557	-28.88
Cd	0.015	0.089	-503.54
Cu	0.095	0.125	-32.57
Pb	0.181	0.115	36.17
Zn	1.725	1.427	17.26
TOC	138.057	171.404	-24.15

Table 5-5(h) - Nov. 11 (Day 315)

	IN (ug/L)	OUT (ug/L)	%
NH4	0.015	0.000	100.00
FTKN	12.926	11.186	13.46
TKN	31.716	36.626	-15.48
NO3N	3.592	1.472	59.02
PO4	0.415	0.092	77.93
FTP	0.175	3.271	-1765.25
TP	2.447	5.439	-122.28
TSS	1953.459	5626.266	-188.02
Cd	0.013	0.021	-58.05
Cu	0.171	0.353	-106.68
Pb	0.307	0.525	-70.79
Zn	1.827	4.505	-146.55
TOC	148.414	209.814	-41.37

Table 5-6. Total Loadings (grams) by Storm Date and Constituent.

Inflows	198	230	239	256	259	265	267	269	277	286	293	300	304	306	311	315	Totals
NH4	135.0	141.0	6.1	59.0	28.9	0.2	0.0	22.1	27.6	6.7	35.5	1.3	0.0	11.0	4.9	0.4	479.8
FTKN	3432.5	667.1	96.0	244.6	176.6	13.8	11.4	111.5	2291.3	47.9	41.6	0.8	0.0	21.1	874.7	314.9	8345.6
TKN	3148.3	2584.0	121.6	444.7	791.9	38.9	11.4	253.4	4029.7	122.6	284.2	12.0	0.0	115.9	690.6	772.6	13421.9
NO3N	1354.1	2344.6	132.0	362.3	809.5	24.9	6.9	190.6	679.5	125.5	456.2	59.0	10.9	72.9	285.7	87.5	7002.3
PO4	23.5	148.9	0.0	0.0	4.0	0.0	0.0	0.0	33.6	1.2	0.0	0.5	0.4	2.4	2.4	10.1	227.0
FTP	0.0	94.0	7.8	3.8	29.4	1.0	0.0	1.4	45.6	3.7	2.9	0.0	0.8	8.0	11.1	4.3	213.8
TP	145.3	688.9	15.9	23.3	111.3	1.2	0.4	23.5	266.7	34.3	82.0	7.9	4.3	27.4	97.7	59.6	1589.5
TSS	378797	291646	875	10325	16580	556	328	11213	131126	10025	24234	3484	1053	11351	26375	47584	965550
Cd	1.3	1.3	0.4	0.4	1.8	0.0	0.0	0.2	6.0	0.2	0.5	0.0	0.1	0.2	0.9	0.3	13.5
Cu	14.7	24.3	4.0	2.6	11.2	0.2	0.1	2.5	14.6	2.5	6.3	0.7	0.2	2.0	5.5	4.2	95.6
Pb	14.1	22.6	3.2	1.6	24.4	0.2	0.1	3.7	49.5	3.2	5.0	0.6	0.4	3.1	10.4	7.5	149.7
Zn	216.5	205.3	56.7	24.8	120.4	1.4	0.7	37.1	273.1	29.7	67.6	7.1	3.0	23.5	99.6	44.5	1211.0
TOC	43179	19212	9118	11075	16072	608	297	3470	19637	4155	6673	2215	867	4137	7974	3615	152303.4
Sed. N	-284.2	1917.0	25.5	200.2	615.3	25.2	0.0	141.9	1738.5	74.7	242.6	11.1	0.0	94.8	-184.0	457.7	5076.2
Sed. P	145.3	594.9	8.1	19.5	81.9	0.2	0.4	22.0	221.0	30.6	79.0	7.8	3.6	19.4	86.6	55.3	1375.7
TN	4502.4	4928.7	253.6	807.0	1601.4	63.9	18.3	444.0	4709.2	248.1	740.4	71.0	10.9	188.8	976.4	860.1	20424.1

Outflows	198	230	239	256	259	265	267	269	277	286	293	300	304	306	311	315	Totals
NH4	0.0			2.4	0.0			0.0	8.4	2.7	1.5			0.0	0.1	0.0	15.1
FTKN	1239.8			125.3	84.8			0.3	1104.6	103.4	163.0			26.4	95.0	272.5	3215.2
TKN	1848.4			284.4	548.2			220.7	2577.7	540.6	30.0			13.9	180.3	892.2	7136.3
NO3N	422.0			67.7	291.8			78.9	247.5	68.9	215.2			36.8	185.5	35.9	1650.2
PO4	92.9			0.0	3.5			0.0	23.8	8.2	7.6			10.2	68.8	2.2	217.3
FTP	153.7			0.3	31.1			0.0	19.0	0.0	27.3			0.0	90.1	79.7	401.2
TP	191.8			31.1	126.9			10.3	119.4	28.7	73.7			32.4	171.8	132.5	918.6
TSS	35682			1035	4032			2093	42116	4851	7154			2759	26743	137049	263515
Cd	0.5			0.1	1.4			0.1	1.7	0.2	0.2			0.2	4.0	0.5	9.0
Cu	9.2			1.5	9.2			1.2	12.1	3.2	2.3			1.8	5.7	8.6	54.9
Pb	11.7			1.5	18.0			1.1	25.9	3.6	4.9			2.0	5.2	12.8	86.6
Zn	137.4			10.2	106.9			8.7	108.2	23.7	27.9			14.9	64.8	109.7	612.5
TOC	12932			6156	10372			2436	16677	4451	5250			3665	7788	5111	74839
Sed. N	608.6			159.1	463.4			220.5	1473.1	437.1	-133.1			-12.5	85.3	619.7	3921.2
Sed. P	38.0			30.8	95.8			10.3	100.4	28.7	46.4			32.4	81.8	52.8	517.3
TN	2270.5			352.2	840.0			299.6	2825.1	609.5	245.2			50.7	365.8	928.0	8786.5

Table 5-7. Percent Removal for All Storm Events.

	In (g)	Out (g)	In-Out	%
NH4	479.83	15.11	464.72	96.85
FTKN	8345.64	3215.15	5130.48	61.48
TKN	13421.86	7136.31	6285.56	46.83
NO3N	7002.26	1650.20	5352.06	76.43
PO4	227.00	217.27	9.73	4.29
FTP	213.83	401.24	-187.40	-87.64
TP	1589.49	918.58	670.91	42.21
TSS	965550.38	263514.67	702035.71	72.71
Cd	13.53	8.96	4.57	33.75
Cu	95.56	54.87	40.69	42.58
Pb	149.67	86.55	63.12	42.17
Zn	1210.97	612.48	598.49	49.42
TOC	152303.45	74838.70	77464.74	50.86
Sed. N	5076.23	3921.15	1155.07	22.75
Sed. P	1375.66	517.34	858.31	62.39
TN	20424.12	8786.50	11637.62	56.98

Note: A negative removal rate indicates that during the detention time, some of the incoming sediment bound pollutant is being dissolved and leaving the facility as a suspended pollutant.

Measuring the removal rates using EMC concentrations in this study yielded the results shown in Table 5-8. These removal rates seem to be lower than the removal rates computed from the loading comparison. These EMC loads were calculated by dividing the total load amount for all storms by the total flow for all storms for both the inflow and the outflow.

Table 5-8. EMC Results for All Storms.

	In(ug/L)	Out (ug/L)	% Removal
NH4	0.02805	0.00110	96.06%
FTKN	0.48782	0.23494	51.84%
TKN	0.78454	0.52147	33.53%
NO3N	0.40930	0.12059	70.54%
PO4	0.01327	0.01588	-19.65%
FTP	0.01250	0.02932	-134.58%
TP	0.09291	0.06712	27.75%
TSS	56.43871	19.25592	65.88%
Cd	0.00079	0.00066	17.18%
Cu	0.00559	0.00401	28.22%
Pb	0.00875	0.00632	27.71%
Zn	0.07078	0.04476	36.77%
TOC	8.90250	5.46872	38.57%
Sed. N	0.29672	0.28653	3.43%
Sed. P	0.08041	0.03780	52.99%
TN	1.19384	0.64206	46.22%

5.3 Comparison of Removal Rates

5.3.1 Grizzard Study

The results obtained in this study are comparable to results reported in Chapter 2 in a study by Grizzard et. al. (1986). Table 5-9 shows a side by side comparison of the field results obtained in this study with parameters studied for extended dry detention basins by Grizzard. This comparison is based on removal rates calculated by observing total load reduction in the observed pollutants between inflow and outflow loads.

Table 5-9. Comparison of Study Results with Grizzard (1986).

Constituent	Grizzard (1986)	VT Study (1997)
TSS	50-70%	72.7%
TP	10-20%	42.2%
Nitrogen	10-20%	57.0%
Lead	75-90%	42.2%
Zinc	30-60%	49.4%

The Virginia Tech removal rates meet or exceed the range of results from the Grizzard study for all constituents except for lead. This is probably due to the fact that since leaded gasolines have been taken off of the market, the lead level in the environment has been significantly reduced. Consequently, a removal rate of 49% is lower than results measured in the past, but is significant with respect to the amount of lead that is left in the environment.

5.3.2 Zarriello and Sherwood Study

In 1993, a study was completed by Zarriello and Sherwood evaluating the EMC removal rates of pollutants based on detention time. This study, as described in Chapter 2, began with a conventional dry detention basin and then retrofitted the outlet structure to increase detention times. With the exception of the removal rate for dissolved phosphorous, the removal rates for this study compare similarly to the rates determined by Zarriello and Sherwood (1993) for a basin with an 11 hour drawdown time. Table 5-10 shows the comparison of the EMC removal rates for both studies.

Table 5-10. EMC Removal Rate Comparison (Percentages).

Constituent	Zarriello & Sherwood, 1993	Virginia Tech Study, 1997
TSS	83.8 %	65.7 %
TOC	47.4 %	38.2 %
NH4	21.5 %	96 %
NO3N	35.2 %	70.4 %
TP	32 %	27.3 %
FTP	11.1 %	-136 %
Pb	37.6 %	27.3 %
Zn	66.1%	36.4%

5.3.3 FHWA Study

As described in Chapter 2, the Federal Highway Administration (FHWA) released the publication *Evaluation and Management of Highway Runoff Water Quality* in 1996. This publication contained extensive data from many sources on many BMP measures including extended dry detention basins. The extended dry detention basins were studied with drawdown times ranging from ½ day to 2 days and the results are reported as a range of data over these time spans. Table 5-11 shows a comparison of how the Virginia Tech study compared for overall removal rates to the results obtained by the FHWA.

Table 5-11. Loading Percent Removal Comparison

Constituent	FHWA Results, 1996	Virginia Tech Study, 1997
Sediments	68-90 %	72.7 %
TP	42-50 %	42.2 %
TN	42-90 %	57 %
Heavy Metals	42-90 %	33.8 - 49.42 %

5.4 Comparison of Loading Prediction Methods

5.4.1 Tasker and Driver Nationwide Equations

Using the NURP database, Tasker and Driver developed regression equations for unmonitored watersheds. Some data gathering is required for analysis; however, it is all physical and climatological. No sampling is necessary to make initial predictions of pollutant washoff. As outlined in Chapter 2, there are two sets of regression curves to predict loading of ten different constituents. The first is more refined and includes more terms. The second set trades some accuracy for simplicity. Load predictions were calculated using the regression methods as outlined in the FHWA 1996 report. For single

storm events, as observed in the original data, the prediction rates were highly erratic. To compare the regression predictions to the observed data, an average storm event was defined using the average rainfall observed for the study period. In addition, Tasker and Driver divide the regression curves into three regions based on mean annual rainfall. Division Region II are those areas with 20-40 inches of annual rainfall and Region III are areas with greater than 40 inches. The study area mean annual rainfall is reported as 40.9 inches of rainfall based on 31 years of climatological data. Since this is so close to the cutoff between regions, both Region II and III regression curves were used for comparison purposes. The method uses the following generalized formula for calculating loads:

$$L_p = [\beta_0 \times X_1^{\beta_1} \times X_2^{\beta_2} \dots \times X_n^{\beta_n} \times BCF] \times 0.4536 \quad 5-1$$

where X_n is the physical, land use or climatic characteristic, β_n are the regression coefficients as shown in Table 5-12, and BCF is the Bias Correction Factor, also shown in Table 5-12. Different combinations of X characteristics are needed to calculate loads based on region and response variable. The simplified rating curves also follow the same general formula shown in equation 5-1, only fewer X characteristics are required. The regression coefficients for this method are shown in Table 5-13

The following comparisons of predicted vs. observed loads were made as shown in Table 5-14 for the average storm, using the more complex rating curves, and Table 5-15 for the simplified rating curves.

Table 5-12. Summary of Regression Coefficients – Complex Method- adapted from Tasker and Driver (1990)

Response Variable and Region	β_0	Xn													BCF
		Hr (inches)	A (sq. mi.)	I+1 (%)	LUI+1 (%)	LUC+1 (%)	LUR+1 (%)	LUN+2 (%)	PD (people per sq. mi.)	tr (minutes)	INT (inches)	Hmar (inches)	MNL (lbs per sq. mi)	Tj (deg. F)	
COD I	7111	0.671	0.617	---	0.415	0.267	---	-0.156	---	---	---	-0.683	---	---	1.304
COD II	36.6	0.878	0.696	---	0.072	0.261	---	-0.056	---	---	---	0.866	---	---	1.389
COD III	479	0.857	0.634	---	0.321	0.217	---	-0.111	---	---	---	---	---	---	1.865
SS I	1518	1.211	0.735	---	---	---	---	---	---	-0.463	---	---	---	---	2.112
SS II	2032	1.233	0.439	0.274	---	---	---	---	0.041	---	---	---	---	-0.590	1.841
SS III	1990	1.017	0.984	---	0.226	0.228	---	-0.286	---	---	---	---	---	---	2.477
DS I	54.8	0.585	1.356	1.383	---	---	---	---	---	---	---	-0.718	---	---	1.239
DS II	2308	1.076	1.285	1.348	---	---	---	---	---	---	---	---	---	-1.395	1.208
TN I	1132	0.798	0.960	---	0.462	0.260	---	-0.194	---	---	---	-0.951	---	---	1.139
TN II	3.173	0.935	0.939	0.672	---	---	---	---	---	---	---	---	0.196	---	1.372
TN III	0.361	0.776	0.474	0.611	---	---	---	---	---	---	---	---	0.863	---	1.709
TKN I	18.9	0.670	0.831	---	0.378	0.258	---	-0.219	---	---	---	---	1.350	---	1.206
TKN II	2.89	0.906	0.768	0.545	---	---	---	---	---	---	---	---	0.225	---	1.512
TKN III	199572	0.875	0.393	---	---	---	---	0.082	---	---	---	-2.643	---	---	1.736
TP I	262	0.828	0.645	---	0.583	0.181	---	-0.235	---	---	---	-1.376	---	---	1.548
TP II	0.153	0.986	0.649	0.479	---	---	---	---	---	---	1.543	---	---	---	1.486
TP III	53.2	1.019	0.846	---	---	0.189	0.103	-0.160	---	---	---	---	---	-0.754	2.059
DP I	588	0.808	0.726	---	0.642	0.096	---	-0.238	---	---	---	-1.899	---	---	1.407
DP II	0.025	0.914	0.699	0.649	---	---	---	---	---	---	1.024	---	---	---	1.591
DP III	0.369	0.955	0.471	---	---	---	---	0.364	---	---	---	---	---	---	2.027
CD I	0.039	0.845	0.753	---	0.138	0.248	---	-0.374	---	---	---	---	---	---	1.244
CD II	0.005	1.168	1.265	---	---	---	---	---	---	---	---	---	---	0.965	1.212
CU I	0.141	0.807	0.590	---	0.424	0.274	---	-0.061	---	---	0.928	---	---	---	1.502
CU II	0.013	0.504	0.585	0.816	---	---	---	---	---	---	---	---	---	---	1.534
CU III	4.508	0.896	0.609	---	0.648	0.253	---	-0.328	---	---	-2.071	---	---	---	2.149
PB I	478	0.764	0.918	---	-0.161	0.276	---	-0.282	---	---	---	-1.829	---	---	1.588
PB II	0.076	0.833	0.381	---	---	0.243	0.087	-0.181	---	---	---	0.574	---	---	1.587
PB III	0.081	0.852	0.857	0.999	---	---	---	---	---	---	---	---	---	---	2.314
ZN I	224	0.745	0.792	---	---	0.172	-0.195	-0.142	---	---	---	-1.355	---	---	1.444
ZN II	0.002	0.796	0.667	1.009	---	---	---	---	---	---	---	---	---	1.148	1.754
ZN III	4.355	0.830	0.555	---	0.402	0.287	-0.191	---	---	---	---	---	---	-0.500	1.942

**Table 5-13. Regression Coefficients–Simplified Method–
adapted from Tasker & Driver (1990)**

Response Variable and Region	X _n				
	β ₀ (inches)	Hr	A (sq. mi.)	I+1 (%)	BCF
COD I	407	0.626	0.71	0.379	1.518
COD II	151	0.823	0.726	0.564	1.451
COD III	102	0.851	0.601	0.528	1.978
SS I	1778	0.867	0.728	0.157	2.367
SS II	812	1.236	0.436	0.202	1.938
SS III	97.7	1.002	1.009	0.837	2.818
DS I	20.7	0.637	1.311	1.18	1.249
DS II	3.26	1.251	1.218	1.964	1.434
TN I	20.2	0.825	1.07	0.479	1.258
TN II	4.04	0.936	0.937	0.692	1.373
TN III	1.66	0.703	0.465	0.521	1.845
TKN I	13.9	0.722	0.781	0.328	1.722
TKN II	3.89	0.944	0.765	0.556	1.524
TKN III	3.56	0.808	0.415	0.199	1.841
TP I	1.725	0.884	0.826	0.467	2.13
TP II	0.697	1.008	0.628	0.469	1.79
TP III	1.618	0.954	0.789	0.289	2.247
DP I	0.54	0.976	0.795	0.573	2.464
DP II	0.06	0.991	0.718	0.701	1.757
DP III	2.176	1.003	0.28	-0.448	2.254
CD I	0.00001	0.886	0.821	2.033	1.425
CD II	0.021	1.367	1.062	0.328	1.469
CU I	0.072	0.746	0.797	0.514	1.675
CU II	0.013	0.504	0.585	0.816	1.548
CU III	0.026	0.715	0.609	0.642	2.819
PB I	0.162	0.839	0.808	0.744	1.791
PB II	0.15	0.791	0.426	0.522	1.665
PB III	0.08	0.852	0.857	0.999	2.826
ZN I	0.32	0.811	0.798	0.627	1.639
ZN II	0.046	0.88	0.808	1.108	1.813
ZN III	0.024	0.793	0.628	1.104	2.533

Table 5-14. Performance of Regression Equation Load Prediction Using the Complex Regression Curves by Tasker and Driver.

	Constituent	Predicted Load Grams	Observed Load Grams	Error	Over-Predict (Pred./Obs.)
Region III	SS	250388.2543	60346.90	-314.91%	4.15
	TKN	3085.479768	838.87	-267.82%	3.68
	TP	877.7808258	99.34	-783.58%	8.84
	DP	121.8271026	13.36	-811.56%	9.12
	CU	208.2600272	5.97	-3386.92%	34.87
	PB	569.5039887	9.35	-5987.93%	60.88
	ZN	739.2918127	75.69	-876.79%	9.77
Region II	TP	708.21279	99.34	-612.89%	7.13
	DP	130.3486349	13.36	-875.33%	9.75
	CD	0.805225869	0.85	4.79%	0.95
	CU	80.22973829	5.97	-1243.30%	13.43
	PB	501.0699369	9.35	-5256.38%	53.56
	ZN	640.177437	75.69	-745.84%	8.46

%error = [(observed load-predicted load)/observed load]*100

Table 5-15. Performance of Regression Equation Load Prediction Using the Simplified Regression Curves by Tasker and Driver.

	Constituent	Predicted Load (Grams)	Observed Load (Grams)	Error	Over-Predict (Pred./Obs.)
Region III	SS	226233.22	60346.90	-274.89%	3.75
	TN	4525.17	1276.51	-254.50%	3.54
	TKN	2607.90	838.87	-210.88%	3.11
	TP	565.89	99.34	-469.63%	5.70
	DP	157.88	13.36	-1081.34%	11.81
	CU	113.13	5.97	-1794.20%	18.94
	PB	686.93	9.35	-7243.17%	73.43
	ZN	657.89	75.69	-769.25%	8.69
Region II	SS	478127.61	60346.90	-692.30%	7.92
	TN	3157.27	1276.51	-147.34%	2.47
	TKN	3289.60	838.87	-292.15%	3.92
	TP	724.77	99.34	-629.56%	7.30
	DP	127.52	13.36	-854.18%	9.54
	CD	1.85	0.85	-118.38%	2.18
	CU	80.96	5.97	-1255.56%	13.56
	PB	404.91	9.35	-4228.41%	43.28
	ZN	666.52	75.69	-780.64%	8.81

%error = [(observed load-predicted load)/observed load]*100

As can be seen by Tables 5-14 and 5-15, the percent errors between the predicted and observed values are significant. However, though the curves over-predict loading values, with the exception of lead and copper the values are all within one order of magnitude, which may be an acceptable margin of error for any initial analysis. Lead values are grossly over-predicted due to the fact that lead has been removed from all gasoline products and therefore greatly reduced in quantity in the environment (since the NURP study was completed). This tends to amplify error differences between computed and observed lead loads.

5.4.2 Schueler Prediction Method

Another simple method for predicting loads on urban watersheds is the Schueler method, which can also be used for a single storm event comparison or for an average event analysis. As described in Chapter 2, the method uses a flow-weighted mean concentration factor from the NURP data for each analyzed pollutant. The calculations for the Schueler method were performed based on the following generalized equation:

$$L_p = \frac{[Hr \cdot Pj \cdot Rv] \cdot [C] \cdot [A]}{98.6} \quad 5-2$$

where Hr = total rainfall (mm), Pj = percent of rainfall that contributes to runoff (equal to 1 for individual storm events), Rv = runoff coefficient estimated as $0.05+0.009 \cdot$ (impervious percentage), C = a flow-weighted pollutant mean concentration in mg/L as shown in Table 5-16, A = watershed area (ha), and 98.6= unit conversion factor. The same average rainfall used previously in the Tasker and Driver analysis was employed,

and an average percent runoff of 83.4% was calculated for the watershed, based on observed data.

Table 5-16. C-Coefficients for the Schueler Method (1987).

Pollutant	National Urban Highway Runoff	New Suburban NURP Sites (Wash. D.C.)	Older Urban Areas (Baltimore)	Central Business District (Wash. D.C.)	National NURP Study Average	Hardwood Forest (Northern Virginia)
Phosphorus						
Total	----	0.26	1.08	----	0.46	0.15
Ortho	----	0.12	0.26	1.01	----	0.02
Soluble	0.59	0.16	----	----	0.16	0.04
Organic	----	0.1	0.82	----	0.13	0.11
Nitrogen						
Total	----	2	13.6	2.17	3.31	0.78
Nitrate	----	0.48	8.9	0.84	0.96	0.17
Ammonia	----	0.26	1.1	----	----	0.07
Organic	----	1.25	----	----	----	0.54
TKN	2.72	1.51	7.2	1.49	2.35	0.61
COD	124	35.6	163	----	90.8	>40
BOD (5-day)	----	5.1	----	36	11.9	----
Metals						
Zinc	0.38	0.037	0.397	0.25	0.176	----
Lead	0.55	0.018	0.389	0.37	0.18	----
Copper	----	----	0.105	----	0.047	----

As can be seen in Table 5-16, there are several sets of C values based on different types of watersheds, but for this analysis the national average from the NURP study were used. Table 5-17 shows the comparison of the Virginia Tech study and the Schueler method for the average storm during the study period. As can be seen from Table 5-17, the same over-prediction results are observed in this method as when using the regression curve analysis. All loads, except for lead and copper are over-predicted, but within an order of magnitude.

Table 5-17. Comparison of Virginia Tech Field Results and the Schueler Method of Predicting Pollutant Loads.

	Predicted Load (Grams)	Observed Load (Grams)	Error	Over Predict (Pred./Obs.)
TP	621.4	99.3	-525.5%	6.3
TN	4,471.5	1,276.5	-250.3%	3.5
Nitrate	1,296.9	437.6	-196.3%	3.0
TKN	3,174.6	838.9	-278.4%	3.8
Zinc	237.8	75.7	-214.1%	3.1
Lead	243.2	9.4	-2499.4%	26.0
Copper	63.5	6.0	-963.1%	10.6

%error = [(observed load-predicted load)/observed load]*100

5.5 Discussion of Water Quality Sampling Results

The results obtained by the research team over an extended sampling period indicate that pollutant removal rates are considered good for the Virginia Tech extended dry detention basin, based on comparison with national studies. It was found that a storm- by-storm analysis yields very sporadic removal results due to variable pollutant inflow, outflow and re-suspension. An aggregated analysis of all storms in the study period provided a more accurate assessment of the pond performance for specific pollutants. This method is always preferred to the individual storm assessment approach.

Prediction rates using regression curves and other data to estimate pollutant loadings appear to be accurate to within one order of magnitude using an average storm for all measured pollutants, except for copper and lead. Copper and lead were both highly over-predicted, indicating that the background levels of these constituents in the

environment have decreased significantly since the completion of the NURP study in 1983. Further investigations should be performed to re-analyze these background levels for modeling purposes.

Chapter 6

Structure of the Rainfall-Runoff-Quality Model

After collecting and analyzing the observed data, the research team used this database of information to calibrate and compare results with a computer model. The Penn State Runoff Model (PSRM-QUAL) was selected because of its capability to model both runoff quality and quantity. This chapter outlines the background of the model and its runoff quantity and quality calculation routines.

6.1 Runoff Quantity Sub-model

One advantage of PRSM-QUAL is that it can be run in quantity mode only, so that the user can predict runoff without having to input any runoff quality parameters. Watershed parameters can be fixed or selected by first modeling quantity only and then water quality issues can be address separately. This makes the calibration process fairly simple. The PSRM model uses the kinematic wave equations to predict overland flow runoff. In addition, instead of using a uniform flow depth and velocity for the whole subarea at a given time step, the model computes an increasing depth and runoff rate as the water moves downstream towards the collection point.

As input to its runoff hydrograph routine, PSRM-QUAL needs information on the storm hyetograph. There are several different storm rainfall options in the model, including: user input, rainfall weighting based on the inverse distance of the watershed from two or more rainfall gages, and synthetic design storms. For this study, as mentioned in a previous chapter, one rain gage was used to collect the data in five-minute increments, and this was then used in the model as a user supplied hyetograph for each storm event.

The user input into the model then includes information on the type and amount of losses incurred in the watershed system. The infiltration loss in the PSRM model is calculated using a combination of the Soil Conservation Service (SCS) and Horton models (PSRM-QUAL User's Manual, 1996). The equations of these two methods are as follows:

$$Q = \frac{(P - IA)^2}{(P - IA) + S_c} \quad 6-1$$

where Q = runoff depth in inches, P is the cumulative precipitation throughout the storm event in inches, IA is the initial abstraction which in inches is recommended to be equal to 0.2S_c by SCS, and S_c is the soil storage capacity. The program computes the initial infiltration rate using the Horton equation as a basis and f_c values compiled by Rawls (1983), yielding the following equation (PSRM-QUAL User's Manual, 1996):

$$f_o = 0.037 + 1.84f_c - 0.0075f_c^2 \quad 6-2$$

with f₀ equal to the initial infiltration rate (in/hr) and f_c is the saturated conductivity values calculated by Rawls (in/hr), with reference values in the User's Manual.

Depression losses are supplied by the model user as a separate model parameter. This loss can be assumed constant or variable and is separated into pervious and impervious values. This allows for more variability in the calibration process. Additional losses are combined in the initial abstraction loss identified by the user.

According to the PSRM-QUAL User's Manual, the overland runoff is a process in which rainfall on the land surface accumulates until the water layer is thick enough to create runoff. Overland flow is then routed by the kinematic wave method, using characteristics. The process is described by partial differential equations for the conservation of mass and

momentum, where the momentum equation is represented by a general uniform flow equation as follows:

$$\frac{\partial y}{\partial t} + \alpha N y^{N-1} \frac{\partial y}{\partial x} = i \quad 6-3$$

and:
$$v = \alpha y^{N-1} \quad 6-4$$

where y = depth of flow (ft); x = distance downstream (ft); α = constant; N = exponent defining the flow regime (5/3 for turbulent flow); t = time (seconds); I = lateral inflow or rain excess rate (cfs per foot of length); v = velocity of flow (ft/second).

The model solves the kinematic wave equations using overland strips of specified width, where the outflow from one strip will become the inflow into the next. The geometric-hydraulic input variables in the program include watershed area, average length, width, and slope. The width is estimated as the area divided by the average length. A sinuosity factor is included to vary the length of the flow path; however, this was not used on the modeled surface by the design team since the majority of the watershed was rigid pavement.

For pipe flow there are several basic parameters needed for flow calculations including pipe capacity, travel time and the pipe connectivity. Pipe flow and channel flow routing is done within the model using the Muskingum routing procedure. The first modeling attempt by the project team was a six-subarea approach. Though the quantity values for the model turned out very well, the quality values did not, due to unexplained pollutant losses in the pipes. To avoid this problem, the watershed was modeled as a single subarea with no storm sewer. In addition, the flow was not routed through a basin. The only

PSRM-QUAL analysis of runoff quantity and quality was for the watershed surface, excluding any storm sewer.

6.2 Runoff Quality Sub-model

PSRM-QUAL has the capability of modeling several different water quality contaminants. These include TSS, TKN, NO₂+NO₃, TP, SP, COD, BOD, and the heavy metals Cu, Zn, and Pb. In addition, the user can track two conservative trace organics. The User's Manual states that all modeled pollutants are directly associated to the total suspended solid load. This means that only solid particles are tracked in the model. To calculate the loading of the remaining pollutants, the model multiplies by a ratio of the modeled pollutant to the TSS load to generate an EMC value for the pollutant as a fraction of the TSS load. These ratio values have been determined by an analysis of the NURP database and other sources for different land uses. These ratios are recorded in a file used by the program (POLC.DAT), and user input based on site calibration is recommended. The numbers in this file are as shown in Table 6-1.

Since all of the data for each chemical parameter is based on the total suspended solid load, it is important to be able to accurately represent the solids washoff occurring on the watershed. If this parameter cannot be accurately modeled, the basis of the model falls apart. It should be obvious that the amount of particle washoff is dependent on many

Table 6-1. The POLC.DAT file from the PSRM-QUAL Model (1995).

Pollutant Concentration Factors in g/100g of TSS									
	Cu	Zn	Pb	TKN	NO2+3	TP	SP	COD	BOD
Residential	0.0327	0.134	0.143	1.88	0.729	0.379	0.142	72.3	9.9
Mixed	0.0403	0.230	0.170	1.93	0.833	0.393	0.084	97.0	11.6
Commercial	0.0420	0.328	0.151	1.71	0.829	0.291	0.116	82.6	13.5
Open/NonUrban	0.01	0.279	0.043	1.38	0.776	0.173	0.037	57.1	7.9

Pollutant Loading Factors		
	Curb-meters/hectare	Build-up exponent
Residential	385	0.2
Mixed	385	0.2
Commercial	385	0.2
Open/NonUrban	385	0.2

different factors including rainfall intensity, particle size and the initial particle density within the watershed. The model uses another data file (PSDIST.DAT) to distribute the initial sediment load into thirteen different particle size ranges. This data file is shown in Table 6-2. The numbers found in this file are considered to be general guidelines, and the model developers suggest that sediment samples be taken and analyzed from the watershed being modeled to make the file more representative of the actual particle distribution in the region. In addition to the distribution of the initial input by the user, a pollutant build-up function is built into the model for evaluating pollutant loads from up to eight consecutive storms. The design team did not use this feature since only individually sampled storms were modeled as a basis for comparison. Therefore, input such as street sweeping intervals, time between rainfall events, and wind erosion was not needed for this modeling effort.

The equation used to estimate sediment dislodgment was developed by Sartor and Boyd and the washoff is determined by the particle drag theory (PSRM-QUAL User's Manual, 1996). The equation is as follows:

$$N_c = N_0(1 - e^{-kt}) \quad 6-5$$

where N_c is equal to the amount of dislodged particles of a given size during the time interval (mass/area), t (min), with runoff intensity, I (in/hr), N_0 is the initial sediment load of a given size available for washoff (mass/area) and k is the Sartor and Boyd dislodging coefficient which is supplied by the model user, a typical value being in the range of 2-10.

Table 6-2. The PSDIST.DAT file from the PSRM-QUAL Model (1995).

PSDIST.DAT: Particle Size Distributions for PSRM-QUAL

Grainsize ID Numbers for 13 groups of sediments

0	1	2	3	4	5	6	7	8	9	10	11	12	13
---	---	---	---	---	---	---	---	---	---	----	----	----	----

Grainsize (microns)

4800	2000	840	250	105	74	65	55	45	35	25	15	5	0.8
------	------	-----	-----	-----	----	----	----	----	----	----	----	---	-----

Distribution for six size groups in surface runoff modeling

21	5	16	20	13	25
----	---	----	----	----	----

UltraFines Distribution in BMP (74 microns and smaller)

41	23	15	9	6	3	2	1
----	----	----	---	---	---	---	---

Suspended Solids Distribution in BMP

0	0	0	0	0	0.5	0.8	1.2	1.5	2	9	25	60
---	---	---	---	---	-----	-----	-----	-----	---	---	----	----

Bottom Sediments Distribution in BMP

5	12	23	11	9	8	7	6	6	5	4	3	1
---	----	----	----	---	---	---	---	---	---	---	---	---

In this study of the commuter parking lot, 83% of the area was impervious. This meant that most of the model calibration was done on the parameters that affected the impervious response, though there are many parameters that affect the response of the pervious areas. The pervious area dislodging amount is determined in the model by the Universal Soil Loss Equation. The input required by the user to solve the USLE includes the following parameters:

K: Subarea soil erodibility factor

LS: Subarea length times the subarea slope

C: Subarea soil cropping management factor.

P: Subarea erosion control practice factor.

Guidelines for all of these values based on soil type, etc. are given in the PSRM-QUAL User's Manual.

Washoff is the most important process in determining the amount of total suspended solids at the watershed outlet. According to the PSRM-QUAL User's Manual, the washoff calculations are done in parallel with the kinematic wave computation and on the same substrip basis. Once a particle is dislodged, the shear forces generated by the runoff cause its movement. This is shown in Figure 6-1 taken from the PSRM-QUAL User's Manual. The most important equation used in the model for washoff is the determination of the critical velocity. This is the point at which the drag force and the resistance forces are equal. For any velocity value above this number there will be

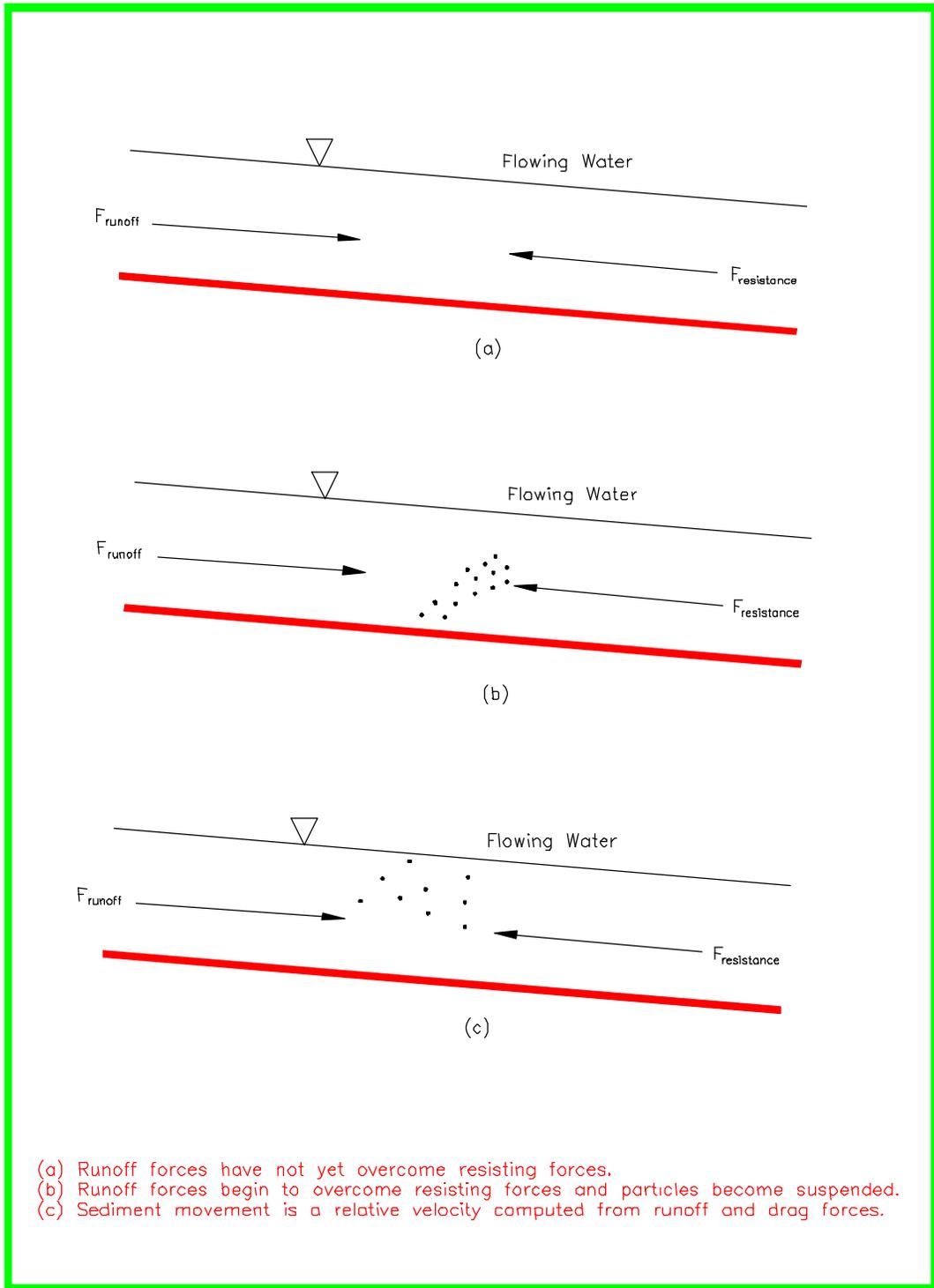


Figure 6-1. Sediment Movement by Runoff (PSRM-QUAL Manual, 1995)

impending sediment entrainment and movement, while for any velocity below this value, the sediment will not be moved by the flow.

Critical velocity is computed for each size range using the following equation from the User's Manual:

$$v_{cr} = \left[\frac{4}{3} \left(\frac{C_s}{C_d} \right) gr(SG - 1) \right]^{1/2} \quad 6-6$$

where V_{cr} is the critical velocity, C_d is the coefficient of drag, C_s is the static coefficient of friction, SG is the sediment specific gravity, r is the average sediment radius and g is the gravitational acceleration constant.

To calculate the amount of sediment movement, the user must input the following parameters into the model:

CD: Drag coefficient

DCF: Dynamic coefficient of drag

SCF: Static coefficient of drag

As can be seen from the above discussions, there are many different parameters that need to be defined by the user. This can make calibration a very difficult process. A sample input file is shown in Table 6-3 to show the file layout and the parameters that need to be defined by the user. Some of the input will vary depending on the exact modeling being performed, but the file shows a typical modeling session. A sample output file is shown in Table 6-4. The next chapter describes the calibration process and the results that the model produced.

Table 6-3. Sample Input File

```

PSRM-QUAL v95.0 INPUT FILE ===== Created: 09-28-1996 at 18:30:02
  QualFile      NHL      Filename
    1          1      230q.INP
quality
WATERSHED ELEMENTS
  NSA      NST      STOPT      NPRT      NOBS      NPFP      NBMP      NORG
    1        1        0          1         0         0         0         0
Subareas with a Hydrograph Printout
  1
TIME PARAMETERS
  KWTI      HYDTI      RFTI      IETI      MaxHNPT      TotNPT
    1         5         5         0        100         100
Storm      HYDNPT      IENPT
  1        100         0
RAINFALL PARAMETERS
Raingage Elements
  NRG      NNRG      NWG      EXW
    1        0         1         1
Recording Raingage Data
  Event      Gage      RFNPT      RGST      XRG      YRG      RGNAME
    1         1         35         0         0         0      pondgage
          0.08      0.20      0.27      0.39      0.27      0.11
          0.05      0.09      0.06      0.05      0.05      0.04
          0.01      0.01      0.01      0.02      0.01      0.01
          0.01      0.00      0.01      0.00      0.00      0.00
          0.00      0.00      0.00      0.00      0.00      0.01
          0.00      0.01      0.01      0.01      0.01
SUBAREA PARAMETERS: ID# = 000 is standard parameter row
Geometry
  ID#      XCG      YCG      AREA      LENG      SLOPE      FRIMP
    1         0         0         21        460      0.040      0.83

```

Table 6-3 Sample Input File (Continued)

Overland Flow Routing							
ID#	MN1	MN2	SF				
000	0.011	0.150	1.00				
1	-1.000	-1.000	-1.00				
Rainfall Losses							
ID#	CN1	CN2	IAF	DS1	DS2	KS	IFSW
000	99	74	0.01	0.00	0.00	0.02	0.50
1	-1	-1	-1.00	-1.00	-1.00	-1.00	-1.00
Landuse & Impervious Sediment Loading							
ID#	LU	MSL	ISL	SWST	SWTI	SWFR	
000	3	150.0	112.0	0.00	0.00	0.00	
1	-1	-1.0	-1.0	-1.00	-1.00	-1.00	
Pervious Sediment Loading; Sediment Dislodging & Wash-Off							
ID#	UK	UC	UP	SBK	CD	DFC	SFC
000	0.20	0.00	0.30	2.00	0.80	0.40	0.80
1	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
DRAINAGE ELEMENT PARAMETERS: ID# = 000 is standard parameter row							
ID#	CAP	PT	MX	CTS	CDE1	CDE2	CDE3
000			0.50	1.50			
1	0.0	0.0	-1.00	-1.00	0	0	0
-- End of File --							

Table 6-4 Sample Output File (Continued)

95	1.740	0.103	2.9	1.0	1.9
100	1.740	0.103	1.9	1.0	0.9
105	1.750	0.104	2.0	1.0	1.0
110	1.750	0.104	1.4	1.0	0.4
115	1.750	0.104	1.0	1.0	0.0
120	1.750	0.104	0.7	0.7	0.0
125	1.750	0.104	0.5	0.5	0.0
130	1.750	0.104	0.4	0.4	0.0
135	1.750	0.104	0.3	0.3	0.0
140	1.750	0.105	0.3	0.3	0.0
145	1.750	0.105	0.2	0.2	0.0
150	1.760	0.105	0.6	0.6	0.0
155	1.760	0.105	0.6	0.6	0.0
160	1.770	0.105	1.1	1.0	0.1
165	1.780	0.106	1.7	1.0	0.7
170	1.790	0.106	2.1	1.0	1.1
175	1.800	0.106	2.2	1.0	1.2
180	1.800	0.107	1.4	1.0	0.4
185	1.800	0.107	0.9	0.9	0.0
190	1.800	0.107	0.6	0.6	0.0
195	1.800	0.107	0.4	0.4	0.0
200	1.800	0.107	0.3	0.3	0.0
205	1.800	0.107	0.2	0.2	0.0
210	1.800	0.107	0.2	0.2	0.0
215	1.800	0.108	0.2	0.2	0.0
220	1.800	0.108	0.1	0.1	0.0
225	1.800	0.108	0.1	0.1	0.0
230	1.800	0.108	0.1	0.1	0.0
235	1.800	0.108	0.1	0.1	0.0
240	1.800	0.108	0.1	0.1	0.0
245	1.800	0.108	0.1	0.1	0.0
250	1.800	0.109	0.1	0.1	0.0
255	1.800	0.109	0.0	0.0	0.0
260	1.800	0.109	0.0	0.0	0.0
265	1.800	0.109	0.0	0.0	0.0
270	1.800	0.109	0.0	0.0	0.0

Table 6-4 Sample Output File (Continued)

POLLUTANT OUTPUT For SUBAREA 1												
Time	TSS	Cu	Zn	Pb	Org1	Org2	TKN	NO2+3	TP	SP	COD	BOD
min	ppm	ppb	ppb	ppb	ppt	ppt	ppb	ppb	ppb	ppb	ppm	ppm
5	813	104	1105	130	-	-	12356	8738	1040	1471	671	110
10	296	38	403	47	-	-	4500	3183	379	536	245	40
15	151	19	206	24	-	-	2300	1627	194	274	125	20
20	76	10	103	12	-	-	1149	813	97	137	62	10
25	35	4	47	6	-	-	528	374	44	63	29	5
30	19	2	25	3	-	-	283	200	24	34	15	3
35	11	1	16	2	-	-	174	123	15	21	9	2
40	16	2	22	3	-	-	249	176	21	30	14	2
45	12	2	16	2	-	-	182	128	15	22	10	2
50	11	1	15	2	-	-	166	118	14	20	9	1
55	11	1	14	2	-	-	162	114	14	19	9	1
60	9	1	12	1	-	-	132	93	11	16	7	1
65	3	0	4	0	-	-	44	31	4	5	2	0
70	4	1	5	1	-	-	60	42	5	7	3	1
75	5	1	7	1	-	-	73	52	6	9	4	1
80	9	1	12	1	-	-	133	94	11	16	7	1
85	4	1	6	1	-	-	66	47	6	8	4	1
90	5	1	7	1	-	-	75	53	6	9	4	1
95	5	1	7	1	-	-	83	59	7	10	5	1
100	0	0	0	0	-	-	0	0	0	0	0	0
105	6	1	8	1	-	-	90	63	8	11	5	1
110	0	0	0	0	-	-	5	3	0	1	0	0
115	0	0	0	0	-	-	0	0	0	0	0	0
120	0	0	0	0	-	-	0	0	0	0	0	0
125	0	0	0	0	-	-	0	0	0	0	0	0
130	0	0	0	0	-	-	0	0	0	0	0	0
135	0	0	0	0	-	-	0	0	0	0	0	0
140	0	0	0	0	-	-	0	0	0	0	0	0
145	0	0	0	0	-	-	0	0	0	0	0	0
150	6	1	9	1	-	-	96	68	8	11	5	1
155	4	0	5	1	-	-	55	39	5	7	3	0

Table 6-4 Sample Output File (Continued)

160	11	1	15	2	-	-	166	117	14	20	9	1
165	11	1	15	2	-	-	166	117	14	20	9	1
170	8	1	11	1	-	-	124	87	10	15	7	1
175	7	1	9	1	-	-	106	75	9	13	6	1
180	0	0	0	0	-	-	0	0	0	0	0	0
185	0	0	0	0	-	-	0	0	0	0	0	0
190	0	0	0	0	-	-	0	0	0	0	0	0
195	0	0	0	0	-	-	0	0	0	0	0	0
200	0	0	0	0	-	-	0	0	0	0	0	0
205	0	0	0	0	-	-	0	0	0	0	0	0
210	0	0	0	0	-	-	0	0	0	0	0	0
215	0	0	0	0	-	-	0	0	0	0	0	0
220	0	0	0	0	-	-	0	0	0	0	0	0
225	0	0	0	0	-	-	0	0	0	0	0	0
230	0	0	0	0	-	-	0	0	0	0	0	0
235	0	0	0	0	-	-	0	0	0	0	0	0
240	0	0	0	0	-	-	0	0	0	0	0	0
245	0	0	0	0	-	-	0	0	0	0	0	0
250	0	0	0	0	-	-	0	0	0	0	0	0
255	0	0	0	0	-	-	0	0	0	0	0	0
260	0	0	0	0	-	-	0	0	0	0	0	0

EMCs	80	10	109	13			1223	865	103	146	66	11
ppm = parts per million	ppt = parts per trillion											
ppb = parts per billion												
OUTFLOW SUMMARY TABLE												
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+												
Subarea	Rainfall	Runoff				Subarea				Global		
No.	cfs-hrs	cfs-hrs				Qpeak	Tpeak	TSSemc		Qpeak	Tpeak	TSSemc
						(cfs)	(min)	(mg/l)		(cfs)	(min)	(mg/l)
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+												
1	37.8	35.7				85.4	20	80		85.4	20	80
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+												
Surcharge occurred in the following subareas:								1				
-+- End of File -+-												

Chapter 7

Runoff Quality and Quantity Model Results

This chapter describes the model calibration process and the results obtained for different model runs using PSRM-QUAL. As stated in the previous chapter, the model calibration process can be completed in two phases: runoff quantity and runoff quality.

7.1 Runoff Quantity Calibration

Runoff quantity calibration is the first step once a representative data set has been gathered from the field. Four of the sixteen sampled events in the summer and autumn of 1995 were used for calibration. The initial quantity calibration was based on the six-subarea discretization of the watershed. This was revised to a one-subarea approach after problems with pollutant transport were encountered in the model. Since the final analysis of the total suspended solids (TSS) load is based on storm volume, the objective of the calibration process was to match the total volume of the storm as closely as possible and then match the peaks if possible. Most of the runoff quantity parameters of the model fall into four main categories: subarea geometry, rainfall losses, overland flow and drainage element hydraulics. Initial values were supplied for all parameters in these categories by the model and then modified by the user until the model yielded hydrographs similar to the observed. Each of the model parameters is described in the following paragraphs.

Subarea geometry includes the subarea's area (AREA), length (LENG), slope (SLOPE) and fraction impervious (FRIMP). These values did not need calibration since they are measurable geometric properties. Drainage element parameters describe the interconnectivity, capacity, travel time, slope, and size of the pipes connecting the subarea

elements. Since the final analysis of the model only used one subarea, these parameters were dropped from the model calibration process, as no pipes were needed. The parameters of overland flow routing, Manning's n, for both impervious (MN1) and pervious (MN2) areas, and the sinuosity factor (SF) for the watershed were assessed. Due to the fairly straight travel path of the watershed, the sinuosity factor was set at 1. A larger number would indicate more of a meander in the flow across the subarea towards the outlet. Manning's n value for the pervious area was set at 0.15, near the low end of the model's suggested range of 0.2-0.4. This factor was fairly insignificant due to the fact that most of the watershed was impervious and it had a rapid response time. The Manning's n for the impervious areas was an important number in the calibration process. After many different calibration runs of the model, it was set at a very low number of 0.011 for asphalt, as recommended in Technical Release-55 (TR-55), 1986.

The rainfall losses were the most variable part of the calibration process, since some of the parameters reflect conditions in the watershed at the time of a specific rainfall event, and a single calibration for all storm events was desired. Curve numbers for pervious and impervious areas were key parameters in the calibration, and the final curve numbers were set at 99 for impervious areas (CN1) of the watershed and 74 for pervious regions (CN2). Due to the high proportion of impervious surface, the initial abstraction factor (IAF) was lowered from the standard 0.2 to a value of 0.01, indicating a very low initial loss throughout the watershed. This parameter was helpful in the calibration process to increase the flow volumes to match those of the observed storms. The depression storage (DS1 and DS2) parameters had the same effect as initial abstraction and were set to zero for both

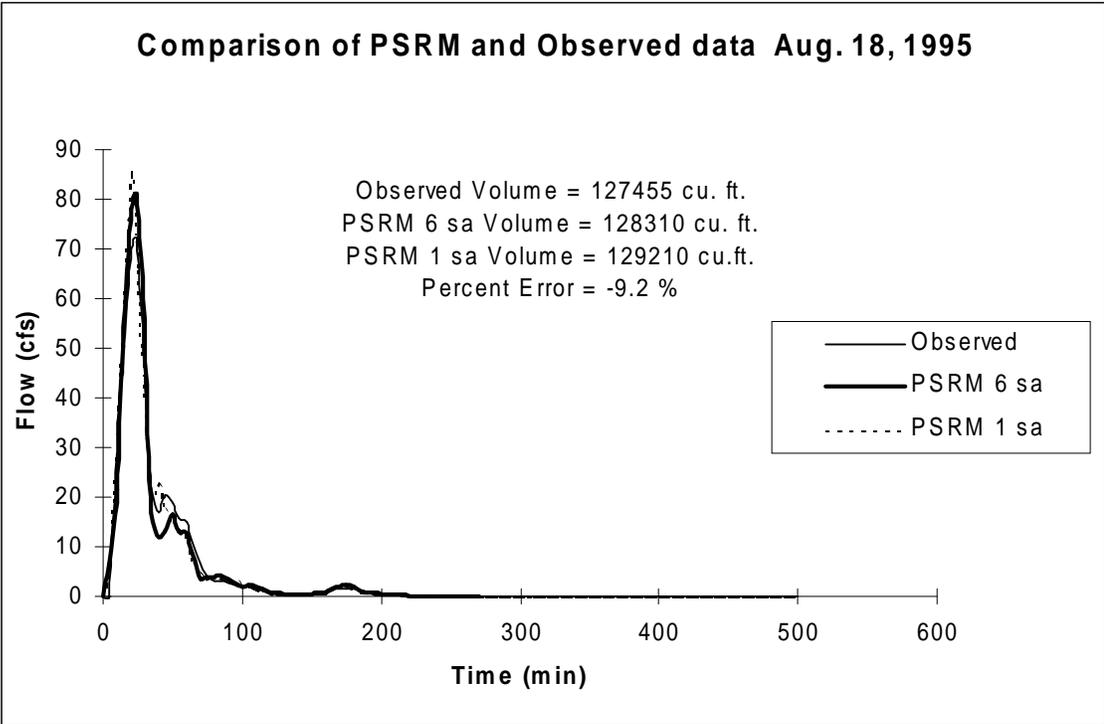
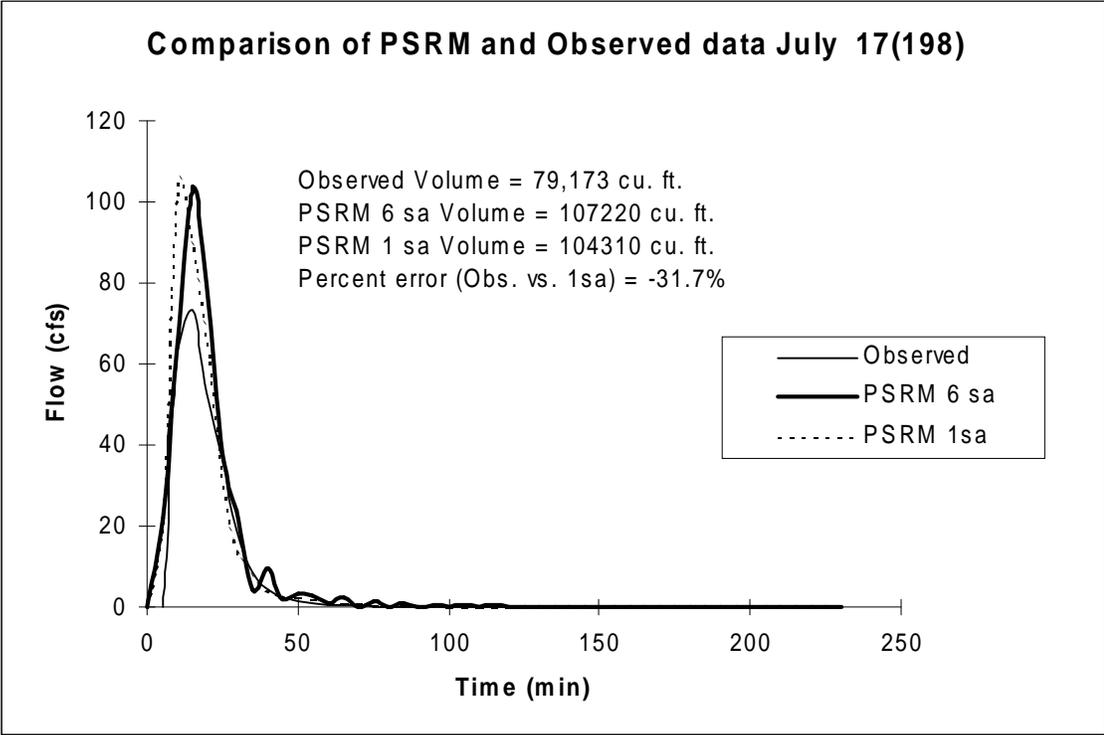
pervious and impervious areas, again to increase computed flow volumes. The saturated hydraulic conductivity of the soil (KS), was a fairly insignificant number, due to the small pervious area, and was set at a low value of 0.02. Finally, the initial fraction of soil wetted capacity (IFSW) ranging from completely dry soil (IFSW=0) to saturated soil (IFSW=1) was set at 0.5 for an average, but again did not make a significant impact on the modeling results due to the small amount of soil area in the watershed.

Figure 7-1 shows the graphical results of the model calibration for runoff quantity only of all the analyzed storms. Table 7-1 is the numerical comparison of these results, showing a -1.23% average error between observed flow volumes and PSRM hydrograph volumes using a single subarea.

Table 7-1. PSRM Quantity Results at Inflow to Pond.

Day/JDay	Observed Volume (ft ³)	PSRM 6 SA Volume (ft ³)	PSRM 1SA Volume (ft ³)	% Error (Obs. vs. 1SA) ¹
July17/198	79,173	107,220	104,310	-31.7
Aug. 18/230	127,455	128,310	139,210	-9.2
Aug. 27/239	30,545	29,100	26,700	12.6
Sept. 13/256	7,763	6,210	6,180	20.4
Sept. 16/259	77,551	63,660	63,327	18.3
Sept. 26/269	9,919	10,530	10,500	-5.9
Oct. 4/277	107,266	114,690	114,630	-6.9
Oct. 13/286	16,971	18,450	18,930	-11.5
Oct. 20/293	46,471	39,360	39,240	15.6
Nov. 2/306	13,578	16,830	17,130	-26.1
Nov. 7/311	57,756	51,960	52,230	9.6
Nov. 11/315	24,359	24,090	24,210	0.6

¹ Percent Error = (Observed Volume-PSRM 1SA Volume)/Observed Volume



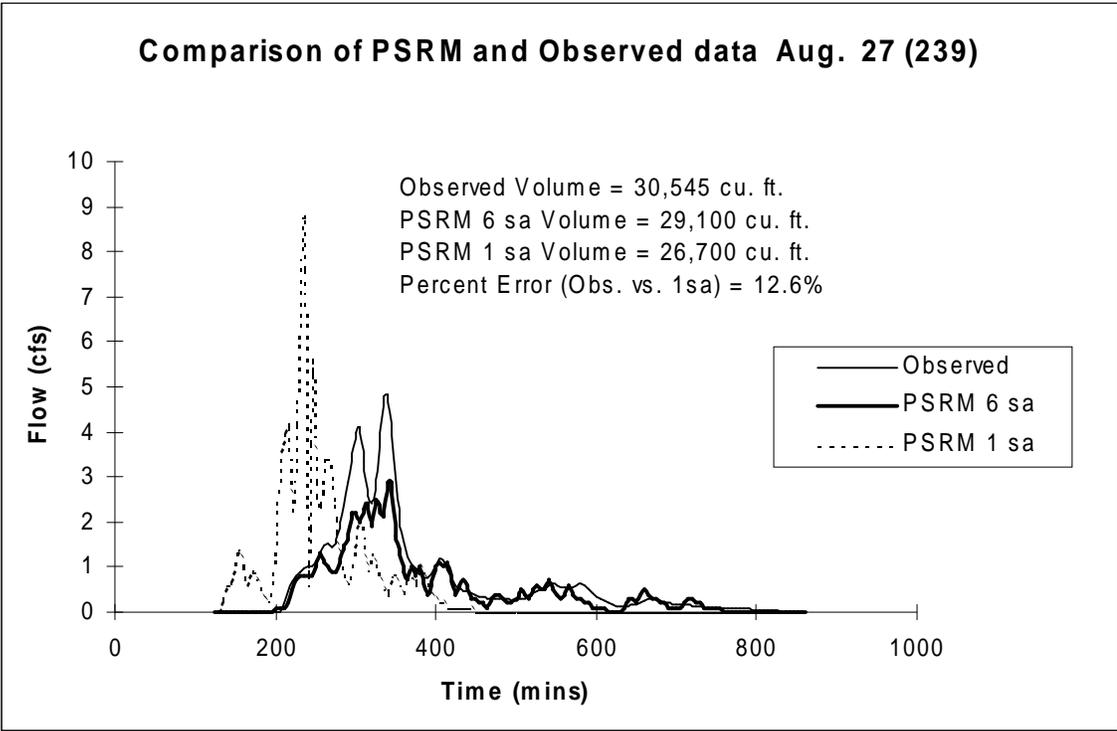


Figure 7-1 (c). Storm event August 27, 1995 - Day 239

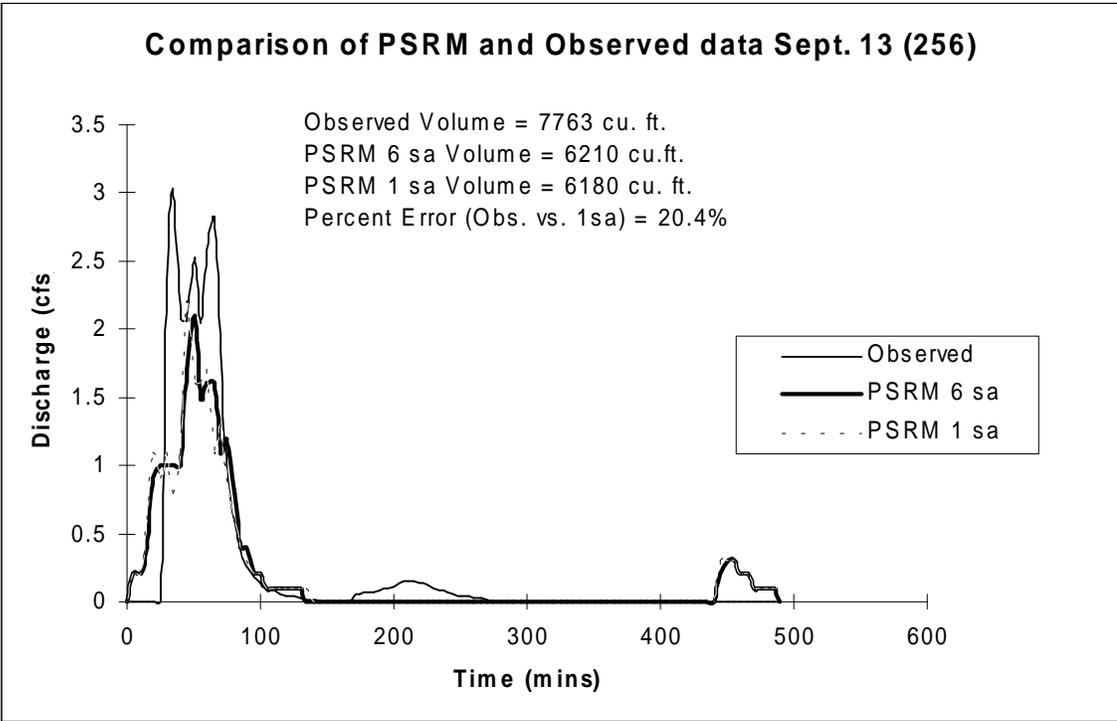


Figure 7-1 (d). Storm event September 13, 1995 - Day 256

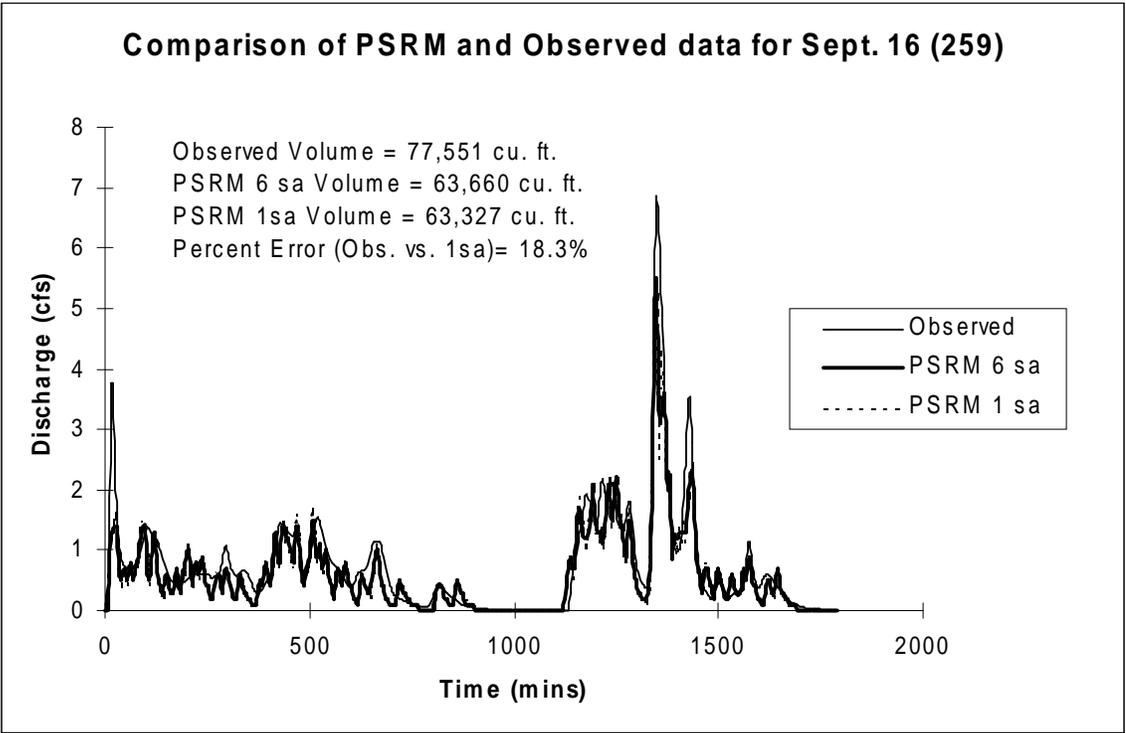


Figure 7-1 (e). Storm event September 16, 1995 - Day 259

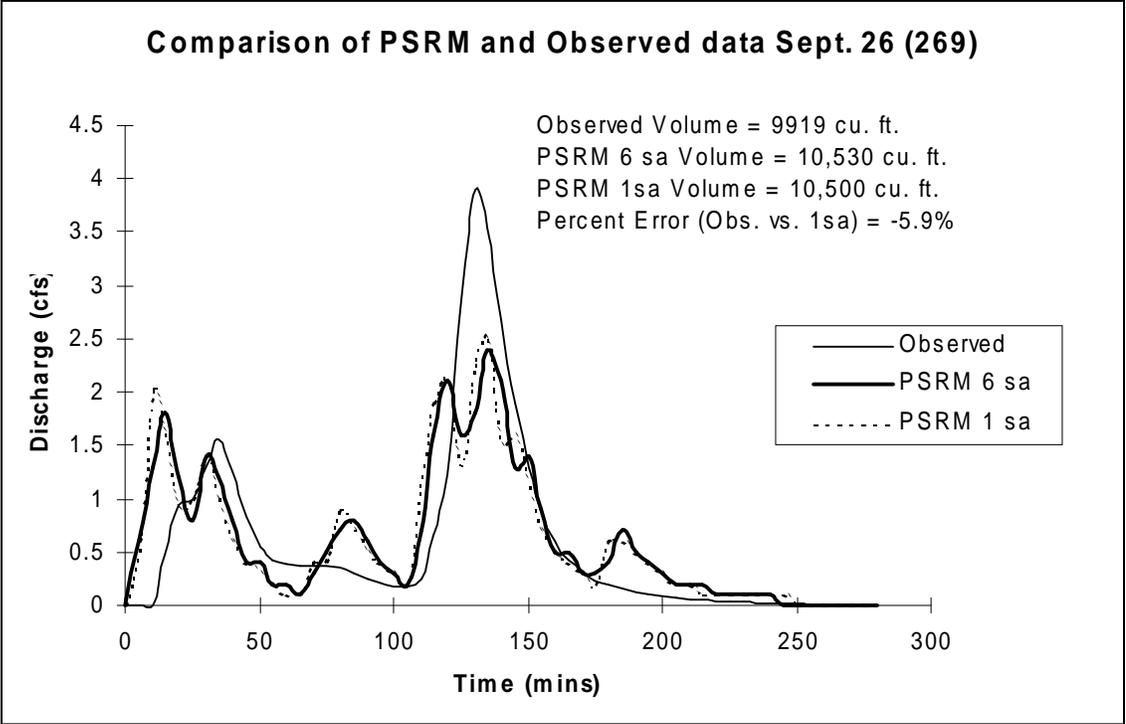


Figure 7-1 (f). Storm event September 26, 1995 - Day 269

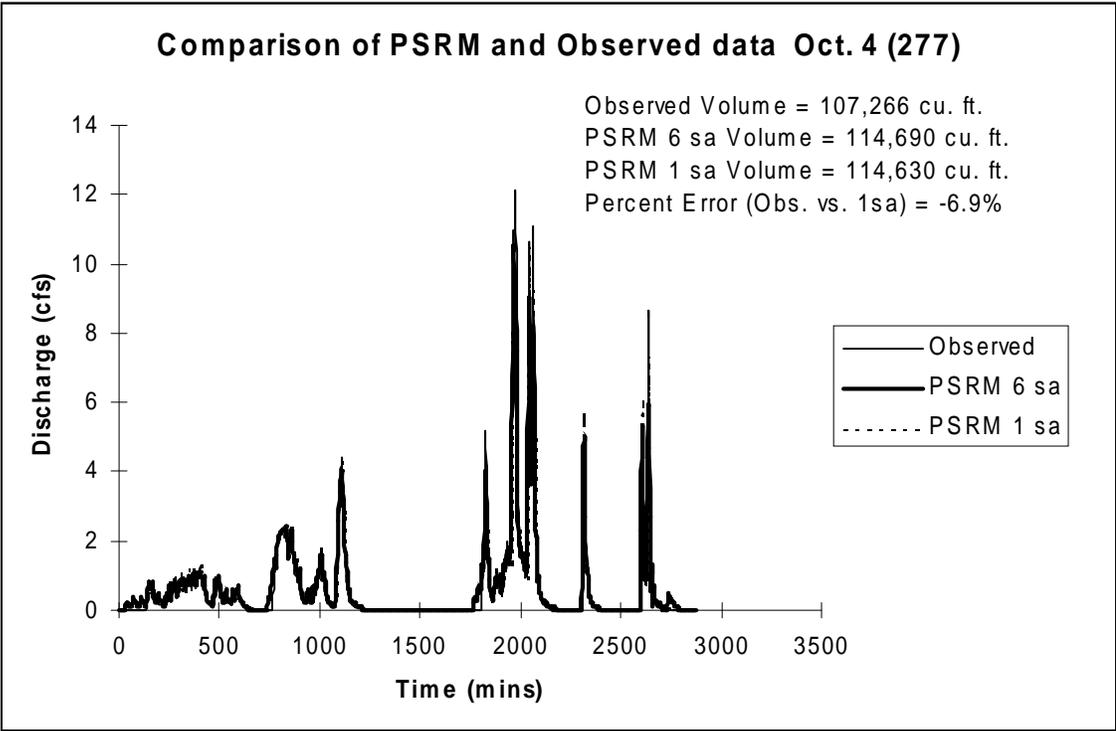


Figure 7-1 (g). Storm event October 4, 1995 - Day 277

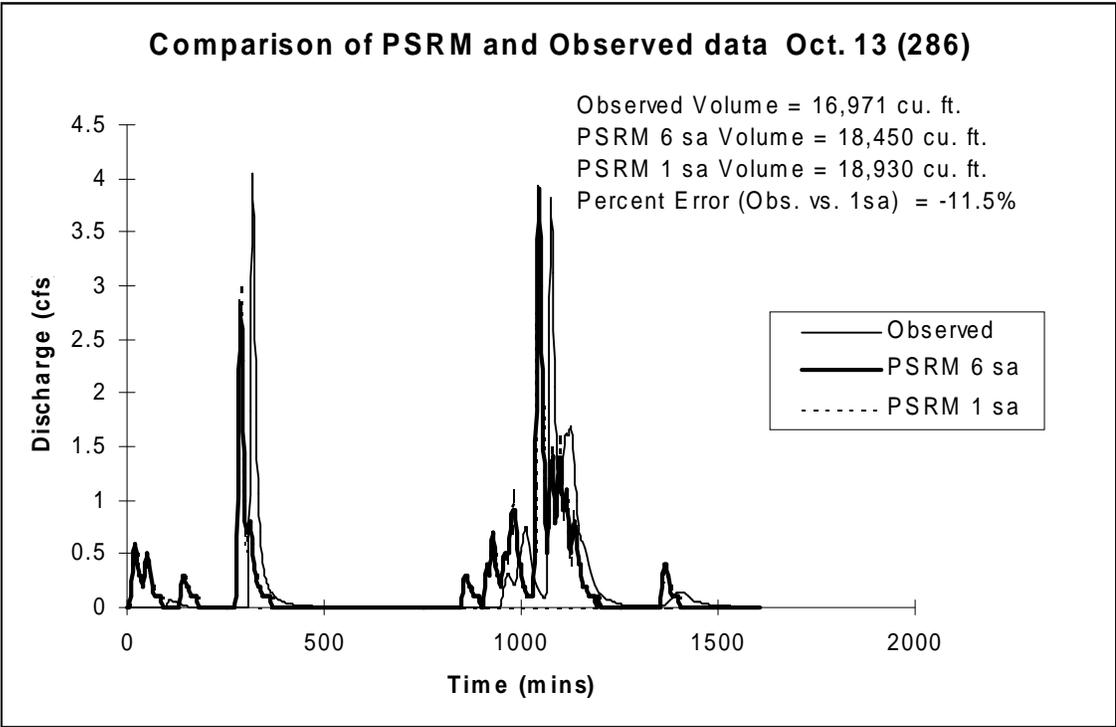


Figure 7-1 (h). Storm event October 13, 1995 - Day 286

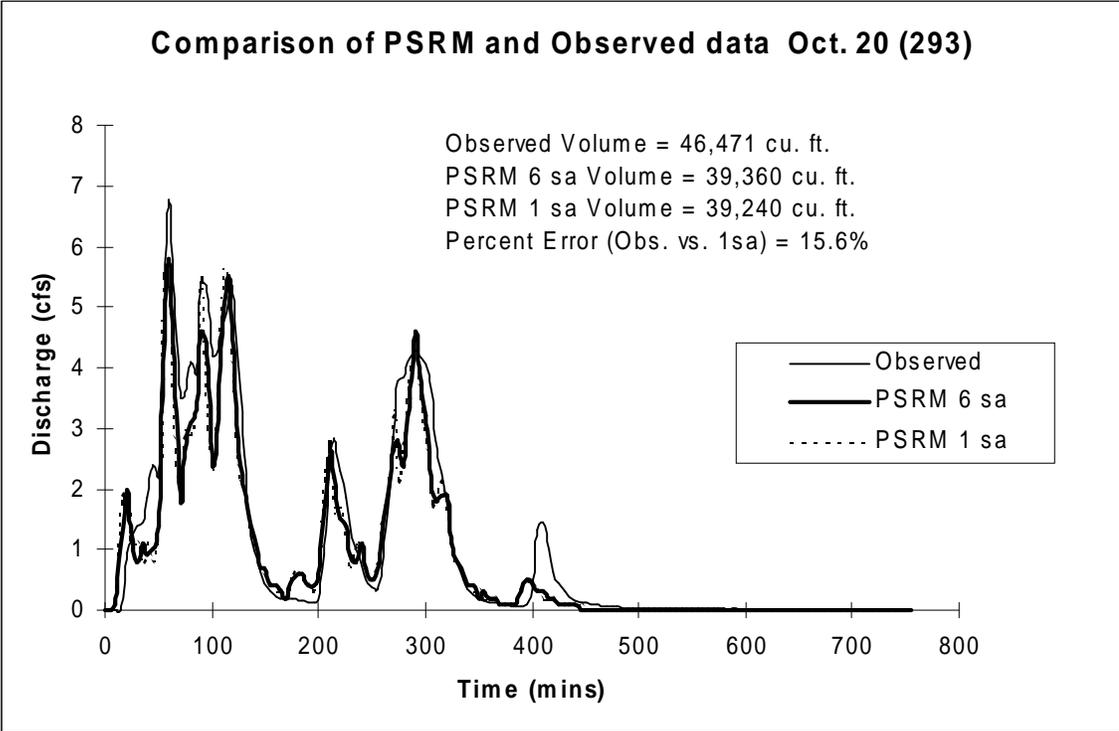


Figure 7-1 (i). Storm event October 20, 1995 - Day 293

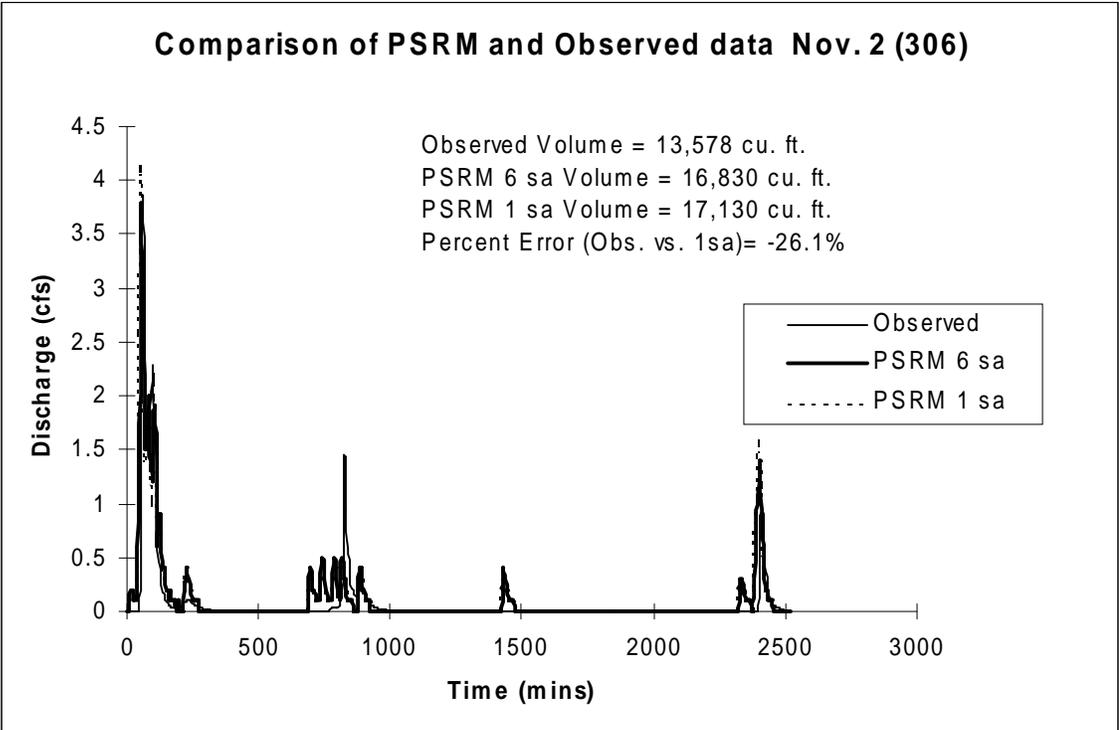


Figure 7-1 (j). Storm event November 2, 1995 - Day 306

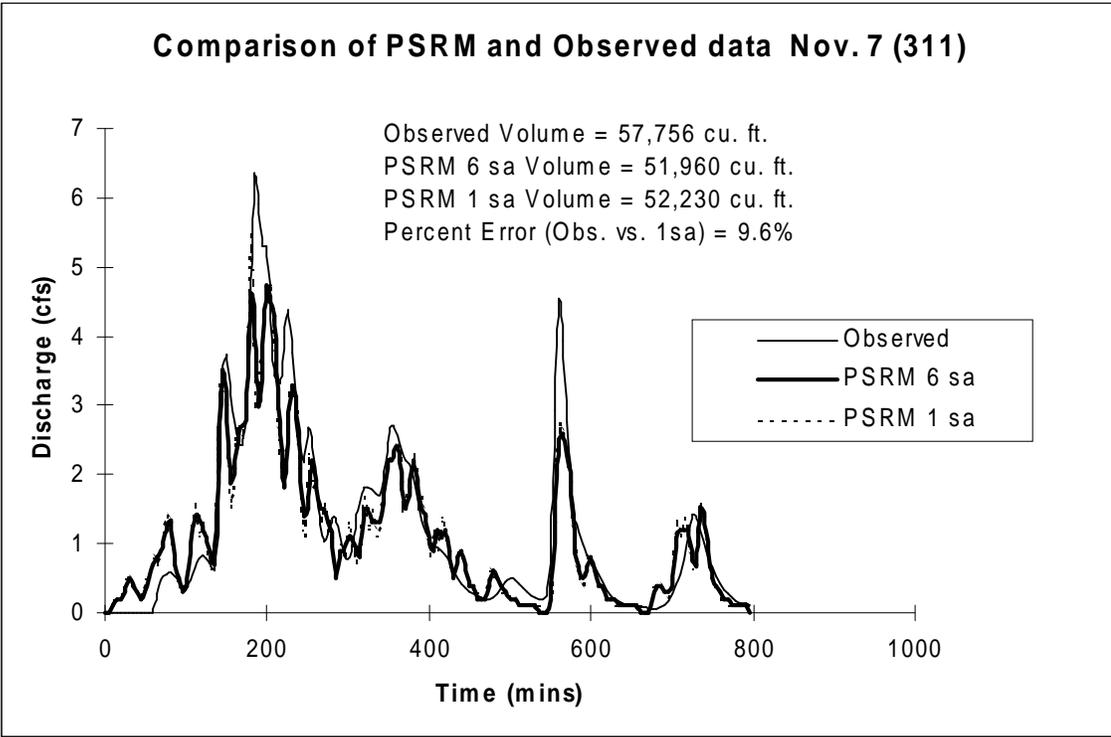


Figure 7-1 (k). Storm event November 7, 1995 - Day 311

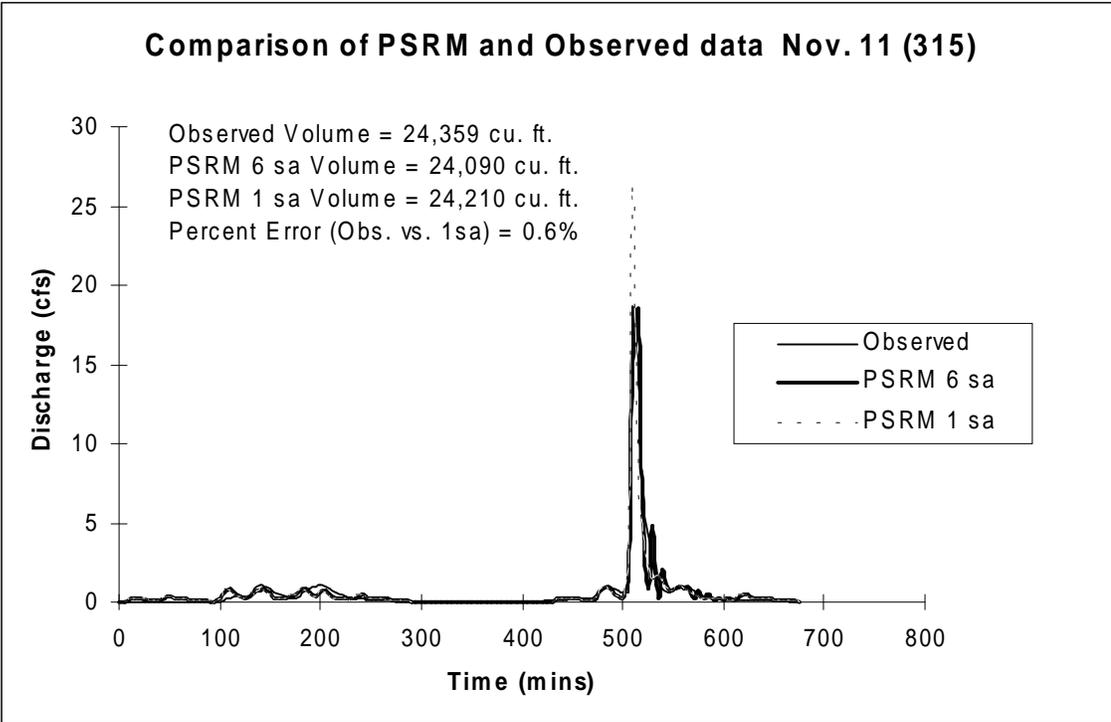


Figure 7-1 (l). Storm event November 11, 1995 - Day 315

7.2 Runoff Quality Calibration

The quality calibration process was more difficult than the quantity calibration since many of the parameters are subjective and not physically based. The runoff quality parameters of the model fall into two categories: land use, impervious area sediment loading and pervious area sediment loading.

The PSRM-QUAL model quality calibration was first attempted using the six-subarea approach. The results obtained were quite out of line with the observed results. Upon further investigation, a flaw was discovered in the model's internal calculations. The error occurs somewhere in the pollutant routing process through the connecting elements, yielding an incorrect value for TSS and therefore incorrect results for all of the modeled constituents. It was at this point that the research team switched from six to one subarea for the watershed, and the conversion was fairly simple due to the consistency of the watershed. The change forced the model to bypass the flawed sections of code. As seen from the quantity results, this caused very little change in the outflow hydrographs of Figure 7-1.

The pervious area parameters included the Universal Soil Loss Equation K, C, and P parameters (UK, UC, and UP), a Sartor-Boyd K value for soil dislodgment (SBK), a drag coefficient (CD), and friction coefficients for static and dynamic motion (DFC and SFC). The USLE parameters of K, C, and P were set at 0.2, 0, and 0.3, respectively based on suggested values due to soil type. Values of 0.8, 0.4, and 0.8 were used for the coefficient of drag, the dynamic friction coefficient and the static friction coefficient, respectively. Each of the above parameters has little effect on the results of the overall model. However, the Sartor-Boyd K value which represents the soil particle dislodging coefficient for

impervious areas did affect the performance of the model. The value was set at 2.0, which is at the low end of the range of suggested values.

The impervious area parameters included the land use index, maximum and initial sediment loads, and information on street sweeping. The land use index (LU) is a number from 1-4 indicating the land use as 1-Residential, 2-Mixed (residential and commercial), 3-Commercial, and 4-Rural areas. A value of 3 for commercial areas was used. The maximum sediment load parameter (MSL) is used for buildup limit if storms are being run consecutively, and the information on street sweeping (SWST, SWTI, and SWFR) is used for inter-event removal. The research team ran the model for individual storms for comparison to the observed results, and therefore, these parameters did not impact the model's performance. The most important parameter in the entire quality modeling process is the initial sediment load (ISL). This is the sediment available for washoff on the watershed surface at the beginning of the storm event. If this number is too low, the model will under-predict the washoff due to the storm and if this number is too high, the model will over-predict the actual observed results. This is the only number, besides the actual storm rainfall information, that will vary with storm event. Since the initial sediment load varies for each storm depending on many varying factors, it was impossible to use a single calibration number for all storms, and since data was not available for every storm event, it was impossible to run the model in continuous mode. To compensate for this, the initial sediment load was evaluated for each storm, so that when the model was run, the TSS load would match the observed value as closely as possible. At this point, the performance of the model was based on the remaining constituents.

The first set of results was obtained using the original default POLC.DAT file.

These results are shown in Table 7-2.

Table 7-2. Model EMC Results with Original Data File

Day	TSS (mg/L)	Cu (ug/L)	Zn (ug/L)	Pb (ug/L)	TKN (ug/L)	NO2+3 (ug/L)	TP (ug/L)	SP (ug/L)
198	167	70	546	252	2849	1381	485	198
230	80	34	264	122	1376	667	234	93
239	1	0	2	1	10	5	2	1
256	48	20	156	72	813	394	138	55
259	7	3	23	11	122	59	21	8
269	40	17	131	61	685	332	117	46
277	43	18	141	65	737	357	125	50
286	21	9	68	31	356	172	61	24
293	18	8	60	28	313	152	53	21
306	30	12	98	45	509	247	87	35
311	16	7	54	25	280	136	48	19
315	69	29	228	105	1187	576	202	81

To assess the prediction results of the model, EMC results from the model were divided by observed data and ratios were determined for each constituent. Single storm anomalies were removed as necessary for a representative average. The ratio results for the POLC.DAT run is shown in Table 7-3 in bold.

Using the bold averages in Table 7-3, the POLC.DAT file was refined to better fit the data. This is suggested by the PSRM-QUAL manual for proper calibration to a specific watershed. In addition, lead levels in the environment have lowered significantly since the discontinuation of leaded gasoline. This is reflected in the extreme over-prediction of the lead EMC. By calibrating the POLC.DAT file and trying to get the average ratio to equal one, the investigator was able to force the model to more accurately match field conditions.

Table 7-3. Ratio (model/observed) Comparison of Original Data File Results.

Day	TSS	Cu	Zn	Pb	TKN	NO2+3	TP	SP
198	0.988	10.7	5.65	39.98	2.03	2.29	7.48	2.97
230	0.99	5.05	4.64	19.52	1.922	1.027	1.226	0.564
239	0.989	0	0.03	0.27	0.07	0.03	0.11	0.1
256	1.02	1.68	1.38	9.61	0.402	0.239	1.3	0.62
259	0.927	0.587	0.419	0.989	0.338	0.16	0.414	0.214
269	1	1.87	0.992	4.59	0.759	0.489	1.4	0.586
277	0.996	3.73	1.57	3.99	0.556	1.6	1.424	0.687
286	1.01	1.74	1.1	4.66	1.4	0.659	0.855	0.377
293	0.978	1.67	1.168	7.4	1.45	0.438	0.851	0.35
306	1.02	2.31	1.6	5.54	1.69	1.3	12.2	0.695
311	0.992	2.1	0.887	3.92	0.663	0.779	0.803	0.359
315	1	4.81	3.53	9.67	1.06	0.454	2.34	1.01
Average	0.9925	3.02058	1.91383	9.17825	1.02833	0.78875	2.53358	0.711
Omit 198	0.99291	2.32245	1.57418	6.37809	0.93727	0.65227	2.08391	0.50564
Omit 198 and 230				5.0639				
Omit 198 and 306							1.0723	

There are two different approaches to calibration of the POLC.DAT file. The first is to divide the original POLC.DAT numbers by the bolded averages for the events shown in Table 7-3. For the commercial area, this would yield the following multipliers: Cu = 0.018, Zn = 0.21, Pb = 0.03, TKN = 1.82, NO₂+NO₃ = 1.25, TP = 0.272, and SP = 0.232. Using these numbers to run the model with a POLCAVG.DAT file, the investigator was able to produce the results in Table 7-4 and Table 7-5.

This time, the average ratio for the POLCAVG.DAT run for each constituent, omitting storm 198 for all constituents and storm 239 for zinc only, was much closer to the value of one. Since there are values above and below one for each constituent, it would appear that over time the results would average out to be fairly close to the observed values.

Table 7-4. Model EMC Results for Average Data File

Day	TSS	Cu	Zn	Pb	TKN	NO2+3	TP	SP
	(mg/L)	(ug/L)						
198	167	30	350	50	3032	2082	453	386
230	80	14	169	24	1465	1006	219	187
239	1	0	1	0	10	7	2	1
256	48	9	100	14	865	594	129	110
259	7	1	15	2	130	89	19	17
269	40	7	84	12	730	501	109	93
277	43	8	91	13	785	539	117	100
286	21	4	44	6	379	260	57	48
293	18	3	38	5	334	229	50	43
306	30	5	62	9	542	372	81	69
311	16	3	34	5	298	205	45	38
315	69	12	146	21	1263	868	151	57

Table 7-5. Ratio (model/observed) Comparison of the Average Data File Results.

Day	TSS	Cu	Zn	Pb	TKN	NO2+3	TP	SP
198	0.989	0.459	3.625	7.931	2.16	3.45	6.99	5.96
230	0.99	2.08	2.97	3.84	2.05	1.549	1.148	1.135
239	0.989	0	15.26	0	0.0711	0.0459	0.109	0.1065
256	1.02	0.757	0.887	1.87	0.428	0.36	1.217	1.24
259	0.927	0.196	0.274	0.18	0.36	0.241	0.375	0.456
269	1	0.772	0.637	0.904	0.809	0.738	1.3	1.19
277	0.996	1.66	1.01	0.798	0.059	2.41	1.33	1.37
286	1.01	0.774	0.713	0.901	1.49	0.996	0.799	0.754
293	0.978	0.627	0.74	1.32	1.57	0.661	0.8	0.716
306	1.02	0.963	1.01	1.11	1.79	1.96	1.14	1.37
311	0.992	0.898	0.558	0.784	0.706	1.17	0.753	0.717
315	1	1.99	2.26	1.93	1.13	6.84	1.86	0.71
Average	0.99258	0.93133	2.49533	1.79733	1.05193	1.70174	1.48508	1.31038
Omit 198	0.99291	0.97427		1.23973	0.95119	1.54281	0.98464	0.88768
Omit 198 and 239			1.1059					

The second method of altering the POLC.DAT file is to use a weighted average based on storm volumes. Since the parameter EMC is calculated based on the TSS load, this method would weight the ratio differences by the amount of TSS for the storm. The

weighting process took the ratios for the POLC.DAT results in Table 7.3 and weighted them based on TSS and total storm volumes to form weighted ratios. These were divided into the POLC.DAT numbers to create a POLCWTD.DAT file with the following numbers: CU = 0.0128, Zn = 0.136, Pb = 0.016, TKN = 1.52, NO₂+NO₃=1.075, TP = 0.128, and SP = 0.181. The results of the model run and the ratios are shown in Tables 7-6 and 7-7.

Table 7-6. Model EMC Results of the Weighted Data File.

Day	TSS (mg/L)	Cu (ug/L)	Zn (ug/L)	Pb (ug/L)	TKN (ug/L)	NO2+3 (ug/L)	TP (ug/L)	SP (ug/L)
230	80	10	109	13	1223	865	103	146
259	7	1	10	1	108	77	9	13
269	40	5	55	6	609	431	51	73
306	30	4	40	5	452	320	38	54
198	167	21	227	27	2532	1791	213	302
293	18	2	25	3	279	197	23	33
277	43	6	59	7	655	463	55	78
239	1	0	1	0	9	6	1	1
311	16	2	22	3	249	176	21	31
286	21	3	28	3	316	224	27	38
256	48	6	65	8	723	511	61	86
315	69	9	94	11	1055	746	89	126

Table 7-7. Ratio (model/observed) Comparison of the Weighted Data File Results.

Day	TSS	Cu	Zn	Pb	TKN	NO2+3	TP	SP
198	0.989	3.212	2.351	4.283	1.803	2.966	3.287	4.66
230	0.99	1.49	1.91	2.08	1.7	1.33	0.54	0.89
239	0.989	0	0.015	0	0.064	0.039	0.055	0.107
256	1.02	0.504	0.577	1.07	0.357	0.31	0.575	0.969
259	0.927	0.196	0.182	0.09	0.3	0.209	0.178	0.348
269	1	0.551	0.417	0.452	0.675	0.635	0.61	0.931
277	0.996	1.245	0.656	0.43	0.494	0.207	0.627	1.072
286	1.007	0.581	0.454	0.451	1.24	0.858	0.379	0.597
293	0.978	0.418	0.487	0.793	1.292	0.568	0.369	0.549
306	1.016	0.77	0.654	0.615	1.5	1.69	0.53	1.07
311	0.992	0.599	0.361	0.47	0.59	1.007	0.352	0.585
315	1	1.49	1.45	1.01	0.94	5.88	1.03	1.57
Average	0.992	0.92133	0.79283	0.97867	0.91292	1.30825	0.711	1.11233
Omit 198	0.99227	0.71309	0.65118	0.67827	0.832	1.15755	0.47682	0.78982

As can be seen by the average of the ratios, this method seems to slightly under-predict the observed results when storm 198 is omitted.

Based upon review of all PSRM-QUAL runoff quality simulations reported above, the author concludes that water quality constituent simulation by PSRM-QUAL is erratic on a storm by storm basis, despite pre-calibration of the carrier pollutant TSS. Even those events whose runoff peaks and volumes are simulated well by PSRM-QUAL do not show correspondingly good matches between computed and observed runoff pollutant loads.

This is clearly an area of needed work if the state-of-the-art in urban stormwater modeling is to be advanced. In the meantime, simple storm total loading models are available as described previously in Chapter 5.

Chapter 8

Summary, Conclusions and Recommendations

8.1 Summary

As the continual development of our natural surroundings into urban areas progresses, the effects of this alteration on the environment becomes much more evident. Uncontrolled stormwater, from both quantity and quality perspectives, has become a leading indicator of by-products of urbanization within a watershed. Flooding and pollution problems in recent years have raised public concern and interest in assessing, controlling and predicting urban stormwater quality and quantity. Many different types of Best Management Practices have been implemented in an attempt to reduce stormwater quantity and improve receiving water quality. The extended dry detention basin used for quality control in this study is just one of the many pollutant reduction techniques used in the management of urban stormwater runoff. The purpose of this research has been to quantify pollutant loads for this parking lot watershed and obtain a better understanding of what types and amount of pollutants can be expected in a growing urban environment. The objectives of this research have been achieved by studying the results of a large stormwater runoff quantity and quality monitoring program and by analyzing different models for both prediction. This comprehensive sampling program has yielded a calibrated model for predicting pollutant runoff as well as validating different desktop prediction methods. It has also presented conclusions on the effectiveness of extended dry detention ponds as pollutant removal mechanisms.

The most important parameters in modeling stormwater quality are the amount of rainfall and the initial sediment load available for runoff. Chapters 3, 4 and 5 provided a complete description of the monitoring process and the steps used to calculate rainfall amounts, intensities and runoff volumes. Monitoring rainfall, as well as calculating inflow and outflow hydrographs provided a good database for understanding watershed losses. These chapters also describe the water quality collection and analysis process to identify pollutants found on the watershed and to determine pollutant removal rates by extended detention.

The results of the extended dry detention basin as a pollutant removal structure were very promising for the removal of sediment bound pollutants. The basin was capable of average removal rates for a six-month period of over 70 percent for total suspended solids, 30-50 percent for heavy metals and almost 60 percent for total nitrogen. As expected, the removal rates of dissolved constituents were not nearly as high. The promising outlook for the future management of stormwater quality is that many pollutants can be easily removed by gravity settling in an extended dry detention pond. Existing conventional dry detention basins, used for peak reduction purposes only, can be modified to detain water for a longer period of time and improve downstream water quality. The removal rate results of this study were comparable to removal rates found by other researchers investigating the potential of the extended dry detention basin as a water quality management tool.

Modeling and prediction of stormwater quality is a very difficult aspect of stormwater management . This study has shown that pollutant runoff associated with any given precipitation event can be highly variable, even in a small area. Even the most

thorough data collection is often insufficient to improve the prediction of pollutant. Chapter 5 described several different desktop prediction methods, and although they used different data inputs, the results were very similar due to the fact that the NURP database was used as the backbone for all of the methods. Each of the methods was highly erratic in predicting pollutant loads on a storm by storm basis as compared to the observed loads, and, in addition, each of the methods grossly overpredicted lead concentrations and removal rates. However, in a long-term analysis, the desktop methods could all predict pollutant loads, with the exception of lead, to within an order of magnitude using very simple input. These methods are therefore well suited for initial prediction and impact assessment.

The larger, more in-depth model used to evaluate stormwater quality that was assessed in this study was the PSRM-QUAL model. As described in Chapters 6 and 7, the model uses the fundamentals of the kinematic wave equations to generate storm hydrographs, and then the NURP database to calculate pollutant loadings. Though some problems were found in the basis of the program code, the computer model yielded results similar to those found using the desktop methods. The quantity portion of the model was easy to calibrate and produced hydrographs that correlated extremely well to those observed on the watershed. The quality portion of the model was again sporadic on a storm by storm analysis. This model was more complex than the simple desktop methods; however, the increase in complexity did not provide better results. Over the entire study period, the PSRM-QUAL model also predicted pollutant loads to be within one order of magnitude of the observed results, with the exception of lead. Due to the problems encountered in the code, the model could not be run on a continuous storm basis to see if prediction rates could

be improved. In addition, for accurate loadings to be calculated, the model needs to be calibrated with observed storm event data, and the most important of these parameters is the initial sediment load.

8.2 Conclusions

The results of this research imparts understanding of urban non-point source pollution.

The following conclusions have been drawn from this study:

- Assessment of detention pond performance during a single storm is likely to provide erratic pollutant removal rates. This analysis should be done on a seasonal, or better yet, an annual basis.
- Extended dry detention basins are a fairly simple, yet effective pollution control measure for sediment bound pollutants. Removal rates of over 70% for total suspended solids, 30-50% for heavy metals and almost 60% for total nitrogen were obtained in this study. This corresponds well with existing published findings.
- Simple desktop methods for predicting pollutant loadings yield results within one order of magnitude for most pollutants, with no sampling required.
- More research needs to be completed to analyze the change in environmental lead levels due to the removal of leaded gasoline from the environment.
- Water quality models can be difficult to calibrate, but once calibrated can provide fairly accurate results with minimal effort.
- Water quality models should not be used without calibration, and some quantity and quality data should be taken to assess the model prediction rates.
- For long term sampling projects, water quality samples should be composited based on flow during the rainfall event to decrease the laboratory analysis cost.

8.3 Recommendations

Future research should include continuing water quality monitoring to assess the seasonal and yearly effects of water quality and removal rates and the effectiveness of the desktop methods to predict pollutant runoff over longer time periods. This monitoring effort should be done using a composite sampling technique for each storm to decrease sampling efforts, while still providing a large database of information for use in future analyses.

A second consideration for future research includes further analysis into background lead levels. Since the elimination of leaded gasoline from the environment, background lead levels have decreased dramatically and due to this, all of the prediction methods greatly over-predict observed lead levels. Another avenue of investigation would be to assess expected removal rates of lead using different traditional Best Management Practices. Since background levels are lower, it is becoming harder to remove the remaining lead from the water column and therefore it appears that future removal percentages for lead will decrease.

Problems encountered in the background code of the PSRM-QUAL model limited the analysis of this model during the study period. The model works properly for predicting stormwater quantity, but for quality prediction it only works for overland flow. Prediction for quality within a storm sewer network does not work properly and this impacts the continuous modeling ability of the program. Future investigations into pollutant routing through a storm sewer would greatly improve the model, and then exploring the calibrated model predictions on an overall basis, not just event by event, may give some new insight

into washoff and removal functions. Finally, comparative research on different management strategies for pollutant reduction in urban stormwater could discover new techniques for sharing and preserving our environment. This could include both removal and preventative techniques to lessen non-point source pollution effects.

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APPENDIX A

Laboratory Procedures

BSEWQL-3 Procedures for the Determination of Total Suspended Solids and Volatile Suspended Solids

A well-mixed water sample is filtered through a weighed standard glass-fiber filter and the residue retained on the filter is dried to a constant weight at 103-105°C. The increase in weight of the filter represents the total suspended solids. The residue and filter are then placed in a muffle furnace and heated to a constant weight at 500°. The decrease in weight of filter and residue represents the volatile suspended solids.

Interferences:

1. Limit the sample size to no more than 200 mg of residue.
2. Rinse the filtration apparatus well with distilled-deionized water for samples that contain large amounts of suspended materials (>100 mg).
3. Remove any non-representative particulates such as leaves and sticks from the filtered solids.

Apparatus:

1. Vacuum Pump
2. Glass-fiber Filters
3. Aluminum Weighing Pans
4. Gelman Filtration Units
5. Oven at 105°C
6. Analytical Balance
7. Muffle Furnace at 500°C

Procedures:

1. Wash clean glass-fiber filters (Gelman Type A/E) with 50 ml distilled water.
2. Dry filters in an oven at 105°C for 24 hours.
3. Store dried filters in a desiccator.
4. Label aluminum weighing pans with the appropriate lab number (only 12 samples at a time).
5. Place a dry, washed filter in each pan.
6. Weigh the pan and filter on an analytical balance and record weight.
7. Filter 12 samples. Record the sample volume used. Never use more than 150 ml of sample (50 ml for average samples, 100 ml for clean samples, and 25 ml for "dirty" samples.)
8. Dry filter, pan, and residue in an oven at 105°C for at least 24 hours.
9. Remove samples from the oven and cool in a desiccator for 30 minutes.
10. Weigh the pan, filter, and residue on an analytical balance; record the weight.

Calculations:

$$\text{total suspended solids} = \frac{(A - B) \times 1000}{\text{sample volume (mL)}}$$

where A = weight of filter, pan, and residue after drying at 105°C

11. Place filter and residue sample in a crucible in muffle furnace at 500°C for 20 minutes.
12. Remove samples and cool in desiccator for 15 minutes.
13. Weigh the pan, filter, and residue on an analytical balance; record the weight.
14. Repeat steps 12-14 until a constant weight is reached.

Calculations:

$$\text{volatile suspended solids} = \frac{(A - C) \times 1000}{\text{sample volume (mL)}}$$

where C = weight of filter, pan, and residue after ashing at 500°C

QA/QC:

1. One duplicate is run for every 10 samples.
2. One blank sample is run for every 10 samples or every 7 days, whichever is more frequent. A blank sample is prepared by filtering 50 ml of distilled-deionized water and obtaining the weight of suspended solids, as in samples.

Precision and Accuracy:

Ave. Standard Deviation = 0.74 mg/L
Minimum Detection Limit = 0.015 mg/L
Standard Deviation is determined quarterly

Reference:

This procedure is based on these methods:

1. EPA Methods for Chemical Analysis of Water and Wastes, VSEPA-600/4-79-020, Residue, Filterable: Method 160.2.
2. Standard Methods for the Examination of Water and Wastewater, 18th Edition, p. 2-54; Method 2540B.

At the beginning of this project a comparison was made between the constant weight method and the 24 hour method. No significant difference was detected (differences less than the standard deviation). The time period for sample drying was adapted from Method 2540B. Standard Methods for the Examination of Water and Wastewater.

BSEWQL-4 Procedures for the Determination of Total Phosphorus (Traacs 800)

Total phosphorus in water and wastewater is first converted to orthophosphorus by hydrolysis with sulfuric acid. The determination of orthophosphorus is then based on the colorimetric method in which a blue color is formed by the reaction of orthophosphate, molybdate ion and antimony ion followed by reduction with ascorbic acid at an acidic pH. The phosphomolybdenum complex is read at 660 nm.

The acid digest samples are prepared by digestion with the Technicon BD-40 Block Digester. Refer to Manual No. TA4-0323-11 and the description in the method for sample preparation.

If analysis of high range samples is required, adjustment of the volume of the sample added to the digestion tube prior to digestion is needed to dilute the sample to the proper range.

Apparatus:

1. Block Digester
2. Computer
3. TRAACS 800 auto analyzer
4. 660 nm filter

Procedures:

A: Digestion (Note: The same digested samples are used for Total Kjeldahl Nitrogen and Total Phosphorous testing.)

1. Label clean dry 50 ml folin-wu tubes with sample numbers.
2. Add 10 ml of well shaken sample to its tube with a calibrated pipet (up to 15 samples, filtered and unfiltered tubes for each sample.)
3. Add 1.5-2.0g Pope Kjeldahl #1 catalyst to each tube with a spoon.
4. Add 3 ml of concentrated sulfuric acid to each tube with a calibrated auto-pipet.
5. Heat in a digestion block 1.5 hours at 150°C to drive off water.
6. Cap each tube with a small funnel.
7. Raise the block temperature to 380°C and digest samples for 3 hours.
8. Turn off digestion block and allow samples to cool (2-3 hours). After the samples have cooled, transfer tem from the block to the fume hood.
9. Rinse the funnels with distilled-deionized water.
10. Vortex the samples until the solids are dissolved. Slowly add distilled-deionized water to the samples while continuing to vortex. Add distilled water to each sample so that the volume of the sample is exactly 50 ml.
11. Cover and invert 20 times.
12. Transfer the samples into auto-analyzer cups, appropriately labeled.
13. Follow the method for Traacs 800.

Reagents:

DI water refers to high quality reagent water, Type I or Type II as defined in ASTM Standards, Part 31, D1193-74.

Sampler IV wash receptacle solution

1. Sulfuric Acid, 4%
80 ml Sulfuric Acid, conc.
2000 ml DI Water, qs
2. Molybdate/Antimony Solution
11 g Ammonium Molybdate
0.25 g Antimony Potassium Tartrate
1000 ml DI Water, qs
3. Ascorbic Acid Solution
154 g Ascorbic Acid -OR- Arboascorbic Acid
1000 ml DI Water, qs
4. Acid/Salt diluent
20 ml Sulfuric Acid
6.3 g Sodium Chloride
1000 ml DI Water, qs
7 ml Levor IV

Standards: Same as orthophosphate BSEWQL-5 (except instead of DI water, qs, substitute 4% sulfuric acid solution.

Calculations:

1. A standard curve is prepared based on the peak heights of each standard. The sample concentrations are determined using linear regression techniques.

QA/QC:

Note: 40 tubes are prepared for each digest, 14-15 filtered and unfiltered each sample, 2-4 duplicates, 3 EPAs and 3 blanks. Two EPA quality control samples are digested to ensure there will be an average value available in case one of the samples is destroyed or contaminated. An average is taken from their measure values.

1. One duplicate is prepared for the every sample numbering a multiple of 10.
2. Three EPA samples are digested with each set of samples.
3. Two blank samples are run with each digest.
4. One spike sample is run for every 10 samples.
5. Please see BSEWQL-13 for more detailed information

Precision and Accuracy:

Ave. Standard Deviation 0.056 mg/L based on 60 samples

Ave. Percent Recovery = 91-94% based on 20 samples

Min. Detection Limit = 0.1 mg/L is defined as 2 times the recorder noise when operating at maximum sensitivity. Precision and Accuracy values are updated quarterly.

Reference:

1. EPA Methods for Chemical Analysis of Water and Wastes, USEPA-600/4-79-020, Phosphorus. All forms; Method 365.1

**BSEWQL-5 Procedures for the Determination of Total Orthophosphates
(TRAACS 800)**

This automated procedure for the determination of orthophosphate is based on the colorimetric method in which a blue color is formed by the reaction of orthophosphate, molybdate ion and antimony ion followed by reduction with ascorbic acid at an acidic pH. The reduced blue phosphomolybdenum complex is read at 660 nm.

Procedures:

1. Filter samples as described in BSEWQL-2.
2. Transfer the filtrate into an auto-analyzer cup. See BSEWQL-2.
3. Analyze samples using an auto-analyzer.

Apparatus:

1. TRAACS 800
2. Computer
3. 660 nm Filter

Reagents:

DI water refers to high quality reagent water, Type I or Type II as defined in ASTM Standards, part 31, D1193-74.

1. Molybdate Reagent
0.12 g Antimony Potassium Tartrate
4.3 g Ammonium Molybdate
27 ml Sulfuric Acid, Concentrated
1000 ml DI Water, qs
7 ml Levor IV

2. Ascorbic Acid

10 g	Ascorbic Acid
100 ml	DI Water

Standards:

1. Stock Standard A, 100 mg/L P

0.4394 g	Potassium Phosphate Monobasic
1000 ml	DI Water, qs

In a one liter volumetric flask containing about 800 ml of DI water, add 0.4349 g of potassium phosphate monobasic and swirl to dissolve. Dilute to one liter with DI water and mix thoroughly.

2. Stock Standard B, 20 mg/L P

20.0 ml	Stock standard A
100 ml	DI Water, qs

Dilute 20.0 ml of stock standard A to 100 ml with DI water and mix thoroughly. Prepare fresh daily.

3. Working Standards Solution

<u>ml Stock B</u>	<u>mg/L P</u>
2.0	0.4
4.0	0.8
6.0	1.2
8.0	1.6
10.0	2.0

Calculations:

1. A standard curve is prepared based on the peak of each standard. The sample concentrations are determined using linear regression techniques.
2. Distilled-deionized water is used for blank measurements.

QA/QC:

1. One Duplicate is run for every 10 samples
2. One EPA standard is run for every 20 samples.
3. One spike is run for every 10 samples.
4. On blank is run daily, or for every 20 samples whichever id more frequent.
5. Please see BSEWQL-13 from more information.

Precision and Accuracy:

Ave. Standard Deviation: 0.013 mg/L based on 52 samples
 Ave. Percent Recovery = 89-94% based on 20 samples
 Minimum Detection Limit = 0.05 mg/L

Precision and Accuracy results are calculated quarterly. Minimum detection limit is defined as 2 times the recorder noise when operating at maximum sensitivity.

References:

1. EPA Methods for Chemical Analysis of Water and Wastes, USEPA-600/4-79-020, Phosphorus, All forms; Method 365.1.
2. "Orthophosphate in (Waste)Water", Technicon AAII Product Information.

BSEWQL-6 Procedures for the Determination of Total Kjeldahl Nitrogen

This method covers the analysis of total Kjeldahl nitrogen in water. The procedure converts nitrogen components of biological origin such as amino acids, proteins, and peptides to ammonia. The range for this test is 0.1 to 10 mg/L total Kjeldahl nitrogen. The range may be extended by sample dilution.

Water samples are heated in the presence of sulfuric acid, potassium sulfate, and mercuric sulfate at 150°C for 1.5 hours and then at 380°C until digestion is complete. The samples are then cooled and diluted to 50 ml using distilled-deionized water. The samples are then analyzed for total Kjeldahl nitrogen.

Reagents:

DI water refers to high quality reagent water, Type I or Type II as defined in ASTM standards, part 31, D1193-74.

1. Total Kjeldahl Nitrogen Wash
20g K_2SO_4
100 ml Concentrated Sulfuric Acid (H_2SO_4)
2000 ml DI water, qs

Add 100 mls of concentrated H_2SO_4 to approximately 1500 mls of DI water, then add 20 grams K_2SO_4 to solution, swirl to dissolve and bring to volume of 2000 mls with DI water.

2. Buffer Stock Solution
134 g Sodium Phosphate, dibasic ($Na_2HPO_4 \cdot 7H_2O$)
20 g Sodium Hydroxide (NaOH)
1000 ml DI Water, qs

Dissolve 134 g of sodium phosphate, dibasic, in approximately 800 ml of DI water. Next, dissolve 20 g of NaOH and bring to volume of 1000 mls with DI water.

3. Sodium Potassium Tartrate Solution (20%)
 200 g Potassium Sodium Tartrate
 1000mL DI Water, qs

Dissolve 200 g of potassium sodium tartrate in approximately 800 ml of DI water, and bring to volume of 1000 mls.

4. NaOH Solution (20%)
 200 g Sodium Hydroxide
 1000 ml DI Water, qs

Dissolve 200 grams of sodium hydroxide in approximately 800 mls of DI water and bring to volume of 1000 ml with DI water.

5. Working Buffer Reagent A

Amount	Amount	Amount	Amount
Buffer Stock Solution	100	200 ml	400 ml
20% Na+k+tart.Solution	125	250 ml	500 ml
20% NaOH Solution	125	250 ml	500 ml
Dichloroisocyanurate	0.5 g	1.0 g	2.0 g
DI Water	500 mls, qs	1000 ml, qs	2000 ml, qs

Combine reagents in specified order, add sodium dichloroisocyanurate and stir to dissolve. Fill to volume with DI water. Store in a dark bottle at 4°C. Stable for 3 days.

6. Sodium Salicylate Reagent B

- 160 g sodium salicylate
 0.6 g sodium nitroferricyanide
 2000mL DI water, qs

Dissolve 160 g of sodium salicylate in approximately 1500 mls of distilled water, add 0.3 g of sodium nirtoferricyanide and dissolve. Fill to 1 liter with distilled water. Store in a dark bottle at 4°C. Stable for 30 days.

Reagents are stored in dark polyethylene bottles at all times. Some reagents are stored at 4°C as indicated.

Standards:

1. Stock Solution A (100 ppm)

Dissolve 0.383 g of ammonium chloride dried at 105°C for 2 hours in approximately 800 ml of distilled water, fill to 1 liter with distilled-deionized water. Stable for 6 months.

2. Stock Solution B (50 ppm)

Pipet 50 mls of stock solution A into a 100 ml volumetric flask and fill to volume with TKN wash.

3. Working Standards

Prepared the working standards in 100 ml volumetric flasks. Fill to 100 ml with TKN wash. Standards are stable for 30 days if stored at 4°C.

<u>Volume of stock standard (ml)</u>	<u>concentration of working standards mg/L</u>
1.0 ml	0.5
2.0 ml	1.0
3.0 ml	1.5
4.0 ml	2.0
5.0 ml	2.5

Fill to 100 ml with TKN wash.

Apparatus:

1. West Co. Auto Analyzer System
2. Strip chart recorder or data handling system
3. Block digester
4. 660 nm filter

Procedures:

Note: The same digested samples are used for TKN and total phosphorus testing.

1. Label clean, dry 50-ml folin-wu tubes with sample numbers.
2. Add 10 ml of well-shaken sample to its tube with a calibrated pipet (up to 15 samples, filtered and unfiltered tubes for each sample.)
3. Add 1.5-2.0g Pope Kjeldahl #1 catalyst to each tube with a spoon.
4. Add 3 ml of concentrated sulfuric acid to each tube with a calibrated auto-pipet.
5. Heat in a digestion block 1.5 hours at 150°C to drive off water.
6. Cap each tube with a small funnel.
7. Raise the block temperature to 380°C and digest samples for 3 hours.
8. Turn off digestion block and allow samples to cool (2-3 hours). After the samples have cooled, transfer them from the block to the fume hood.

9. Rinse the funnels with distilled-deionized water.
10. Vortex the samples until the solids are dissolved. Slowly add distilled-deionized water to the samples while continuing to vortex. Add distilled water to each sample so that the volume of the sample is exactly 50 ml.
11. Cover and invert 20 times.
12. Transfer the samples into auto-analyzer cups, appropriately labeled.
13. Follow the method for Traacs 800.

Calculations:

1. A standard curve is prepared based on the peak height of each standard. The sample concentrations are determined using linear regression techniques.

QA/QC:

Note: 40 tubes are prepared for each digest, 14-15 filtered and unfiltered each sample, 2-4 duplicates, 3 EPAs and 3 blanks. Two EPA quality control samples are digested to ensure there will be an average value available in case one of the samples is destroyed or contaminated. An average is taken from their measure values.

1. One duplicate is prepared for the every sample numbering a multiple of 10.
2. Three EPA samples are digested with each set of samples.
3. Two blank samples are run with each digest.
4. One spike sample is run for every 10 samples.
5. Pleas see BSEWQL-13 for more detailed information

Precision and Accuracy:

Ave. Standard Deviation - 0.126 mg/L based on 40 samples
Ave. Percent Recovery - 97-101% based on 20 samples
Minimum Detection Limit - 0.10 mg/L

Minimum Detection Limit is defined as 2 times the recorder noise when operating at maximum sensitivity.

Reference:

1. EPA Methods for Chemical Analysis of Water and Wastes, USEPA-600/4-79-020, Nitrogen, Kjeldahl Total; Method 351.2
2. “Block Digester, Total Kjeldahl Nitrogen”, Scientific Instruments Product Information.

BSEWQL-7 - Procedures for the Determination of Ammonia (TRAACS 800)

The automated procedure for the determination of ammonia utilizes the Berthelot Reaction, in which the formation of a blue colored compound believed to be closely related to indophenol occurs when the solution of an ammonium salt is added to sodium phenoxide, followed by the addition of sodium hypochlorite. A solution of EDTA is added to the sample stream to eliminate the precipitation of the hydroxides of calcium and magnesium. Sodium nitroprusside is added to intensify the blue color.

Procedures

1. Filter samples as described in BSEWQL-2.
2. Transfer the filtrate into an autoanalyzer cup (see BSEWQL-2)
3. Analyze samples using an autoanalyzer.

Apparatus:

Same as BSEWQL-5

Reagents:

DI water refers to high quality reagent water, Type I or II as defined in ASTM Standards, Part 31, D1193-74.

1. Alkaline Phenol
83 g Phenol, Liquefied
96.0g -70 mls Sodium Hydroxide Solution, 50% w/w
1000 ml DI Water, qs
2. Sodium Hypochlorate Solution
86 ml Sodium Hypochlorate Solution, 5%
100 ml DI Water, qs
3. Sodium Nitroprusside Solution
1.1 g Sodium Nitroprusside
1000 ml DI Water, qs
4. Disodium EDTA
41.0 g Disodium EDTA
1.0 g Sodium Hydroxide, 50% w/w

Standards:

1. Stock Standard A (100 mg/L N)
0.4717 g Ammonium Sulfate
1000 ml DI Water, qs

In a one-liter volumetric flask containing about 800 ml of DI water, add 0.4717 g of ammonium sulfate and swirl to dissolve. Dilute to one liter with distilled water and mix thoroughly.

2. Stock Standard B (20 mg/L N)
20.0 ml Stock Standard A
100 ml DI Water, qs

Dilute 20.0 ml of stock standard A to 100 ml with DI water and mix thoroughly. Prepare fresh daily.

3. Working standard solutions

<u>ml Stock B</u>	<u>mg/L N</u>
2.0	0.4
4.0	0.8
6.0	1.2
8.0	1.6
10.0	2.0
15.0	3.0

Transfer aliquots of Stock Standard B as noted above to individual 100-ml volumetric flasks. Dilute to volume with DI water and mix thoroughly. Prepare fresh daily.

Calculations:

1. A standard curve is prepared based on the peak height of each standard. The sample concentrations are determined using linear regression techniques.
2. Distilled-deionized water is used for blank measurements.

QA/QC:

1. One duplicate is run for every 10 samples
2. One EPA standard is run for 20 samples
3. One spike is run for every 10 samples
4. One blank is run daily, or for every 20 samples, whichever is more frequent.
5. Please see BSEWQL-13 for more information.

Precision and Accuracy:

Ave. Standard Deviation - 0.060 mg/L based on 49 samples

Ave. Percent Recovery - 98-102% based on 20 samples

Minimum Detection Limit - 0.01 mg/L

Precision and accuracy results are calculated quarterly. The minimum detection limit is defined as 2 times the recorder noise when operating at maximum sensitivity.

Reference:

1. EPA Method for Chemical Analysis of Water and Wastes, VSEPA-600/4-79-020, Nitrogen, Ammonia: Method 350.1

BSEWQL-8 - Procedures for the Determination of Nitrite plus Nitrate (TRAACS 800)

The automated procedure for the determination of nitrate utilizes the reaction whereby nitrate is reduced to nitrite by an alkaline solution of hydrazine sulfate containing a copper catalyst. The stream is then treated with sulfanilamide under acidic conditions to form a soluble dye which is measured colorimetrically. The final product measured represents the nitrite ion originally present plus that formed from the nitrate. Chloride, sulfide, ferric ion and phosphate ion interfere.

In order to determine nitrate levels, the nitrite alone must be subtracted from the total (nitrate + nitrite). This can be achieved by substituting, distilled water for the copper, hydrazine and NaOH lines on the manifold. A separate calibration curve should be determined for nitrate plus nitrite and for nitrite alone.

Procedures:

Same as BSEWQL -7

Apparatus:

Same as BSEWQL-7, except use 500 mm filter.

Reagents:

DI water refers to high quality reagent waters, Type I or Type II as defined in ASTM standards, Part 31, p. 1193-74.

1. Color Reagent
 - 10g Sulfanilamide
 - 200 ml Phosphoric Acid, conc. (H_3PO_4)
 - 0.8 g N-1-Naphthylethylenediamine dihydrochloride
 - 1000 ml DI Water, qs
 - 1 ml Brij-35
2. Stock Copper Solution
 - 3.0 g Cupric Sulfate
 - 1000 ml DI Water, qs
3. Stock Hydrazine Sulfate Solution
 - 30.0 g Hydrazine Sulfate
 - 1000 ml DI Water, qs

4. Working Reductor Solution

30 ml	Hydrazine Sulfate Stock Solution
10 ml	Cupric Sulfate Stock Solution
1000 ml	DI Water, qs

5. Sodium Hydroxide Solution

14.4 g (10.5 ml)	Sodium Hydroxide, 50% w/w
1000 ml	DI Water, qs
2 ml	Brij-35

Standards:

1. Stock Solution A (100 mg/L N)

0.7218 g	Potassium Nitrate
1000 ml	DI Water, qs

Dry about 1 gram of potassium nitrate in an oven at 100-150°C for two hours. Desiccate until cool. Dissolve 0.7128 grams of dried KNO₃ in about 800 ml of DI water. Dilute to 1 liter.

2. Stock Solution B (20 mg/L N)

20.0 ml	Stock Solution A
100 ml	DI water, qs

Dilute 20.0 ml of stock solution A to 100 mls with DI water and mix thoroughly. Prepare fresh daily.

3. Working Standards Solutions

<u>ml Stock B</u>	<u>mg/L N</u>
2.0	0.4
4.0	0.8
6.0	1.2
8.0	1.6
10.0	2.0

Transfer aliquots of stock solution B as noted to individual 100-ml volumetric flasks. Dilute to volume with DI water and mix thoroughly. Prepare fresh daily.

Calculations:

1. A standard curve is prepared based on the peak heights of each standard. The sample concentrations are determined using linear regression techniques.
2. Distilled-deionized water is used for blank measurements.

QA/QC:

1. One duplicate is run for every 10 samples.
2. One EPA standard is run for every 20 samples
3. One spike is run for every 10 samples
4. One blank is run daily, or every 20 samples, whichever is more frequent.
5. Please see BSEWQL-13 for more information.

Precision and Accuracy:

Ave. Standard Deviation = 0.026 mg/L based on 52 samples.

Ave. Percent Recovery = 96-100% based on 20 samples.

Minimum Detection Limit = 0.05 mg/L

Precision and Accuracy results are calculated quarterly. The minimum detection limit is defined as 2 times the recorder noise when operating at maximum sensitivity.

Reference:

1. EPA Methods for Chemical Analysis of Water and Wastes, USEPA-600/4-79-020, Nitrogen, Nitrate-Nitrite; Method 353.2.
2. “Nitrite plus Nitrite in Water and Wastewater”, Scientific Instruments Products Information.

Procedure for Metals Preservation and Digestion

Preservation:

1. Before storm event, soak bottle used to store sample in 10% Nitric acid bath for 48 hours, rinse with distilled-deionized water, dry and store with lids on in a clean dry environment.
2. After storm event, invert sample 20 times to mix thoroughly. Pour 250 mls into properly labeled acid-soaked bottle. For every 10th sample pour 500 mls into bottle for duplicate sample.
3. Store samples in a cool dry environment. Do not refrigerate or freeze.

Digestion:

Apparatus:

1. Fume hood
2. Nitric Acid
3. 250 ml beakers
4. Ribbed glass beaker covers
5. 125 ml bottles
6. Graduated cylinder
7. Bunsen Burners
8. Perkin-Elmer Atomic Absorbtion Spectrophotometer (See Figure A1)



Figure A1. Perkin-Elmer Atomic Absorbtion Spectrophotometer

Procedure:

1. Soak all necessary materials in 10% Nitric acid solution for 24 hours.
2. Rinse all equipment with distilled-deionized water.
3. Turn on fume hood and Bunsen burners.
4. Fill labeled beakers with 100 ml of thoroughly mixed sample.
5. Under the hood add 5 ml of concentrated HNO_3 (Trace Metal Grade) and place on burner with ribbed cover on to allow venting.
6. Rinse graduated cylinder thoroughly with distilled-deionized water.
7. Repeat steps 4-6 with remaining samples. Also prepare one blank and two duplicates. A total of nine samples (with one blank and two duplicates) can be digested in one session.
8. Reflux – don't boil – the sample until total sample volume is approximately 25 ml. (Approximately 2 hours).
9. Remove from heat and cool.
10. When sample is sufficiently cool, add distilled-deionized water to bring volume back to 100 ml. Be sure to rinse out all residue remaining on the beaker and cover.
11. Pour into properly labeled 125-ml bottles.
12. Repeat steps 9-11 for all remaining samples.
13. Analyze samples using the Perkin-Elmer Atomic Absorbtion Spectrophotometer

Copper, cadmium and lead were analyzed by graphite furnace atomic absorption, and zinc was analyzed by flame atomic absorption.

Total Organic Carbon Analysis

Apparatus:

1. Dohrmann Carbon Analyzer (See Figure A2)
2. 2000 mg/L Carbon Standard
3. Potassium Persulfide (H_3PO_4)



Figure A2. Dohrmann Carbon Analyzer Used for TOC Analysis

Procedure:

1. Prepare Carbon standard fresh daily for 10 mg/L standard setting.
2. Warm refrigerated to room temperature.
3. Add 5 drops of H_3PO_4 and sparge samples 5 minutes each.
4. Calibrate TOC Machine to standard.
5. Insert sample carefully into machine with proper syringe being sure no air bubble are trapped in the syringe.
6. Measure each sample twice and average the readings.
7. Record results.

Note: More information can be obtained on any of these procedures through Dr. David F. Kibler at Virginia Tech.

Appendix B

Selected Program Codes

Inflow Hydrograph

```
Sub Command1_Click ()
Static startdate, StopDate, Startyear, StormOn As Integer
Static BeginEnd(50, 2) As String * 12
Static Coll, Yr, Jday, mtime, Crap, Dip, BadList As Integer
Static MV, depth, PTemp, Stemp, DLTemp, Volt, Feet, Flow, TimeHours, Volume, FlowHold As Double
Static Ar, DX, Aa, Pa, area1, Perimeter1 As Double
startdate = CInt(Text1.Text)
Startyear = CInt(Text3.Text)
StormOn = 0
Volume = 0
Flow = 0
Ar = 0
DX = 0
area1 = 0
Perimeter1 = 0

If Startyear = 95 Then
    Open "c:\thedata\1995\DL1.DIR" For Input As 1
ElseIf Startyear = 96 Then
    Open "c:\thedata\1996\dl1.dir" For Input As 1
End If

FileCounter = 0
Do While Not EOF(1)
    FileCounter = FileCounter + 1
    Input #1, BeginEnd(FileCounter, 1)
    BeginEnd(FileCounter, 2) = Mid$(BeginEnd(FileCounter, 1), 10, 12)
Loop
```

```

Close #1
For I = 1 To FileCounter
  If startdate <= CInt(BeginEnd(I, 2)) Then
    Exit For
  End If
Next I

If Startyear = 95 Then
  Open "c:\thedata\hyd95\" + "PIPEHY2." + CStr(startdate) For Output As 3
ElseIf Startyear = 96 Then
  Open "c:\thedata\hyd96\" + "PIPEHY2." + CStr(startdate) For Output As 3
End If

TimeHours = 0
FileCheck:

If Startyear = 95 Then
  Open "c:\thedata\1995\" + BeginEnd(I, 1) For Input As 2
ElseIf Startyear = 96 Then
  Open "c:\thedata\1996\" + BeginEnd(I, 1) For Input As 2
End If

Do While Not EOF(2)
  Input #2, Col1
  If Col1 = 111 Then
    Input #2, Yr, Jday, mtime, Crap, MV, depth, PTemp, Stemp, DLTemp, Volt, Dip
    BadList = 1
  Else
    Input #2, Dummy2, Dummy3, Dummy4, Dummy5, Dummy6, Dummy7
  End If

```

BadList = 0

End If

If Jday >= startdate Then

 If depth > 0 And StormOn = 0 Then

 StormOn = 1

 End If

FlowHold = Flow

If depth > 0 Then

 If startdate > 237 And Startyear = 95 Then

 Feet = depth / 1000# * 3.281

 Flow = 4# ^ (5 / 2) * 3.685 * (Feet / 4#) ^ (1.868) * (21.676 / 20.46)

 ElseIf startdate < 237 And startdate > 227 And Startyear = 95 Then

 depth = .8277 * MV - 163.55

 Feet = depth / 25.4 / 12#

 If Feet > 0 Then

 Flow = 4# ^ (5 / 2) * 3.685 * (Feet / 4#) ^ (1.868) * (21.676 / 20.46)

 Else Flow = 0

 End If

 ElseIf startdate <= 227 And Startyear = 95 And startdate > 170 Then

 Feet = depth - .6666

 If Feet > 0 Then

 Flow = 4# ^ (5 / 2) * 3.685 * (Feet / 4#) ^ (1.868) * (21.676 / 20.46)

 Else Flow = 0

 End If

 ElseIf startdate < 170 And Startyear = 95 Then

 If depth > 2# Then

 depth = depth - 2#

```

Ar = (4# - depth ^ 2) ^ .5 * depth
DX = .001
Aa = 0
Pa = 0
For I = (4# - depth ^ 2) ^ .5 To (2 - DX) Step DX
  Aa = Aa + DX * (4# - (I + DX / 2#) ^ 2) ^ .5
  Pa = Pa + ((I - (I + DX)) ^ 2 + ((4# - I ^ 2) ^ .5 - (4# - (I + DX) ^ 2) ^ .5) ^ 2) ^ .5
Next I
area1 = 2# * (Ar + Aa) + 3.14159 * 4 / 2#
Perimeter1 = 2# * (Pa) + 3.14159 * 2
Flow = 1.49 / .015 * area1 * (area1 / Perimeter1) ^ (2# / 3#) * (.00515) ^ .5 * (21.676 / 20.46)
Else
  depth = 2# - depth
  Ar = (4# - depth ^ 2) ^ .5 * depth
  DX = .001
  Aa = 0
  Pa = 0
  For I = (4# - depth ^ 2) ^ .5 To (2 - DX) Step DX
    Aa = Aa + DX * (4# - (I + DX / 2#) ^ 2) ^ .5
    Pa = Pa + ((I - (I + DX)) ^ 2 + ((4# - I ^ 2) ^ .5 - (4# - (I + DX) ^ 2) ^ .5) ^ 2) ^ .5
  Next I
  area1 = 3.14159 * 4# / 2 - 2 * (Ar + Aa)
  Perimeter1 = 3.14159 * 2# - 2 * (Pa)
  Flow = 1.49 / .015 * area1 * (area1 / Perimeter1) ^ (2# / 3#) * (.00515) ^ .5 * (21.676 / 20.46)
End If
ElseIf Startyear = 96 Then
  Feet = depth / 1000# * 3.281
  Flow = 4# ^ (5 / 2) * 3.685 * (Feet / 4#) ^ (1.868) * (21.676 / 20.46)
End If
Else

```

```
Flow = 0
End If
If BadList = 1 Then
    Write #3, Jday, mtime, Flow
    Volume = Volume + ((Flow + FlowHold) / 2# * 5# * 60#)
End If

If StormOn = 1 And Jday = (startdate + 2) Then
    StormOn = 2
    Exit Do
End If
End If

Loop

Close #2

If StormOn = 2 Then
Else
I = I + 1
GoTo FileCheck
End If

Write #3, Volume
Close #3
MsgBox "Finished Processing", 64

End Sub
```

Outflow Hydrograph

```
Sub Command3_Click ()
Static startdate, Startyear, StormOn As Integer
Static BeginEnd(50, 2) As String * 12
Static Col1, Yr, Jday, mtime, Serial, Rain, Dip, count, BadList As Integer
Static MV, depth, Feet, PTemp, Ctemp, DLTemp, Volt, Atemp, Flow, TimeHours As Double
Static Volume, depthsum, average As Double
startdate = CInt(Text1.Text)
Startyear = CInt(Text3.Text)
count = 1#
depthsum = 0
StormOn = 0
Volume = 0
average = 0

If Startyear = 95 Then
    Open "c:\thedata\1995\DL2.DIR" For Input As 1
ElseIf Startyear = 96 Then
    Open "c:\thedata\1996\dl2.dir" For Input As 1
End If

FileCounter = 0
Do While Not EOF(1)
    FileCounter = FileCounter + 1
    Input #1, BeginEnd(FileCounter, 1)
    BeginEnd(FileCounter, 2) = Mid$(BeginEnd(FileCounter, 1), 10, 12)
Loop

Close #1
```

```

For I = 1 To FileCounter
  If startdate <= CInt(BeginEnd(I, 2)) Then
    Exit For
  End If
Next I

If Startyear = 95 Then
  Open "c:\thedata\hyd95\" + "PONDHYD." + CStr(startdate) For Output As 3
ElseIf Startyear = 96 Then
  Open "c:\thedata\hyd96\" + "PONDHYD." + CStr(startdate) For Output As 3
End If

TimeHours = 0
FileCheck2:

If Startyear = 95 Then
  Open "c:\thedata\1995\" + BeginEnd(I, 1) For Input As 2
ElseIf Startyear = 96 Then
  Open "c:\thedata\1996\" + BeginEnd(I, 1) For Input As 2
End If

Do While Not EOF(2)

Input #2, Col1
If Col1 = 113 Then
  Input #2, Yr, Jday, mtime, Serial, Rain, MV, Feet, PTemp, Ctemp, DLTemp, Volt, Atemp, Dip
  BadList = 1
ElseIf Col1 = 210 Then
  Input #2, Dummy2, Dummy3, Dummy4, Dummy5, Dummy6
  BadList = 0

```

```

ElseIf Col1 = 540 Then
    Input #2, Dummy2, Dummy3, Dummy4, Dummy5, Dummy6, Dummy7, Dummy8, Dummy9, Dummy10, Dummy11
    BadList = 0
Else
    Input #2, Dummy2, Dummy3, Dummy4, Dummy5, Dummy6, Dummy7
    BadList = 0
End If

```

depth = .00512 * MV - 1.6709

```

If StormOn = 0 And Jday = startdate Then
    If count = 1# Then
        average = depth
        depthsum = depth
        count = 2#
    ElseIf depth < (1.1 * average) And BadList = 1 Then
        depthsum = depthsum + depth
        average = depthsum / count
        count = count + 1#
    End If
End If

```

```

If Jday >= startdate Then
    If depth >= (1.1 * average) And StormOn <= 1 Then
        StormOn = 1
        If depth <= 4.24 Then
            Flow = .6 * .0491 * (2# * 32.2 * (depth - .24)) ^ .5
        Else
            Flow = .6 * .0491 * (2# * 32.2 * (depth - .24)) ^ .5 + (3# * 17.33 * (depth - 4.24) ^ 1.5)
        End If
    End If

```

```

If BadList = 1 Then
    Write #3, Jday, mtime, Flow, Rain
    Volume = Volume + (Flow * 5# * 60#)
End If
End If

If StormOn = 1 And depth <= (1.025 * average) And Jday > startdate Then
    StormOn = 2
End If

If StormOn = 1 And Jday > (startdate + 3) Then
    StormOn = 2
End If
End If
Loop
Close #2

If StormOn = 2 Then
Else
I = I + 1
GoTo FileCheck2
End If

Write #3, Volume
Close #3
MsgBox "Finished Processing", 64
End Sub

```

Inflow Loads (Code for outflow loads is the same, but uses different files for input flows output loadings)

```
Sub Command1_Click ()
Static startdate, JDay As Integer
Static hydro(1 To 1000, 1 To 3) As Double
Static pollute(1 To 100, 1 To 16) As Variant
Static NH4, FTKN, TKN, NO3N, PO4, FT, TP, TSS As Double
Static Cd, Cu, Pb, Zn, TOC As Variant
Static MTime As String
pollute(1, 1) = -1
startdate = CInt(Text1.Text)
NH4 = 0
FTKN = 0
TKN = 0
NO3N = 0
PO4 = 0
FTP = 0
TP = 0
TSS = 0
Cd = 0
Cu = 0
Pb = 0
Zn = 0
TOC = 0
temp = 0

Open "c:\thedata\labdata\labdata.csv" For Input As 1

pcounter = 1
```

```

Do While pollute(1, 1) < startdate
Input #1, pollute(1, 1)
If IsNumeric(pollute(1, 1)) Then
Input #1, dummy, dummy, dummy, pollute(1, 2), pollute(1, 3), pollute(1, 4), pollute(1, 5), pollute(1, 6), pollute(1, 7), pollute(1, 8), pollute(1, 9), pollute(1, 10), pollute(1, 11), pollute(1, 12), pollute(1, 13), pollute(1, 14), pollute(1, 15), pollute(1, 16)
pollute(pcounter, 2) = Mid$(pollute(pcounter, 2), 1, 3)

If Len(CStr(pollute(pcounter, 3))) = 4 Then
    pollute(pcounter, 3) = CDbI(pollute(pcounter, 1) + (CDbl(Mid$(CStr(pollute(pcounter, 3)), 3, 2)) / 60# +
CDbl(Mid$(CStr(pollute(pcounter, 3)), 1, 2))) / 24#)
    ElseIf Len(CStr(pollute(pcounter, 3))) = 3 Then
        pollute(pcounter, 3) = CDbI(pollute(pcounter, 1) + (CDbl(Mid$(CStr(pollute(pcounter, 3)), 2, 2)) / 60# +
CDbl(Mid$(CStr(pollute(pcounter, 3)), 1, 1))) / 24#)
    ElseIf Len(CStr(pollute(pcounter, 3))) = 2 Then
        pollute(pcounter, 3) = CDbI(pollute(pcounter, 1) + (CDbl(Mid$(CStr(pollute(pcounter, 3)), 1, 2)) / 60#) / 24#)
    ElseIf Len(CStr(pollute(pcounter, 3))) = 1 Then
        pollute(pcounter, 3) = CDbI(pollute(pcounter, 1) + (CDbl(Mid$(CStr(pollute(pcounter, 3)), 1, 1)) / 60#) / 24#)
End If

If pollute(pcounter, 2) = "QV2" Then
    pollute(1, 1) = -1
    End If
Else
pollute(1, 1) = -1
End If

Loop

Do While Not EOF(1)

```

```

pcounter = pcounter + 1
Input #1, pollute(pcounter, 1)
If IsNumeric(pollute(pcounter, 1)) Then
Input #1, dummy, dummy, dummy, pollute(pcounter, 2), pollute(pcounter, 3), pollute(pcounter, 4), pollute(pcounter, 5),
pollute(pcounter, 6), pollute(pcounter, 7), pollute(pcounter, 8), pollute(pcounter, 9), pollute(pcounter, 10), pollute(pcounter,
11), pollute(pcounter, 12), pollute(pcounter, 13), pollute(pcounter, 14), pollute(pcounter, 15), pollute(pcounter, 16)
pollute(pcounter, 2) = Mid$(pollute(pcounter, 2), 1, 3)

If Len(CStr(pollute(pcounter, 3))) = 4 Then
    pollute(pcounter, 3) = CDbI(pollute(pcounter, 1) + (CDbl(Mid$(CStr(pollute(pcounter, 3)), 3, 2)) / 60# +
CDbl(Mid$(CStr(pollute(pcounter, 3)), 1, 2))) / 24#)
    ElseIf Len(CStr(pollute(pcounter, 3))) = 3 Then
        pollute(pcounter, 3) = CDbI(pollute(pcounter, 1) + (CDbl(Mid$(CStr(pollute(pcounter, 3)), 2, 2)) / 60# +
CDbl(Mid$(CStr(pollute(pcounter, 3)), 1, 1))) / 24#)
    ElseIf Len(CStr(pollute(pcounter, 3))) = 2 Then
        pollute(pcounter, 3) = CDbI(pollute(pcounter, 1) + (CDbl(Mid$(CStr(pollute(pcounter, 3)), 1, 2)) / 60#) / 24#)
    ElseIf Len(CStr(pollute(pcounter, 3))) = 1 Then
        pollute(pcounter, 3) = CDbI(pollute(pcounter, 1) + (CDbl(Mid$(CStr(pollute(pcounter, 3)), 1, 1)) / 60#) / 24#)
End If

If pollute(pcounter, 2) = "QV2" Then
    pcounter = pcounter - 1
End If
Else
    pcounter = pcounter - 1
Exit Do
End If

Loop

```

Close #1

Open "c:\thedata\hyd95\" + "PIPEHY2." + CStr(startdate) For Input As 2

Hcounter = 0

Do While Not EOF(2)

Hcounter = Hcounter + 1

Input #2, hydro(Hcounter, 1)

If Len(CStr(hydro(Hcounter, 1))) <= 3 Then

 Input #2, hydro(Hcounter, 2), hydro(Hcounter, 3)

 Else

 Hcounter = Hcounter - 1

 Exit Do

End If

If Len(CStr(hydro(Hcounter, 2))) = 4 Then

 hydro(Hcounter, 2) = CDbl(hydro(Hcounter, 1) + (CDbl(Mid\$(CStr(hydro(Hcounter, 2)), 3, 2)) / 60# +
CDbl(Mid\$(CStr(hydro(Hcounter, 2)), 1, 2))) / 24#)

 ElseIf Len(CStr(hydro(Hcounter, 2))) = 3 Then

 hydro(Hcounter, 2) = CDbl(hydro(Hcounter, 1) + (CDbl(Mid\$(CStr(hydro(Hcounter, 2)), 2, 2)) / 60# +
CDbl(Mid\$(CStr(hydro(Hcounter, 2)), 1, 1))) / 24#)

 ElseIf Len(CStr(hydro(Hcounter, 2))) = 2 Then

 hydro(Hcounter, 2) = CDbl(hydro(Hcounter, 1) + (CDbl(Mid\$(CStr(hydro(Hcounter, 2)), 1, 2)) / 60#) / 24#)

 ElseIf Len(CStr(hydro(Hcounter, 2))) = 1 Then

 hydro(Hcounter, 2) = CDbl(hydro(Hcounter, 1) + (CDbl(Mid\$(CStr(hydro(Hcounter, 2)), 1, 1)) / 60#) / 24#)

End If

Loop

Close #2

scounter = 1
p2counter = 1

If startdate < 198 Then

Do While scounter <= Hcounter

If hydro(scounter, 2) < pollute(p2counter, 3) Then

NH4 = NH4 + (pollute(p2counter, 4) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
FTKN = FTKN + (pollute(p2counter, 5) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
TKN = TKN + (pollute(p2counter, 6) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
NO3N = NO3N + (pollute(p2counter, 7) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
PO4 = PO4 + (pollute(p2counter, 8) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
FTP = FTP + (pollute(p2counter, 9) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
TP = TP + (pollute(p2counter, 10) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
TSS = TSS + (pollute(p2counter, 11) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
scounter = scounter + 1

End If

If hydro(scounter, 2) >= pollute(p2counter, 3) And hydro(scounter, 2) <= pollute(pcounter, 3) Then

If hydro(scounter, 2) <= pollute(p2counter + 1, 3) Then

NH4 = NH4 + (pollute(p2counter + 1, 4) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
FTKN = FTKN + (pollute(p2counter + 1, 5) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
TKN = TKN + (pollute(p2counter + 1, 6) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
NO3N = NO3N + (pollute(p2counter + 1, 7) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
PO4 = PO4 + (pollute(p2counter + 1, 8) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
FTP = FTP + (pollute(p2counter + 1, 9) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)

```
TP = TP + (pollute(p2counter + 1, 10) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
TSS = TSS + (pollute(p2counter + 1, 11) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
scounter = scounter + 1
```

```
ElseIf p2counter <= (pcounter - 1) Then
```

```
p2counter = p2counter + 1
NH4 = NH4 + (pollute(p2counter + 1, 4) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
FTKN = FTKN + (pollute(p2counter + 1, 5) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
TKN = TKN + (pollute(p2counter + 1, 6) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
NO3N = NO3N + (pollute(p2counter + 1, 7) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
PO4 = PO4 + (pollute(p2counter + 1, 8) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
FTP = FTP + (pollute(p2counter + 1, 9) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
TP = TP + (pollute(p2counter + 1, 10) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
TSS = TSS + (pollute(p2counter + 1, 11) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
scounter = scounter + 1
```

```
End If
```

```
End If
```

```
If hydro(scounter, 2) > pollute(pcounter, 3) Then
```

```
NH4 = NH4 + (pollute(pcounter, 4) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
FTKN = FTKN + (pollute(pcounter, 5) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
TKN = TKN + (pollute(pcounter, 6) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
NO3N = NO3N + (pollute(pcounter, 7) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
PO4 = PO4 + (pollute(pcounter, 8) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
FTP = FTP + (pollute(pcounter, 9) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
TP = TP + (pollute(pcounter, 10) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
TSS = TSS + (pollute(pcounter, 11) * hydro(scounter, 3) * 5 * 60 * .02832 * 1000 / 1000)
scounter = scounter + 1
```

```
End If
```

Loop

End If

If startdate >= 198 Then

Do While scounter <= Hcounter

If hydro(scounter, 2) < pollute(1, 3) Then

NH4 = NH4 + (pollute(p2counter, 4) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)

FTKN = FTKN + (pollute(p2counter, 5) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)

TKN = TKN + (pollute(p2counter, 6) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)

NO3N = NO3N + (pollute(p2counter, 7) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)

PO4 = PO4 + (pollute(p2counter, 8) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)

FTP = FTP + (pollute(p2counter, 9) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)

TP = TP + (pollute(p2counter, 10) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)

TSS = TSS + (pollute(p2counter, 11) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)

Cd = Cd + (pollute(p2counter, 12) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000# / 1000#)

Cu = Cu + (pollute(p2counter, 13) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000# / 1000#)

Pb = Pb + (pollute(p2counter, 14) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000# / 1000#)

Zn = Zn + (pollute(p2counter, 15) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)

TOC = TOC + (pollute(p2counter, 16) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)

End If

If hydro(scounter, 2) >= pollute(p2counter, 3) And hydro(scounter, 2) <= pollute(pcounter, 3) Then

If hydro(scounter, 2) <= pollute(p2counter + 1, 3) Then

NH4 = NH4 + (pollute(p2counter + 1, 4) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)

FTKN = FTKN + (pollute(p2counter + 1, 5) * CDbl(hydro(scounter, 3)) * 5# * 60# * .02832 * 1000# / 1000#)

TKN = TKN + (pollute(p2counter + 1, 6) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)

NO3N = NO3N + (pollute(p2counter + 1, 7) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)

```

PO4 = PO4 + (pollute(p2counter + 1, 8) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)
FTP = FTP + (pollute(p2counter + 1, 9) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)
TP = TP + (pollute(p2counter + 1, 10) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)
TSS = TSS + (pollute(p2counter + 1, 11) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)
Cd = Cd + (pollute(p2counter + 1, 12) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000# / 1000#)
Cu = Cu + (pollute(p2counter + 1, 13) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000# / 1000#)
Pb = Pb + (pollute(p2counter + 1, 14) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000# / 1000#)
Zn = Zn + (pollute(p2counter + 1, 15) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)
TOC = TOC + (pollute(p2counter + 1, 16) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)
ElseIf p2counter <= (pcounter - 1) Then
  p2counter = p2counter + 1
  NH4 = NH4 + (pollute(p2counter + 1, 4) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)
  FTKN = FTKN + (pollute(p2counter + 1, 5) * CDbl(hydro(scounter, 3)) * 5# * 60# * .02832 * 1000# / 1000#)
  TKN = TKN + (pollute(p2counter + 1, 6) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)
  NO3N = NO3N + (pollute(p2counter + 1, 7) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)
  PO4 = PO4 + (pollute(p2counter + 1, 8) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)
  FTP = FTP + (pollute(p2counter + 1, 9) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)
  TP = TP + (pollute(p2counter + 1, 10) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)
  TSS = TSS + (pollute(p2counter + 1, 11) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)
  Cd = Cd + (pollute(p2counter + 1, 12) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000# / 1000#)
  Cu = Cu + (pollute(p2counter + 1, 13) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000# / 1000#)
  Pb = Pb + (pollute(p2counter + 1, 14) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000# / 1000#)
  Zn = Zn + (pollute(p2counter + 1, 15) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)
  TOC = TOC + (pollute(p2counter + 1, 16) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)
End If
End If

If hydro(scounter, 2) > pollute(pcounter, 3) Then
  NH4 = NH4 + (pollute(pcounter, 4) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)
  FTKN = FTKN + (pollute(pcounter, 5) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)

```

```

TKN = TKN + (pollute(pcounter, 6) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)
NO3N = NO3N + (pollute(pcounter, 7) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)
PO4 = PO4 + (pollute(pcounter, 8) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)
FTP = FTP + (pollute(pcounter, 9) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)
TP = TP + (pollute(pcounter, 10) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)
TSS = TSS + (pollute(pcounter, 11) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)
Cd = Cd + (pollute(pcounter, 12) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000# / 1000#)
Cu = Cu + (pollute(pcounter, 13) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000# / 1000#)
Pb = Pb + (pollute(pcounter, 14) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000# / 1000#)
Zn = Zn + (pollute(pcounter, 15) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)
TOC = TOC + (pollute(pcounter, 16) * hydro(scounter, 3) * 5# * 60# * .02832 * 1000# / 1000#)

```

End If

```
scounter = scounter + 1
```

Loop

End If

```
Open "c:\thedata\labdata\loads95\" + "PIPELOD2." + CStr(startdate) For Output As 3
```

```
If startdate < 198 Then
```

```
Write #3, "NH4", NH4
```

```
Write #3, "FTKN", FTKN
```

```
Write #3, "TKN", TKN
```

```
Write #3, "NO3N", NO3N
```

```
Write #3, "PO4", PO4
```

```
Write #3, "FTP", FTP
```

```
Write #3, "TP", TP
```

```
Write #3, "TSS", TSS
```

```
ElseIf startdate >= 198 Then
```

```
Write #3, "NH4", NH4
```

```
Write #3, "FTKN", FTKN
```

```
Write #3, "TKN", TKN
Write #3, "NO3N", NO3N
Write #3, "PO4", PO4
Write #3, "FTP", FTP
Write #3, "TP", TP
Write #3, "TSS", TSS
Write #3, "Cd", Cd
Write #3, "Cu", Cu
Write #3, "Pb", Pb
Write #3, "Zn", Zn
Write #3, "TOC", TOC
End If
Close #3
MsgBox "Finished Processing", 64
End Sub
```

Appendix C

Discrete Sample Lab Results

Date	Sample #	TIME	NH4 (ppm)	FTKN (ppm)	TKN (ppm)	NO3-N (ppm)	TN (ppm)	PO4 (ppm)	FTP (ppm)	TP (ppm)
6/1/95	QV12	8:35	0.087	1.370	12.448	0.949	13.397	ND	0.05	0.31
6/2/95	QV13	8:50	0.013	0.998	2.569	0.706	3.275	ND	ND	0.15
6/1/95	QV14	9:05	0.049	1.411	1.370	0.625	1.995	ND	ND	0.06
6/1/95	QV16	9:35	0.047	0.709	3.023	0.737	3.760	ND	0.01	0.06
6/1/95	QV17	9:50	0.08	1.039	1.081	0.803	1.884	ND	ND	0.04
6/1/95	QV18	10:05	0.085	1.949	1.453	0.831	2.284	ND	ND	0.105
6/1/95	QV19	10:20	0.069	1.205	0.998	0.805	1.803	ND	ND	0.05
6/1/95	QV110	11:20	0.004	0.874	0.585	0.331	0.916	ND	ND	0.08
6/1/95	QV111	12:20	0.011	1.039	0.130	0.28	0.410	ND	ND	0.025
6/1/95	QV112	13:20	0.089	0.006	0.213	0.407	0.620	ND	ND	0.07
6/1/95	QV113	14:20	0.049	1.205	4.760	0.787	5.547	ND	ND	0.04
6/1/95	QV115	8:32	ND	0.419	2.238	1.098	3.336	0.004	ND	0.11
6/1/95	QV116	8:47	ND	0.171	1.081	0.812	1.893	0.002	ND	0.145
6/1/95	QV117	9:02	ND	0.461	0.667	0.655	1.322	0.002	ND	0.075
6/1/95	QV118	9:17	ND	0.089	0.419	0.656	1.075	ND	0.065	0.01
6/1/95	QV119	9:32	ND	0.006	1.577	0.727	2.304	0.001	0.075	ND
6/1/95	QV120	9:47	ND	0.184	ND	0.706	0.706	0.01	ND	0.1
6/1/95	QV121	10:02	ND	ND	ND	0.738	0.738	0.006	ND	0.08
6/1/95	QV122	10:17	ND	0.303	0.343	0.796	1.139	0.016	ND	0.075
6/1/95	QV123	10:32	ND	0.858	0.501	0.928	1.429	0.011	ND	0.04
6/1/95	QV124	11:32	ND	0.580	0.184	1.399	1.583	ND	ND	0.005
6/1/95	QV126	12:50	ND	0.580	0.303	0.523	0.826	ND	ND	0.155
6/1/95	QV127	13:05	ND	ND	0.144	0.512	0.656	ND	ND	0.12
6/1/95	QV128	13:20	ND	ND	0.224	0.538	0.762	ND	ND	0.105
6/1/95	QV129	13:35	ND	ND	0.541	0.483	1.024	ND	ND	0.105
6/1/95	QV130	13:50	ND	ND	0.382	0.367	0.749	ND	ND	0.08
6/1/95	QV131	14:05	0.028	ND	0.343	0.335	0.678	ND	ND	0.07
6/1/95	QV132	14:20	ND	ND	0.105	0.42	0.525	ND	0.005	0.06
6/1/95	QV133	14:35	0.023	7.237	0.144	0.527	0.671	ND	ND	0.005
6/1/95	QV134	15:35	0.019	ND	0.977	0.336	1.313	ND	0.08	0.05
6/1/95	QV135	16:35	ND	0.065	0.224	0.604	0.828	ND	0.05	ND
6/1/95	QV21	18:08	ND	ND	ND	0.374	0.374	ND	ND	0.075
6/2/95	QV22	11:38	ND	ND	ND	0.232	0.232	ND	ND	0.075
6/2/95	QV23	13:37	ND	ND	ND	0.253	0.253	ND	ND	0.045
6/1/95	QV136	20:18	0.087	ND	1.161	0.954	2.115	ND	ND	0.155
6/1/95	QV137	20:33	ND	ND	0.091	0.257	0.348	ND	ND	0.14
6/1/95	QV138	20:48	ND	ND	ND	0.189	0.189	ND	ND	0.11
6/1/95	QV139	21:03	0.012	ND	0.091	0.166	0.257	ND	ND	0.09
6/1/95	QV140	21:18	ND	ND	0.052	0.181	0.233	ND	0.005	0.22
6/1/95	QV141	21:33	NS	NS	NS	NS	NS	NS	NS	NS
6/1/95	QV142	21:48	ND	0.091	ND	0.32	0.320	ND	ND	0.05
6/1/95	QV143	22:03	ND	ND	ND	0.411	0.411	ND	0.015	0.035
6/1/95	QV144	22:18	ND	ND	ND	0.527	0.527	0.001	0.02	0.025
6/1/95	QV145	23:18	ND	ND	ND	0.789	0.789	ND	ND	0.075

Sample from DL1 (QV1###), Sample from DL2 (QV2###)

Date	Sample #	TIME	TSS (ppm)	Cd (ug/L)	Cu (ug/L)	Pb (ug/L)	Zn (mg/L)	TOC (mg/L)
6/1/95	QV12	8:35	138.000	NA	NA	NA	NA	NA
6/2/95	QV13	8:50	38.000	NA	NA	NA	NA	NA
6/1/95	QV14	9:05	12.000	NA	NA	NA	NA	NA
6/1/95	QV16	9:35	8.000	NA	NA	NA	NA	NA
6/1/95	QV17	9:50	16.000	NA	NA	NA	NA	NA
6/1/95	QV18	10:05	18.000	NA	NA	NA	NA	NA
6/1/95	QV19	10:20	34.000	NA	NA	NA	NA	NA
6/1/95	QV110	11:20	24.000	NA	NA	NA	NA	NA
6/1/95	QV111	12:20	18.000	NA	NA	NA	NA	NA
6/1/95	QV112	13:20	ND	NA	NA	NA	NA	NA
6/1/95	QV113	14:20	ND	NA	NA	NA	NA	NA
6/1/95	QV115	8:32	66.000	NA	NA	NA	NA	NA
6/1/95	QV116	8:47	56.000	NA	NA	NA	NA	NA
6/1/95	QV117	9:02	48.000	NA	NA	NA	NA	NA
6/1/95	QV118	9:17	34.000	NA	NA	NA	NA	NA
6/1/95	QV119	9:32	32.000	NA	NA	NA	NA	NA
6/1/95	QV120	9:47	40.000	NA	NA	NA	NA	NA
6/1/95	QV121	10:02	26.000	NA	NA	NA	NA	NA
6/1/95	QV122	10:17	18.000	NA	NA	NA	NA	NA
6/1/95	QV123	10:32	4.000	NA	NA	NA	NA	NA
6/1/95	QV124	11:32	0.000	NA	NA	NA	NA	NA
6/1/95	QV126	12:50	104.000	NA	NA	NA	NA	NA
6/1/95	QV127	13:05	34.000	NA	NA	NA	NA	NA
6/1/95	QV128	13:20	22.000	NA	NA	NA	NA	NA
6/1/95	QV129	13:35	12.000	NA	NA	NA	NA	NA
6/1/95	QV130	13:50	52.000	NA	NA	NA	NA	NA
6/1/95	QV131	14:05	47.800	NA	NA	NA	NA	NA
6/1/95	QV132	14:20	28.000	NA	NA	NA	NA	NA
6/1/95	QV133	14:35	10.000	NA	NA	NA	NA	NA
6/1/95	QV134	15:35	36.000	NA	NA	NA	NA	NA
6/1/95	QV135	16:35	30.000	NA	NA	NA	NA	NA
6/1/95	QV21	18:08	ND	NA	NA	NA	NA	NA
6/2/95	QV22	11:38	38.000	NA	NA	NA	NA	NA
6/2/95	QV23	13:37	14.000	NA	NA	NA	NA	NA
6/1/95	QV136	20:18	166.000	NA	NA	NA	NA	NA
6/1/95	QV137	20:33	188.000	NA	NA	NA	NA	NA
6/1/95	QV138	20:48	82.000	NA	NA	NA	NA	NA
6/1/95	QV139	21:03	22.000	NA	NA	NA	NA	NA
6/1/95	QV140	21:18	36.000	NA	NA	NA	NA	NA
6/1/95	QV141	21:33	NS	NA	NA	NA	NA	NA
6/1/95	QV142	21:48	80.000	NA	NA	NA	NA	NA
6/1/95	QV143	22:03	6.000	NA	NA	NA	NA	NA
6/1/95	QV144	22:18	ND	NA	NA	NA	NA	NA
6/1/95	QV145	23:18	ND	NA	NA	NA	NA	NA

Sample from DL1 (QV1###), Sample from DL2 (QV2###)

Date	Sample #	TIME	NH4 (ppm)	FTKN (ppm)	TKN (ppm)	NO3-N (ppm)	TN (ppm)	PO4 (ppm)	FTP (ppm)	TP (ppm)
6/2/95	QV146	0:18	ND	0.014	ND	1.159	1.159	ND	0.01	0.035
6/2/95	QV147	1:11	ND	ND	ND	1.11	1.110	ND	ND	0.03
6/2/95	QV148	1:26	ND	ND	ND	0.866	0.866	ND	0.05	0.045
6/2/95	QV149	1:41	ND	ND	ND	0.79	0.790	ND	ND	0.004
6/2/95	QV150	1:56	ND	0.213	0.060	0.626	0.686	ND	ND	0.021
6/2/95	QV151	2:11	ND	ND	0.289	0.208	0.497	0.006	ND	0.02
6/2/95	QV152	2:26	ND	ND	0.098	0.153	0.251	0.005	ND	0.011
6/2/95	QV153	2:41	ND	ND	0.366	0.265	0.631	ND	ND	0.018
6/2/95	QV154	2:56	ND	1.245	0.328	0.407	0.735	ND	ND	0.015
6/2/95	QV155	3:11	ND	0.519	ND	0.584	0.584	0.001	ND	0.008
6/2/95	QV156	4:11	ND	0.442	0.366	1.082	1.448	0.006	ND	0.002
6/2/95	QV157	5:11	ND	0.480	0.786	1.448	2.234	ND	ND	ND
6/2/95	QV158	19:49	ND	0.825	1.895	0.797	2.692	ND	ND	0.031
6/2/95	QV159	20:04	0.057	0.442	1.589	0.694	2.283	ND	ND	0.02
6/2/95	QV160	20:19	0.147	0.060	0.442	0.708	1.150	0.001	ND	0.021
6/2/95	QV161	20:34	0.128	0.404	0.022	0.825	0.847	ND	ND	0.004
6/2/95	QV162	20:49	0.091	0.404	0.022	0.961	0.983	ND	0.056	ND
6/2/95	QV163	21:49	0.066	0.786	0.213	1.497	1.710	ND	0.01	ND
							0.000			
6/21/95	QV1101	21:24	ND	1.115	3.030	1.518	4.548	ND	ND	ND
6/21/95	QV1102	21:39	ND	1.780	3.382	1.818	5.200	ND	ND	ND
6/21/95	QV1103	21:54	0.026	2.483	3.343	1.759	5.102	ND	ND	ND
6/21/95	QV1104	22:09	0.188	1.780	3.343	1.662	5.005	ND	ND	ND
6/21/95	QV1105	22:24	0.064	1.897	2.913	1.711	4.624	ND	ND	ND
6/21/95	QV1106	22:39	0.074	1.858	4.281	1.832	6.113	ND	ND	ND
6/21/95	QV1107	22:54	0.016	1.858	4.125	1.91	6.035	ND	ND	ND
6/21/95	QV1108	23:09	0.102	2.170	2.991	1.853	4.844	ND	ND	ND
6/21/95	QV1109	23:24	ND	2.366	2.913	1.885	4.798	ND	ND	ND
6/22/95	QV1110	0:24	ND	1.780	2.053	1.105	3.158	ND	ND	ND
6/22/95	QV1111	1:24	ND	1.467	1.272	0.888	2.160	0.002	ND	ND
6/22/95	QV1112	2:24	0.101	1.115	1.193	0.409	1.602	ND	ND	ND
6/22/95	QV1113	3:24	0.094	0.685	5.180	0.079	5.259	0.004	ND	ND
6/22/95	QV1114	4:24	ND	0.646	0.803	0.468	1.271	ND	ND	ND
6/22/95	QV1115	5:24	ND	0.334	0.568	0.712	1.280	ND	ND	ND
6/22/95	QV1116	6:24	ND	0.724	0.724	1.082	1.806	0.003	ND	ND
6/22/95	QV1117	7:24	ND	0.048	0.164	1.464	1.628	0.009	ND	0.02
6/22/95	QV1118	8:24	ND	ND	ND	1.675	1.675	0.007	ND	ND
6/22/95	QV1119	9:24	ND	0.515	0.242	1.785	2.027	0.022	ND	0.03
6/22/95	QV1120	10:24	ND	0.125	1.333	1.89	3.223	ND	ND	0.005
6/22/95	QV1121	11:24	ND	0.125	0.359	1.885	2.244	ND	ND	0.065
6/22/95	QV1122	12:24	ND	ND	1.021	0.411	1.432	ND	ND	0.19
6/22/95	QV1123	13:24	ND	ND	1.411	0.208	1.619	ND	ND	0.045
6/22/95	QV1124	14:24	ND	ND	ND	0.349	0.349	ND	0.01	ND

Sample from DL1 (QV1###), Sample from DL2 (QV2###)

Date	Sample #	TIME	TSS (ppm)	Cd (ug/L)	Cu (ug/L)	Pb (ug/L)	Zn (mg/L)	TOC (mg/L)
6/2/95	QV146	0:18	ND	NA	NA	NA	NA	NA
6/2/95	QV147	1:11	ND	NA	NA	NA	NA	NA
6/2/95	QV148	1:26	ND	NA	NA	NA	NA	NA
6/2/95	QV149	1:41	10.000	NA	NA	NA	NA	NA
6/2/95	QV150	1:56	ND	NA	NA	NA	NA	NA
6/2/95	QV151	2:11	ND	NA	NA	NA	NA	NA
6/2/95	QV152	2:26	44.000	NA	NA	NA	NA	NA
6/2/95	QV153	2:41	104.000	NA	NA	NA	NA	NA
6/2/95	QV154	2:56	ND	NA	NA	NA	NA	NA
6/2/95	QV155	3:11	ND	NA	NA	NA	NA	NA
6/2/95	QV156	4:11	72.000	NA	NA	NA	NA	NA
6/2/95	QV157	5:11	ND	NA	NA	NA	NA	NA
6/2/95	QV158	19:49	ND	NA	NA	NA	NA	NA
6/2/95	QV159	20:04	40.000	NA	NA	NA	NA	NA
6/2/95	QV160	20:19	8.000	NA	NA	NA	NA	NA
6/2/95	QV161	20:34	ND	NA	NA	NA	NA	NA
6/2/95	QV162	20:49	ND	NA	NA	NA	NA	NA
6/2/95	QV163	21:49	ND	NA	NA	NA	NA	NA
6/21/95	QV1101	21:24	92.000	NA	NA	NA	NA	NA
6/21/95	QV1102	21:39	98.000	NA	NA	NA	NA	NA
6/21/95	QV1103	21:54	80.000	NA	NA	NA	NA	NA
6/21/95	QV1104	22:09	56.000	NA	NA	NA	NA	NA
6/21/95	QV1105	22:24	46.000	NA	NA	NA	NA	NA
6/21/95	QV1106	22:39	34.000	NA	NA	NA	NA	NA
6/21/95	QV1107	22:54	22.000	NA	NA	NA	NA	NA
6/21/95	QV1108	23:09	25.120	NA	NA	NA	NA	NA
6/21/95	QV1109	23:24	30.000	NA	NA	NA	NA	NA
6/22/95	QV1110	0:24	26.000	NA	NA	NA	NA	NA
6/22/95	QV1111	1:24	10.000	NA	NA	NA	NA	NA
6/22/95	QV1112	2:24	22.000	NA	NA	NA	NA	NA
6/22/95	QV1113	3:24	70.000	NA	NA	NA	NA	NA
6/22/95	QV1114	4:24	14.000	NA	NA	NA	NA	NA
6/22/95	QV1115	5:24	4.000	NA	NA	NA	NA	NA
6/22/95	QV1116	6:24	6.000	NA	NA	NA	NA	NA
6/22/95	QV1117	7:24	6.000	NA	NA	NA	NA	NA
6/22/95	QV1118	8:24	8.000	NA	NA	NA	NA	NA
6/22/95	QV1119	9:24	2.000	NA	NA	NA	NA	NA
6/22/95	QV1120	10:24	8.000	NA	NA	NA	NA	NA
6/22/95	QV1121	11:24	ND	NA	NA	NA	NA	NA
6/22/95	QV1122	12:24	116.000	NA	NA	NA	NA	NA
6/22/95	QV1123	13:24	28.000	NA	NA	NA	NA	NA
6/22/95	QV1124	14:24	8.000	NA	NA	NA	NA	NA

Sample from DL1 (QV1###), Sample from DL2 (QV2###)

Date	Sample #	TIME	NH4 (ppm)	FTKN (ppm)	TKN (ppm)	NO3-N (ppm)	TN (ppm)	PO4 (ppm)	FTP (ppm)	TP (ppm)
6/22/95	QV2101	0:44	ND	0.710	1.372	0.97	2.342	ND	ND	0.115
6/27/95	QV11	15:15	ND	0.281	0.865	0.524	1.389	ND	ND	0.065
6/27/95	QV12	15:30	ND	0.125	0.164	0.605	0.769	ND	0.01	0.02
6/27/95	QV13	15:45	ND	ND	0.943	0.639	1.582	ND	ND	0.045
6/27/95	QV14	16:00	ND	ND	1.060	0.351	1.411	ND	0.005	0.255
6/27/95	QV15	16:15	ND	ND	0.554	0.075	0.629	0.037	0.07	0.185
6/27/95	QV16	16:30	ND	0.164	0.710	0.351	1.061	0.098	0.15	0.24
6/27/95	QV17	17:30	ND	0.504	0.937	0.981	1.918	ND	ND	0.09
6/27/95	QV21	16:00	ND	0.244	1.053	0.36	1.413	ND	ND	0.075
6/27/95	QV22	16:05	ND	0.301	1.371	0.318	1.689	ND	0.02	0.115
6/27/95	QV23	16:09	ND	0.157	2.585	0.272	2.857	0.107	0.02	0.185
6/28/95	QV24	7:48	ND	0.442	0.504	0.219	0.723	0.007	0.07	0.125
6/28/95	QV11	8:30	ND	0.088	1.505	1.353	2.858	ND	0.07	0.075
6/28/95	QV12	9:30	ND	0.058	1.204	1.782	2.986	ND	0.065	0.025
6/28/95	QV13	10:30	ND	0.329	1.023	1.763	2.786	ND	0.01	0.02
6/28/95	QV14	11:30	ND	0.329	0.872	1.729	2.601	ND	0.025	0.04
6/28/95	QV15	12:30	ND	0.299	0.932	1.714	2.646	ND	0.065	0.015
6/28/95	QV16	13:30	ND	0.571	1.083	1.677	2.760	ND	0.045	0.02
6/28/95	QV17	14:30	ND	0.209	0.269	1.674	1.943	ND	0.09	ND
6/28/95	QV18	15:30	ND	ND	0.480	1.65	2.130	ND	0.02	0.015
6/28/95	QV19	16:30	0.147	0.299	1.174	0.689	1.863	0.027	0.06	0.14
6/28/95	QV110	17:30	ND	0.661	1.174	0.873	2.047	0.008	0.05	0.07
6/28/95	QV111	18:30	ND	0.329	0.540	1.238	1.778	ND	0.085	ND
6/28/95	QV112	19:30	ND	0.631	0.510	1.366	1.876	ND	0.045	0.06
6/28/95	QV113	20:30	ND	1.867	0.571	0.858	1.429	ND	0.06	0.03
6/28/95	QV114	21:30	ND	1.143	0.209	0.988	1.197	ND	0.12	0.01
6/28/95	QV115	22:30	ND	0.932	0.782	1.136	1.918	ND	0.09	0.03
6/28/95	QV116	23:30	ND	1.791	0.944	1.155	2.099	ND	ND	ND
6/29/95	QV117	0:30	ND	0.974	0.944	1.208	2.152	ND	ND	ND
6/29/95	QV118	1:30	ND	0.944	0.389	1.251	1.640	0.003	ND	ND
6/29/95	QV119	2:30	ND	0.681	0.652	1.248	1.900	0.025	ND	ND
6/29/95	QV120	3:30	ND	0.681	0.039	1.329	1.368	0.009	ND	ND
6/29/95	QV121	4:30	ND	0.652	0.068	1.347	1.415	ND	ND	ND
6/29/95	QV122	5:30	ND	0.681	0.623	1.323	1.946	ND	ND	ND
6/29/95	QV123	6:30	ND	0.974	0.039	1.279	1.318	ND	ND	ND
6/29/95	QV124	7:30	ND	1.266	0.068	1.287	1.355	ND	ND	ND
6/28/95	QV21	19:09	ND	0.360	0.389	0.3	0.689	0.015	ND	ND
6/29/95	QV22	4:17	ND	0.652	0.039	0.383	0.422	ND	ND	ND
7/17/95	QV1201	18:28	0.117	2.083	1.762	0.894	2.656	ND	ND	0.01
7/17/95	QV1202	18:43	ND	0.974	1.149	0.266	1.415	0.019	ND	0.145
7/17/95	QV1203	18:58	ND	0.711	0.302	0.359	0.661	0.037	ND	ND
7/17/95	QV1204	19:13	ND	1.324	0.360	0.662	1.022	0.036	ND	ND

Sample from DL1 (QV1###), Sample from DL2 (QV2###)

Date	Sample #	TIME	TSS (ppm)	Cd (ug/L)	Cu (ug/L)	Pb (ug/L)	Zn (mg/L)	TOC (mg/L)
6/22/95	QV2101	0:44	6.000	NA	NA	NA	NA	NA
6/27/95	QV11	15:15	10.000	NA	NA	NA	NA	NA
6/27/95	QV12	15:30	6.000	NA	NA	NA	NA	NA
6/27/95	QV13	15:45	14.000	NA	NA	NA	NA	NA
6/27/95	QV14	16:00	354.000	NA	NA	NA	NA	NA
6/27/95	QV15	16:15	286.000	NA	NA	NA	NA	NA
6/27/95	QV16	16:30	150.000	NA	NA	NA	NA	NA
6/27/95	QV17	17:30	34.000	NA	NA	NA	NA	NA
6/27/95	QV21	16:00	62.000	NA	NA	NA	NA	NA
6/27/95	QV22	16:05	150.000	NA	NA	NA	NA	NA
6/27/95	QV23	16:09	190.000	NA	NA	NA	NA	NA
6/28/95	QV24	7:48	34.000	NA	NA	NA	NA	NA
6/28/95	QV11	8:30	6.000	NA	NA	NA	NA	NA
6/28/95	QV12	9:30	ND	NA	NA	NA	NA	NA
6/28/95	QV13	10:30	20.000	NA	NA	NA	NA	NA
6/28/95	QV14	11:30	8.000	NA	NA	NA	NA	NA
6/28/95	QV15	12:30	6.000	NA	NA	NA	NA	NA
6/28/95	QV16	13:30	4.000	NA	NA	NA	NA	NA
6/28/95	QV17	14:30	8.000	NA	NA	NA	NA	NA
6/28/95	QV18	15:30	2.000	NA	NA	NA	NA	NA
6/28/95	QV19	16:30	8.000	NA	NA	NA	NA	NA
6/28/95	QV110	17:30	ND	NA	NA	NA	NA	NA
6/28/95	QV111	18:30	6.000	NA	NA	NA	NA	NA
6/28/95	QV112	19:30	ND	NA	NA	NA	NA	NA
6/28/95	QV113	20:30	ND	NA	NA	NA	NA	NA
6/28/95	QV114	21:30	6.000	NA	NA	NA	NA	NA
6/28/95	QV115	22:30	48.000	NA	NA	NA	NA	NA
6/28/95	QV116	23:30	ND	NA	NA	NA	NA	NA
6/29/95	QV117	0:30	ND	NA	NA	NA	NA	NA
6/29/95	QV118	1:30	2.000	NA	NA	NA	NA	NA
6/29/95	QV119	2:30	ND	NA	NA	NA	NA	NA
6/29/95	QV120	3:30	ND	NA	NA	NA	NA	NA
6/29/95	QV121	4:30	ND	NA	NA	NA	NA	NA
6/29/95	QV122	5:30	ND	NA	NA	NA	NA	NA
6/29/95	QV123	6:30	2.000	NA	NA	NA	NA	NA
6/29/95	QV124	7:30	ND	NA	NA	NA	NA	NA
6/28/95	QV21	19:09	18.000	NA	NA	NA	NA	NA
6/29/95	QV22	4:17	6.000	NA	NA	NA	NA	NA
7/17/95	QV1201	18:28	138.000	0.8	8	5	0.15	33.2
7/17/95	QV1202	18:43	224.000	0.3	5	8	0.04	4.27
7/17/95	QV1203	18:58	98.000	0.4	5	6	0.04	4.88
7/17/95	QV1204	19:13	38.000	0.4	4	7	0.04	7.75

Sample from DL1 (QV1###), Sample from DL2 (QV2###)

Date	Sample #	TIME	NH4 (ppm)	FTKN (ppm)	TKN (ppm)	NO3-N (ppm)	TN (ppm)	PO4 (ppm)	FTP (ppm)	TP (ppm)
7/17/95	QV1205	19:28	ND	0.526	0.803	0.865	1.668	0.026	ND	0.065
7/17/95	QV1206	19:43	ND	0.775	1.135	1.081	2.216	0.023	ND	0.04
7/17/95	QV1207	19:58	0.022	1.107	1.135	1.222	2.357	0.017	ND	0.08
7/17/95	QV1208	20:13	ND	0.775	0.996	1.394	2.390	0.009	ND	0.04
7/17/95	QV2209	18:17	ND	1.107	1.384	0.701	2.085	ND	0.285	0.015
7/17/95	QV2210	18:20	0.026	1.107	1.079	0.525	1.604	ND	ND	0.02
7/17/95	QV2211	18:24	ND	0.858	0.747	0.377	1.124	ND	ND	0.045
7/17/95	QV2212	18:34	ND	0.858	0.886	0.279	1.165	0.025	0.02	0.1
7/17/95	QV2213	19:22	ND	0.360	1.107	0.278	1.385	0.012	ND	0.06
7/17/95	QV2214	22:36	ND	0.553	0.969	0.269	1.238	0.029	0.03	0.06
7/17/95	QV2215	6:35	ND	0.194	0.581	0.255	0.836	0.076	0.06	0.125
7/18/97	QV2216	13:33	ND	0.249	0.803	0.255	1.058	0.073	0.085	0.19
7/18/97	QV2217	15:58	ND	1.052	0.609	0.254	0.863	0.062	0.095	0.165
7/18/97	QV2218	23:16	ND	0.886	1.135	0.104	1.239	0.048	0.19	0.08
7/18/97	QV2219	23:24	ND	1.107	1.079	0.097	1.176	0.044	0.12	0.05
8/18/95	QV1231	14:09	0.358	0.186	2.873	2.117	4.990	ND	ND	0.046
8/18/95	QV1232	14:24	0.018	ND	0.050	0.512	0.562	ND	ND	0.019
8/18/95	QV1233	14:39	0.069	ND	ND	0.661	0.661	0.091	0.06	0.32
8/18/95	QV1234	14:54	0.029	ND	ND	0.475	0.475	ND	0	0.115
8/18/95	QV1235	15:09	0.000	ND	ND	0.528	0.528	0.015	0	0.205
8/18/95	QV1236	15:24	0.000	ND	ND	1	1.000	ND	0	0.115
8/18/95	QV1237	15:39	0.056	ND	ND	1.3	1.300	ND	0	0.085
8/18/95	QV1238	15:54	0.036	ND	ND	1.461	1.461	ND	0	0.04
8/18/95	QV1239	16:09	ND	ND	ND	1.441	1.441	ND	0	0.01
8/18/95	QV1240	17:09	ND	ND	ND	0.826	0.826	ND	0	0.01
8/18/95	QV1241	18:09	ND	ND	6.402	1.411	7.813	ND	0	0
8/18/95	QV1242	19:09	ND	ND	ND	1.689	1.689	ND	0	0.02
8/27/95	QV1251	8:15	0.037	1.522	1.816	1.531	3.347	0.003	0	0.01
8/27/95	QV1252	8:30	0.006	1.620	1.784	1.425	3.209	ND	0	0
8/27/95	QV1256	9:30	0.025	1.227	1.162	0.723	1.885	ND	0	0.07
8/27/95	QV1257	9:45	0.013	2.831	0.867	0.392	1.259	ND	0.05	0.03
8/27/95	QV1258	10:00	0.01	1.129	0.900	0.248	1.148	ND	0.11	0
8/27/95	QV1259	10:15	0.003	0.605	0.900	0.175	1.075	ND	0.115	0
8/27/95	QV1260	11:15	0.017	ND	ND	0.101	0.101	ND	0	0.04
8/27/95	QV1261	12:15	ND	ND	ND	0.108	0.108	ND	0	0.015
8/27/95	QV1262	13:15	ND	ND	0.057	0.174	0.231	ND	0	0
8/27/95	QV1263	14:15	0.018	ND	1.052	0.247	1.299	ND	0	0.01
8/27/95	QV1264	15:15	0.007	ND	0.153	0.188	0.341	ND	0	0
8/27/95	QV1265	16:15	ND	ND	0.024	0.237	0.261	ND	0	0
8/27/95	QV1266	17:15	0.002	ND	0.057	0.22	0.277	ND	0	0.02
8/27/95	QV1267	18:15	ND	ND	0.346	0.306	0.652	ND	0.05	0
8/27/95	QV1268	19:15	0.013	ND	0.024	0.389	0.413	ND	0	0

Sample from DL1 (QV1###), Sample from DL2 (QV2###)

Date	Sample #	TIME	TSS (ppm)	Cd (ug/L)	Cu (ug/L)	Pb (ug/L)	Zn (mg/L)	TOC (mg/L)
7/17/95	QV1205	19:28	32.000	0.3	6	5	0.04	8.92
7/17/95	QV1206	19:43	24.000	0.1	5	3	0.03	9.57
7/17/95	QV1207	19:58	26.000	0.1	9	4	0.03	9.6
7/17/95	QV1208	20:13	ND	0.3	5	5	0.03	9.11
7/17/95	QV2209	18:17	156.000	0.6	11	12	0.12	15
7/17/95	QV2210	18:20	38.000	0.2	5	6	0.06	10.5
7/17/95	QV2211	18:24	206.000	0.4	28	13	0.12	4.66
7/17/95	QV2212	18:34	82.000	0.4	9	11	0.5	4.51
7/17/95	QV2213	19:22	34.000	0.3	5	7	0.03	5.38
7/17/95	QV2214	22:36	24.000	0.1	4	3	0.03	5.43
7/17/95	QV2215	6:35	10.000	0.4	4	7	0.03	5.84
7/18/97	QV2216	13:33	4.000	0.2	4	3	0.03	6.23
7/18/97	QV2217	15:58	12.000	0.2	4	10	0.03	6.45
7/18/97	QV2218	23:16	4.000	0.2	4	2	0.04	8.2
7/18/97	QV2219	23:24	2.000	0.1	4	6	0.04	8.1
8/18/95	QV1231	14:09	224.000	1	14	16	0.23	20
8/18/95	QV1232	14:24	124.000	0.4	8	8	0.08	4.36
8/18/95	QV1233	14:39	98.000	0.35	7	6	0.055	4.83
8/18/95	QV1234	14:54	50.000	0.3	6	5	0.04	4.36
8/18/95	QV1235	15:09	44.000	0.3	5	4	0.05	5.35
8/18/95	QV1236	15:24	38.000	0.4	8	11	0.06	7.54
8/18/95	QV1237	15:39	22.000	0.5	6	9	0.06	8.51
8/18/95	QV1238	15:54	20.000	0.4	5	4	0.045	10.1
8/18/95	QV1239	16:09	6.000	0.6	5	11	0.04	11.3
8/18/95	QV1240	17:09	6.000	0.4	5	4	0.04	14.5
8/18/95	QV1241	18:09	6.000	0.25	4	2	0.06	11.4
8/18/95	QV1242	19:09	2.000	0.4	3	4	0.1	9.9
8/27/95	QV1251	8:15	2.000	0.85	23	4.5	0.095	100.05
8/27/95	QV1252	8:30	2.000	0.8	14	7	0.09	91.45
8/27/95	QV1256	9:30	4.000	0.6	10	6	0.08	61.99
8/27/95	QV1257	9:45	0.000	0.4	8	3	0.06	45.33
8/27/95	QV1258	10:00	ND	0.45	6.5	4.5	0.06	30.585
8/27/95	QV1259	10:15	0.000	0.3	6	3	0.06	20.03
8/27/95	QV1260	11:15	ND	0.5	5	4	0.06	6.86
8/27/95	QV1261	12:15	2.000	0.4	3	3	0.08	6.79
8/27/95	QV1262	13:15	ND	0.5	6	5	0.04	9.511
8/27/95	QV1263	14:15	ND	0.45	4.5	3.5	0.05	13.8
8/27/95	QV1264	15:15	ND	0.7	6	4	0.05	13.14
8/27/95	QV1265	16:15	6.000	0.8	5	5	0.08	13.27
8/27/95	QV1266	17:15	ND	1.25	5.5	2.5	0.045	14.76
8/27/95	QV1267	18:15	0.000	0.4	4	4	0.12	15.4
8/27/95	QV1268	19:15	4.000	0.3	4	3	0.07	16.2

Sample from DL1 (QV1###), Sample from DL2 (QV2###)

Date	Sample #	TIME	NH4 (ppm)	FTKN (ppm)	TKN (ppm)	NO3-N (ppm)	TN (ppm)	PO4 (ppm)	FTP (ppm)	TP (ppm)
8/27/95	QV2269	10:27	ND	ND	0.314	0.32	0.634	ND	0	0.005
9/13/95	QV1292	16:44	0.616	2.626	5.260	2.535	7.795	ND	0	0.205
9/13/95	QV1293	16:59	0.364	1.631	3.558	1.668	5.226	ND	0	0.16
9/13/95	QV1294	17:14	0.354	1.374	1.984	1.117	3.101	ND	0	0.16
9/13/95	QV1295	17:29	0.236	0.827	1.406	2.438	3.844	ND	0.005	0.08
9/13/95	QV1296	17:44	0.194	0.442	1.341	1.670	3.011	ND	0.12	0
9/13/95	QV1297	17:59	0.141	0.686	1.204	0.795	1.999	ND	0	0.115
9/13/95	QV1298	18:14	0.092	0.925	1.005	0.790	1.795	ND	0	0.11
9/13/95	QV1299	18:29	0.123	1.204	1.005	0.818	1.823	ND	0	0.09
9/13/95	QV1300	19:29	0.049	1.403	4.195	0.862	5.057	ND	0	0.08
9/13/95	QV1301	19:30	0.042	1.363	1.802	0.869	2.671	ND	0	0.055
9/13/95	QV1302	19:45	0.036	1.403	1.403	0.853	2.256	ND	0	0.065
9/13/95	QV1303	20:00	0.026	1.164	1.483	0.860	2.343	ND	0	0.04
9/13/95	QV1304	20:15	0.009	1.124	1.722	0.869	2.591	ND	0	0.03
9/13/95	QV1305	20:30	0.028	1.324	1.762	0.847	2.609	ND	0	0.03
9/13/95	QV1306	20:45	0.022	1.005	1.722	0.816	2.538	ND	0	0
9/13/95	QV2307	17:04	0.211	2.201	5.152	2.145	7.297	ND	0	0.22
9/13/95	QV2308	17:27	0.265	1.762	3.717	1.528	5.245	ND	0.035	0.175
9/13/95	QV2309	20:53	ND	0.925	2.121	0.456	2.577	ND	0	0.25
9/16/95	QV1313	4:29	0.063	1.084	2.680	1.472	4.152	0.013	0	0.205
9/16/95	QV1314	4:44	0.144	1.005	2.201	1.337	3.538	0.016	0.155	0.09
9/16/95	QV1315	4:59	0.161	0.686	2.161	1.344	3.505	0.008	0.125	0
9/16/95	QV1316	5:14	0.118	0.262	0.604	1.315	1.919	0.004	0	0.105
9/16/95	QV1317	5:29	0.086	0.262	0.842	1.239	2.081	0.003	0	0.065
9/16/95	QV1318	5:44	0.054	0.365	0.535	1.136	1.671	0.002	0	0.04
9/16/95	QV1319	5:59	0.035	ND	0.194	0.902	1.096	ND	0	0.05
9/16/95	QV1320	6:14	0.036	0.160	0.467	0.728	1.195	0.001	0	0.05
9/16/95	QV1321	6:29	0.016	ND	0.194	0.600	0.794	ND	0	0.03
9/16/95	QV1322	7:29	ND	ND	0.126	0.442	0.568	ND	0	0.035
9/16/95	QV1323	8:29	ND	ND	0.092	0.270	0.362	ND	0	0.035
9/16/95	QV1324	9:29	ND	ND	0.160	0.185	0.345	ND	0	0.025
9/16/95	QV1325	10:29	ND	ND	0.126	0.203	0.329	ND	0	0.01
9/16/95	QV1326	11:29	ND	ND	0.774	0.154	0.928	0.001	0	0.025
9/16/95	QV1327	12:29	ND	ND	0.160	0.198	0.358	0.002	0	0.025
9/16/95	QV2328	4:41	ND	0.569	1.866	1.539	3.405	0.007	0	0.305
9/16/95	QV2329	5:37	ND	0.911	1.115	1.333	2.448	0.003	0.165	0.065
9/16/95	QV2330	11:47	ND	ND	0.501	0.292	0.793	0.003	0.105	0.01
9/16/95	QV2331	2:45	ND	0.119	ND	0.188	0.188	0.005	0	0.06
9/16/95	QV2332	4:04	ND	0.143	0.024	0.229	0.253	0.002	0	0.065
9/16/95	QV1333	13:29	0.001	0.143	ND	0.266	0.266	ND	0	0.085
9/16/95	QV1334	14:29	ND	0.119	ND	0.507	0.507	ND	0	0.04
9/16/95	QV1335	15:29	0.029	0.095	0.167	0.614	0.781	ND	0	0.04

Sample from DL1 (QV1###), Sample from DL2 (QV2###)

Date	Sample #	TIME	TSS (ppm)	Cd (ug/L)	Cu (ug/L)	Pb (ug/L)	Zn (mg/L)	TOC (mg/L)
8/27/95	QV2269	10:27	4.000	1.3	6	3	0.07	39.17
9/13/95	QV1292	16:44	158.000	2.4	25	12	0.27	140.95
9/13/95	QV1293	16:59	94.000	2.7	15	9	0.17	82.89
9/13/95	QV1294	17:14	48.000	1.55	11.5	7	0.12	52.055
9/13/95	QV1295	17:29	40.000	1.6	11	6	0.09	34.515
9/13/95	QV1296	17:44	18.000	0.75	10.5	9	0.09	33.49
9/13/95	QV1297	17:59	18.000	0.7	10	9	0.08	36.025
9/13/95	QV1298	18:14	20.000	0.6	9	9	0.07	36.115
9/13/95	QV1299	18:29	8.000	0.8	12	10	0.08	36.135
9/13/95	QV1300	19:29	8.000	0.8	14	10.5	0.08	54.28
9/13/95	QV1301	19:30	8.000	1	9	8	0.06	56
9/13/95	QV1302	19:45	6.000	1.1	11	5	0.06	53.95
9/13/95	QV1303	20:00	4.000	1.9	12	6	0.07	52.575
9/13/95	QV1304	20:15	6.000	0.9	13	6	0.1	54.84
9/13/95	QV1305	20:30	2.000	1.3	9	6	0.06	54.225
9/13/95	QV1306	20:45	8.000	0.7	9	8	0.08	56.05
9/13/95	QV2307	17:04	40.000	1	16	10	0.11	106.75
9/13/95	QV2308	17:27	36.000	1.6	13.5	6.5	0.085	80.55
9/13/95	QV2309	20:53	6.000	1	12	12	0.08	45.895
9/16/95	QV1313	4:29	234.000	1.35	20	18.5	0.36	43.195
9/16/95	QV1314	4:44	64.000	0.7	10	8	0.12	31.115
9/16/95	QV1315	4:59	24.000	0.6	7.5	6.5	0.075	27.895
9/16/95	QV1316	5:14	16.000	0.4	6	4	0.04	26.725
9/16/95	QV1317	5:29	12.000	0.7	7	5	0.05	24.1
9/16/95	QV1318	5:44	14.000	0.5	6	4	0.04	22.21
9/16/95	QV1319	5:59	12.000	0.5	5	6	0.05	15.59
9/16/95	QV1320	6:14	4.000	0.8	6	9	0.05	12.49
9/16/95	QV1321	6:29	2.000	0.4	5	5	0.04	10.145
9/16/95	QV1322	7:29	ND	0.4	5	6	0.06	10.565
9/16/95	QV1323	8:29	ND	0.5	6	5	0.05	9.17
9/16/95	QV1324	9:29	10.000	0.4	4.5	5.5	0.055	7.468
9/16/95	QV1325	10:29	2.000	0.4	4	6	0.04	8.743
9/16/95	QV1326	11:29	2.000	0.7	5	8	0.06	7.513
9/16/95	QV1327	12:29	6.000	0.5	6	7	0.06	5.597
9/16/95	QV2328	4:41	62.000	0.8	0.5	10	0.13	40.05
9/16/95	QV2329	5:37	20.000	0.5	9	8	0.09	29.65
9/16/95	QV2330	11:47	6.000	0.8	10	15	0.14	11.18
9/16/95	QV2331	2:45	0.000	1.05	6.5	13.5	0.06	6.543
9/16/95	QV2332	4:04	4.000	0.7	6	10	0.06	4.4475
9/16/95	QV1333	13:29	0.000	0.7	5	11	0.06	4.967
9/16/95	QV1334	14:29	4.000	0.95	5.5	16	0.055	6.397
9/16/95	QV1335	15:29	6.000	0.6	4	9	0.04	5

Sample from DL1 (QV1###), Sample from DL2 (QV2###)

Date	Sample #	TIME	NH4 (ppm)	FTKN (ppm)	TKN (ppm)	NO3-N (ppm)	TN (ppm)	PO4 (ppm)	FTP (ppm)	TP (ppm)
9/16/95	QV1336	16:29	0.018	0.143	ND	0.800	0.800	ND	0	0.015
9/16/95	QV1337	17:29	ND	0.239	0.167	0.893	1.060	ND	0	0.015
9/16/95	QV1338	18:29	0.038	0.143	1.341	0.640	1.981	ND	0	0.055
9/16/95	QV1339	19:29	ND	0.143	0.431	0.670	1.101	ND	0	0.025
9/16/95	QV1341	23:16	ND	0.239	0.479	0.617	1.096	ND	0	0.02
9/16/95	QV1342	23:31	ND	0.071	1.605	0.416	2.021	ND	0	0.005
9/16/95	QV1343	23:46	ND	ND	0.622	0.340	0.962	ND	0	0.015
9/17/95	QV1344	0:01	ND	0.239	0.407	0.314	0.721	ND	0	0.105
9/17/95	QV1345	0:16	ND	ND	0.646	0.294	0.940	ND	0	0.02
9/17/95	QV1346	0:31	ND	ND	1.533	0.271	1.804	ND	0.205	0
9/17/95	QV1347	0:46	0.007	ND	0.670	0.239	0.909	ND	0.1	0
9/17/95	QV1348	1:01	ND	ND	ND	0.189	0.189	ND	0	0.07
9/17/95	QV1349	1:16	ND	ND	ND	0.171	0.171	ND	0	0.075
9/17/95	QV1350	2:16	ND	ND	0.210	0.228	0.438	ND	0	0.045
9/17/95	QV1351	3:16	ND	ND	0.150	0.085	0.235	0.002	0	0.075
9/17/95	QV1352	4:16	ND	ND	0.120	0.139	0.259	ND	0	0.07
9/17/95	QV1353	5:16	ND	ND	ND	0.294	0.294	0.004	0	0.07
9/17/95	QV1354	6:16	ND	ND	0.598	0.343	0.941	0.021	0	0.055
9/17/95	QV1355	7:16	ND	ND	0.329	0.344	0.673	0.009	0	0.06
9/17/95	QV1356	8:16	ND	ND	0.329	0.402	0.731	ND	0	0.075
9/17/95	QV2357	14:03	ND	ND	0.389	0.183	0.572	0.001	0.01	0.13
9/17/95	QV2358	19:18	ND	ND	0.688	0.099	0.787	ND	0	0.14
9/17/95	QV2359	23:34	ND	ND	0.748	0.070	0.818	ND	0.01	0.08
9/18/95	QV2360	1:49	ND	ND	0.479	0.077	0.556	ND	0.025	0.05
9/22/95	QV1362	10:38	ND	0.628	1.675	1.618	3.293	ND	0.11	0.12
9/22/95	QV1363	10:53	0.031	0.778	1.944	1.721	3.665	ND	0.125	0.04
9/22/95	QV1364	11:08	ND	1.499	2.693	1.641	4.334	ND	0	0.105
9/22/95	QV1365	11:23	0.007	0.673	2.739	1.597	4.336	ND	0	0.095
9/22/95	QV1366	11:38	0.032	0.581	2.785	1.602	4.387	ND	0.165	0.055
9/24/95	QV1372	13:29	0.100	0.627	1.912	0.502	2.414	ND	0	0.085
9/24/95	QV1373	13:44	ND	1.132	1.316	0.616	1.932	ND	0	0.015
9/24/95	QV1374	13:59	ND	0.949	1.040	0.656	1.696	ND	0	0.045
9/24/95	QV1375	14:14	ND	1.132	0.581	0.673	1.254	ND	0	0.045
9/24/95	QV1376	14:29	ND	0.563	0.994	0.706	1.700	ND	0	0.03
9/26/95	QV1381	7:06	ND	4.253	1.958	1.341	3.299	ND	0	0.11
9/26/95	QV1382	7:21	0.036	1.086	2.463	1.309	3.772	ND	0	0.095
9/26/95	QV1383	7:36	0.072	1.040	1.086	1.091	2.177	ND	0	0.03
9/26/95	QV1384	7:51	0.089	1.040	2.326	1.046	3.372	ND	0	0.035
9/26/95	QV1385	8:06	0.106	1.362	0.994	1.084	2.078	ND	0.02	0.085
9/26/95	QV1386	8:21	0.111	0.994	1.867	1.129	2.996	ND	0	0.075
9/26/95	QV1387	8:36	0.110	0.949	0.994	1.174	2.168	ND	0.115	0

Sample from DL1 (QV1###), Sample from DL2 (QV2###)

Date	Sample #	TIME	TSS (ppm)	Cd (ug/L)	Cu (ug/L)	Pb (ug/L)	Zn (mg/L)	TOC (mg/L)
9/16/95	QV1336	16:29	ND	0.8	5	12	0.05	5.769
9/16/95	QV1337	17:29	ND	0.6	4	11	0.04	8.1075
9/16/95	QV1338	18:29	ND	NA	NA	NA	NA	NA
9/16/95	QV1339	19:29	2.000	0.8	5	13	0.06	7.557
9/16/95	QV1341	23:16	16.000	1.2	6	12	0.065	NA
9/16/95	QV1342	23:31	6.000	NA	NA	NA	NA	NA
9/16/95	QV1343	23:46	2.000	NA	NA	NA	NA	NA
9/17/95	QV1344	0:01	4.000	0.5	6	9	0.05	4.5895
9/17/95	QV1345	0:16	6.000	NA	NA	NA	NA	NA
9/17/95	QV1346	0:31	4.000	NA	NA	NA	NA	NA
9/17/95	QV1347	0:46	6.000	NA	NA	NA	NA	NA
9/17/95	QV1348	1:01	ND	0.9	4	9	0.05	NA
9/17/95	QV1349	1:16	ND	NA	NA	NA	NA	NA
9/17/95	QV1350	2:16	2.000	1.3	4.5	16.5	0.05	NA
9/17/95	QV1351	3:16	16.000	NA	NA	NA	NA	NA
9/17/95	QV1352	4:16	6.000	0.9	4	16	0.05	NA
9/17/95	QV1353	5:16	ND	NA	NA	NA	NA	NA
9/17/95	QV1354	6:16	4.000	NA	NA	NA	NA	NA
9/17/95	QV1355	7:16	2.000	NA	NA	NA	NA	NA
9/17/95	QV1356	8:16	ND	1.5	7	11	0.07	3.7105
9/17/95	QV2357	14:03	ND	0.6	4	9	0.05	4.1985
9/17/95	QV2358	19:18	8.000	1.1	6	12	0.08	5.1635
9/17/95	QV2359	23:34	0.000	0.8	4	9	0.05	6.214
9/18/95	QV2360	1:49	6.000	1.1	5	10	0.06	7.1695
9/22/95	QV1362	10:38	60.000	0.9	20	12.5	0.125	45.375
9/22/95	QV1363	10:53	40.000	0.6	12	11	0.09	41.28
9/22/95	QV1364	11:08	40.000	0.7	11	12	0.1	40.135
9/22/95	QV1365	11:23	34.000	0.8	11	15	0.09	39.56
9/22/95	QV1366	11:38	32.000	0.7	12	11	0.1	38.77
9/24/95	QV1372	13:29	68.000	0.8	11	15	0.105	29.215
9/24/95	QV1373	13:44	28.000	0.6	9	12	0.07	26.035
9/24/95	QV1374	13:59	32.000	0.7	9	11	0.07	28.69
9/24/95	QV1375	14:14	32.000	0.6	10	9	0.06	28.525
9/24/95	QV1376	14:29	20.000	NA	NA	NA	NA	NA
9/26/95	QV1381	7:06	110.000	1.2	16	22	0.18	29.595
9/26/95	QV1382	7:21	70.000	1.15	12	24	0.125	25.175
9/26/95	QV1383	7:36	42.000	0.9	8	19	0.08	20.225
9/26/95	QV1384	7:51	26.000	1	10	21	0.08	15.85
9/26/95	QV1385	8:06	10.000	0.7	7	14	0.06	15.1
9/26/95	QV1386	8:21	10.000	0.45	6.5	10	1.3	16.82
9/26/95	QV1387	8:36	12.000	0.4	9	7	0.07	15.185

Sample from DL1 (QV1###), Sample from DL2 (QV2###)

Date	Sample #	TIME	NH4 (ppm)	FTKN (ppm)	TKN (ppm)	NO3-N (ppm)	TN (ppm)	PO4 (ppm)	FTP (ppm)	TP (ppm)
9/26/95	QV1388	8:51	0.126	1.132	1.453	0.947	2.400	ND	0.07	0
9/26/95	QV1389	9:06	0.075	ND	0.410	0.439	0.849	ND	0	0.125
9/26/95	QV1390	10:06	0.083			0.403	0.403	ND		
9/26/95	QV1391	11:06	ND	ND	0.629	0.549	1.178	ND	0	0.06
9/26/95	QV2392	7:35	ND	0.278	8.397	1.186	9.583	ND	0	0.16
9/26/95	QV2393	9:28	ND	ND	2.209	1.002	3.211	ND	0	0.065
9/26/95	QV2394	14:30	ND	ND	0.717	0.208	0.925	ND	0	0.045
10/4/95	QV1402	0:46	0.056	0.805	2.472	0.956	3.428	ND	0	0.04
10/4/95	QV1403	1:01	0.036	0.322	2.736	0.805	3.541	ND	0	0.07
10/4/95	QV1404	1:16	ND	0.147	3.438	0.753	4.191	ND	0	0.02
10/4/95	QV1405	1:31	0.002	0.059	2.911	0.625	3.536	ND	0	0.015
10/4/95	QV1406	1:46	0.010	0.454	2.385	0.582	2.967	ND	0	0.04
10/4/95	QV1407	2:01	0.008	ND	2.692	0.568	3.260	ND	0	0.045
10/4/95	QV1410	2:46	ND	0.498	2.692	0.387	3.079	ND	0	0.02
10/4/95	QV1412	4:46	ND	0.322	2.341	0.214	2.555	ND	0.01	0.075
10/4/95	QV1414	6:46	ND	ND	2.209	0.167	2.376	ND	0.15	0.05
10/4/95	QV1416	8:46	ND	0.508	1.855	0.21	2.065	ND	ND	ND
10/4/95	QV2417	3:23	ND	0.484	0.075	0.283	0.358	0.018	ND	ND
10/4/95	QV2418	5:17	ND	0.532	0.484	0.255	0.739	ND	ND	ND
10/4/95	QV2419	9:09	ND	ND	ND	0.119	0.119	0.004	ND	ND
10/4/95	QV1420	9:46	ND	ND	0.051	0.319	0.370	0.001	ND	ND
10/4/95	QV1422	11:14	ND	0.821	0.972	0.403	1.375	0.005	ND	0.115
10/4/95	QV1423	11:29	ND	1.512	1.572	0.205	1.777	0.004	ND	0.08
10/4/95	QV1424	11:44	ND	1.512	1.872	0.151	2.023	0.009	ND	0.105
10/4/95	QV1426	12:14	ND	1.302	1.302	0.145	1.447	0.012	ND	0.075
10/4/95	QV1428	12:44	ND	0.942	0.972	0.09	1.062	0.026	ND	0.05
10/4/95	QV1429	12:59	0.006	0.972	1.002	0.105	1.107	0.024	ND	0.065
10/4/95	QV1430	13:14	ND	0.972	1.572	0.116	1.688	0.016	ND	0.055
10/4/95	QV2432	13:01	ND	0.851	1.572	0.195	1.767	0.005	ND	0.11
10/4/95	QV1433	15:14	ND	0.972	1.542	0.121	1.663	ND	ND	0.05
10/4/95	QV1435	17:14	ND	1.572	1.002	0.11	1.112	ND	ND	0.06
10/4/95	QV1437	19:14	ND	1.362	1.572	0.247	1.819	ND	ND	0.005
10/4/95	QV1438	4:35	0.043	0.942	1.572	0.306	1.878	ND	ND	0.075
10/4/95	QV1439	4:50	0.039	0.942	1.542	0.223	1.765	ND	ND	0.09
10/4/95	QV1440	5:05	0.121	0.671	1.272	0.168	1.440	0.013	0.075	0.035
10/4/95	QV1443	5:50	0.034	0.701	1.062	0.166	1.228	0.008	0.055	ND
10/4/95	QV2446	3:53	ND	2.345	0.692	0.044	0.736	0.008	ND	0.245
10/5/95	QV1447	6:35	0.001	1.203	1.744	0.123	1.867	ND	ND	0.165
10/5/95	QV1449	8:35	0.010	0.662	1.684	0.076	1.760	0.008	ND	0.135
10/5/95	QV1452	11:35	ND	0.813	0.602	0.618	1.220	0.033	ND	0.11
10/5/95	QV1453	13:04	ND	0.843	1.143	0.522	1.665	0.029	ND	0.115
10/5/95	QV1454	13:19	0.012	0.542	1.113	0.254	1.367	0.017	ND	0.085
10/5/95	QV1456	13:49	0.052	0.242	1.413	0.255	1.668	0.028	ND	0.055

Sample from DL1 (QV1###), Sample from DL2 (QV2###)

Date	Sample #	TIME	TSS (ppm)	Cd (ug/L)	Cu (ug/L)	Pb (ug/L)	Zn (mg/L)	TOC (mg/L)
9/26/95	QV1388	8:51	38.000	0.7	9	15	0.11	14.24
9/26/95	QV1389	9:06	60.000	0.9	11	13	0.14	9.608
9/26/95	QV1390	10:06	30.000	0.5	8	9	0.07	7.7305
9/26/95	QV1391	11:06	22.000	0.45	6.5	6.5	0.065	8.8825
9/26/95	QV2392	7:35	58.000	0.8	8	18	0.08	27.095
9/26/95	QV2393	9:28	9.800	0.4	6	6	0.05	15.445
9/26/95	QV2394	14:30	10.000	0.3	6	5	0.04	10.755
10/4/95	QV1402	0:46	90.000	1.7	19.5	20	0.14	68.935
10/4/95	QV1403	1:01	28.000	1.1	11	14	0.12	47.18
10/4/95	QV1404	1:16	28.000	0.9	11	14	0.1	37.155
10/4/95	QV1405	1:31	14.000	0.75	7.5	13	0.65	29.47
10/4/95	QV1406	1:46	4.000	0.6	7	11	0.05	25.755
10/4/95	QV1407	2:01	10.000	0.8	8	10	0.06	23.68
10/4/95	QV1410	2:46	18.000	0.6	8	10	0.06	17.6
10/4/95	QV1412	4:46	16.000	0.4	4	9	0.05	6.5925
10/4/95	QV1414	6:46	18.000	0.8	7	14	0.09	6.6605
10/4/95	QV1416	8:46	32.000	0.8	7	16	0.08	11.545
10/4/95	QV2417	3:23	14.000	NA	NA	NA	NA	11.345
10/4/95	QV2418	5:17	10.000	0.6	6	13	0.06	22.005
10/4/95	QV2419	9:09	6.000	0.4	4	8	0.06	9.4875
10/4/95	QV1420	9:46	26.000	0.9	8	16	0.1	12.805
10/4/95	QV1422	11:14	36.000	0.95	9	16.5	0.1	15.4
10/4/95	QV1423	11:29	68.000	1.3	11	23	0.13	15.71
10/4/95	QV1424	11:44	76.000	1	11	19	0.12	11.49
10/4/95	QV1426	12:14	56.000	1.55	12	26.5	0.125	6.055
10/4/95	QV1428	12:44	30.000	1	7	16	0.08	6.5425
10/4/95	QV1429	12:59	32.000	1.7	5.5	9	0.08	5.127
10/4/95	QV1430	13:14	30.000	0.8	5	9	0.06	5.611
10/4/95	QV2432	13:01	36.000	0.8	6	8	0.07	8.723
10/4/95	QV1433	15:14	28.000	0.6	5	6	0.06	7.8195
10/4/95	QV1435	17:14	36.000	0.8	5	9	0.07	NS
10/4/95	QV1437	19:14	2.000	0.7	4	5	0.05	5.837
10/4/95	QV1438	4:35	30.000	0.9	7	7.5	0.08	13.865
10/4/95	QV1439	4:50	66.000	1.1	8	9	0.1	10.515
10/4/95	QV1440	5:05	60.000	2.2	8	10	0.12	5.0775
10/4/95	QV1443	5:50	14.000	1.4	7	18	0.07	4.013
10/4/95	QV2446	3:53	0.000	1.5	5	18	0.07	7.385
10/5/95	QV1447	6:35	14.000	1.1	4	12	0.06	3.574
10/5/95	QV1449	8:35	80.000	4.55	0	23	0.12	4.065
10/5/95	QV1452	11:35	14.000	1.2	5	17	0.07	6.355
10/5/95	QV1453	13:04	46.000	1.95	12	23.5	0.115	11.54
10/5/95	QV1454	13:19	64.000	1.7	10	19	0.11	12.15
10/5/95	QV1456	13:49	30.000	1.4	6	16	0.07	9.8

Sample from DL1 (QV1###), Sample from DL2 (QV2###)

Date	Sample #	TIME	NH4 (ppm)	FTKN (ppm)	TKN (ppm)	NO3-N (ppm)	TN (ppm)	PO4 (ppm)	FTP (ppm)	TP (ppm)
10/5/95	QV1461	15:49	0.001	0.512	0.873	0.476	1.349	0.011	ND	0.03
10/5/95	QV2462	6:58	ND	0.272	1.143	0.176	1.319	ND	ND	0.04
10/5/95	QV2464	7:24	ND	0.723	1.383	0.117	1.500	ND	ND	0.04
10/5/95	QV2465	8:51	0.012	0.512	1.924	0.074	1.998	ND	ND	0.05
10/5/95	QV2466	0:59	0.008	0.873	1.173	0.026	1.199	0.001	ND	0.045
10/5/95	QV2467	6:30	ND	0.723	1.624	0.108	1.732	0.014	0.005	0.065
10/5/95	QV1468	17:55	0.042	0.332	2.946	0.239	3.185	0.007	ND	0.23
10/5/95	QV1469	18:10	0.015	0.482	1.684	0.151	1.835	0.001	0.2	0.125
10/5/95	QV1472	18:55	ND	0.155	0.155	0.205	0.360	0.004	N	0.075
10/5/95	QV1476	19:55	ND	ND	ND	0.367	0.367	0.024	ND	0.06
10/6/95	QV2478	11:59	ND	ND	0.505	0.027	0.532	0.033	ND	0.065
10/6/95	QV2789	16:38	ND	ND	0.941	0.023	0.964	0.034	ND	0.055
10/6/95	QV2480	19:14	0.035	0.214	0.767	0.034	0.801	0.016	0.29	0.035
10/6/95	QV2481	20:18	ND	0.097	1.000	0.195	1.195	0.033	ND	0.075
10/13/95	QV1501	22:24	0.070	1.378	1.931	1.202	3.133	ND	ND	ND
10/13/95	QV1502	22:39	0.071	0.912	2.135	1.28	3.415	ND	ND	0.015
10/13/95	QV1503	22:54	0.063	0.796	1.378	1.16	2.538	ND	ND	0.055
10/13/95	QV1504	23:09	0.060	0.767	2.484	1.125	3.609	ND	ND	0.055
10/14/95	QV1505	1:55	0.179	0.563	2.193	0.401	2.594	ND	ND	0.075
10/14/95	QV1506	2:10	0.039	ND	0.709	0.23	0.939	ND	ND	0.125
10/14/95	QV1507	2:25	0.034	ND	0.185	0.196	0.381	ND	ND	0.055
10/14/95	QV1508	2:40	ND	0.010	0.126	0.237	0.363	ND	0.19	ND
10/14/95	QV1509	2:55	0.007	0.097	0.650	0.25	0.900	0.033	0.14	ND
10/14/95	QV1510	3:10	ND	0.759	1.160	0.291	1.451	0.03	ND	0.175
10/14/95	QV1511	3:25	0.002	0.304	0.812	0.324	1.136	0.022	ND	0.09
10/14/95	QV1512	3:40	0.069	0.358	0.652	0.329	0.981	0.007	ND	0.07
10/14/95	QV1513	3:55	0.015	0.304	1.026	0.347	1.373	ND	ND	0.05
10/14/95	QV1514	4:55	0.038	ND	0.999	0.387	1.386	0.01	ND	0.045
10/14/95	QV2515	2:11	0.139	0.385	1.988	0.548	2.536	0.052	ND	0.17
10/14/95	QV2516	5:48	ND	0.465	1.641	0.2	1.841	0.05	ND	0.11
10/14/95	QV2517	14:40	0.023	0.679	1.641	0.164	1.805	0.013	ND	0.07
10/14/95	QV2518	15:10	0.005	0.117	1.106	0.149	1.255	0.012	ND	0.055
10/14/95	QV1519	12:33	0.016	0.545	1.507	0.324	1.831	0.015	ND	0.035
10/14/95	QV1520	12:48	0.052	0.999	1.641	0.272	1.913	0.013	ND	0.03
10/14/95	QV1521	13:03	0.065	0.625	1.561	0.295	1.856	0.015	ND	0.045
10/14/95	QV1522	13:33	0.048	0.812	0.465	0.246	0.711	0.011	ND	0.035
10/14/95	QV1523	14:03	0.012	0.411	0.545	0.247	0.792	0.006	ND	0.07
10/14/95	QV1524	14:33	0.054	0.786	0.786	0.177	0.963	0.01	0.19	0.06
10/14/95	QV1525	16:33	ND	ND	ND	0.247	0.247	ND	0	0.07
10/14/95	QV1526	18:33	ND	ND	ND	0.431	0.431	0.024	0	0.035
10/14/95	QV1527	19:35	ND	ND	ND	0.482	0.482	0.017	0	0.03
10/14/95	QV1528	20:05	ND	ND	ND	0.478	0.478	0.006	0	0.055
10/14/95	QV1529	20:35	ND	ND	ND	0.446	0.446	ND	0	0.005

Sample from DL1 (QV1###), Sample from DL2 (QV2###)

Date	Sample #	TIME	TSS (ppm)	Cd (ug/L)	Cu (ug/L)	Pb (ug/L)	Zn (mg/L)	TOC (mg/L)
10/5/95	QV1461	15:49	20.000	1.4	6	13	0.06	9.143
10/5/95	QV2462	6:58	28.000	0.75	5	12.5	0.045	6.973
10/5/95	QV2464	7:24	42.000	1	8	16	0.06	4.473
10/5/95	QV2465	8:51	32.000	0.6	5	11	0.04	4.428
10/5/95	QV2466	0:59	14.000	0.65	5	12	0.04	5.306
10/5/95	QV2467	6:30	28.000	1.1	6	13	0.06	5.839
10/5/95	QV1468	17:55	130.000	1.2	4	23	0.14	10.37
10/5/95	QV1469	18:10	94.000	0.8	9	17	0.09	9.073
10/5/95	QV1472	18:55	30.000	1	9	16	0.07	4.774
10/5/95	QV1476	19:55	8.000	0.7	6	13	0.04	6.331
10/6/95	QV2478	11:59	4.000	0.4	4	9	0.03	5.961
10/6/95	QV2789	16:38	4.000	1.4	7	8	0.04	6.606
10/6/95	QV2480	19:14	2.000	0.5	4	7	0.04	7.764
10/6/95	QV2481	20:18	10.000	0.6	4	6	0.04	9.265
10/13/95	QV1501	22:24	54.000	0.4	13	5	0.08	70.955
10/13/95	QV1502	22:39	20.000	0.4	11	6	0.06	59.38
10/13/95	QV1503	22:54	22.000	0.5	12	8	0.05	56.23
10/13/95	QV1504	23:09	12.000	0.5	11	8	0.06	56.77
10/14/95	QV1505	1:55	64.000	1	11.5	16.5	0.17	29.995
10/14/95	QV1506	2:10	70.000	0.7	8	15	0.1	12.705
10/14/95	QV1507	2:25	26.000	0.5	5	9	0.05	9.7985
10/14/95	QV1508	2:40	22.000	0.3	5	4	0.03	9.7835
10/14/95	QV1509	2:55	14.000	0.6	6	7	0.04	10.315
10/14/95	QV1510	3:10	14.000	0.45	4.5	4	0.03	10.46
10/14/95	QV1511	3:25	10.000	0.3	5	5	0.03	10.61
10/14/95	QV1512	3:40	8.000	0.5	4	5	0.03	11.3
10/14/95	QV1513	3:55	8.000	0.4	4	5	0.03	11.21
10/14/95	QV1514	4:55	10.000	0.3	4	5	0.03	11.44
10/14/95	QV2515	2:11	52.000	0.7	10	12.5	0.095	26.097
10/14/95	QV2516	5:48	-4.000	0.5	6	6	0.04	12.385
10/14/95	QV2517	14:40	12.000	0.5	7	8	0.05	15.255
10/14/95	QV2518	15:10	14.000	0.5	8	9	0.06	9.091
10/14/95	QV1519	12:33	10.000	0.55	9	8.5	0.05	29.195
10/14/95	QV1520	12:48	16.000	0.5	8	9	0.05	28.105
10/14/95	QV1521	13:03	18.000	0.3	7	4	0.055	28.52
10/14/95	QV1522	13:33	22.000	0.5	8	9	0.05	15.925
10/14/95	QV1523	14:03	6.000	0.4	6	7	0.14	13.325
10/14/95	QV1524	14:33	76.000	0.8	10	16	0.05	10.214
10/14/95	QV1525	16:33	8.000	0.3	4	4	0.05	4.7975
10/14/95	QV1526	18:33	6.000	0.2	2	2	0.04	5.9215
10/14/95	QV1527	19:35	2.000	0.5	4	10	0.04	6.6135
10/14/95	QV1528	20:05	8.000	0.3	3	3	0.03	8.1165
10/14/95	QV1529	20:35	ND	0.3	4	4	0.04	8.3495

Sample from DL1 (QV1###), Sample from DL2 (QV2###)

Date	Sample #	TIME	NH4 (ppm)	FTKN (ppm)	TKN (ppm)	NO3-N (ppm)	TN (ppm)	PO4 (ppm)	FTP (ppm)	TP (ppm)
10/14/95	QV1530	21:05	ND	0.264	ND	0.486	0.486	ND	0	0.01
10/14/95	QV1531	22:20	ND	0.492	ND	0.502	0.502	ND	0	0.02
10/20/95	QV2541	19:07	0.148	0.605	0.577	1.157	1.734	0.014	0	0.165
10/20/95	QV2542	19:21	0.052	ND	0.321	1.002	1.323	ND	0	0.085
10/20/95	QV2543	19:51	0.023	ND	0.009	0.67	0.679	ND	0.075	0.035
10/20/95	QV2544	20:33	0.018	0.605	0.492	0.531	1.023	ND	0	0.025
10/20/95	QV2545	23:33	ND	0.605	ND	0.428	0.428	ND	0	0.23
10/20/95	QV2546	7:20	ND	0.066	ND	0.273	0.273	0.004	0	0.185
10/20/95	QV1547	18:35	0.119	0.804	2.196	1.007	3.203	ND	0.18	0.3
10/20/95	QV1548	18:50	0.071	0.463	1.230	1.097	2.327	ND	0.1	0.14
10/20/95	QV1549	19:05	0.080	0.204	1.130	0.857	1.987	ND	ND	0.19
10/20/95	QV1550	19:20	0.099	0.031	1.246	0.63	1.876	ND	ND	0.135
10/20/95	QV1551	19:35	0.090	ND	0.204	0.514	0.718	ND	ND	0.07
10/20/95	QV1552	19:50	ND	ND	ND	0.422	0.422	ND	ND	0.06
10/20/95	QV1553	20:05	0.081	0.117	0.291	0.375	0.666	ND	ND	0.055
10/20/95	QV1555	20:35	ND	ND	ND	0.294	0.294	ND	ND	0.04
10/20/95	QV1558	23:35	ND	0.002	ND	0.135	0.135	ND	ND	0.05
10/21/95	QV1560	1:35	ND	ND	ND	0.374	0.374	ND	ND	0.01
10/21/95	QV1561	3:39	ND	ND	ND	0.583	0.583	ND	ND	0.015
10/21/95	QV1562	4:24	ND	ND	ND	0.556	0.556	ND	ND	0.01
10/21/95	QV2563	12:37	ND	0.002	0.031	0.195	0.226	0.007	0.035	0.055
10/21/95	QV2564	17:25	ND	0.349	ND	0.148	0.148	0.017	0.04	0.045
10/21/95	QV2565	20:18	ND	0.146	ND	0.129	0.129	0.017	0.045	0.055
10/21/95	QV2566	21:30	ND	0.320	ND	0.177	0.177	0.009	0.005	0.15
10/27/95	QV1570	14:52	0.169	1.217	1.102	1.23	2.332	ND	0.205	0.09
10/27/95	QV1571	15:07	0.060	ND	0.508	1.06	1.568	ND	ND	0.15
10/27/95	QV1572	15:22	0.015	ND	0.165	0.793	0.958	ND	ND	0.11
10/27/95	QV1573	15:37	ND	ND	ND	0.71	0.710	ND	ND	0.07
10/27/95	QV1574	15:52	0.022	ND	ND	0.715	0.715	ND	ND	0.045
10/27/95	QV1575	16:07	ND	ND	ND	0.726	0.726	0.002	ND	0.02
10/27/95	QV1576	16:22	0.010	ND	ND	0.751	0.751	0.058	ND	0.03
10/27/95	QV1577	16:37	ND	ND	ND	0.786	0.786	0.028	ND	0.04
10/28/95	QV1580	16:57	ND	ND	0.308	0.028	0.336	0.023	ND	0.12
10/28/95	QV1581	17:12	ND	ND	0.165	0.237	0.402	0.033	ND	0.105
10/28/95	QV1582	17:27	ND	ND	ND	0.312	0.312	0.03	ND	0.065
10/28/95	QV1583	17:42	ND	ND	ND	0.329	0.329	0.032	ND	0.045
10/28/95	QV1584	17:57	ND	ND	ND	0.329	0.329	0.028	ND	0.19
10/28/95	QV1585	18:12	ND	0.765	ND	0.336	0.336	0.045	0.04	0.125
10/31/95	QV1591	20:37	ND	ND	ND	0.265	0.265	0.015	0.26	0.04
10/31/95	QV1592	20:52	ND	ND	ND	0.239	0.239	0.013	0.135	ND
10/31/95	QV1593	21:07	ND	ND	ND	0.288	0.288	0.01	ND	0.185

Sample from DL1 (QV1###), Sample from DL2 (QV2###)

Date	Sample #	TIME	TSS (ppm)	Cd (ug/L)	Cu (ug/L)	Pb (ug/L)	Zn (mg/L)	TOC (mg/L)
10/14/95	QV1530	21:05	4.000	0.2	3	3	0.03	8.275
10/14/95	QV1531	22:20	ND	0.4	4	3	0.06	NA
10/20/95	QV2541	19:07	36.000	0.3	10	6.5	0.06	37.68
10/20/95	QV2542	19:21	18.000	0.2	7	4	0.05	26.83
10/20/95	QV2543	19:51	14.000	0.2	4	3	0.04	11.51
10/20/95	QV2544	20:33	6.000	0.2	4	3	0.04	6.7245
10/20/95	QV2545	23:33	8.000	0.4	3	3	0.03	6.2785
10/20/95	QV2546	7:20	ND	0.2	3.5	3	0.03	5.861
10/20/95	QV1547	18:35	164.000	0.8	17	16	0.26	44.67
10/20/95	QV1548	18:50	68.000	0.4	10	8	0.12	35.375
10/20/95	QV1549	19:05	34.000	0.3	8	6	0.07	21.765
10/20/95	QV1550	19:20	50.000	0.4	6	6	0.09	9.89
10/20/95	QV1551	19:35	12.000	0.6	5.5	4	0.06	5.3815
10/20/95	QV1552	19:50	22.000	0.5	4	3	0.06	4.252
10/20/95	QV1553	20:05	16.000	0.4	4	4	0.05	3.463
10/20/95	QV1555	20:35	10.000	0.5	6	4	0.04	2.9375
10/20/95	QV1558	23:35	14.000	0.3	4	3	0.04	2.147
10/21/95	QV1560	1:35	6.000	0.2	3	3	0.04	3.7155
10/21/95	QV1561	3:39	4.000	0.25	3	2	0.045	3.925
10/21/95	QV1562	4:24	10.000	0.4	4	2	0.06	4.536
10/21/95	QV2563	12:37	10.000	0.2	2	6	0.03	5.065
10/21/95	QV2564	17:25	2.000	0.3	2	4.5	0.025	4.877
10/21/95	QV2565	20:18	8.000	0.3	3	6	0.03	
10/21/95	QV2566	21:30	ND	0.5	5	7	0.04	6.711
10/27/95	QV1570	14:52	68.000	0.65	12.5	12	0.16	44.22
10/27/95	QV1571	15:07	60.000	0.5	10	9	0.13	34.34
10/27/95	QV1572	15:22	48.000	0.5	9	8	0.09	27.42
10/27/95	QV1573	15:37	30.000	0.3	7	5	0.07	24.83
10/27/95	QV1574	15:52	30.000	0.3	6	5	0.06	23.11
10/27/95	QV1575	16:07	26.000	0.95	6.5	8.5	0.06	23.82
10/27/95	QV1576	16:22	24.000	0.7	6	5	0.06	24.325
10/27/95	QV1577	16:37	20.000	1	7	6	0.08	24.55
10/28/95	QV1580	16:57	74.000	1.1	9.5	10.5	0.11	34.785
10/28/95	QV1581	17:12	54.000	0.9	8	7	0.08	18.63
10/28/95	QV1582	17:27	34.000	0.6	5	6	0.08	25.21
10/28/95	QV1583	17:42	22.000	0.6	7	6	0.06	26.125
10/28/95	QV1584	17:57	28.000	0.7	5	8	0.08	27.2
10/28/95	QV1585	18:12	22.000	0.6	7	7	0.07	27.295
10/31/95	QV1591	20:37	40.000	1.25	7.5	10	0.085	36.275
10/31/95	QV1592	20:52	50.000	1	5	10	0.08	31.111
10/31/95	QV1593	21:07	28.000	1.8	8	9	0.08	23.235

Sample from DL1 (QV1###), Sample from DL2 (QV2###)

Date	Sample #	TIME	NH4 (ppm)	FTKN (ppm)	TKN (ppm)	NO3-N (ppm)	TN (ppm)	PO4 (ppm)	FTP (ppm)	TP (ppm)
10/31/95	QV1594	21:22	ND	ND	ND	0.277	0.277	0.009	ND	0.115
10/31/95	QV1595	21:37	ND	ND	ND	0.254	0.254	0.009	ND	0.09
10/31/95	QV1596	21:52	ND	ND	ND	0.238	0.238	0.006	ND	0.11
10/31/95	QV1597	22:07	ND	ND	ND	0.242	0.242	0.006	ND	0.05
10/31/95	QV1598	22:22	ND	ND	ND	0.259	0.259	0.002	ND	0.05
10/31/95	QV1599	22:37	ND	ND	ND	0.247	0.247	0.004	ND	0.08
11/2/95	QV2601	1:42	ND	ND	ND	0.208	0.208	0.009	ND	0.16
11/2/95	QV2602	2:10	ND	ND	ND	0.297	0.297	0.054	ND	0.11
11/2/95	QV2603	7:53	ND	ND	ND	0.099	0.099	0.053	ND	0.095
11/2/95	QV1604	1:27	ND	ND	ND	0.262	0.262	0.015	ND	0.105
11/2/95	QV1605	1:42	ND	ND	ND	0.243	0.243	0.007	ND	0.07
11/2/95	QV1606	1:57	0.188	ND	ND	0.176	0.176	0.007	0.01	0.04
11/2/95	QV1607	2:27	ND	ND	ND	0.089	0.089	0.003	0.02	0.07
11/2/95	QV1608	2:57	ND	ND	ND	0.136	0.136	0.009	0.135	0.015
11/2/95	QV1609	3:27	ND	ND	ND	0.174	0.174	0.005	ND	0.065
11/2/95	QV1610	6:27	ND	ND	0.583	0.236	0.819	0.009	ND	0.06
11/2/95	QV2611	9:01	ND	ND	ND	0.043	0.043	0.022	ND	0.095
11/2/95	QV2612	14:48	ND	ND	0.688	0.179	0.867	0.015	ND	0.14
11/2/95	QV2613	17:50	ND	0.217	ND	0.109	0.109	0.006	ND	0.095
11/2/95	QV1614	13:42	ND	0.086	0.426	0.408	0.834	0.01	ND	0.085
11/2/95	QV1615	13:57	ND	ND	0.976	0.193	1.169	0.016	ND	0.1
11/2/95	QV1616	14:12	0.082	ND	0.217	0.286	0.503	0.017	ND	0.09
11/2/95	QV1617	14:27	ND	ND	0.243	0.231	0.474	0.009	ND	0.115
11/2/95	QV1618	14:42	ND	ND	0.400	0.301	0.701	0.012	ND	0.125
11/2/95	QV1619	14:57	ND	ND	0.557	0.307	0.864	0.01	ND	0.075
11/2/95	QV1620	15:12	ND	ND	0.662	0.32	0.982	0.028	0.015	0.165
11/2/95	QV1621	15:27	ND	ND	1.080	0.322	1.402	0.016	ND	0.09
11/2/95	QV1622	16:27	ND	ND	1.290	0.371	1.661	0.006	0.14	0.025
11/2/95	QV1623	17:27	ND	ND	0.740	0.403	1.143	ND	0.13	ND
11/3/95	QV1631	16:35	0.028	0.755	2.059	0.02	2.079	ND	ND	0.215
11/3/95	QV1632	16:50	ND	0.867	1.351	0.167	1.518	ND	ND	0.135
11/3/95	QV1633	17:05	ND	0.159	1.686	0.184	1.870	ND	ND	0.1
11/3/95	QV1634	17:20	ND	0.234	1.649	0.18	1.829	ND	ND	0.075
11/3/95	QV1635	17:35	ND	0.718	1.724	0.217	1.941	ND	ND	0.06
11/3/95	QV1636	17:50	ND	0.755	1.835	0.216	2.051	ND	ND	0.07
11/7/95	QV1641	2:29	0.200	0.792	3.251	0.125	3.376	0.027	ND	0.18
11/7/95	QV1642	2:44	0.251	1.09	3.623	0.201	3.824	0.051	0.02	0.15
11/7/95	QV1643	2:59	0.169	1.128	1.91	0.34	2.250	0.035	0.015	0.13
11/7/95	QV1644	3:14	0.045	0.532	2.245	0.404	2.649	0.029	0.005	0.155
11/7/95	QV1645	3:29	0.028	1.128	3.363	0.377	3.740	0.025	0.01	0.095
11/7/95	QV1646	3:44	ND	0.42	1.91	0.358	2.268	0.013	0.01	0.075
11/7/95	QV1647	3:57	ND	0.457	2.953	0.2	3.153	ND	ND	0.08

Sample from DL1 (QV1###), Sample from DL2 (QV2###)

Date	Sample #	TIME	TSS (ppm)	Cd (ug/L)	Cu (ug/L)	Pb (ug/L)	Zn (mg/L)	TOC (mg/L)
10/31/95	QV1594	21:22	22.000	1.4	5.5	8	0.065	19.35
10/31/95	QV1595	21:37	20.000	1.6	5	8	0.07	17.43
10/31/95	QV1596	21:52	18.000	1.2	5	10	0.07	17.04
10/31/95	QV1597	22:07	14.000	1.1	4	7	0.06	16.335
10/31/95	QV1598	22:22	18.000	1.8	6	7	0.06	16.545
10/31/95	QV1599	22:37	8.000	1.7	5	8	0.07	16.295
11/2/95	QV2601	1:42	56.000	0.9	6	15	0.08	20.68
11/2/95	QV2602	2:10	22.000	0.8	5	8	0.06	12.235
11/2/95	QV2603	7:53	0.000	0.8	4	8	0.04	9.356
11/2/95	QV1604	1:27	74.000	0.9	9	12.5	0.135	20.305
11/2/95	QV1605	1:42	48.000	1	5	12	0.08	10.755
11/2/95	QV1606	1:57	24.000	0.5	3	7	0.05	7.332
11/2/95	QV1607	2:27	6.000	0.6	2	6	0.03	4.762
11/2/95	QV1608	2:57	4.000	0.7	3	6	0.04	5.284
11/2/95	QV1609	3:27	ND	0.8	3	6	0.03	5.97
11/2/95	QV1610	6:27	ND	0.3	4	4	0.06	9.591
11/2/95	QV2611	9:01	2.000	0.3	5	2	0.04	9.272
11/2/95	QV2612	14:48	48.000	0.4	9	8	0.08	20.7
11/2/95	QV2613	17:50	11.600	0.3	6.5	4	0.045	11.945
11/2/95	QV1614	13:42	30.000	1.85	11	9	0.105	28.54
11/2/95	QV1615	13:57	48.000	1.2	14	10	0.13	33.48
11/2/95	QV1616	14:12	48.000	0.8	12	9	0.11	28.195
11/2/95	QV1617	14:27	72.000	0.8	12	9	0.12	23.55
11/2/95	QV1618	14:42	72.000	0.6	12	9	0.1	20.18
11/2/95	QV1619	14:57	50.000	0.4	9	8.5	0.07	15.61
11/2/95	QV1620	15:12	36.000	0.3	8	6	0.06	14.42
11/2/95	QV1621	15:27	36.000	0.4	8	8	0.07	13.99
11/2/95	QV1622	16:27	28.000	0.4	8	7	0.06	13.77
11/2/95	QV1623	17:27	26.000	0.4	8	7	0.08	13.675
11/3/95	QV1631	16:35	70.000	0.7	15	11	0.135	35.93
11/3/95	QV1632	16:50	50.000	0.5	9	11	0.09	21.275
11/3/95	QV1633	17:05	40.000	0.5	8	11	0.08	17.405
11/3/95	QV1634	17:20	34.000	0.5	8	10	0.07	16.68
11/3/95	QV1635	17:35	24.000	0.5	6	11	0.06	15.495
11/3/95	QV1636	17:50	24.000	0.6	6	14	0.07	14.79
11/7/95	QV1641	2:29	38.000	0.7	8.5	13	0.095	40.16
11/7/95	QV1642	2:44	26.000	0.6	7	9	0.07	28.08
11/7/95	QV1643	2:59	16.000	0.4	4	7	0.06	19.77
11/7/95	QV1644	3:14	10.000	0.4	4	6	0.06	15.09
11/7/95	QV1645	3:29	12.000	0.4	3	6	0.05	12.13
11/7/95	QV1646	3:44	8.000	0.6	5	12	0.065	9.507
11/7/95	QV1647	3:57	40.000	0.6	4	12	0.08	6.3475

Sample from DL1 (QV1###), Sample from DL2 (QV2###)

Date	Sample #	TIME	NH4 (ppm)	FTKN (ppm)	TKN (ppm)	NO3-N (ppm)	TN (ppm)	PO4 (ppm)	FTP (ppm)	TP (ppm)
11/7/95	QV1648	4:14	ND	2.32	1.575	0.153	1.728	ND	ND	0.085
11/7/95	QV1649	4:29	ND	0.83	1.575	0.093	1.668	ND	0.155	0.045
11/7/95	QV1651	6:29	ND	0.5	0.005	0.098	0.103	ND	ND	0.055
11/7/95	QV1652	8:29	ND	0.161	ND	0.144	0.144	ND	ND	0.075
11/7/95	QV1653	10:29	ND	1.985	1.281	0.228	1.509	ND	ND	0.06
11/7/95	QV1654	12:29	ND	ND	0.239	0.289	0.528	ND	ND	0.035
11/7/95	QV2655	3:39	ND	ND	1.073	0.518	1.591	0.026	ND	0.235
11/7/95	QV2656	4:06	ND	ND	0.578	0.443	1.021	0.045	ND	0.205
11/7/95	QV2657	4:37	ND	ND	0.343	0.225	0.568	0.018	ND	0.12
11/7/95	QV2658	5:12	ND	ND	0.63	0.144	0.774	0.021	ND	0.24
11/7/95	QV2659	7:07	ND	ND	ND	0.129	0.129	0.008	ND	0.09
11/7/95	QV1660	15:29	ND	0.291	ND	0.379	0.379	0.005	ND	0.04
11/7/95	QV2661	23:59	ND	ND	0.161	0.148	0.309	0.059	0.04	0.16
11/8/95	QV2662	5:05	ND	ND	ND	0.096	0.096	0.056	0.035	0.11
11/8/95	QV2663	9:47	ND	0.63	0.005	0.124	0.129	0.063	0.05	0.12
11/8/95	QV2664	12:39	0.002	0.083	0.448	0.159	0.607	0.064	0.16	0.08
11/8/95	QV2665	13:54	ND	ND	ND	0.15	0.150	0.032	0.555	0
11/11/95	QV1671	8:48	0.020	0.831	1.377	0.202	1.579	0.037	ND	0.27
11/11/95	QV1672	9:03	0.045	1.296	1.276	0.758	2.034	0.041	ND	0.2
11/11/95	QV1673	9:18	0.019	0.548	0.952	0.681	1.633	0.022	ND	0.12
11/11/95	QV1674	9:33	ND	0.427	0.892	0.487	1.379	0.015	ND	0.095
11/11/95	QV1675	10:03	ND	0.811	0.508	0.377	0.885	0.017	ND	0.065
11/11/95	QV1676	10:33	ND	0.811	0.973	0.216	1.189	0.014	ND	0.065
11/11/95	QV1677	11:48	ND	0.872	0.952	0.243	1.195	0.036	ND	0.075
11/11/95	QV1678	13:51	ND	0.71	0.872	0.349	1.221	0.03	ND	0.07
11/11/95	QV2679	9:47	ND	1.074	1.033	0.675	1.708	0.021	ND	0.1
11/11/95	QV1680	14:36	ND	0.952	2.753	0.216	2.969	0.031	ND	0.07
11/11/95	QV1681	14:51	ND	0.831	1.215	0.152	1.367	0.024	0.015	0.06
11/11/95	QV1682	15:51	ND	0.184	1.296	0.037	1.333	0.01	0.005	0.09
11/11/95	QV1683	16:51	ND	0.831	0.851	0.145	0.996	0.018	0.015	0.085
11/11/95	QV2684	15:38	ND	0.791	1.094	0.097	1.191	0.016	ND	0.215
11/11/95	QV2685	15:44	ND	0.305	1.397	0.036	1.433	ND	0.15	0.195

Sample from DL1 (QV1###), Sample from DL2 (QV2###)

Date	Sample #	TIME	TSS (ppm)	Cd (ug/L)	Cu (ug/L)	Pb (ug/L)	Zn (mg/L)	TOC (mg/L)
11/7/95	QV1648	4:14	12.000	0.4	3	7	0.04	3.7695
11/7/95	QV1649	4:29	28.000	0.4	4	7	0.07	3.146
11/7/95	QV1651	6:29	10.000	0.3	2	5	0.08	3.026
11/7/95	QV1652	8:29	20.000	0.35	4	7	0.045	4.22
11/7/95	QV1653	10:29	22.000	0.4	4	6	0.04	8.2545
11/7/95	QV1654	12:29	20.000	0.5	4	8	0.04	6.0045
11/7/95	QV2655	3:39	28.000	0.45	5	8	0.04	23.135
11/7/95	QV2656	4:06	30.000	0.5	4	8	0.04	11.755
11/7/95	QV2657	4:37	18.000	0.3	2	8	0.03	5.1835
11/7/95	QV2658	5:12	24.000	2	5	6	0.05	3.805
11/7/95	QV2659	7:07	16.000	3.1	4	6	0.05	2.9335
11/7/95	QV1660	15:29	16.000	2.5	6	5	0.06	7.778
11/7/95	QV2661	23:59	24.000	3.45	4.5	4	0.055	6.2765
11/8/95	QV2662	5:05	6.000	2.7	4	3	0.04	5.4065
11/8/95	QV2663	9:47	30.000	4.2	4	4	0.05	5.983
11/8/95	QV2664	12:39	30.000	1.7	4	4	0.05	6.7895
11/8/95	QV2665	13:54	0.000	2.4	7	3	0.04	5.595
11/11/95	QV1671	8:48	48.000	2.6	11	7.5	0.095	36.635
11/11/95	QV1672	9:03	30.000	0.5	8	9	0.08	24.805
11/11/95	QV1673	9:18	22.000	0.5	7.5	15	0.07	17.895
11/11/95	QV1674	9:33	22.000	0.6	6	8	0.06	12.395
11/11/95	QV1675	10:03	16.000	0.4	4	7	0.05	10.375
11/11/95	QV1676	10:33	14.000	0.5	4	9	0.05	7.168
11/11/95	QV1677	11:48	ND	0.8	5	5	0.05	8.8195
11/11/95	QV1678	13:51	ND	0.5	4	6	0.04	11.825
11/11/95	QV2679	9:47	20.000	0.4	6	9	0.05	19.1
11/11/95	QV1680	14:36	2.000	0.4	4	7	0.04	12.47
11/11/95	QV1681	14:51	8.000	0.3	4	6	0.04	11.335
11/11/95	QV1682	15:51	100.000	0.45	6.5	12.5	0.075	3.4735
11/11/95	QV1683	16:51	48.000	0.4	6	10	0.05	4.405
11/11/95	QV2684	15:38	96.000	0.6	8.5	12	0.105	5.512
11/11/95	QV2685	15:44	234.000	0.8	14	21	0.18	8.0445

Sample from DL1 (QV1###), Sample from DL2 (QV2###)

Vita

Kimberly Jean Corcoran Hodges was born into a military family February 29, 1972 in Heidelberg, Germany. She graduated from Thomas Jefferson High School for Science and Technology, Alexandria, Virginia, in 1990 as a member of the school's second graduating class. In August 1990 she began her studies at Virginia Tech and graduated cum laude with her Bachelor's of Science degree in Civil Engineering in May of 1994. In August of 1994 she began her graduate studies in the Virginia Tech Civil Engineering Department's Hydrosystems Division. She was married in August 1995 and began full time employment with Anderson & Associates, Inc. in Blacksburg, Virginia in July 1996 where she currently works as a Project Engineer in the Land Development group.