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Pollutant Removal Efficiency of a Stormwater Wetland BMP during Baseflow and Storm Events.

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Pollutant Removal Efficiency of a Stormwater Wetland BMP during Baseflow and Storm Events.

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Abstract

An existing dry detention basin was retrofitted into a stormwater wetland best management practice (BMP) on Villanova University's campus. This site is designed for water quality treatment purposes, as well as maintaining the original stormwater detention controls. The wetland is continuously monitored for multiple parameters, including conductivity, dissolved oxygen, pH, temperature, and flow. Automated samplers are located at both inlet points and the outlet structure, and can be programmed for variable interval sampling based upon storm size.

The water quality treatment by this BMP is the focus of the study. Water samples were collected at two inlets and the outlet using a number of different sampling protocols. Samples were collected for seven storm events, ranging from .25 to 2.1 inches, as well as for baseflow conditions. Samples were analyzed for pH, conductivity, and concentrations of reactive phosphorus, suspended solids, dissolved solids, chloride, total phosphorous, total nitrogen, nitrite, and nitrate.

During storm events, the wetland showed a removal efficiency of nearly 70 percent for total suspended solids, while dissolved components such as reactive phosphorus and chlorides showed little or no overall removal. A significant "first flush" can be seen during storm events, with large peak inflow concentrations. These high concentrations are reduced greatly by flow through the wetland. During baseflow conditions, the wetland shows approximately 60 percent removal of reactive and total phosphorus, and nearly 80 percent removal of total nitrogen. Chloride passed directly through the system for storm events and baseflow. Overall, the levels of all nutrients and pollutants in both influent and effluent are well below recommended values.

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Chapter 1: Overview

1.1 Introduction

Stormwater runoff has been identified as one of the leading causes of degradation of water quality in receiving waters in the United States (Lee et. al, 2002). Urbanization and the resulting increase in impervious surface cause “flashier” water systems, increased runoff due to decreased infiltration, and higher pollutant loads from human and industrial sources. For years the major concern of dealing with this increase in runoff has been to delay its release into receiving waters through the use of detention basins and ponds. This practice does not address the increase in pollutants that are passed along the system to rivers and streams. It also does not address the concern that the total volume of water passed through the hydrologic system is increased from what would be considered natural. Due to these concerns, new methods have been devised to deal with infiltration and treatment of the stormwater runoff issue termed Best Management Practices (BMP). This paper will focus solely on the water quality performance of the wetland BMPs treatment of stormwater runoff.

Best Management Practices (BMP’s) are a recent evolution in stormwater runoff treatment, dealing with storage, infiltration, and treatment of urban runoff. Of these BMP’s, the stormwater wetland is a tool used to address the water quality and quantity issues associated with urban runoff. The construction of wetlands to manage stormwater runoff has been used in the United States since the early 1980’s (Carlisle and Mulamoottil, 1991). There has been a significant amount of research concerning the ability of wetlands to remove suspended solids from influent waters. Several studies have also been performed to determine the ability of constructed wetlands to retain and use certain nutrients such as nitrogen and phosphorus. The majority of these studies either used baseflow sampling or composite sampling to determine the removal effectiveness of the constructed wetland system. Through use of discreet sampling, this study gives a more detailed picture of how nutrients and pollutants move through the system and how they are retained and released.

1.2 Site Location

The stormwater wetlands site is located on the campus of Villanova University in Villanova, Pennsylvania. More specifically, the site is located behind the law school parking lot, near he facilities building (Figure 1)

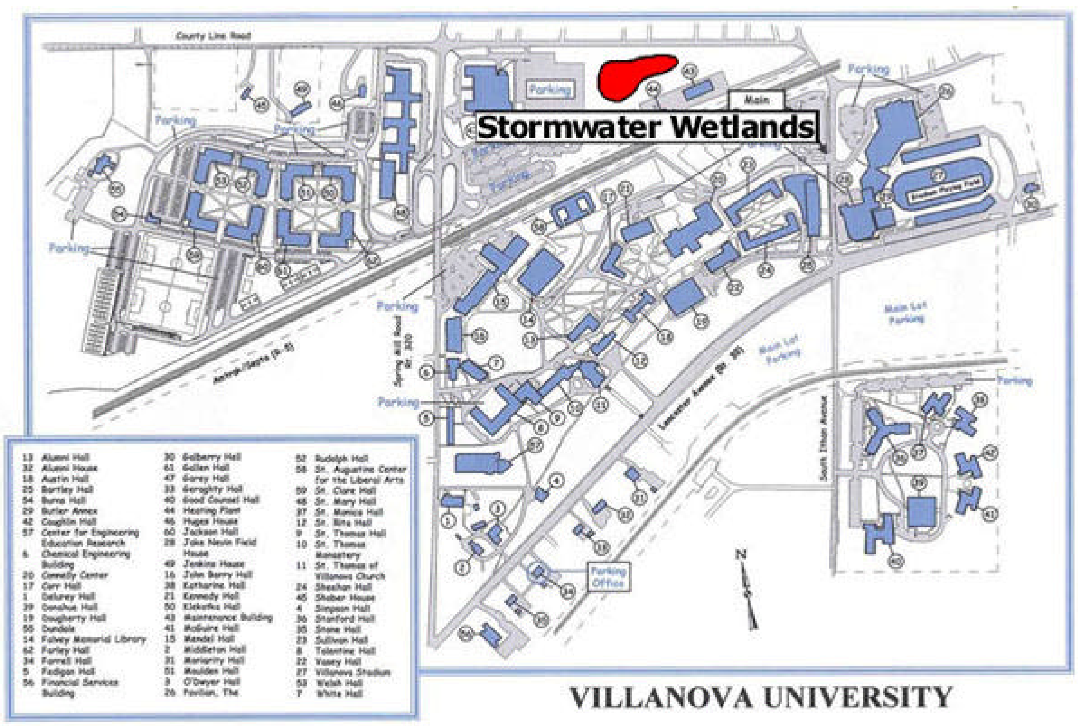

Figure 1. Stormwater wetland BMP site location map

The site is located at the headwaters of the Mill Creek watershed (Figure 2). This watershed is listed as medium priority on the PA degraded watershed list. This site also treats waters that are discharged to a high-priority stream segment on the 303(d) list. As such, it is important to maintain the health of these waters. Any damage imparted at this point will similarly deteriorate the waters downstream.

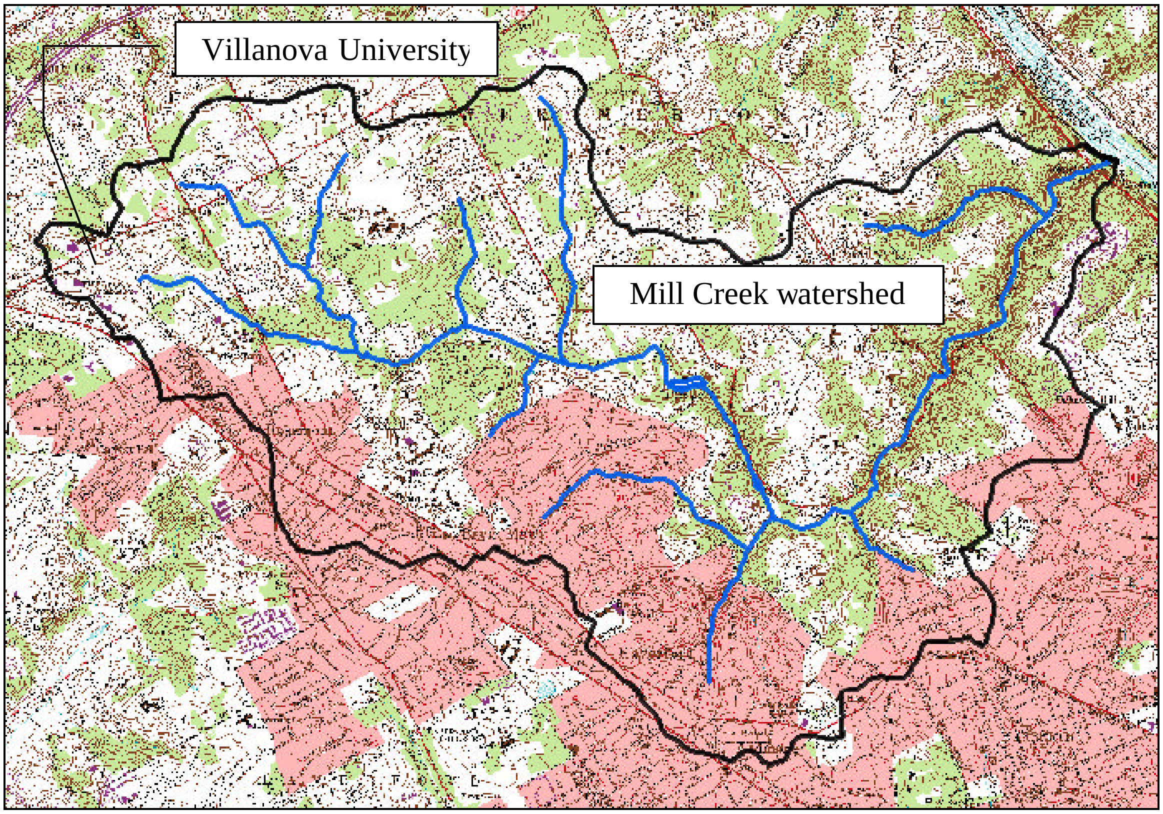

Figure 2. Site location with respect to Mill Creek watershed

1.3 Site Description

This site was originally a detention basin consisting of two inflow pipes (48" and 36"), an outflow structure designed for the 100 year storm, and a 12" underdrain to keep the site dry. Villanova University kept the detention basin mowed throughout the year.

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Figure 3. Pre-wetland dry detention basin

During the dry summer season, it was noticed that the detention basin's underdrain would consistently have flowing water. This led to the conclusion that springs fed into the basin, causing a steady baseflow, and made a stormwater wetland possible.

Using the design criteria of the Pennsylvania Handbook of Best Management Practices for Developing Areas (PACD 1998), Villanova transformed the existing detention basin into a stormwater wetland. In order to do so, many modifications were required. Detention basins are used to control the water quantity of stormwater runoff, with little regard for water quality. The idea behind designing a stormwater wetland was to address the issue of water quality without losing the capability to control flooding and water quantity related issues. The design focus when dealing with water quality is greatly different than that for quantity control. The initial stages of a rain event, or the "first flush" phenomenon discussed in the literature review is now an essential element of the design. During this "first flush" the runoff is generally the most polluted, so capturing and treating this amount is vital when water quality is the site major focus. For our purposes, the part of the rainstorm focused on for design capture is the initial one inch. This one inch of rain accounts for nearly 75% of all the rainfall on a site during an average year (PACD 1998). The site also needed to continue to function as a flood control device, maintaining the detention capacity for the 100 year storm. To accomplish both of these objectives, four main components were constructed.

1.3.1 Sediment Forebay

A sediment forebay is an open body of water, a permanent pool located within the BMP device. Its purpose is to allow the settling of suspended particles from influent waters. Since suspended solids account for the majority of pollutant load in influent stormwater, this is function vital for water quality. Traditionally, sediment forebays are located directly downstream from the influent discharge. For our site, the sediment forebay has been shifted to a location placing it out of the direct path of the influent. The reason for this design modification is the high volume of inflow water during large storm events. In the event of a large storm, a sediment forebay in direct line with the influent stream would be churned up and sediments would be resuspended and passed downstream. By placing the forebay to the side, large storm flows flow directly through the wetlands, bypassing the sediment forebay and leaving it undisturbed. All low flows, however, are routed through the sediment forebay. The sediment forebay was originally designed to hold 0.1 inch of water over the entire watershed. This resulted in a structure

40’ x 50’ structure approximately 4.5’ deep. This original design was modified to a structure 40’ x 40’ and 4’ deep, assuming that sloping sides could account for the lost volume. The forebay was excavated with the underdrain intact to prevent flooding. Once excavated, a reinforced concrete pad was constructed to serve as a base for maintenance vehicles (Figure 4).

Figure 4. Concrete pad to form base of sediment forebay

After the concrete pad was poured, gabions were placed along the downstream side, using a geotextile wrap and earthen berms to make them impervious. Materials for the earthen berm were from the excavation for forebay; the volume of the basin was not altered. The completed gabions formed a stepped weir, with the low flow weir passing the 2 year and under storms, and the higher step passing the 10+ year storms. Riprap was placed around the edges to ensure safety of visitors to the site and to allow access to the basin by maintenance equipment.

1.3.2 Meanders

The theory behind wetlands' impact on water quality is closely related to water retention capabilities. In order for a wetland adequately to treat stormwater runoff, that water must be held within the wetland system as long as possible. Maximum exposure to plants allows for maximum absorption or conversion of pollutants. To achieve the maximum retention time of water entering the wetlands system, a series of meanders was developed and constructed. The meanders were formed by moving existing earth around creating earthen berms maximizing flow length with as flat a bottom as possible. The grading was left intentionally rough to allow for multiple micro-habitats and to strengthen plant hold in the soil. The meandering design was sloped as little as possible to avoid high velocities and channelization.

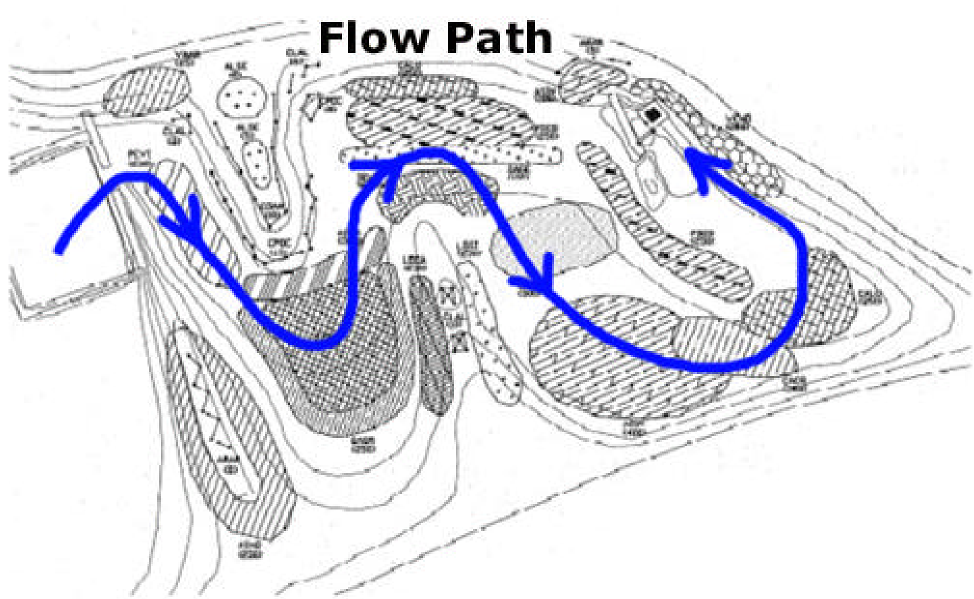

Figure 5. Meander design and wetland flow path

1.3.3 Wetlands Planting

Wetland areas are difficult habitat for many species due to the flashy nature of the watershed. Plants must be able to tolerate varying water levels, as well as complete inundation. Plant selection is also important for aesthetic beauty of the wetland, as well as nutrient and metal removing capacities. The Villanova wetland was planted by Chuck Leeds, the chief horticulturist of Villanova University. Plants were selected for their ability to thrive in wetlands habitat and for species diversity. At the time of the planting, it was noted that natural competition would be the driving force in the future species concentration, and with the arrival and dominance of *Phragmites* and cattails, we can see this to be true. Below is a list of the plants and quantities planted in the wetlands.

Key	Quantity	Description
ACCA:	500	ACORUS CALAMUS (SWEET FLAG)
ASIN:	500	ASCLEPIAS INCARNATA (SWAMP MILKWEED)
ASNO:	250	ASTER NOVAE-ANGLIA (NEW ENGLAND ASTER)
CACA:	500	CALAMAGROSTIS CANADENSIS (BLUE-JOINT GRASS)
CACR:	500	CAREX CRINATA (FRINGED SEDGE)
CALU:	500	CAREX LURIDA (LURID SEDGE)
CAST:	500	CAREX STRICTA (TUSSOCK SEDGE)
IRVE:	###	IRIS VERSICOLOR (BLUE FLAG IRIS)
LOCA:	250	LOBELIA CARDINALIS (CARDINAL FLOWER)
LOSII	###	LOBELIA SIPHILITICA (BLUE LOPELIA)
PEVI:	###	PELTANDRA VIRGINICA (ARROW ARUM)
POCO:	###	PONDETERIA CORDATA (PICKERELWEED)
SACE:	###	SAURURUS CERNUS (LIZARDS TAIL)
VENO:	250	VERNONIA NOVEBORACENCIS (NEW YORK IRONWEED)
ALSE:	10	ARNUS SERRULATA (SMOOTH ALDER)
ARAR:	20	ARONIA ARBUTIFOLIA (RED CHOKEBERRY)
CPOC:	20	CEPHALANTHUS OCCIDENTALIS (BUTTONBUSH)
CLAL:	20	CLETHRA ALNIFOLIA (SWEET PEPPERBUSH)
COAM:	10	CORNUS AMOMUM (SILKY DOGWOOD)
VAAN:	25	VACCINIUM ANGUSTIFOLIUM

Figure 6. Wetland planting list

1.3.4 Outlet Structure

The original outlet structure contained a 12” orifice connected to the underdrain that kept the basin dry. Above this, a t-shaped weir controlled both the 25 and 50 year storms. On the top of the outlet structure was a grate that was designed to handle the 100 year storm. As it was our focus to capture and retain the first inch of rainfall and not to modify the detention capacity of the basin, the outlet structure itself was left unchanged. The underdrain was removed, and in front of the 12” orifice a series of gabions wrapped in geotextiles were placed. At the end of the gabions, a weir was placed at a height to control the majority of the low flow storms and baseflow conditions. During storm events, water would flow over the weir into the 12” orifice or other weirs depending on the severity of the storm (Figure 7).

Figure 7. Modified outlet structure during moderate storm event

1.4 Research Objective

The main objective of this study is to show that a stormwater wetland designed and placed properly can treat stormwater pollution to such a degree as to improve downstream aquatic habitat and ecosystems, as well as being a viable habitat in itself. The Villanova University Stormwater Wetlands treats water from a 41 acre watershed located on the Villanova University Campus. Of these 41 acres, nearly 16 acres are of impervious surfaces such as parking lots and sidewalks. Traditionally, receiving waters from sites that are 40% impervious are devoid of life and have poor water quality. With the previous detention basin, all stormwater was directly discharged to the receiving streams. Much research on nutrient and pollutant loading through wetland systems has used composite sampling during storms. It is a secondary goal of this research to explore the “first flush” phenomenon both in influent and effluent flows through the use of discreet sampling specific to storm event. As much research has been published on suspended solids, dissolved solids, and nitrogen retention, the nutrient of most value to the research community would be that of chloride. Is chloride removed by a wetland system? Is it retained and released slowly? These are the questions this research hopes to answer, as deicing of roadways becomes more and more common and chloride loading is an issue of great importance. The use of discreet sampling could provide some insight into the first flush phenomenon, looking at whether storm size or duration affects the initial pollutant load. Recommendations will also be made as to discrete sampling protocol based upon storm size and storm duration.

Chapter 2: Literature Review

2.1 Introduction

Prior to 1980, the major source of water pollution and contamination in the United States was from point sources. After the passage of the Water Pollution Control Act and the Clean Water Act amendments of 1977 and 1983, attention was shifted towards non-point source pollution as the predominant cause of water quality degradation in the United States. Many studies have shown that urban stormwater runoff is the second or third greatest source of water quality impairment in rivers and lakes (USEPA, 1990; Novotny, 1991; Lee and Jones-Lee, 1994). It was these and other similar studies that led to more stringent stormwater planning, through the use of BMPs (Best Management Practices). It is important to understand the factors that contribute and affect urban pollution so as to learn how they can effectively be treated by BMPs. It is also important to understand the basic nature of the BMP tested in this paper, namely the created or constructed wetland.

2.2 Urban Pollution Factors

In urbanized areas, water must pass through many sources of contamination before it reaches its receiving water body. The amount of these contaminants is contingent on many factors including land use, traffic volume, antecedent dry days, geographic and geologic characteristics of the area, maintenance, and drainage design (Tsihrintzis and Hamid, 1997). Of these factors, land use is the most significant when determining type and amount of stormwater pollution. Construction activities directly contribute to stormwater pollution, and the amount of impervious area in a watershed is also a good indicator of how much pollution will be entered into the system. On areas with a great deal of impervious surface, antecedent dry weather allows for buildup of pollutants and therefore an increased pollutant load during storms.

2.2.1 Pollutant Processes

There are five processes through which pollutants can enter stormwater to be carried to receiving waters throughout the watershed system. These include the following (Tsihrintzis and Hamid, 1997):

Impervious surface washoff: this is the most commonly regarded contributor to stormwater runoff pollution. Pollutants from automobiles and foot traffic over impervious areas buildup during dry weather periods and are simply "rinsed" off the surface by rainwater and flushed downstream. This is also the main component of the "first flush" phenomenon that will be discussed later.

Erosion: this occurs due to two processes, rainfall drop impact and runoff scour. Intense rainfall on exposed land surface can loosen and detach soil which is then carried downstream by runoff. Also, the velocity and friction of the stormwater runoff over the land surface can also cleave solids from soil. These solids can contain large amounts of pollutants due to soil fertilization or pesticide applications.

Deposition: this process, the opposite of erosion, is not often thought of as a pollution source. The reason it is included is two-fold. Deposition of eroded sediments in areas downstream can disrupt normal stream or river behavior and flow, causing altered habitat and a change in the aquatic ecosystem. Secondarily, the sediments deposited can be high in pollutant levels, which can diffuse out over time.

Atmospheric Scrubbing: this is most prevalent downwind of highly urbanized and industrial areas. Pollutants such as dust, aerosols and emitted gases, are brought down with rainfall and directly enter runoff. One highly publicized example of this would be acid-rain.

Transformation: the final pollutant process is probably the most difficult to study and quantify. Biological, chemical and physical transformations of pollutants can take place during runoff events. Occasionally these transformations can turn a mildly harmful pollutant into one that is much more environmentally damaging.

2.2.2 Types of Pollutants

Much like the processes that produce and move pollutants through watersheds, there are many types of pollutants that are of concern. Brown et. al (1999) categorized stormwater pollutants into five subdivisions: suspended solids, nutrients, litter and refuse, bacteria and pathogens, and pesticides and heavy metals.

2.2.2.1 Suspended Solids

Suspended solids are perhaps the greatest component, both in quantity and environmental impact, of urban stormwater runoff. Dust and dirt from impervious surfaces, along with eroded sediment caught in stormwater flow are considered suspended solids. Technically, suspended solids are particles whose size is greater than forty-five microns. Suspended solids are detrimental to receiving waters for many reasons. A large amount of suspended solids may make water turbid, and if settled, may smother fish eggs and alter aquatic habitat (Ferrara 1986, Schueler, 1987). Pollutants, heavy metals in particular, adhere to suspended sediments and if settled, may diffuse back into the water system given the appropriate environmental conditions. It is actually known that urban stormwater runoff generally contains more suspended solids than treated sewage (Waller and Hart, 1986)

2.2.2.2 Nutrients

The term nutrient is misleading in the realm of stormwater management. What may be nutrients to certain plants, can be deadly to aquatic life. Nutrients are common in aquatic systems, and are a necessity for aquatic life. In excess amounts, however, nutrients reduce the water quality for organisms and human uses. There are three nutrients that are of interest to water quality: nitrogen (both nitrate and nitrite), phosphorus, and chloride. Chloride is not technically a nutrient, but is included here due to it being an anion similar to nitrate, nitrite, and phosphate.

Natural nutrient inputs into a watershed system include plant decay and natural soil erosion (Clark et. al, 1985). Nutrients become detrimental to water quality when excess quantities are brought into the system. Excess quantities of nutrients are usually human caused, either from agriculture or soil fertilization. Agriculture is the leading cause of nutrient pollution in the United States, contributing 70% of the yearly load of nitrogen and phosphorus (Chesters and Schierow, 1985). Chloride pollution is not as well documented as nitrogen and phosphorus and is mainly due to road salting in northern and cold climates during winter months. Chloride concentrations are not detrimental to human health, but can cause harm to the aquatic ecosystem.

The most significant impact of nutrient pollution is eutrophication in streams, rivers, and lakes. Eutrophication is defined as the excess growth of algae and other aquatic plants due to excess nutrient levels. The excess plant growth removes large amounts of oxygen from the water body, leaving a great oxygen demand and leading to fish kills and a general depletion of the aquatic habitat. Secondarily, the water body can be choked with algae and lose recreational appeal. Hall and Risser (1993) found that increased nitrate concentration in water could lead to methemoglobinemia, a disorder that causes the blood to carry less oxygen, and may be linked to birth defects and an increased risk in stomach cancer.

2.2.2.3 Litter and Refuse

Not much is known about the effect of litter and garbage on water quality. It would be safe to assume that certain types of garbage and litter, namely pet waste and food products, could provide bacterial influxes into water systems. Wastes could also increase levels of nitrogen in a system. Litter and refuse is also aesthetically polluting and could also alter flow paths and natural stream patterns if it gets lodged or blocks natural flows.

2.2.2.4 Bacteria and Pathogens

Waterborne bacteria, protozoa, and viruses cause many diseases that infect both humans and livestock. These diseases include salmonellosis, mastitis, anthrax, tuberculosis, tetanus and colibaciliosis (Chesters and Schierow, 1985). The primary sources of bacteria in the United States waterways are from livestock manure applications and urban sewer overflows. Bacteria generally die off quickly in open waters; however, the high sediment load of stormwater increases their survival rate by giving bacteria an adsorption site. The increased sediment and nutrient levels associated with rural stormwater flow also increases bacteria survival by providing nutrition and protection for the sun. Many of the bacteria that are harmful to humans are not harmful to aquatic organisms. However, they become stored in fish and shellfish and can be passed to humans during consumption (U.S. EPA 1998).

2.2.2.5 Pesticides, Heavy Metals and Toxins

Pesticides, compounds sprayed on grass or foliage to kill insects, are commonly used in urban areas on lawns and gardens, and on golf courses and plant nurseries. Pesticides can be highly detrimental to aquatic habitat; however, they are generally contained. Chesters and Schierow (1985) and Johnson et. al (1994) found that pesticide losses to the environment are less than 5% of those applied, and the concentration of pesticides in surface waters were extremely low.

Heavy metals are of much greater concern. Industrial process, mining, urban runoff, and transportation all contribute to metal contamination of water. Metals are highly detrimental to aquatic systems due to their inability to degrade and subsequent accumulation in sediment beds. When these metals are toxic, such as mercury, organisms that feed either on or in the sediment bed can accumulate high mercury concentrations and become toxic for human consumption. Concentration of heavy metals in stormwater is nearly twice that of sanitary sewage (Tsihrintzis and Hamid, 1997). Typical metals found in urban runoff include lead, zinc, copper, chromium, arsenic, cadmium, nickel, antimony and selenium (Norman, 1991). Typically, only 5% of metal deposits in urban runoff come from vehicles. This 5% however, does contain some of the most environmentally damaging contaminants. Lead oxide and zinc come from tire wear, copper, chromium and nickel come from wear on a car’s plating, bearings, and brake linings.

Also included in this category are toxins; oil, grease and other related hydrocarbon compounds. Highway runoff sources and parking lots constitute approximately 70% of Polycyclic Aromatic Hydrocarbons (PAHs) in receiving waters. PAHs and oils are toxic to aquatic organisms and alter fish reproduction.

2.3 Best Management Practices

Best Management Practices (BMPs) are part of the solution to today's growing stormwater pollution problem. In the past 20 years, BMP design and implementation has emphasized the specific problem of water volume. Urban watersheds generate greater volume of runoff, with increased peak flows due to the amount of newly created impervious surface (Smith et. al 1993). It has only been in the last few years that attention has shifted towards not only water quantity, but the quality of water released into receiving water systems. The Maryland BMP manual (MDE 2000) divides BMPs into five separate categories: ponds, wetlands, infiltration systems, filtering systems, and open channels. There is extensive research and documentation on each type of BMP listed. For the sake of brevity, only wetlands will be discussed here.

2.3.1 Created Wetlands

There are two reasons for the increased use of created wetlands in the United States. Wetlands are regulated under Section 404 of the Federal Water Pollution Control Act, which recommends that no net loss of area and function of wetlands should be allowed due to construction or development. Due to the unknown functional comparison between created and natural wetlands, many areas require developers to create double the amount of area of wetlands that they destroy. Secondly, and more befitting this study, wetlands have become popular stormwater management tools due to their water quality benefits. Stormwater wetlands have been defined by the International Conference on Wetland Systems for Water Pollution Control to be "any wetland setup that has been realized by human interference in order to treat wastewater and is inhabited by plants". It is for the reason of stormwater control that wetlands in this category do not fall under federal regulations for wetlands. Created wetlands provide a low-cost, easily managed system that can treat water to acceptable levels for waterway discharge (USEPA, 1977). Not only can stormwater wetlands treat polluted water, but they can add to the aesthetic of a residential landscape (Coleman et. al, 2001).

2.3.1.1 Wetland Processes

Wetlands treat polluted stormwater through complex interactions, both biological and chemical, between plants and water flow. Wetland plants facilitate microbial activity though the addition of carbon, oxygen, and attachment locations in their rhizosphere (Brix, 1994, 1997). Plant roots are not usually effective in oxygenation of entire water systems, but local oxidized sites on root systems harbor aerobic microbes that promote many treatment processes (Coleman et. al, 2001). Plant roots may also increase microbial activity through the production of organic carbon and the release of amino acid exudates. Constructed wetland plants also serve to stabilize the bed surface, increase wetland porosity, insulate the wetland bed from freezing, absorb and store nutrients, prevent channelized flow, and improve site aesthetics (Tanner and Sukias, 1995).

2.3.1.2 Wetland Nutrient Uses

Since nitrogen and phosphorus are the main constituents of this study, the biology of wetland nutrient uptake and use must be discussed. The primary mechanism for nitrate removal by wetlands is through denitirification. This is a process whereby nitrate (NO_3^-) is converted to gaseous N_20 and N_2 and released into the atmosphere (Lowrance et. al, 1995). Other nitrate removal mechanisms include vegetation uptake, in which plants extract large quantities of nitrogen as they form roots, leaves and stems. This mechanism, however, is not a permanent nitrogen removal, as nearly 80% of uptake is returned in the form of decayed leaf litter (Peterjohn and Corell, 1984). This is still an important part of water quality treatment, as nitrate uptake is converted to organic nitrogen in plant tissues, which is more readily denitrified by microbes.

Removal of phosphorus is equally important for water quality concerns. The primary mechanism for phosphorus removal by wetlands is not through uptake, but by sediment deposition (Walbridge and Struthers, 1993). Dissolved, or reactive phosphorus, may be removed through adsorption to clay particles, particularly clay soils rich in aluminum and iron (Cooper and Gilliam, 1987). Brown et. al (1999) listed various removal efficiencies for total phosphorus and nitrogen over a range of BMP designs (Table 1), which shows that created wetlands provide the greatest removal percentages

BMP type	Removal %	Removal %	Removal %
	Suspended Solids	Total Phosphorus	Total Nitrogen
Infiltration trench	50	35	50
Grass Swale	70	30	30
Created Wetland	70	85	95
Porous Pavement	90	80	65

Table 1. Summary of removal efficiencies for selected BMP designs

for both total phosphorus and total nitrogen. Some research, however, has shown that nutrient retention in wetlands fluctuates seasonally with retention capacity greatest during the growing season. During some time periods there actually might be a net export of nutrients. Other dissolved nutrient constituents, such as chloride, may pass through the system unaltered (Carlisle and Mulamoottil, 1991).

The long term effects of high levels of chloride concentrations on receiving waters are not well known. Due to the nature of stormwater wetlands as a water quality BMP, chloride levels may play an important role in determining the plant biology in created wetlands. Moore et. al (1999) found that created wetlands often had much greater chloride loads than reference natural wetlands. This was due to the proximity to roads and urban development and their application of road salt to highways and parking lots. These high influxes of chlorides were the driving force allowing *Phragmites* to outcompete native vegetation for wetlands dominance. *Phragmites* has been shown to be a salt tolerant opportunistic species (Weisner 1993). The same study, however, found that while *Phragmites* was abundant in created sites, those sites showed no lack of biological and wildlife diversity, in fact exceeding natural wetlands in some surveys. Because of the nature of the created wetlands, *Phragmites* may not be as detrimental as originally thought, perhaps even acting to help nutrient removal due to its high level of tolerance.

2.3.2 First Flush Phenomenon

Because of the nature of created wetlands and their proximity to urban areas, they have a much different hydrology than a natural wetland. Urban areas create higher volumes of runoff, resulting in hydrologic regimes that are flashier than normal, with different timing, frequency and duration of high water (Bonilla-Warford and Zedler, 2002). It is this initial period of stormwater runoff during which pollutant concentration is higher than in later periods that is called the first flush phenomenon (Lee et. al 2002).

This phenomenon has been highly debated over the years. Numerous studies have shown a significant first flush effect (Betrand et. al, 1998, Butler and Davies, 2000). Others have shown that peak pollutant concentrations can vary even within the same storm (Gupta and Saul, 1996). It is apparent throughout the majority of the research on the first flush phenomenon that small watershed areas show a much greater first flush effect (Lee et. al 2002). Many factors contribute to the severity and impact of the first flush including watershed area, rainfall intensity, impervious cover, and antecedent dry weather period. There are also many definitions as to what accounts for a first flush occurrence. Saget et. al (1995) suggest a first flush occurs when 80% of the pollution load is contained within the first 30% of runoff volume. Others have chosen 25% of runoff volume as a cutoff. Still others have used a pollutant mass/ runoff volume curve method in which slopes of greater than 45 degrees constitutes a first flush (Geiger 1987). It is easy to see why the first flush phenomenon is not so easily understood.

2.4 Example Removal Efficiencies

Marsalek and Marsalek (1997) found created wetlands to have effective removal rates of suspended solids and associated pollutants to be 90% or greater. Similarly, Mashauri et. al (2000) found an 80% removal efficiency for suspended solids, 66% for chemical oxygen demand (COD), 91% for fecal coliforms, and 90% for total coliforms (Table 2). In Table 2, Phase 1 is a low infiltration rate of .27 m/h while Phase 2 is a high infiltration rate of 2.3 m/h.

Indicator	Phase 1	Phase 1	Phase 2	Phase 2
	Inlet	Outlet	Inlet	Outlet
Temp. C	26.0	25.3	26.4	25.9
Turbidity FTU	102.5	43	98.6	61.0
S. S. (mg/L)	104.8	21.2	101.8	51
T.D.S. (mg/L)	178	194	158	170
C.O.D (mg/L)	100.75	34.5	125.75	62.25
T.C.	60,000	5850	71,250	51,500
F.C.	48,250	4525	62,000	41,000

S.S. = Suspended Solids
T.D.S = Total Dissolved Solids
C.O.D. = Chemical Oxygen Demand
T.C. = Total Coliform
F.C. = Fecal Coliform

Table 2. Average indicators of the treatment effectiveness in the constructed wetland.

A third study (Brown 1984) also found constructed wetlands to remove nearly 97% of all suspended solids. This study, however, showed much lower removal rates for nutrients, with removal rates of 48% for total phosphorus, 4% for dissolved phosphorus, 3% of dissolved nitrate and nitrite, 1% of ammonia, and 47% of total nitrogen. There has been much research done on the treatment time and the resultant pollutant reduction. As reported by Hvitved-Jacobsen et. al (1988), Gizzard et. al (1986) found that stormwater retained for 24 hours showed a 90% removal of suspended solids and associated pollutants, while Yousef (1986) showed a 95% removal for 72 hours of retention.

2.5 The role of wetland plants

Ideal plants for use in constructed wetlands would be robust, perennial and easily propagated (Chambers and McComb 1994). They would also have dense roots and rhizomes for sediment trapping (Ferguson 1998), and would be native to the region. However, due to flashy hydroperiods and varying levels of nutrients and pollutants, created wetlands are often dominated by high tolerance plant species such as *Phragmites australis*, and *Typha spp*.

The process behind plant effects on metals, nutrients, and other pollutants is well understood. Current research has attempted to identify which specific wetlands plants have the greatest pollutant removal efficiencies while maintaining wildlife habitat and aesthetic qualities. One such plant, invasive at most sites, is the common cattail (*Typha Latifolia* L.)

Coleman et. al (2001) devised a study to examine the water treatment capabilities of three common wetland plants, *Juncus effuses* L., *Scirpus validus* L., and *Typha latifolia* L.. Using small controlled wetlands, Coleman et. al planted each of three wetlands with one of the three varieties of plants, and a fourth with a combination of all three. They found that the average removal rates were 70% for total suspended solids and BOD, 55% removal of total nitrogen, ammonia and phosphate. They also found that *Typha latifolia* L, the common cattail, outperformed the other plant species in effluent quality improvement (Table 3).

Treatment	*pH*	*Conductivity*	*TDS*	*TSS*	*DO*	*BOD*	*TKN*	*Ammonia*	*Total P.*	*Fecal C.*
		mS/cm	g/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	log(Cfu)
Influent	7.13	.72	.36	74.5	1.23	137.2	14.7	12.2	1.28	8.21
Juncus	6.89	.79	.39	16.7	2.22	48.2	7.7	6.1	.47	5.30
Scirpus	6.90	.86	.43	15.7	1.58	41.3	11.0	9.1	.66	5.86
Typha	6.80	.86	.43	18.3	2.56	33.0	5.6	4.7	.24	4.69
Mixture	6.70	.97	.49	19.9	2.72	35.5	3.8	3.2	.19	4.68

.

Table 3. Influent and effluent measurements of pH, conductivity, total dissolved solids (TDS), total suspended solids (TSS), dissolved oxygen (DO), biological oxygen demand (BOD), total Kjedhal nitrogen (TKN), ammonia, total phosphate and fecal coliform

Typha outcompeted the other species in the mixture; the mixture maintained the greatest effluent quality improvement. These results are of particular interest as *Typha* cattails are one of the dominant species in Pennsylvania created wetlands. Goulet and Pick (2001) studied the ability of *Typha Latifolia* L to extract and partition metals in constructed wetlands. They found that the presence of cattails did not affect the concentration of metals in sediments. They did find, however, that wetlands with cattails had higher organic content in their soils. This substrate fuels microbial activity, a fundamental element of other water quality concerns.

Phragmites (*Phragmites australis*), or the common reed, is an invasive species of plant known for its high tolerances of growth conditions. In native wetlands, the presence of *Phragmites* may be seen as detrimental, due to the decrease in native avian species present (Benoit and Askins, 1999). For created wetlands, however, the presence of *Phragmites* may be beneficial to water quality concerns. Ruckauf et. al (2004) experimentally determined that *Phragmites* planted sites show an increase in N_2O emission of 50% over unplanted sites. Windham et. al (2004) found that *Phragmites* took up 60% more nitrogen than other common wetland plants and nitrogen immobilization was nearly 300% greater. However, this study also suggests that the nitrogen balance is not affected, as *Phragmites* cause an increase in microbial formed inorganic nitrogen. The effects of *Phragmites* on phosphorus and chlorides are not as widely known. *Phragmites* also does an excellent job of removing particulate metals from influent waters. Samecka et. al (2004) compared the metal removal rates of three common wetland species, *Phragmites australis*, *Salix viminalis* and *Populus Canadensis*. They found that wetlands dominated by *Phragmites* were best in removing Aluminum (81-97%), Barium (70-95%), Lead (64-81%), Strontium (24-51%) and Manganese (99%). They also noted that levels of removal were highest in the summer months and lowest in the winter months.

Chapter 3: Methods

3.1 Introduction

The purpose of this section is to describe the methods and setup involved in the collection and analysis of data. The water quality portion of the study will be described in depth with respect to the instrumentation and test procedures. Detailed description of event by event sampling protocols will be discussed, as well as sampler programming and time interval determination.

3.2 Water Quality

Water quality is the major focus of the stormwater wetland BMP device. At the wetland, many automated devices have been installed for monitoring and collecting. The devices allow for the collection of samples, which are transported to a laboratory and analyzed for total suspended solids (TSS), total dissolved solids (TDS), chloride, total phosphorous, reactive phosphorus, total nitrogen, nitrate, nitrite, and phosphate.

3.2.1 Instrumentation and Setup

For the purposes of this report, the Villanova stormwater wetlands will be divided into four separate entities: the main campus inlet, the west campus inlet, the sediment forebay, and the outlet. Each location will be described in great detail as to its relevant instrumentation and sample collection procedures. For brevity, each parameter discussed (other than stormwater sampling) is recorded in 5 minute intervals.

3.2.1.1 Main Campus Inlet

The main campus inlet is a 42” pipe that conveys flows from the main campus of Villanova University. Its watershed consists of areas around Mendel Hall, Falvey Library, John Barry Hall, and Tolentine Hall. Of the 41 acres in the total watershed, approximately 25-27 come from the main campus pipe. In order to measure multiple variables at constant intervals, an American Sigma 950 Flow Meter has been installed for the main campus inlet pipe. It is housed in waterproof lock boxes located above the inlet structure. The American Sigma 950 for the main campus inlet is programmed and outfitted to record data from an area / velocity bubbler probe and a raingauge. It has also been equipped with an external modem and has the capability to run an American Sigma 900 automated sampler. The lockboxes are wired to provide constant A/C power to all instrumentation, so that battery power may not be needed.

Figure 8. American Sigma 950 flow meter.

The raingauge attached to the main campus Sigma 950 is an American Sigma Model 2149 tipping bucket raingauge. It has been placed and leveled on a poured concrete surface at the headwaters of the wetlands. The raingauge has been modified with external birdwire placed along the edges to keep birds from perching and possibly clogging the spout.

In order to measure velocity and depth of flow in this pipe, it has been outfitted with an American Sigma area / velocity bubbler probe. The area / velocity probe uses two different forms of technology in order to measure both depth and velocity. A small air line is located within the probes cable and is attached to the American Sigma 950. The 950 pumps air bubbles through this tube and into the flowing water of the pipe. The 950 then measures the pressure of the air bubble at the release point, and calculates the depth of the water from a calibration standard. Each area / velocity probe is calibrated at 6 month intervals. In order to measure velocity of the flowing pipe, the probe uses the Doppler Effect. By releasing a sound wave from one end of the probe, the Sigma 950 can measure the shift in its frequency as it moves away with the flow. Based on this shift, the 950 can calculate a velocity of the flowing water. The minimum default velocity is .20 feet per second.

The external modem on the Sigma 950 is connected to phone lines that have been installed inside the lockboxes at the site. Each Sigma 950 has a unique phone number and is can be called and programmed or downloaded from a remote location. American Sigma Insight v.5.01 software is used to connect and download data from the Sigma 950's. Data is stored in text form and is easily converted to Microsoft Excel spreadsheets for analysis.

The Sigma 950 here is also connected to a Sigma 900 automated sampler. The Sigma 900 automated sampler is a stand-alone unit capable of taking up to 24 discreet water samples per storm event. The 900 for the main campus inlet is kept outside of the main campus lockbox and has 30 ft of 3'8" tubing ending in the pipe to collect sample. Each sample is collected in a special 350 ml glass bottle made especially to fit in the automated sampler. Sampler programming will be discussed in a later section.

Figure 9. American Sigma 900 automated sampler.

3.2.1.2 West Campus Inlet

The second location setup for sampling and data recording is the west campus inlet. Villanova University's west campus consists of the law school, the law school parking lot, the nursing college, and the west campus apartments. The area of this watershed draining to the stormwater wetland is approximately 14-16 acres. A 48" inch pipe conveys stormwater from west campus into the wetland system. The west campus inlet has also been outfitted with its own American Sigma 950 Flow Meter. It has also been equipped with an area/velocity probe, an external modem and a Sigma 900 automated sampler. Details of these can be found above in the main campus section. Unlike the main campus inlet, however, the west campus pipe is equipped with probes to measure conductivity, pH, and dissolved oxygen.

To measure conductivity, an American Sigma conductivity probe model number 3328 was installed. The probe measures the conductivity of the water by measuring the ability of a solution to conduct current. In solution, this current flows by ion transport, therefore, an increase in ions means an increase in conductivity. The conductivity probe applies a potential difference between two probe electrodes of a known distance. The resulting current is proportional to the conductivity of the solution. The American Sigma probe more accurately measures conductance, the reciprocal of resistance, and is converted into conductivity by knowing the distance between the electrodes and the electrode surface area.

To measure pH, an American Sigma pH probe, catalog number 3328-89, was installed. This sensor operates in principle as if it contained two 'batteries' whose voltages are measured and transmitted by electronic amplifiers. One battery is formed by the ground electrode and the glass process electrode. The voltage of this battery is a function of the solution pH. The other battery is formed by the same ground electrode and the standard electrode which contains a pH electrode in a chemical standard of fixed pH value. The voltage of the second battery is subtracted from the voltage of the first battery. The result is a differential pH measurement, the final signal being that of an pH electrode in the process compared to a pH electrode in a chemical standard solution.

A temperature sensitive resistor inside of the sensor automatically compensates the pH measurement for temperature variations by adjusting the output of the sensor

To measure dissolved oxygen, an American Sigma dissolved oxygen probe, catalog number 3216-88, was installed. In order to understand the complexity of its operation, an excerpt from the user's manual has been included:

This sensor contains a platinum-lead galvanic couple in electrolyte. A membrane that is permeable to gases but not liquids is positioned over the cathode. The membrane separates the galvanic cell from the sample. The gaseous oxygen in the sample diffuses through the membrane to the platinum cathode of the galvanic cell, where it is reduced to form hydroxide ions. Lead metal is oxidized at the anode. The electrical current is generated without the aid of an applied voltage. Diffusion through the membrane occurs because the oxygen in the sample has a partial pressure while the oxygen pressure at the cathode surface is essentially zero. Thus, the rate of oxygen reduction at the cathode is directly proportional to the partial pressure contributed by the oxygen dissolved in the sample. The current generated is also proportional to the dissolved oxygen in the sample. The rate of oxygen reduction, and therefore the calibration, also depends on the rate of diffusion through the membrane. A thinner membrane offers faster oxygen diffusion, and therefore faster response. Temperature will affect the permeability characteristic of the plastic membrane. As the membrane's permeability changes, the rate of oxygen diffusion will change. The effect of temperature on diffusion rate is automatically compensated in the instrument by a temperature compensation circuit. It also corrects for the effect of temperature on the solubility of oxygen. In operation, the layer of liquid nearest the *working sensor surface is depleted of oxygen. For adequate operation, a flow of liquid near the working sensor surface must be maintained. This can be achieved either by driving the test solution past the surface of the sensor or by moving the sensor in the test solution. Adequate flow of the test solution across the sensor surface leads to an oxygen concentration at the membrane surface that is equal to that of the bulk solution. Only under this condition is the measured electrical current directly proportional to the oxygen concentration in the bulk of the test sample* (American Sigma 2000).

3.2.1.3 Sediment Forebay

The third sampling site is referred to as the sediment forebay, which is discussed in the overview section. The sediment forebay is equipped with an American Sigma 950 Flow Meter, but unlike the other sites, does not continually monitor flow. Instead of being equipped with an area / velocity bubbler, the sediment forebay uses an ultrasonic level detector to determine the depth of the water contained in the forebay. It is also equipped with an American Sigma 900 automated sampler and an external modem.

3.2.1.4 Outlet

The final sampling location is the outlet structure. Like all the other sites, the outlet is outfitted with an American Sigma 950 Flow Meter. This flow meter is located within a lockbox behind the outlet structure. The outlet 950 is equipped with an area / velocity bubbler probe, an external modem, a 900 automated sampler, a pH probe, a conductivity probe, and a dissolved oxygen probe. A special structure was built to house all the probes and the sampler tube (Figure 10)

Figure 10. Outlet outfitted with pH, conductivity, dissolved oxygen, and sampler.

3.2.2 Automated Sampler Communication

In order to get a sampling routine that would be consistent, the automated samplers needed to communicate and be able to be triggered simultaneously. The four sampling locations had been wired together during construction of the site. A four-way splitter was used to connect directly all four automated samplers to one Sigma 950. The Sigma 950 used to trigger all four samplers was located at the main campus inlet. This flow meter was selected due to its connection to the raingauge. There are many parameters that the automated samplers can use to trigger a start or stop condition. These include high levels of rainfall, high level of flow, low level of flow and total flow volume.

3.2.2 Sampler Programming

The automated sampler can be programmed to start on one of these conditions, or to start and stop on any of these conditions. For our research purposes, we initially had the automated samplers start and stop based on rainfall only. Our initial trigger point was .05 inches of rain in thirty minutes. If .05 inches of rain fell in any time within a thirty minute period, the 950 flow meter would send an electronic signal through the four-way splitter, awaking all four samplers to begin their sampling routine. If any period of thirty minutes elapsed without .05 inches of rain falling, the signal would be cut off and the samplers would put their sampling routines on hold until the signal was reissued. After much trial and error, this was revised to .04 inches of rain in 25 minutes. The idea to use both start and stop conditions is in order to reduce the amount of "false" storms recorded and minimize waste of glassware and manpower if a small storm of only .05 inches fell. After using only rainfall as a trigger point, it was noted that the level in the main campus inlet was much more stable for a start and stop trigger, due to the flashy nature of many storms causing multiple starts and stops of the program. By setting a baseline flow level as a stop condition, we could ensure that the entire storm was captured, not being terminated by intermittent rainfall.

The program used by the Sigma 900 automated samplers was individualized for a storm-by-storm basis. The Sigma 900 allows for a program to take samples at a variable interval once the program had been started. During trial runs and sample storms, we discovered that the ideal number of samples per storm ranged from 6-14 based on storm size. With our interest in first flush, we wanted the majority of these samples to be in the beginning of each storm, but did not want to compromise to miss the majority of the storms duration. We based initial programming on a 1 inch storm. Initial intervals were set at immediate, five minutes, fifteen minutes, thirty minutes, and hourly for the duration of the storm. For example, if a storm were to begin at 1:00 pm, a sample would be taken at 1:00 pm, 1:05 pm, 1:20 pm, 1:50 pm, 2:10 pm, 3:10 pm, and hourly until the completion of the storm or the end of the program. What we found was this did not yield enough sample during the first flush interval we had hoped to capture. From initial observations, the majority of this first flush occurred between the initial sample and 30 minutes after. In order to capture more of this first flush, the sampling interval was revised to be at immediate, five minutes, five minutes, ten minutes, ten minutes, twenty minutes, thirty minutes, and hourly afterward. This gave an ample number of samples during in the initial thirty minutes of the storm for first flush analysis. This basic template was modified dependant upon storm size. Due to limited manpower, the number of samples taken during a storm needed to be kept under 14, so during larger storms, the intervals were lengthened to capture as much of the storm as possible. All intervals for each storm will be reported in the results section.

3.2.3 Baseflow Sampling

In conjunction with storm sampling, baseflow conditions were also included in our study and analysis. Baseflow, or background flow, should theoretically contain a fixed amount of nutrient load and solids load. By recording and calculating these loads, we can get an better idea of what is brought into the site during storm conditions. For the purposes of our study, we determined baseflow conditions to be those that occur after a period of 48 hours with no precipitation. Baseflow samples were taken on a monthly basis, weather permitting.

3.2.4 Sampling Protocol

All glassware and caps used during storm sampling had been acid-washed in a 10% HCL solution as per EPA recommendation and by HACH spectrophotometric protocol. They were then rinsed in deionized water three times and allowed to air dry. All caps were labeled with the ID of the site location, the sample number, and the date of the storm. The main campus inlet was abbreviated as IM, the west campus inlet as IW, the sediment forebay as SF, and the outlet as O. These abbreviations will be used throughout the results section for the sake of brevity. All storms sampled were collected within 12 hours of the completion of the storm.

The samples were analyzed immediately upon collection for most cases. However, in the event that the samples could not be analyzed promptly, a preservation plan was used. Each of the tests had a specific method required to properly preserve the sample. Preservation methods included pH control, chemical addition, and refrigeration. Sample preservation was performed according to the Hach testing procedures.

Table 4 is a summary of the specific preservation instructions as well as the maximum holding times until sample analysis.

Parameter	Container Type	Preservation	Holding Time
pH	Plastic	store at 4^oC	24 hours
Conductivity	Plastic	store at 4^oC	24 hours
Chloride	Plastic	store at room temp.	28 days
Total Dissolved Solids	Plastic	store at 4^oC	24 hours
Total Suspended Solids	Plastic	store at 4^oC	24 hours
Nutrients			
Total Phosphorus	Plastic	H_2SO_4 to pH <2, store at 4^oC	28 days
Total Nitrogen	Plastic	H_2SO_4 to pH <2, store at 4^oC	28 days
Nitrate	Plastic	store at 4^oC	2 days
Nitrite	Plastic	store at 4^oC	2 days
Metals - Dissolved			
Copper	Plastic	HNO_3 to pH < 2, store at room temp.	6 months

Table 4. Sample preservation summary

3.2.5 Analytical Methods

This section will discuss the analytical methods for the various parameters of interest in the water quality study of the stormwater wetland. Included in each subsection is a description of the test apparatus and overview, or reference to an overview, of the specific test procedures. The capabilities and limitations of the instruments and procedures are also discussed when merited.

3.2.5.1 Reactive Phosphorus, Total Phosphorus, and Total Nitrogen

The reactive phosphorus, total phosphorus, and total nitrogen tests were all conducted using the Hach DR/4000 Spectrophotometer. The parameters are listed in Table 5 with their respective test methods and associated Hach method number. The EPA approval verification is also listed.

Parameter	Test Method	Hach Method Number	EPA Approved
Nutrients			
Phosphorous - Total	PhosVer3 with acid persulfate digestion	8190	YES
Nitrogen - Total	Persulfate digestion	10071	YES

Table 5. Spectrophotometer test table

Spectrophotometry is the measurement of the light absorbance of a sample. This absorbance can be related to various chemical parameters through the use of experimental procedures. The spectrophotometer's light source can be set to a wide range of wavelengths from the visible to the ultraviolet scale.

TenSette Pipets were used to make accurate measurements when performing tests using this apparatus. Both models 19700-01 (1 ml max) and 19700-10 (10 ml max) pipets were used depending on the volume of sample needed. For quality assurance purposes, the tip was replaced between uses to prevent cross-contamination between samples.

The reactive phosphorus spectrophotometric analysis was performed in square, glass, 2.54 cm (1 in.) sample cells. The recommended cleaning and handling procedures were strictly followed to prevent interference from the glassware. Contact was avoided with the clear sides of the cells with fingers to avoid the possible creation of imperfections or smudges in the samples cells which could potentially cause unanticipated absorbance and inaccurate readings. The cells were wiped with a soft cloth to remove any smudges or inadvertent fingerprints. To avoid degradation or staining of the sample cells, they were emptied immediately following the analysis and were cleaned in between each use, as per Hach's instructions, to avoid degradation or staining. When not in use, the sample cells were stored in their boxes to protect them from damage.

The Total Nitrogen and Total Phosphorus spectrophotometric analyses were performed in manufacturer prepared digestion vials. Care was again taken not to touch the glass vials, which were handled by the plastic caps. The glass vials were also wiped with a soft cloth prior to analysis in the spectrophotometer as a precaution against inadvertent smudges or smears. The vials were not reusable and were disposed of as per the product's Material Safety Data Sheet (MSDS).

The Total Nitrogen and Total Phosphorus tests required the samples to undergo a digestion period at specific temperatures. The Hach COD Reactor Model 45600 was used to incubate the samples for the required times. The COD Reactor holds up to 25, 16 mm x 100 mm vials and is capable of sustaining temperatures up to 150 degrees Celsius with an accuracy of ± 2 degrees Celsius. A thermometer was used to verify the temperature.

3.2.5.2 Chloride, Nitrate, Nitrite, and Phosphate

Chloride, nitrate, nitrite, and phosphate were tested using a High Pressure Liquid Chromatograph (HPLC) / Ion Chromatograph (IC). In general, the machine works by injecting small amounts of sample into an anion exchange column where the various anions present are separated out. Once through the anion exchange column, they enter and are read by a conductivity detector. The determined conductivities are plotted and software is used to integrate the area underneath the peaks for the each individual anion. These areas are related back to calibration standards to determine the concentrations of the various parameters within each sample. Figure 11 is an example of a resulting chromatogram for a sample, or in this case, a standard.

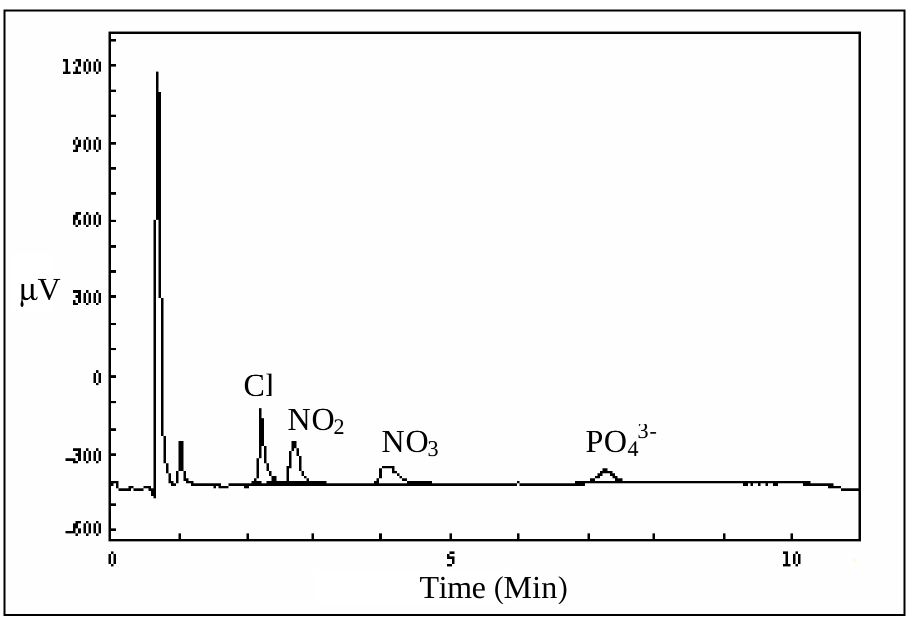

Figure 11. Sample chromatogram

The resulting peaks for chloride (Cl), nitrite (NO_2), nitrate (NO_3), and phosphate (PO_4^{3-}) are denoted on the plot. The areas beneath these peaks are integrated and related to the calibration standards, as described previously, to determine the concentrations. The chromatogram is specific to the column utilized. All tests were conducted with a Hamilton PRP-X110 column, using 2mM p-hydroxybenzoic acid with 2.5% MeOH eluent at a pH of 9.3.

3.2.5.3 Total Dissolved Solids (TDS) and Total Suspended Solids (TSS)

The Standard Methods (APHA, 1995) procedure 2540C was followed for TDS analysis. A filter paper with a 1.5 micron pore size was utilized to filter out the suspended solids in the sample. The filtrate was then evaporated accordingly in pre-weighed and properly prepared evaporating dishes.

The Standard Methods procedure 2540D was followed for TSS analysis. Predetermined volumes of sample were filtered through 1.5 micron pore size filters. These filter papers were then transferred to pre-weighed tins and were dried at 105 degrees C according to standard methods. Once completely heated and dessicated the tins were reweighed and the resultant difference of weight per unit volume gave the total suspended solids. In areas of particularly clear water, such as the outlet structure, or during baseflow conditions, large volume of sample was needed. Maximum sample volume for our study was 350 mL for a storm sample, and 1L for baseflow samples. Actual sample volume used varied depending upon turbidity of the water and available sample left over from other nutrient testing.

Chapter 4: Results

4.1 Storm Events

A total of eight storm events were sampled during the course of the study. The events range in size from .12 inches to 2.74 inches of rainfall and span a time frame from July 2003 to Aug 2004. Due to lack of sample, sampler errors or lack of testing materials, not all tests were run for all storms. Below is a table listing the storm date, rainfall amount, and tests performed on each storm event.

Date	Rainfall	R.P	T.P	T.N.	Nitrite	Nitrate	Phosphate	D.S.	S.S.	Chloride
3-Jul-03	.24 in	x	x	x						x
24-Jul-03	.37 in	x	x					x	x	x
30-Aug-03	.84 in	x		x	x	x		x	x	x
18-Sep-03	1.47 in	x	x	x		x		x	x	x
27-Oct-03	1.5 in	x			x		X	x	x	x
19-Nov-03	2.01 in	x	x		x	x	X	x	x	x
31-Jul-04	.12 in	x			x	x	X	x	x	x
1-Aug-04	2.74	x			x	x	X	x	x	x
Legend: RP-Reactive Phosphorus, TP-Total Phosphorus, TN-Total Nitrogen										
DS-Dissolved Solids, SS-Suspended Solids										

Table 6. Summary table for all storm events with date, rainfall and tests performed.

4.1.1 Sampler Storm Intervals

Sampler programming was individually determined on a storm basis. One of the goals of this study was to determine the effects of “first flush”, if any. Samplers were set to start sampling upon either significant rainfall or a rise in inflow level. Table 7 lists the individual storm sampling protocols and interval times. While sampling intervals are listed, lack of rainfall or adequate level sometimes caused the samplers to pause, starting where they left off when rainfall or level resumed its breakpoint. The samplers collected both the July 30th and August 1st storms with one program, as the July 30th storm was unexpected and triggered the first 3 sampling points.

Storm Date	Sampler time Intervals (min)
19-Nov-03	0,5,10,20,30,30,30,30,60
27-Oct-03	0,30,30,30,30,30,30,30,60,60
18-Sep-03	0,60,60,60,60,60,60,60,60
30-Aug-03	0,5,10,10,10
24-Jul-03	0,5,5,10,10,20,20,30,30
3-Jul-03	0,5,5,10,10,20
30-Jul-04	0,5,10
1-Aug-04	20,30,30,60

Table 7. Pre-Storm programmed sampling intervals

30-Jul-04	1-Aug-04	19-Nov-03	27-Oct-03	18-Sep-03	30-Aug-03	24-Jul-03	3-Jul-03
4:55 PM	6:10 AM	4:45 PM	1:00 PM	8:00 PM	2:55 PM	2:55 AM	5:35 AM
5:00 PM	6:30 AM	4:50 PM	1:30 PM	9:00 PM	3:00 PM	3:00 AM	5:40 AM
5:10 PM	7:00 AM	5:00 PM	2:00 PM	10:00 PM	3:05 PM	3:05 AM	5:45 AM
	7:30 AM	5:20 PM	2:30 PM	11:00 PM	3:15 PM	3:15 AM	5:55 AM
	8:30 AM	5:50 PM	3:00 PM	12:00 AM	3:25 PM	3:25 AM	6:05 AM
		6:20 PM	3:30 PM	1:00 AM		3:45 AM	6:25 AM
		6:50 PM	4:00 PM	2:00 AM		4:05 AM	
		7:20 PM	4:30 PM	3:00 AM		4:35 AM	
		10:50 PM	5:30 PM	4:00 AM		5:05 AM	
		12:30 AM	6:30 PM				

Table 8. Actual time of taken samples during storm events

4.1.2 Storm Results Interpolation

As evident in Table 8, sampling points are varied and spaced out over time, ranging from twenty minutes to eight hours. During these time periods, flows are recorded at five minute intervals. In order to use the full flow data between sampling points, the decision was made to interpolate between the sample points linearly. This linear interpolation was performed using an add-in for Microsoft Excel named XLInterp. While interpolating points over the course of a storm may not take into account random fluctuations, it will give a better idea of the total amount of nutrients and pollutants going through the system during a storm event. Below is a sample of the excel interpolation.

Inlet Main	Rain	Flow	Reactive P	Incremental Loading
			mg/L	(g)
11/19/03 4:45 PM	0.06	0.677	0.63	3.60
11/19/03 4:50 PM	0.05	0.791	0.78	5.24
11/19/03 4:55 PM	0.06	0.928	0.44	3.47
11/19/03 5:00 PM	0.01	0.978	0.10	0.83
11/19/03 5:05 PM	0.02	0.977	0.12	1.02
11/19/03 5:10 PM	0.01	0.965	0.15	1.20
11/19/03 5:15 PM	0.03	0.947	0.17	1.36
11/19/03 5:20 PM	0	0.925	0.19	1.51

Table 9. Interpolated data sample from Nov 19th storm event

In the above table, actual laboratory tested reactive phosphorus points occur at 4:45, 4:50, 5:00 and 5:20 PM. Points between these actual data points are the result of the linear interpolation over the time frame given. These results are then multiplied by the corresponding flow data and converted into grams to give a nutrient yield every five minutes. These yields are then summed to determine the total yield entering or exiting the system over the course of the rainfall event.

4.2 Baseflow Sampling

Baseflow for this study occurs when no antecedent rainfall has fallen for 48 hours or more. The following table summarizes the dates of baseflow sampling and the tests performed on each sample. It must be noted that suspended solids testing was performed on the first four baseflow samples, but was eliminated from the sampling protocol due to lack of quantifiable results.

Date	R.P	T.P	T.N.	D.S./S.S.	Chloride
27-Jun-03	x	x	x	/x	x
18-Jul-03	x	x	x	/x	x
20-Aug-03	x	x	x	x/x	x
10-Sep-03	x			x/x	x
7-Oct-03	x	x	x	x/	
24-Jun-04	x		x		x
7-Jul-04	x	x	x	x/	
21-Jul-04	x	x	x	x/	x
Legend: RP-Reactive Phosphorus, TP-Total Phosphorus, DS-Dissolved Solids					

Table 10. Dates of baseflow sampling and summary of tests performed.

Unlike storm events in which flow is multiplied by concentration to get load, it is assumed that during baseflow the combination of the inlets equals that of the outlet. For that reason, the results for baseflow can be reported in concentration units. A majority of the baseflow into the wetlands is the result of sub-pumps (as observed)that empty the SEPTA train station underground walkway. Our assumption of inflow-outflow quality is approximate. There are springs located within the wetland that add some flow to the system, while evapotranspiration removes an unknown amount of flow.

4.3 Flow Modeling

After reviewing storm events, it was noticed that on occasion the recorded inflow and outflow differed greatly. Inspecting the level and velocity data showed that the area/velocity probes in one of the inlets and at the outlet were giving false readings. The inlet readings were artificially high due to a faulty probe, while the outlet readings were artificially low due to turbulent flows directly over the probes. A replacement probe was installed in the inlet and the outlet probe was extended down the outlet pipe. Flow readings for storms after this installation were correct and matched well. In order to use the laboratory tested data for storms sampled with incorrect flow data, flow modeling was used. An existing calibrated HEC-HMS model used in a previous study was employed. The model was retested on the wetland system after the installation of the new probes and the flow results were nearly identical. Rainfall from storms with erroneous flow was entered into the HEC-HMS model, and the resultant flows were used to determine the loading through the wetland system for those storms. It must be noted that by employing this model, the removal efficiencies of the system are lowered; therefore the model is used only for flow parity and not to enhance results.

4.4 Individual Storm Results

Results for storm sampling are reported in two sections, those by individual storm, and those summarizing all storms. Sample results are included within this report, all pollutographs and other results can be viewed in Appendix 1.

4.4.1 July 24th 2003

July 24th was a relatively small storm, with .35 inches falling in roughly 100 minutes time. Nine samples were taken from this storm, giving a very in-depth view of what happened throughout the duration of this storm.

4.1.1.1 Nutrient Loading

Pollutographs for this storm are remarkably similar. Every nutrient tested for in the inlet samples peaks in the same samples, corresponding with the highest rainfall intensity during the storm. Similarly, the outlet samples follow the same pattern throughout all different nutrient parameters. They start at low loads, and begin to build toward the end of the storm, always remaining less than the inflow loads.

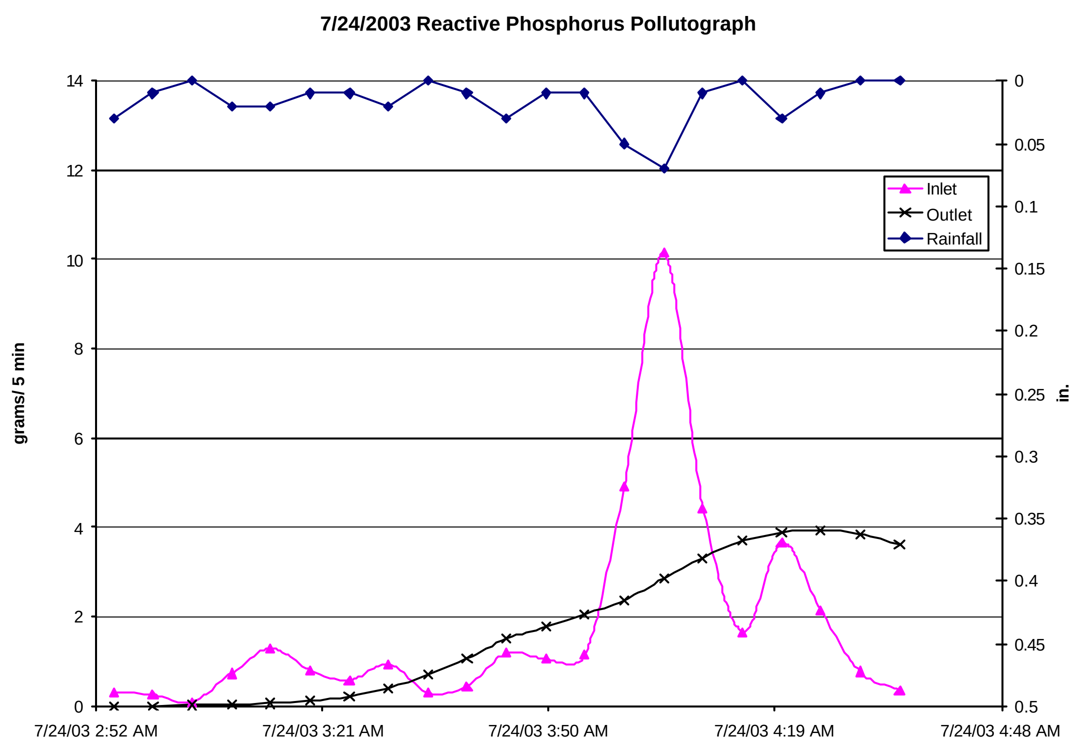

Figure 12. Reactive phosphorus pollutograph for July 24th 2003 event

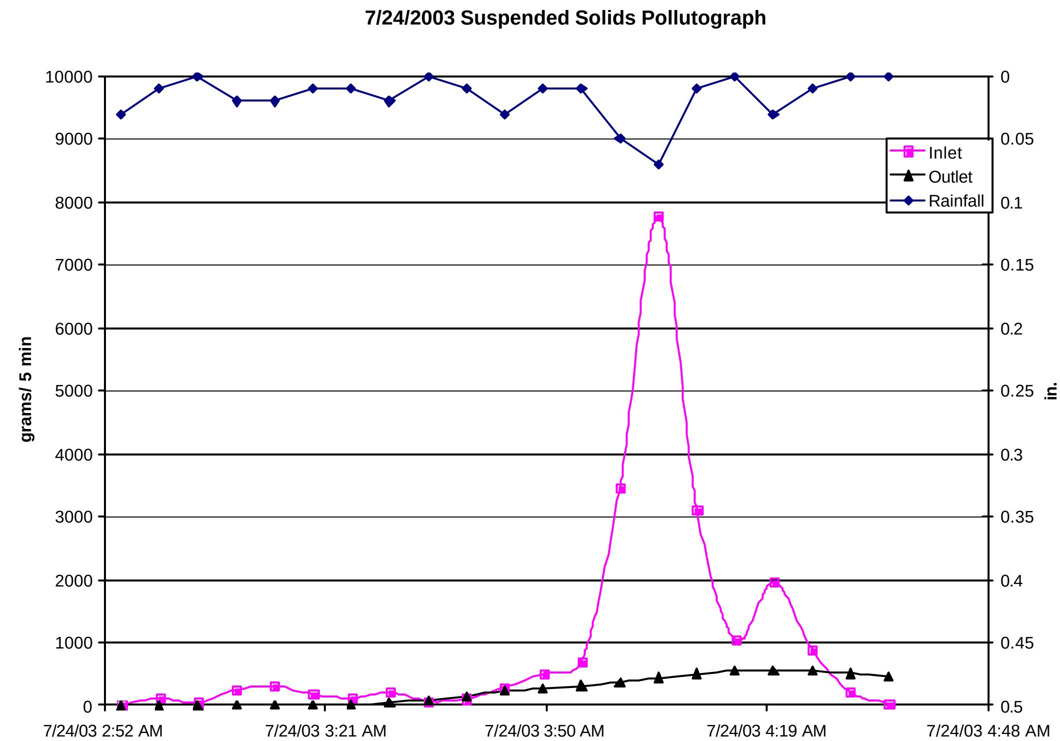

Figure 13. Suspended solids pollutograph for July 24th 2003 event

The full range of pollutographs for this storm can be found in Appendix 1.

4.1.1.2 Nutrient Total Mass

Pollutographs show how nutrients and pollutants move throughout the wetland system over the duration of the storm. It is clear that the inlet has a spike of influent that sharply drops off, while the outlet continuously rises throughout the duration of the storm. By looking at the total mass passing through the inlet and outlet, one can determine if nutrients are being removed, or simply being held and discharged at a later time.

July 24th, 2003	R.P.	T.P.	S.S.	D.S.
	(kg)	(kg)	(kg)	(kg)
Inlet	0.037	0.21	21.38	98.83
Outlet	0.035	0.03	5.06	41.49
Removal %	4.68	86.50	76.33	58.02
R.P. = Reactive Phosphorus, T.P = Total Phosphorus				
S.S. = Suspended Solids, D.S. = Dissolved Solids				

Table 11. Total mass (kg) of pollutants for July 24th, 2003 event

For the four parameters tested for this storm, total phosphorus, suspended solids and dissolved solids showed greater than a 50% reduction in outflow mass compared to inflow. Reactive phosphorus showed little removal, but it must be noted that very little reactive phosphorus was recorded at either the inlet or outlet during this event.

4.1.2 August 30th 2003.

The storm on August 30th was a severe thunderstorm event, raining .75 inches in only thirty minutes. Five samples were taken during this thirty minute storm. This storm differs from all other captured events due in that due to its short time frame and high intensity, the flow in is much greater than the flow out. Implications of this will be discussed in later chapters.

4.4.2.1 Nutrient Loading.

All the pollutographs for this storm are similar due to the massive differential in inflow and outflow.

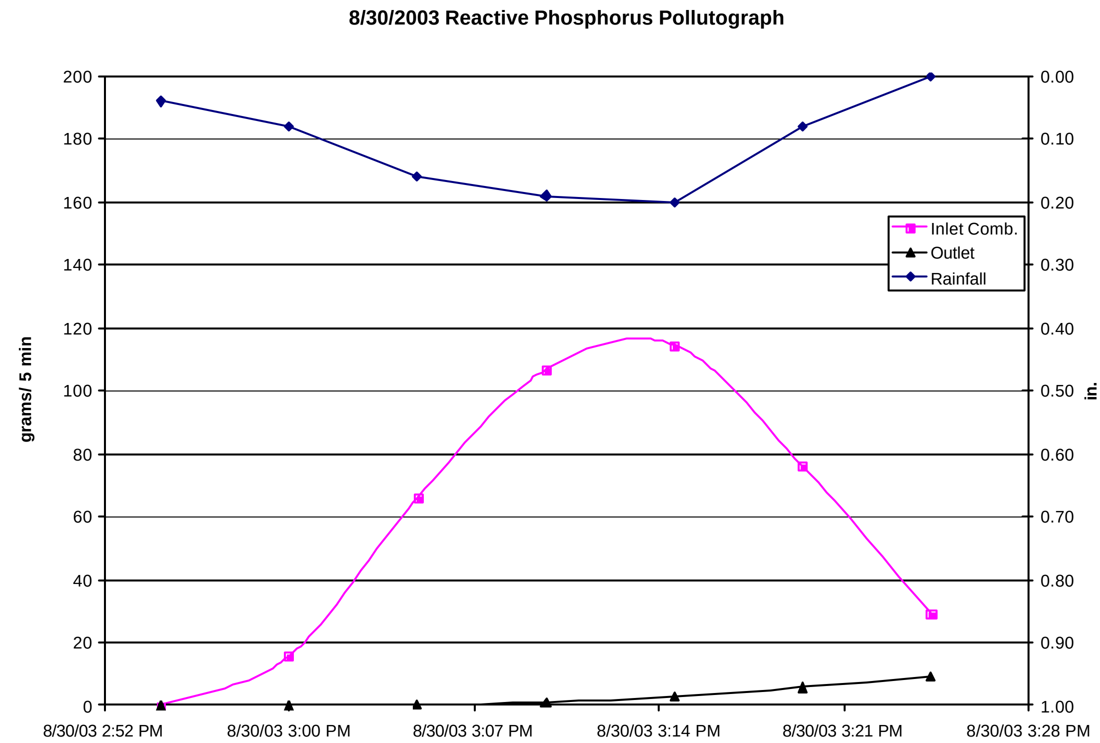

Figure 14. Reactive phosphorus pollutograph for August 30th 2003 event

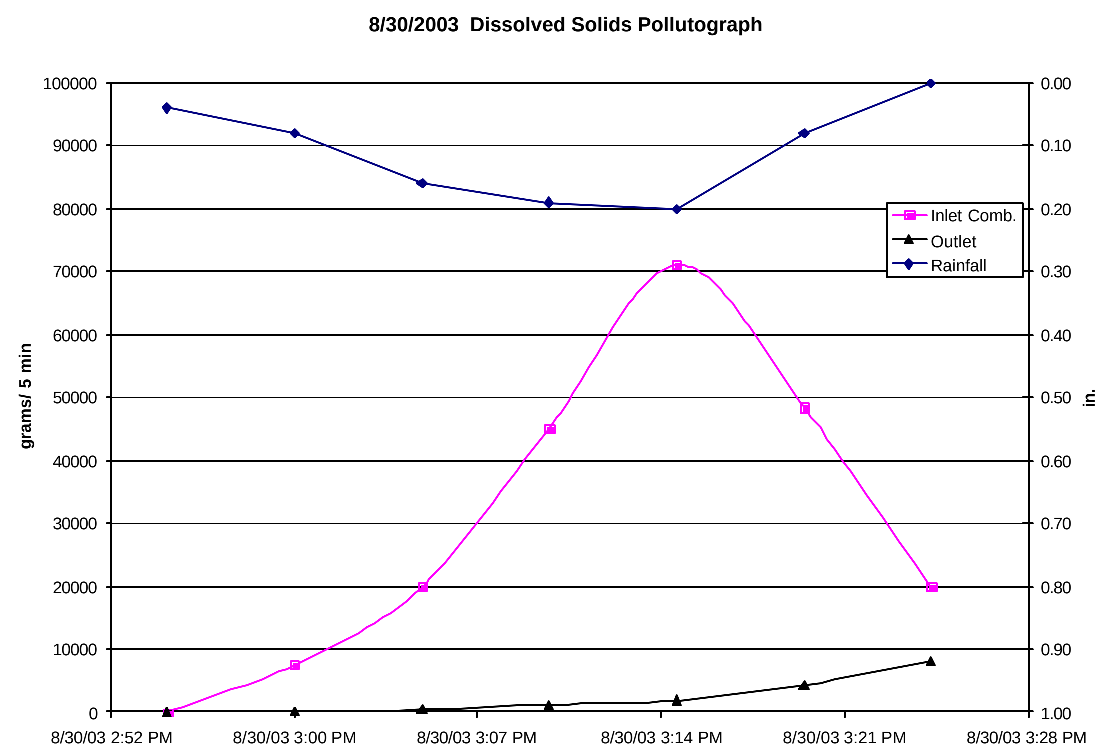

Figure 15. Dissolved solids pollutograph for August 30th 2003 event

These two graphs are nearly identical in showing the “first flush” effect that occurs during a severe rainfall event. On both graphs, however, the outflow mass seems to be just starting its increase at the end of the sampling routine. For this storm there is a large amount of error and these results should only really be used to see the concentrations coming in during a “first flush”. The ability of the wetlands to remove or clean the stormwater cannot be determined due to lack of flow matching of the inlet and outlet.

4.4.2.2 Nutrient Total Mass

In order to justify earlier statements regarding this storm, flow measurements are included with the chart of total mass for this storm. While inflow and outflow are never exactly equal for a storm event due to storage and additional inflow points, they are generally within 10% of each other. For this storm inflow was 25 times greater than outflow, due to the residency time of the wetlands. Outflows dramatically increase after the last sample was taken, but unfortunately we cannot incorporate this into our study.

30-Aug-03	R.P.	S.S.	D.S.	Nitrate	T.N.	Chloride	Volume
	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(cf)
Inlet	0.41	257.70	211.90	0.40	2.81	84.42	3.04E+05
Outlet	0.02	8.10	15.80	0.02	0.11	7.00	1.23E+04
Removal %	95.12	96.86	96.86	92.54	96.09	91.71	
R.P. = Reactive Phosphorus, T.N. = Total Nitrogen							
S.S. = Suspended Solids, D.S. = Dissolved Solids							

Table 12. Total mass (kg) of pollutants for August 20th 2003 event.

4.1.3 September 18-19th 2003.

The storm event of September 18th and 19th of 2003 was forecast as the result of Hurricane Isabel. Due to the forecast of extreme amounts of rain, the sampling protocol was changed in order to sample from as much of the storm as possible. The forecast turned out to be incorrect, with only 1.35 inches of rain falling in a eight hour period. Rainfall was too light in the beginning of the storm to trigger the samplers, therefore the initial .15 inches of rain was not captured, and the sampler intervals were hourly, not capturing the initial runoff captured in many other storms. The implications of this will be discussed in the following chapter.

4.1.3.1 Nutrient Loading.

While the results may differ from previous storms, they are again consistent with each other over the range of test parameters. As you can see in figure 16, inflow loading of reactive phosphorus is much flashier, with peak loading levels occurring during the highest rainfall increments. The outlet steadily rises, then falls as rain stops for a period of time, only to rise again as the rain resumes.

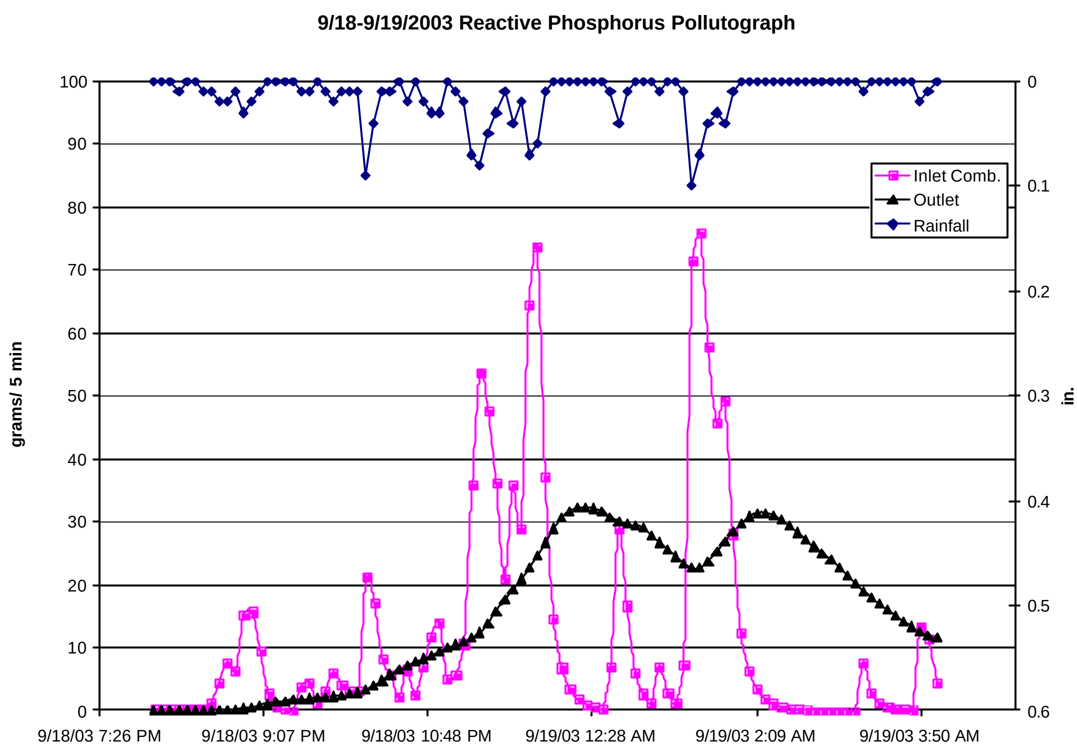

Figure 16. Reactive phosphorus pollutograph for September 18th event

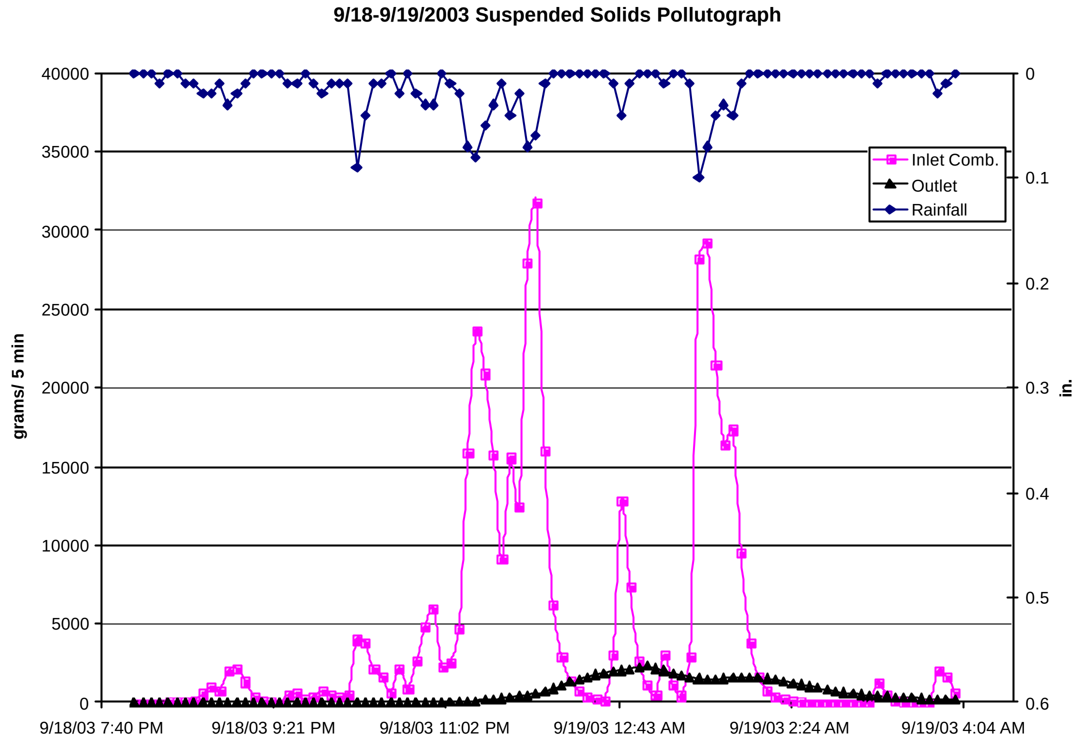

Figure 17. Suspended solids pollutograph for September 18th event

4.4.3.2 Total Nutrient Mass

By missing the initial inflow flush of nutrients, this event gives us a better idea of how the system performs during the duration of a storm event.

18-Sep-03	R.P.	S.S.	D.S.	Nitrate	T.N.	Chloride
	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)
Inlet	1.15	421.80	192.50	6.40	5.55	45.30
Outlet	1.51	60.60	177.80	6.30	5.10	76.20
Removal %	-31.30	85.63	7.64	1.56	8.11	-68.21
R.P. = Reactive Phosphorus, T.N. = Total Nitrogen						
S.S. = Suspended Solids, D.S. = Dissolved Solids						

Table 13. Total mass (kg) of pollutants for September 18th event.

By looking at the total mass in Table 13 the only pollutant that is still being removed after the "first flush" is suspended solids. Reactive phosphorus, which in other events shows good removal, actually shows addition. Reactive phosphorus generally has a large inflow during the initial stages of rainfall. Dissolved solids and chloride loads are consistent with other storms.

4.4.4 October 27th 2003

The event on October 27th 2003 consisted of 1.09 inches of rain over a five and one half hour period. During this time period ten samples were taken at each inlet and at the outlet. This storm event represents the greatest number of samples taken during any storm event throughout this study. Again we see consistency within sampling locations for different elements, seemingly tied in with peak rainfall periods.

4.4.4.1 Nutrient Loading

The pollutographs for suspended solids, reactive phosphorus, total phosphorus follow a similar pattern, with inflow peaks and valleys, followed by a much lower outflow loading. For dissolved solids and chlorides a much different trend appears. While we can see a "first flush" of both dissolved solids and chlorides entering the system, the outflow quickly increases and actually has more area.

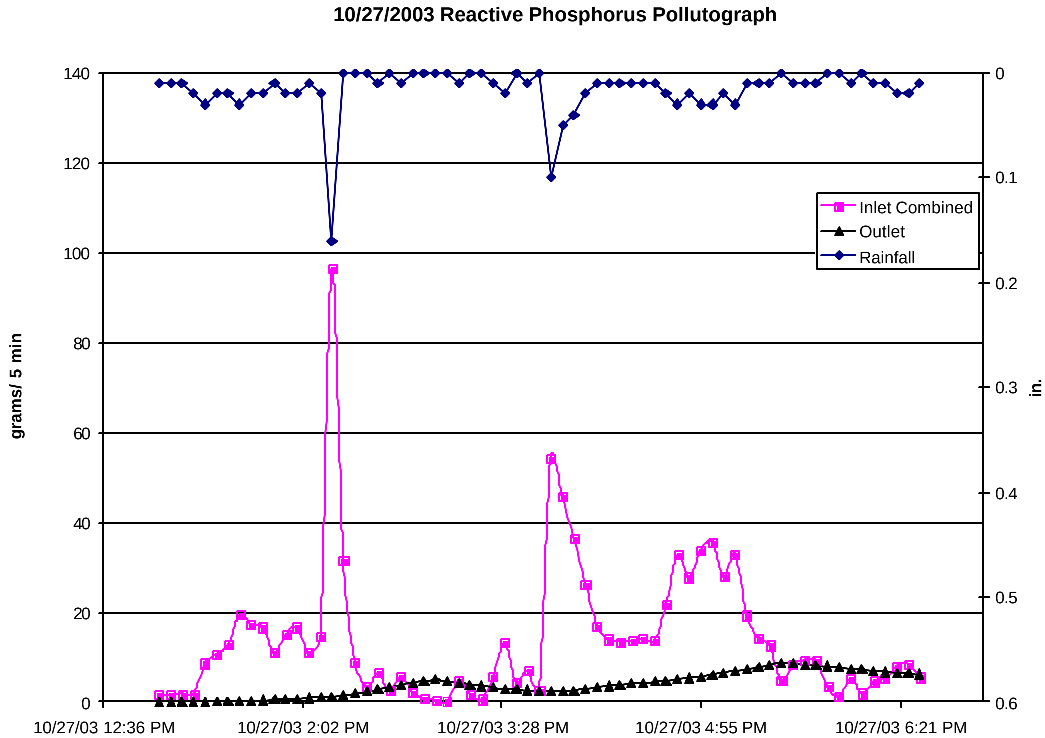

Figure 18. Reactive phosphorus pollutograph for October 27th event

You can see in the above figure (18) the initial spikes of inflow match with the spikes of rainfall. Also note the substantial difference between the mass of inflow and mass of outflow. In contrast to this is figure 19..

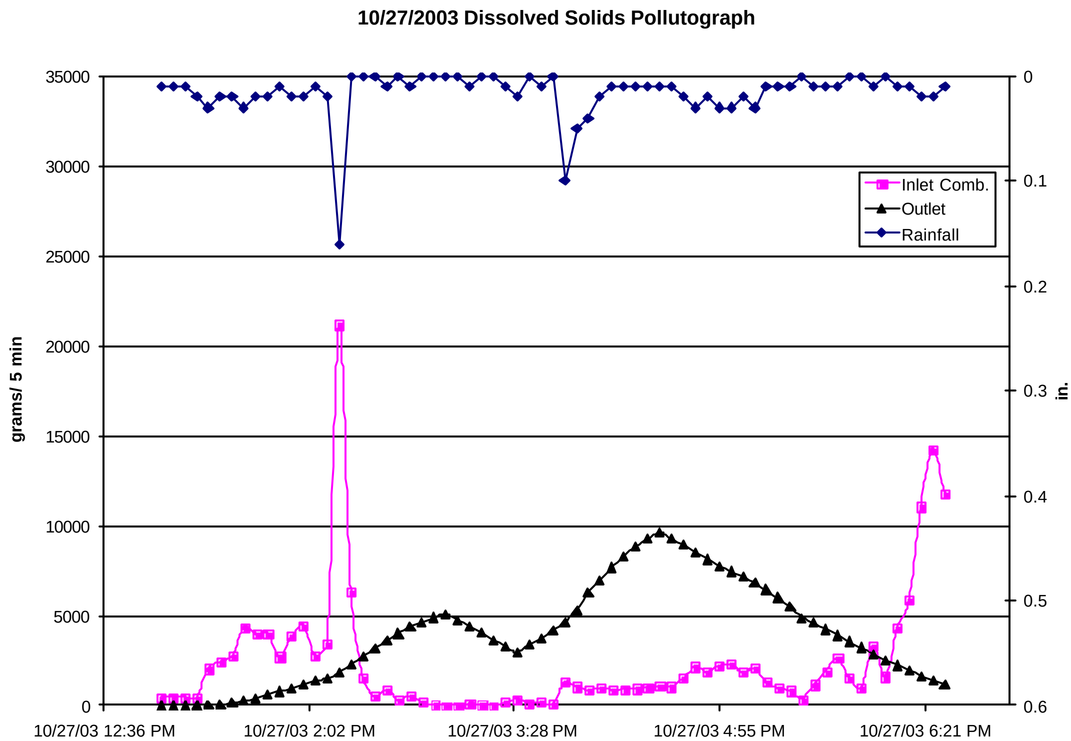

Figure 19. Dissolved solids pollutograph for October 27^{th} event

In this pollutograph you can see the initial entry of dissolved solids into the system. The outflow load surpasses the inflow load about two hours into the storm and continues at a higher level until the very end of the storm. A similar trend can be seen in the chloride pollutograph (Appendix 1).

4.4.4.2 Total Nutrient Mass

By observation, the pollutographs of reactive phosphorus, total phosphorus and suspended solids have a total mass of the inflow that is greater than that of the outflow. However, for the dissolved solids and chloride graphs, one must look at the total mass from the storm to compare the initial mass spike of the inlet to the overall higher value of the outlet.

27-Oct-03	R.P.	S.S.	D.S.	T.P.	Chloride
	(kg)	(kg)	(kg)	(kg)	(kg)
Inlet	0.94	58.80	158.80	3.50	32.60
Outlet	0.26	16.90	264.70	1.80	45.10
Removal %	72.34	71.26	-66.69	48.57	-38.34
R.P. = Reactive Phosphorus, T.P = Total Phosphorus					
S.S. = Suspended Solids, D.S. = Dissolved Solids					

Table 14. Total mass (kg) of pollutants for October 27th, 2003 event.

As seen in Table 14, the outflow mass for both chloride and dissolved solids is much higher than that of the inflow mass. While the maximum concentration is much greater in the inlet first flush, the outflow's steady levels have a greater overall mass. For suspended solids, reactive phosphorus and total phosphorus the wetland system showed a 71, 72, and 48 percent reduction, respectively.

4.4.5 November 19th 2003

November 19th was a large storm event, with nearly 1.8 inches of rain falling over seven hours and fifty minutes. During this event ten samples were taken from both inlets and the outlet.

4.4.5.1 Nutrient Loading

Nearly identical to the storm event on October 27th, pollutograph results are split into two forms. Those for reactive phosphorus (Figure 20), total phosphorus, and suspended solids show the classic inflow spike or "first flush" followed by much less inflow and a slightly increasing outflow.

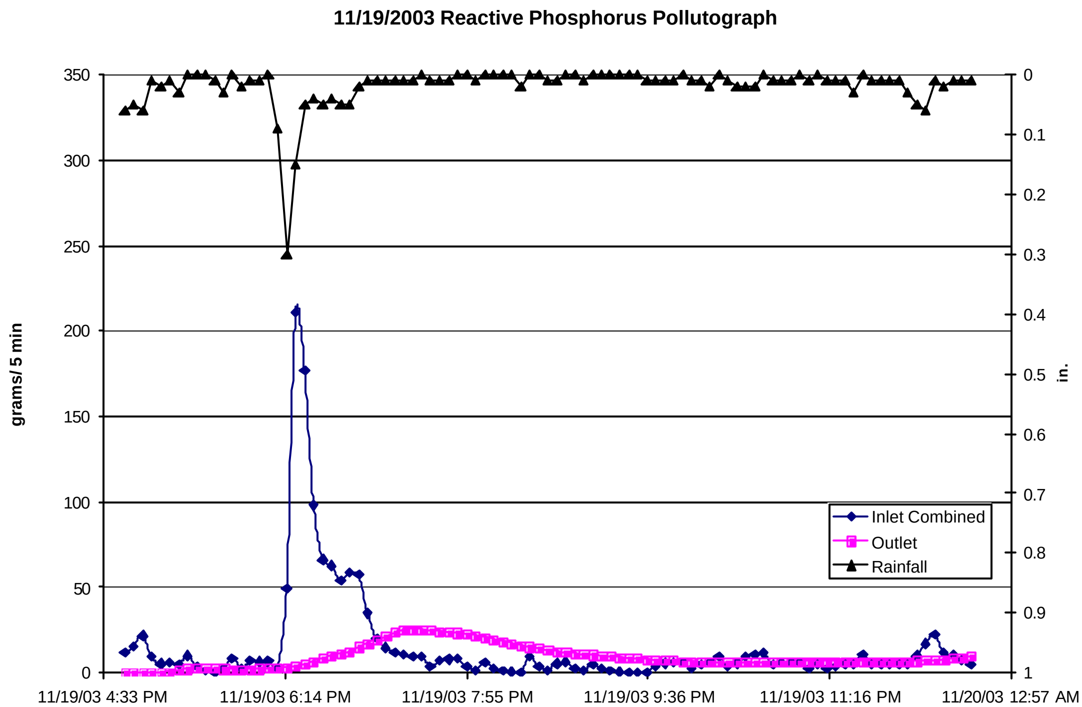

Figure 20. Reactive phosphorus pollutograph for November 19th event

For chloride, nitrate, and dissolved solids, there is no clearly visible pattern. The ranges of outflows are much closer than that of inflow, but a large amount of randomness appears evident. There is a large initial inflow spike for all of these pollutants during the heavy spike of rainfall near the beginning of the storm, but after a short time the outlet and inlets seem to be approximately the same.

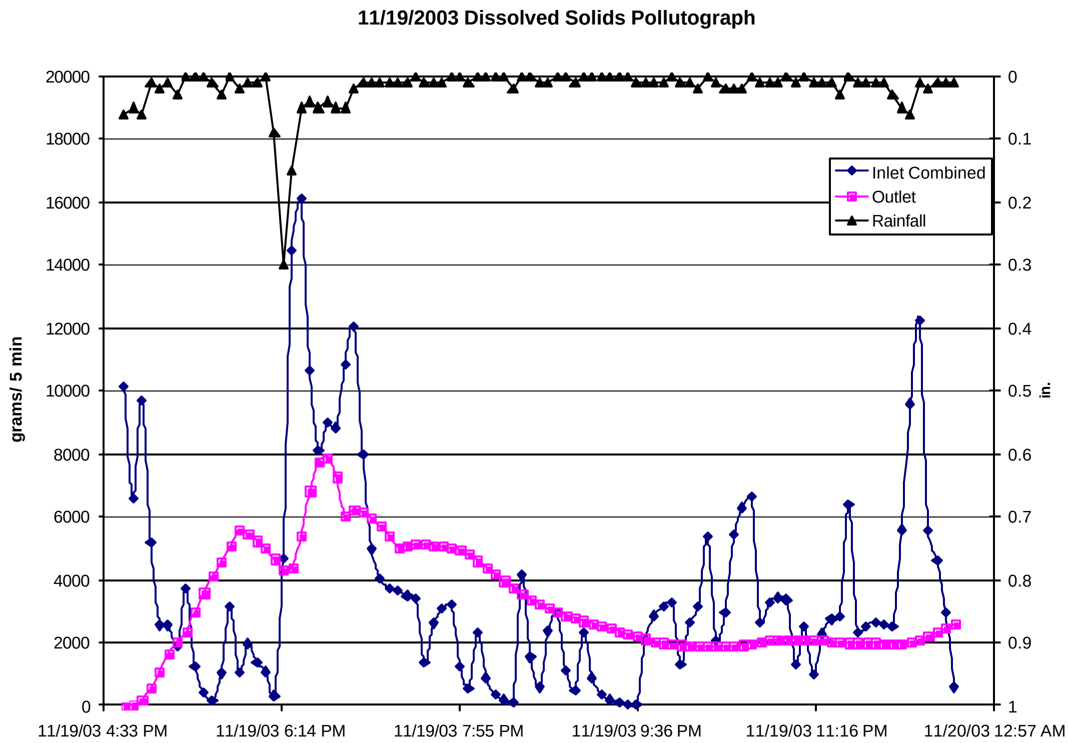

Figure 21. Dissolved solids pollutograph for November 19th event

4.4.5.2 Total Nutrient Mass

Total nutrient mass for this event can be used to determine system processes for those events where no trend is evident on the graph. Table 15 shows that dissolved

19-Nov-03	R.P.	S.S.	D.S.	Nitrate	T.P.	Chloride
	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)
Inlet	1.40	278.80	345.20	7.70	6.40	45.30
Outlet	0.90	141.30	312.00	5.80	2.70	76.20
Removal %	35.71	49.31	9.62	24.68	57.81	-68.21
R.P. = Reactive Phosphorus, T.P = Total Phosphorus						
S.S. = Suspended Solids, D.S. = Dissolved Solids						

Table 15. Total mass (kg) of pollutants for November 19th, 2003 event.

solids seem to pass directly through the system during this event, chlorides are added and nitrates are reduced by 25%.

4.4.6 August 1, 2004

The event of August 1, 2004 lasted approximately two hours and 1.71 inches of rain was recorded. Samplers were erroneously started the day before by a quick thunderstorm, so for this event, the samplers started with a greater interval. Initial rainfall in this storm was captured, and an even interval was maintained throughout.

4.4.6.1 Nutrient Loading

An unusual pattern for all pollutographs emerged from this storm. As you can see in Figure 22, there is no initial spike or "first flush" evident for reactive phosphorus, but the mass load increases toward the end of the storm. This is the same for chloride, the only difference being the equality of the inlet and the outlet (Figure 23).

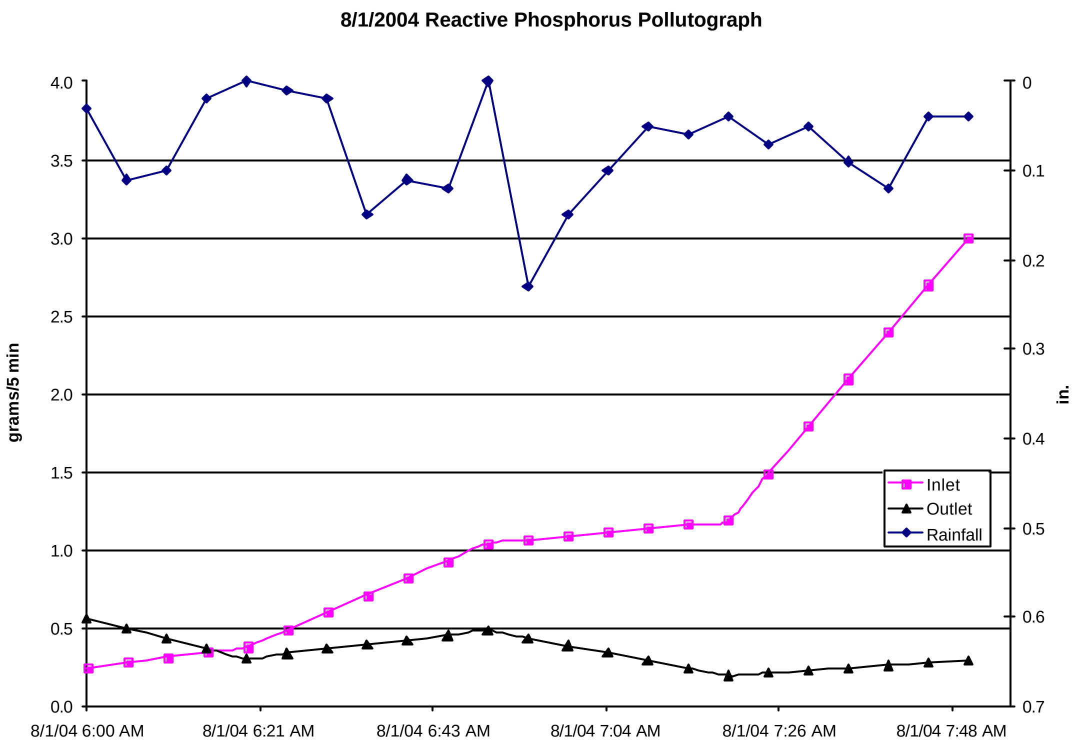

Figure 22. Reactive phosphorus pollutograph for August 1st, 2004 event

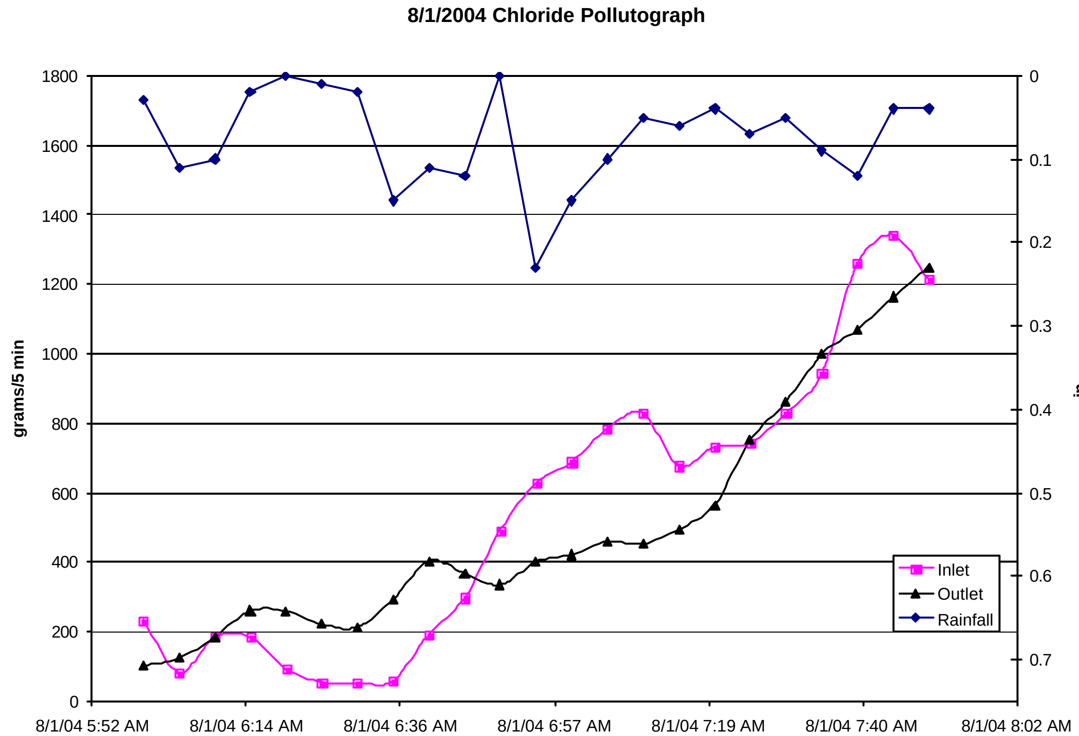

Figure 23. Chloride pollutograph for August 1st, 2004 event

4.4.6.2 Total Nutrient Mass

With no evident first flush, would the results for total mass differ? Looking at Table 16, it appears that although the pollutograph may look different, similar full storm functions are similar, with removal percentages similar to those showing an initial inflow spike in concentration..

1-Aug-04	R.P.	S.S.	D.S.	Chloride
	(kg)	(kg)	(kg)	(kg)
Inlet	2.50	128.00	118.60	12.60
Outlet	0.40	63.10	409.00	11.60
Removal %	84.00	50.70	-244.86	7.94
R.P. = Reactive Phosphorus, T.P = Total Phosphorus				
S.S. = Suspended Solids, D.S. = Dissolved Solids				

Table 16. Total mass (kg) of pollutants for August 1st, 2004 event.

Removal efficiencies for reactive phosphorus and suspended solids are 84 and 50 percent, respectively. Similarly to most storm events, chlorides and dissolved solids are not removed, and in many cases are added to the system.

4.5 Storm Summary Results

This section presents results for each individual parameter for all storm events. These results give a better idea of the range of values present on a storm-by-storm basis, listing maximum, minimum, and event mean concentration values. Event mean concentration is a flow-weighted value that is more representative than a simple arithmetic average. Assuming flows are equal, comparisons of event mean concentrations should give a good idea of the removal efficiencies of the system.

4.5.1 Reactive Phosphorus

The event mean concentrations for reactive phosphorus are higher in the outflow for the first three sampled events, and then switch to be higher in inflow for the final three. It must be noted that for the two initial storm events, samples from the second inlet point were not used in the calculations, due to an automated sampler problem. The results were computed using a flow-weighted average, and since the inflow point missing averages only 25% of the flow, these results would generally be in a similar range. The addition of these inflow points may or may not have increased the event mean concentration, but in three out of four instances in which it was included, the event mean of the inflow was higher than that of the outflow.

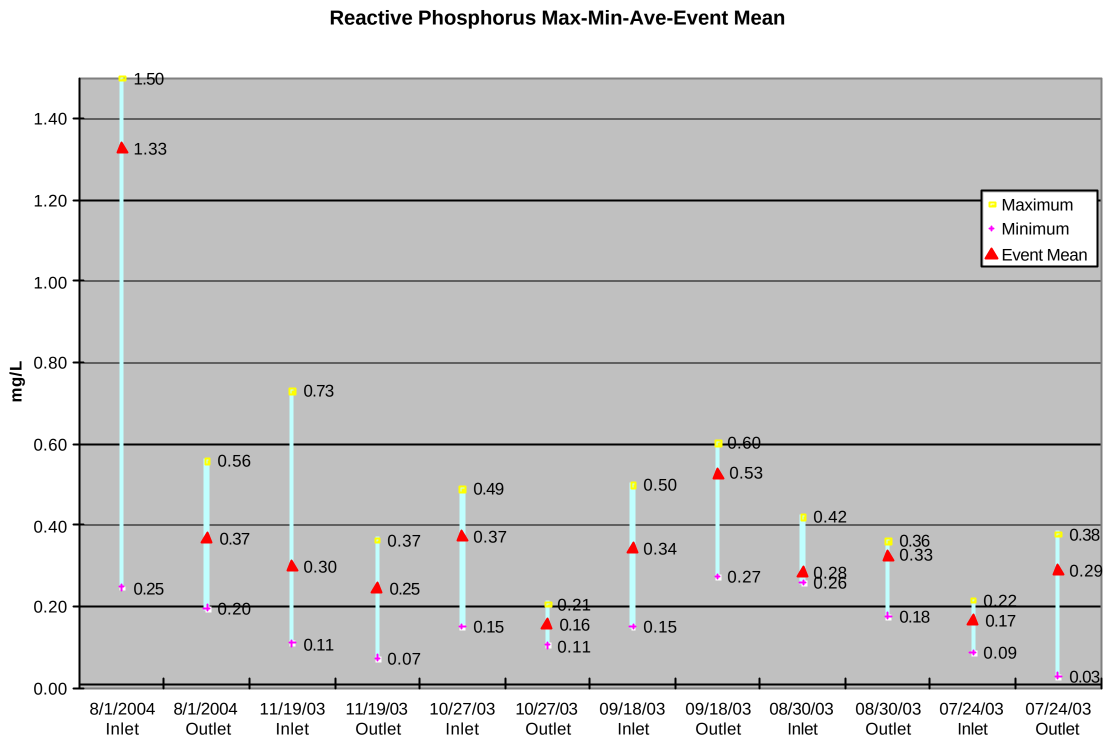

Figure 24. Maximum, minimum, and event mean concentration for reactive phosphorus for all storm events

Reactive phosphorus shows a maximum concentration of 1.5 mg/L at the inlet, while the outlet maxes out at .60 mg/L. The average event mean concentration for the inlet over the full range of storms was .47 mg/L, while the outlet average was .32 mg/L.

4.5.2 Total Phosphorus

Total phosphorus and suspended solids yielded the most consistent results of all tested parameters. All event mean concentrations of total phosphorus showed a reduction from inlet to outlet.

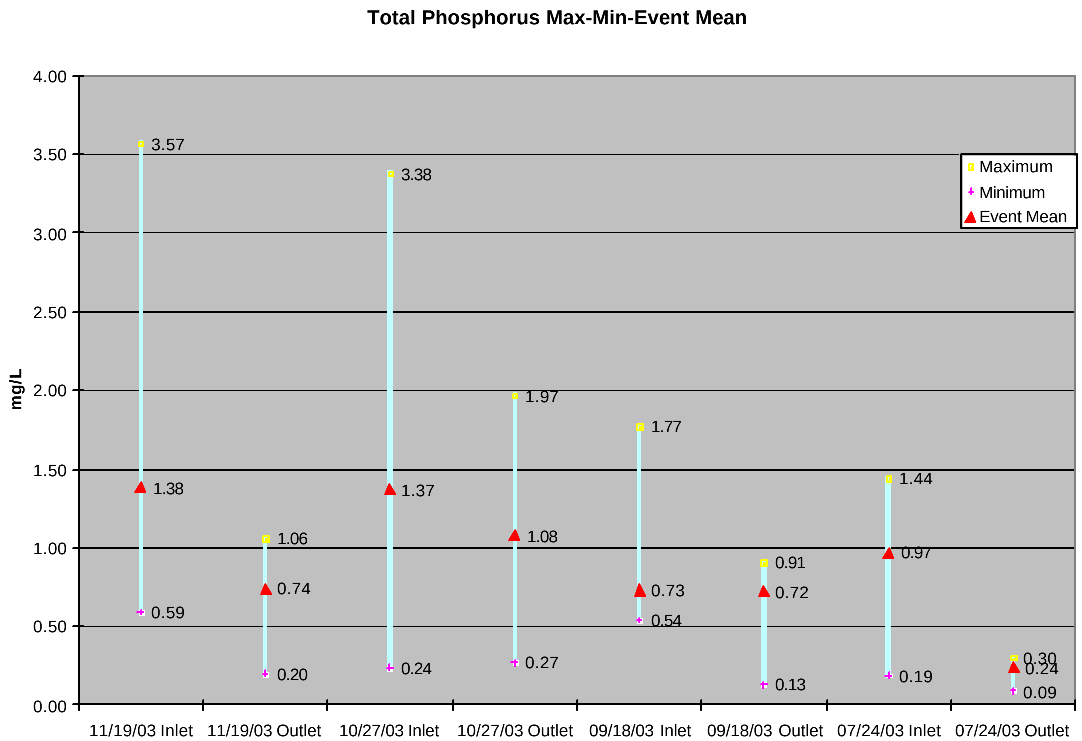

Figure 25. Maximum, minimum and event mean concentrations for total phosphorus for all storm events

The storm event of September 18th, 2003 only shows a .01 reduction in event mean concentration, but as stated previously, this is the storm where the initial stages of rainfall and runoff were not recorded.

4.5.3 Total Nitrogen

Figure 26 for total nitrogen brings demonstrates the discrepancy between removal efficiency and event mean concentration. According to Table 12, total nitrogen showed a 96% reduction. According to Figure 26, however, the event mean concentration for the outflow is very near that of the inlet. This illustrates the importance of mass balancing for accurate results. The event mean concentration more accurately gives an idea of the concentration differential between outlet and inlets.

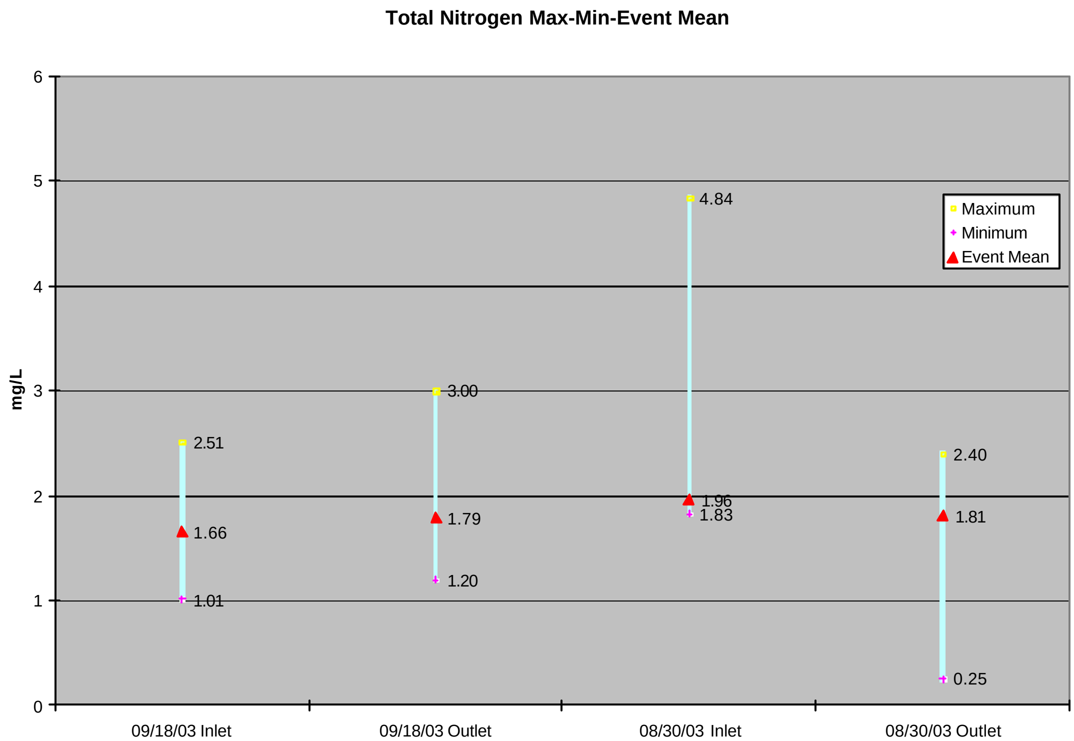

Figure 26. Maximum, minimum and event mean concentration for total nitrogen for all storm events

This figure shows that total nitrogen is relatively consistent at both inlet and outlet. A maximum value of 4.84 mg/L is observed at the inlet while a maximum value of 3.0 mg/L occurs at the outlet. Lack of usable test results calls into question the conclusions that can be made for this specific nutrient.

4.5.4 Nitrate

Nitrate concentrations follow along with the patterns of total nitrogen. While maximum values may be higher at inlet points, possibly due to a first flush effect, the entire system seems to be in stasis when it comes to nitrate. Event mean concentrations are roughly equal for every storm tested.

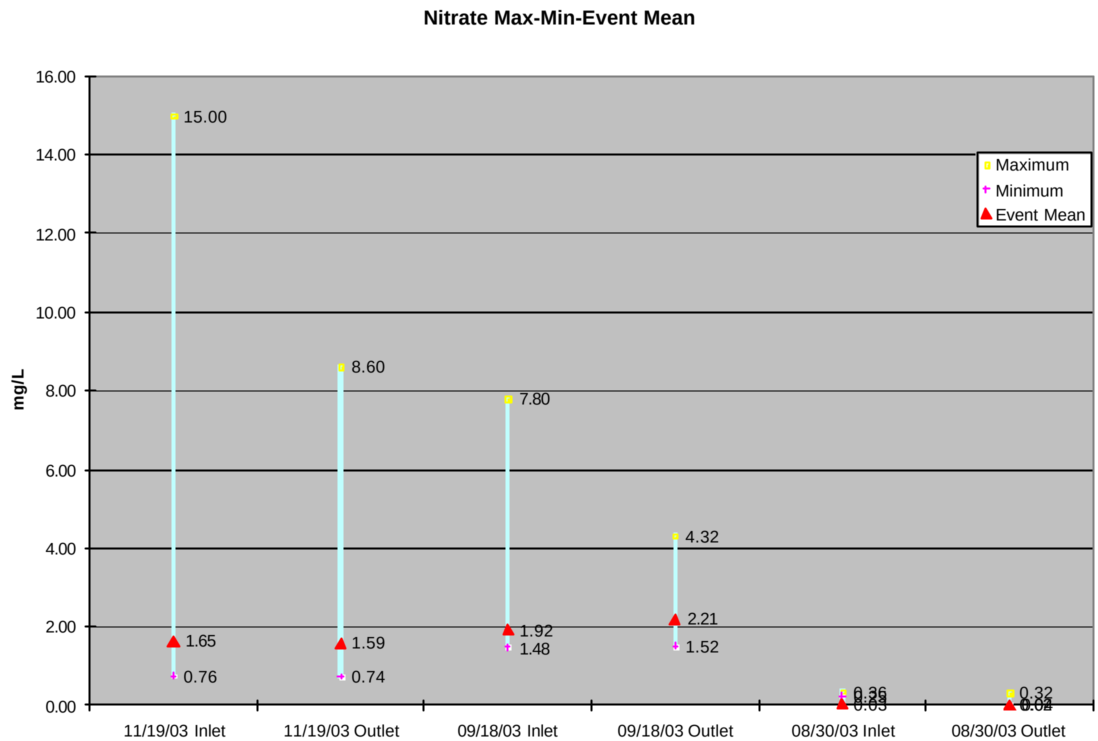

Figure 27. Maximum, minimum and event mean concentration for nitrate for all storm events

There storm events of October 27th, 2003 and August 1, 2004 were also tested for nitrate and yielded no identifiable results. Again, a high concentration spike is evident in the inflow, but overall removal seems negligible.

4.5.5 Chloride

Chloride is of great interest to this study as extensive research on how it is affected by wetlands has not been done. During winter months the wetlands receive large quantities of chlorides from snowmelt that is plowed into the inlet. During preliminary testing in the months of January and February, it was common to find chloride levels at the inlet of over 500 mg/L. During storm events during the summer months, we would expect the chloride input to be much less.

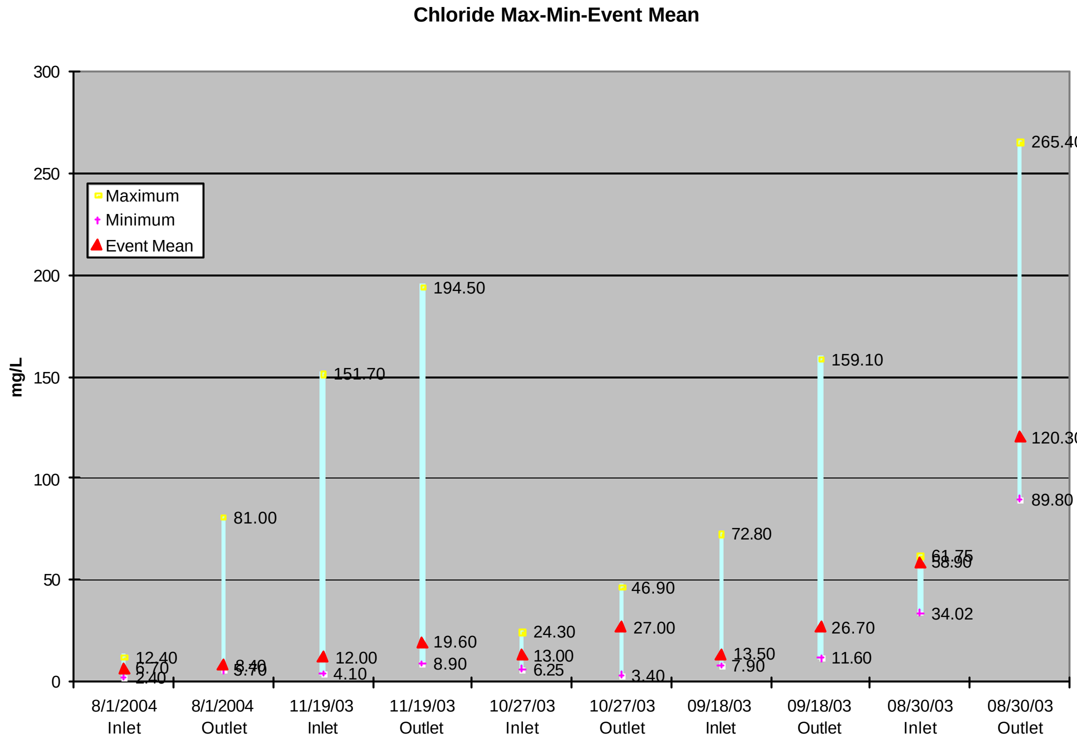

Figure 28. Maximum, minimum and event mean concentration for chloride for all storm events

In every instance, the event mean concentration for chloride is higher in the outflow than in the inflow. This is not unexpected and will be discussed in great detail in Chapter 5.

4.5.6 Nitrite

Each storm event after July 27ty, 2003 was tested for nitrite. Only one storm yielded quantifiable results, and they were so low as to be insignificant.

4.5.7 Total Suspended Solids

Often considered the most important function of a wetland, the removal of suspended solids is of great concern to our study.

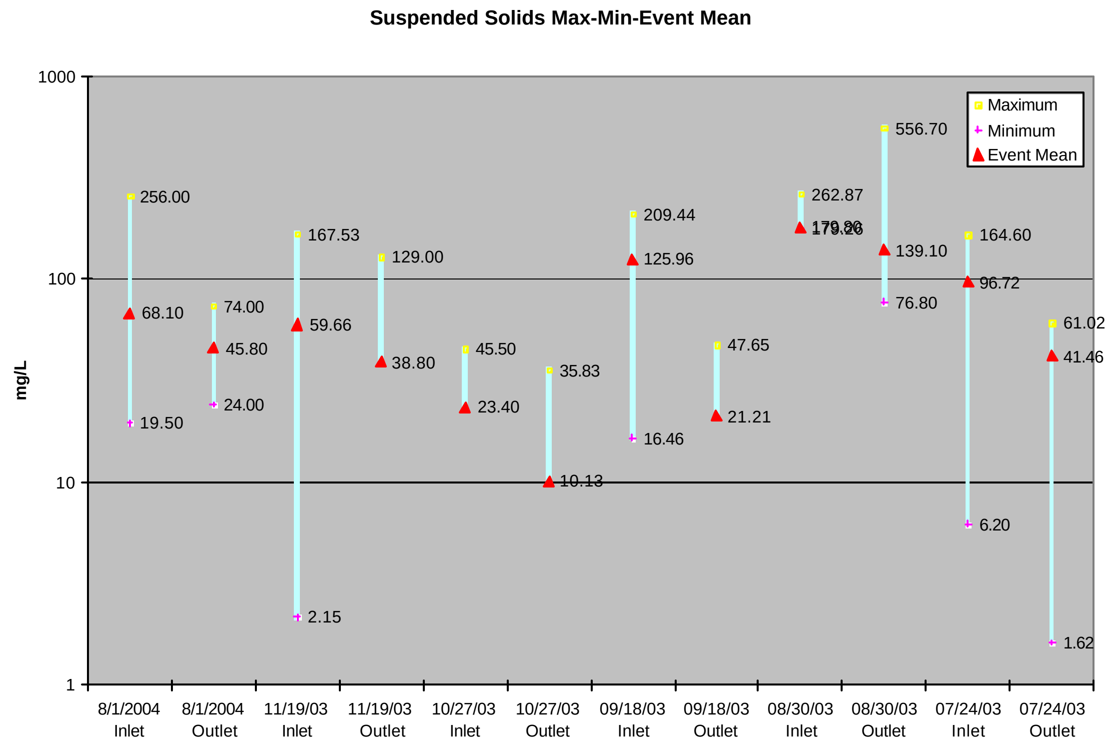

Figure 29. Maximum, minimum and event mean concentrations for suspended solids for all storm events (Minimum values of zero are not displayed)

The extremely high maximum concentration at the outlet on August 30, 2003 is due to construction of a berm at the outlet during the month of August. Event mean concentration is considerably less in every storm event sampled, with a maximum difference of over 100 mg/L and a minimum difference of 13 mg/L.

4.5.8 Dissolved Solids

Storm events may initially contain dissolved solids, but rainwater is generally low in dissolved solids. The expected trend, therefore, would be for dissolved solids to come out of the wetland, giving higher outflow values.

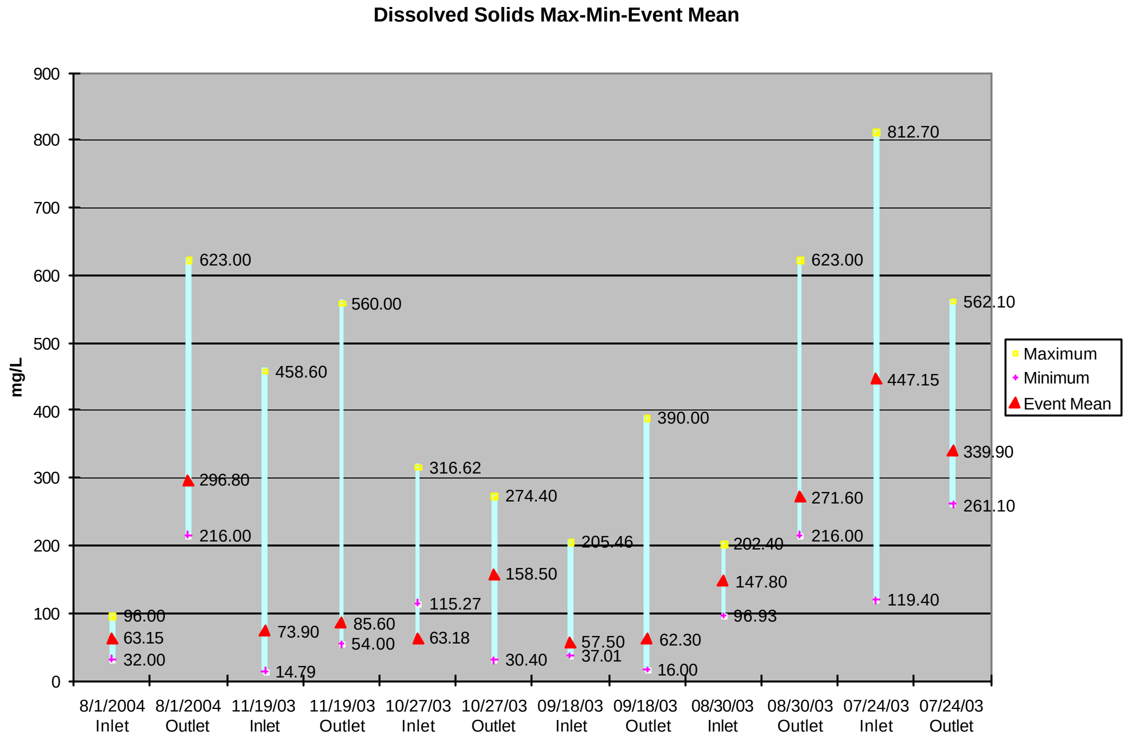

Figure 30. Maximum, minimum and event mean concentrations for dissolved solids for all storm events

In Figure 30, the event mean concentrations are significantly higher in the outflows during all storm events except for the July 27th, 2003 storm. The increase in dissolved solids is maximized during the August 1st, 2004 storm, with a difference of over 230 mg/L event mean concentration from inlet to outlet.

4.6 Baseflow Results

Baseflow results are reported in either mg/L or percentage removal due to the equality of inflow and outflow. Results are categorized by pollutant, not by sampling date, as all samples were of equal volume and during similar baseflow conditions.

4.6.1 Reactive Phosphorus

The wetland showed excellent removal rates for reactive phosphorus for all baseflow sampling events.

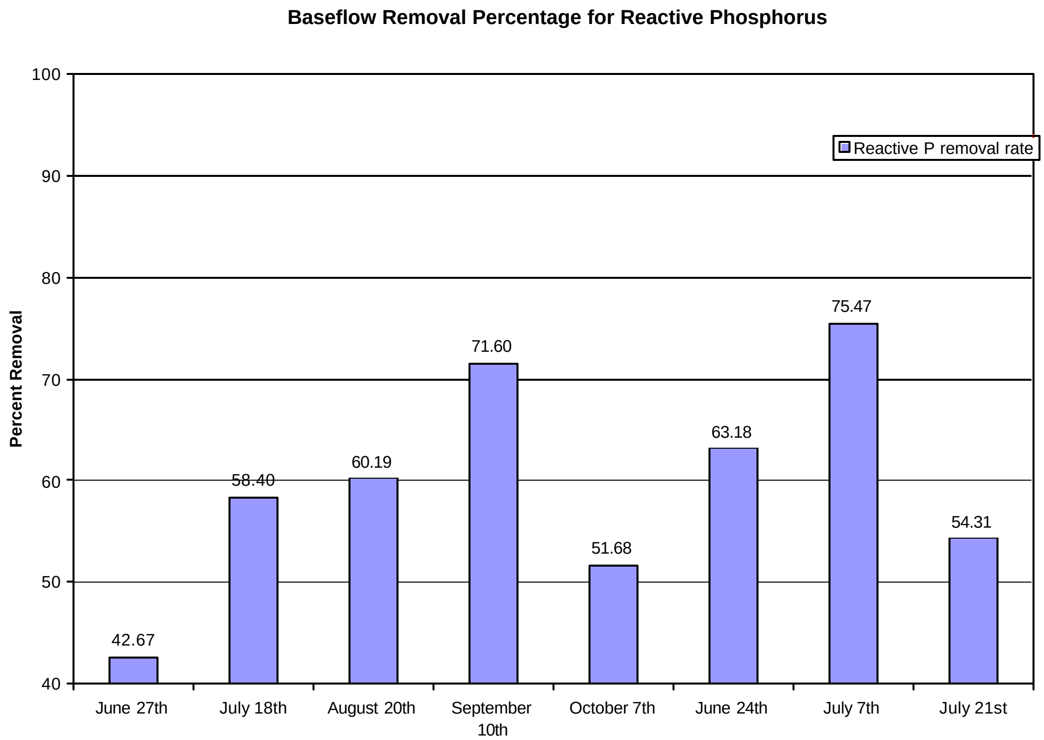

Figure 31. Reactive phosphorus removal rates for baseflow sampling (2003-2004)

Removal percentages range from 43 to 75, with an average removal of nearly 60 percent.

4.6.2 Total Phosphorus

The removal rates for total phosphorus are much more varied and spread out than those of reactive phosphorus. While all samples showed a significant amount of removal, the values ranged from 16 to 79 percent, with an average removal of 42 percent.

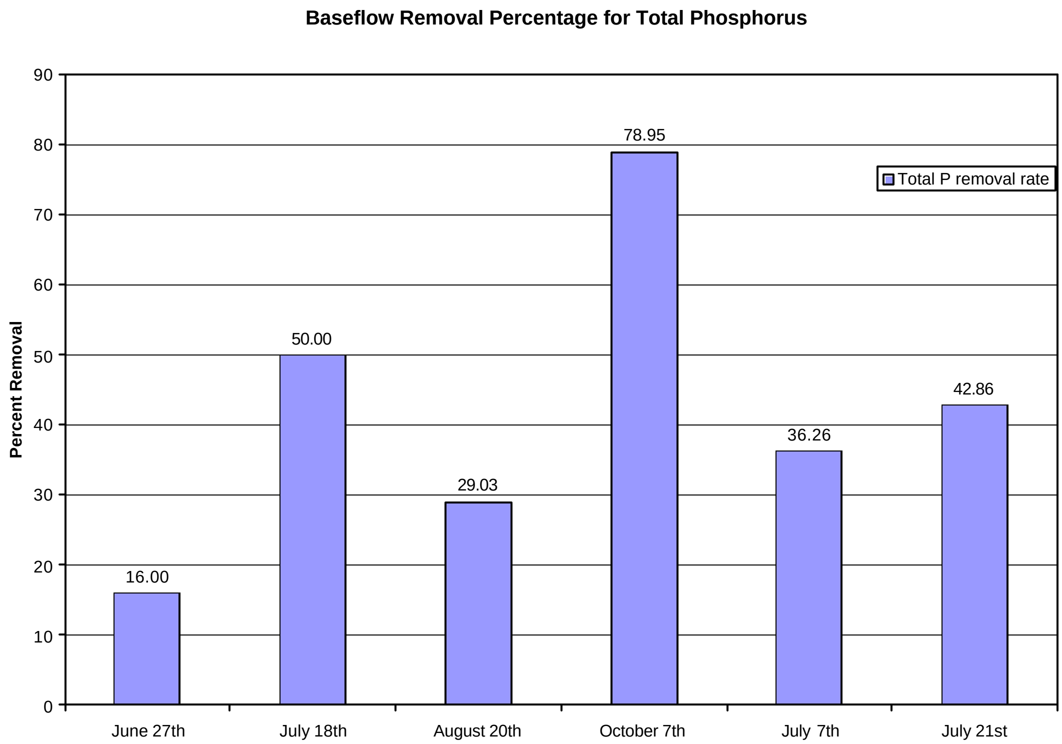

Figure 32. Total phosphorus removal rates for baseflow sampling (2003-2004)

It should be noted that both minimum values for total and reactive phosphorus occurred on June 27th and were considerably below the average.

4.6.3 Total Nitrogen

The removal efficiency of the wetlands at removing total nitrogen was greatly enhanced from storm events to baseflow events. While little removal was seen during storm events, nearly all total nitrogen was removed during baseflow. Removal rate averaged nearly 84 percent, and one sampling time yielded no quantifiable results at the outlet giving a removal of 100 percent.

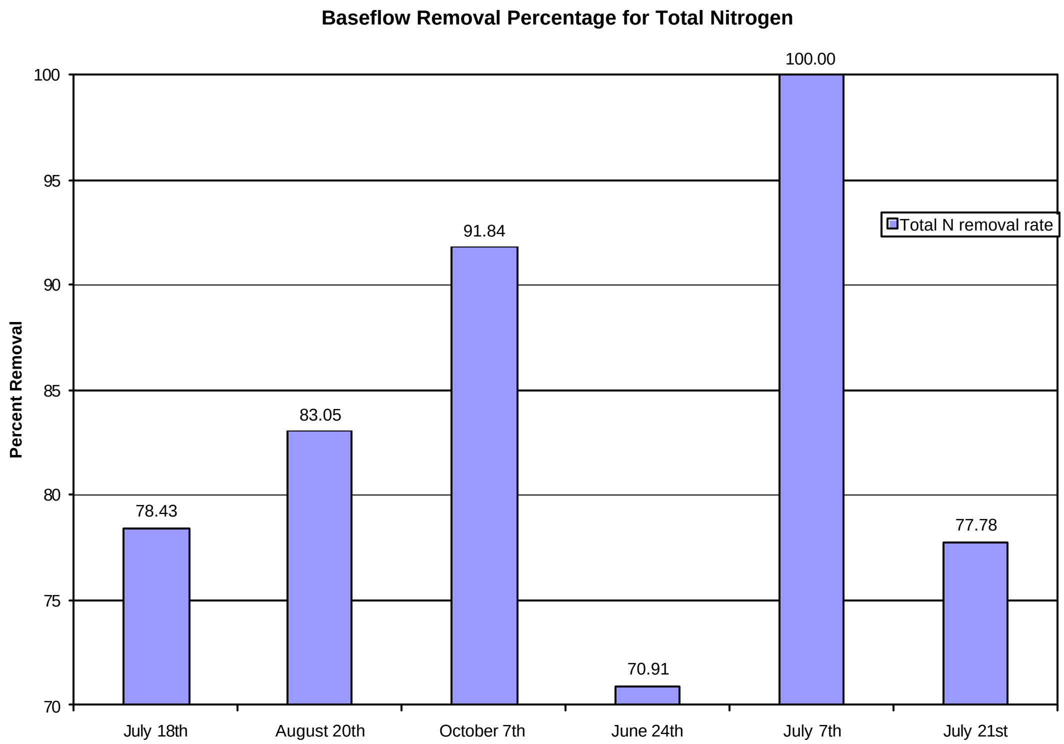

Figure 33. Total nitrogen removal rates for baseflow sampling (2003-2004)

The high removals of nitrogen during baseflow conditions, and the debate on the nitrogen cycle, will be discussed in detail in the following chapter.

4.6.4 Chloride

Chloride, as mentioned previously, was a focus of this research. Already it has been shown that during storm events chloride seems to be added to the system. Would it be the same for baseflow? Figure 34 shows that chlorides seem to pass directly through the wetlands during baseflow.

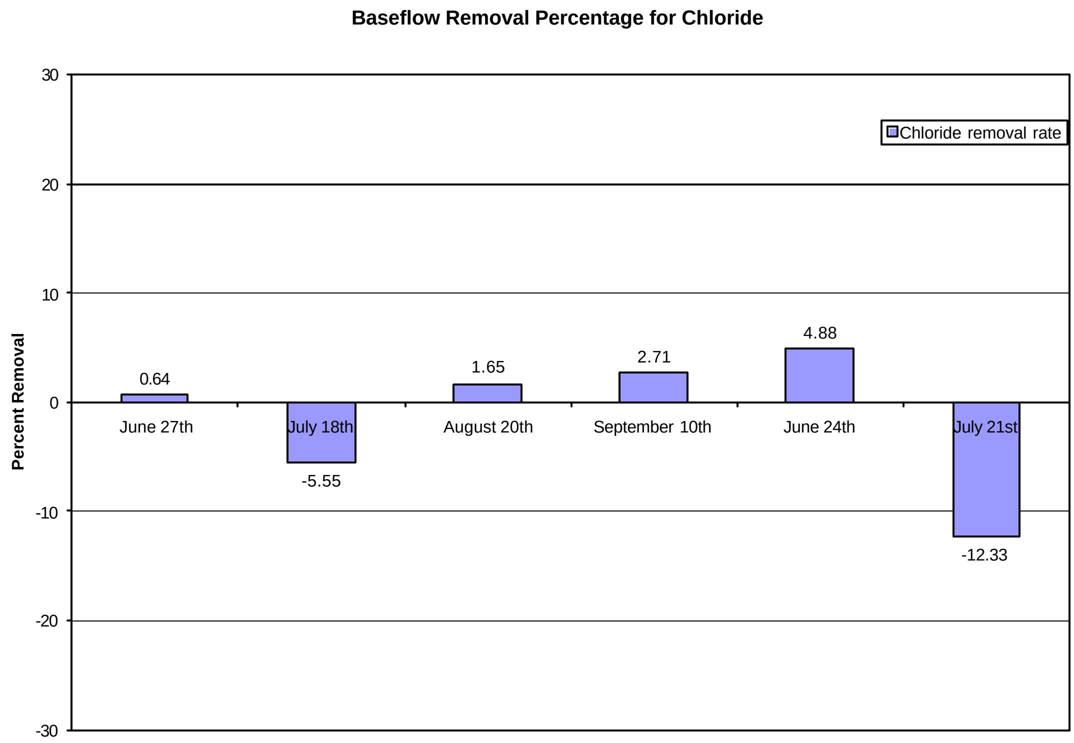

Figure 34. Chloride removal rates for baseflow sampling (2003-2004)

With four samples showing slight removal, and two samples showing addition, it seems that the chloride concentrations tend to stay nearly unchanged from inlet to outlet.

4.6.5 Suspended Solids, Nitrate, Nitrite

Suspended solids, one of the main foci of our storm research, were surprisingly absent from baseflow samples. Suspended solids tests were run on the initial four baseflow samples, with no quantifiable results. Inspection of all subsequent baseflow samples showed no sign of suspended solids, so testing was discontinued. For nitrite, no quantifiable results were found in any samples. For nitrate, small concentrations were found at the inlets during 2 samples, but it was felt that there was not enough data to report.

4.6.6 Total Dissolved Solids

Dissolved Solids, similarly to chlorides, were found to pass through the wetland system during storm events. The results for baseflow seem to follow the same pattern.

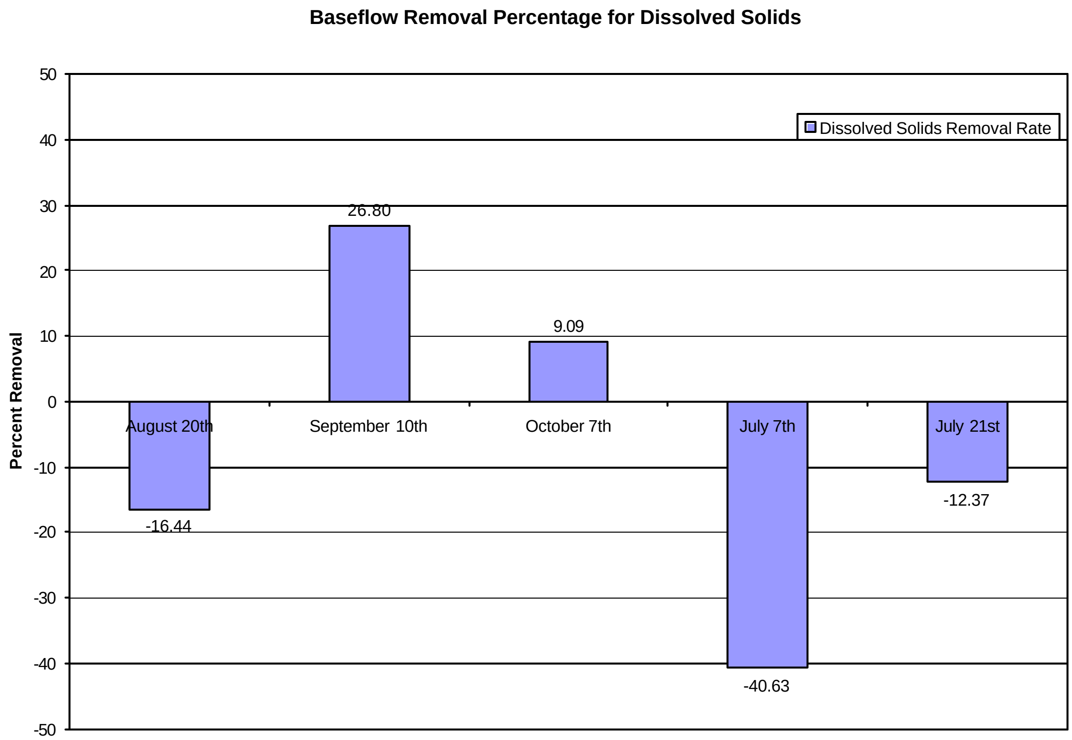

Figure 35. Dissolved solids removal rate for baseflow sampling (2003-2004)

Results range from 40 percent addition to 27 percent removal. There is no clear pattern of removal or addition, results are seemingly random and average values point to no change occurring to dissolved solids during baseflow.

Chapter 5: Discussion

5.1 Introduction

The purpose of this chapter is to expand on the significance of the results presented in Chapter 4. Results were separated into storm events and baseflow events, and discussion will be partitioned similarly. The discussion will follow the same outline as the results, using the same order of nutrients and pollutants for organizational purposes.

5.2 Storm Events

Instead of discussing each parameter for each storm, the discussion will focus on the summary of all storms. References will be made to individual storms if required for further explanation. Each pollutant type will be discussed in detail.

5.2.1 Reactive Phosphorus

Reactive Phosphorus is a dissolved form of phosphorus and is the form that is available for usage and uptake by plants. For wetlands, the hypothesis is that residence time should be correlated to the amount of removal of reactive phosphorus. From this, one would expect greater removals during baseflow than during storm events. This is exactly what has been observed. During storm events, reactive phosphorus concentrations have similar event mean concentrations, averaging a slight removal. Maximum values are always higher at the inlet than at the outlet, due to the first flush. Phosphorus occurs naturally in rocks and organic material and can be found in decaying animals and feces. Initial rainfall takes these phosphorus sources and washes them into the wetlands, leading to the initial spikes that we see on our storm pollutographs. It seems that the size and volume of the wetlands acts to dilute these high levels to a consistent value leaving at the outlet. While significant removal of reactive phosphorus may not be occurring during the storm, the wetland is still effective in diluting high concentrations. High concentrations of phosphorus can lead to eutrophication and other biological problems. Phosphorus is generally not harmful to humans unless it is found in extremely high concentrations. The concentrations of reactive phosphorus found in this study were not high enough for water quality concerns for humans or aquatic habitats, with a study-high concentration of 1.5 mg/L at the inlet and an average of less than .5 mg/L for both the inlet and the outlet.

5.2.2 Total Phosphorus

Total Phosphorus includes both reactive phosphorus and forms of phosphorus sorbed to suspended solids. A reasonable hypothesis would be that the majority of suspended phosphorus would be removed, and the dissolved portions of phosphorus would pass through the system. This is exactly what is seen. Maximum concentrations and event mean concentrations are higher at the inlet for all storms sampled. Average mass removal of total phosphorus is near 50 percent. It can be assumed that this represents the majority of the total phosphorus found in solid form. By comparing to suspended solids removal, which shows an average removal during storm events of greater than 50 percent, we can speculate that the majority of phosphorus entering the wetlands is in insoluble form. Removal of phosphorus by removal of suspended solids brings into question whether the solid form of phosphorus removed can be converted or dissolved into a reactive form over time. If this were the case, one should expect an increase in outflow reactive phosphorus during baseflow conditions. This question will be discussed further in the section dealing with baseflow sampling. Again, as with reactive phosphorus, the levels of total phosphorus found at the wetland site are not considered harmful levels. Levels at the inlet peak at 3.7 mg/L for the inlet, and 2.0 mg/L at the outlet. Mean concentrations are much lower, 1.0 mg/L or lower for both inlet and outlet. The first flush is again clearly evident for total phosphorus. This follows along with what should be expected. The initial flush of pollutants into the system is high in suspended solids. The sedimentation of the suspended particles greatly decreases the concentrations that exit the wetland system.

5.2.3 Total Nitrogen

Usable results were only obtained for two storms for total nitrogen. Due to this fact, conclusions made will be extremely speculative and should be interpreted thusly.

Nitrogen comes from two sources at the wetlands, atmospheric deposition and fertilizers. Villanova University actively sprays grassy and horticultured areas in the wetland watershed with fertilizers. The washoff from these sprayed areas is assumed to be the major nitrogen source for the wetlands. The event mean concentrations at the inlet and outlet are nearly identical, leading us to believe that nitrogen is not being removed over the duration of a storm. It is assumed that a similar pattern to that of total phosphorus and reactive phosphorus would be found if more storms were to be sampled. High inflow maximum concentrations would be greatly reduced at the outlet due to the removal of the portion of nitrogen fixed to suspended solids.

5.2.4 Nitrate

Nitrate is of more concern than total nitrogen due to its possible detrimental health effects on infants. Infant digestive systems readily convert nitrate to nitrite which can lead to oxygen depravation, a disease called methemoglobinemia. The federal guidelines for nitrate levels in drinking water allows for a maximum level of 10 mg/L nitrate as N (USEPA, 1997). This value is significant as one of our maximum values at an inflow point was much greater than this, at 15 mg/L nitrate-N. The wetland was able to reduce this value to a maximum concentration of 8 mg/L nitrate-N at the outlet, within the drinking water standard. While event mean concentrations show that the amount of nitrate removed is insignificant during a storm event, this shows the importance of being able to reduce and dilute the initial first flush concentrations. A concentration considered possibly harmful was not passed along to receiving waters as would have been the case without the wetland system in place. The lack of overall removal is due to the lack of residence time of the water. During storm events the flow of the water through the wetland system does not allow for significant nutrient uptake by the wetlands plants, which would be the only removal process for nitrate.

5.2.5 Nitrite

As mentioned previously, nitrite is much a much more dangerous form of nitrogen than nitrate. Nitrite is formed by the reduction of nitrate and is highly unstable. The allowable drinking water concentration for nitrite is 1.0 mg/L (USEPA, 1997). In this case, lack of quantifiable results is a good thing. During only one storm did we detect nitrite, and it was in concentrations that ranged from .03 to .06 mg/L, two orders of magnitude less than acceptable levels. Nitrite was sampled for every storm and only one result was ever recorded. It is for this reason that no nitrite results are reported..

5.2.6 Chloride

In previous studies, chloride levels have not been altered by passing through wetland systems (Carlisle and Mulamoottil, 1991). The grounds crew for the campus use calcium chloride pellets, called Peladow, exclusively in this area. Manufactured by the Dow Chemical Company, the pellets consist of 90 – 97% calcium chloride, 1 – 2% sodium chloride, and 2 – 3% potassium chloride. Any runoff resulting from the treated surfaces is therefore highly concentrated with chloride. It can be hypothesized for this study that due to their dissolved nature, lack of residence time, and lack of plant uptake, chlorides will not be altered as they pass through the wetland system. What is observed follows closely with that hypothesis. Event mean concentrations are either unchanged or show a net increase in chlorides from inlet to outlet. The net increase is caused by the flushing of the wetland system. During baseflow, water is stored in the wetlands. During the initial storm phase, this resident water is then flushed out, causing higher levels of chloride in the outflow than the inflow. As mentioned previously, levels of chlorides have been measured during baseflow test sampling in the range of 500-1000 mg/L during winter months. These levels are directly related to the de-icing procedures. During the summer and fall months, concentrations of inflow are much lower, roughly 30 mg/L on average. This is what can be considered as natural levels of chlorides. An interesting phenomenon seems to be occurring in this system. The unnatural high concentrations during the winter months cause a buildup in the wetland. Often times chlorides are trapped in the plowed snow and are not released into the system until after melting has occurred. The wetland therefore acts as a sink of chloride in the winter. This role is reversed in the spring, summer, and fall, as the wetland puts more chloride into the outflow, acting as a chloride source. As with other pollutants, it can be said that the slight increase of chloride added to the outflow is far less detrimental than a massive spike of extreme concentration would be. By intercepting the road salts, allowing them to slowly dissolve and be retained in the wetland provides relief to the downstream receiving waters from the extreme concentrations. What happens during rainfall events in the winter is a question that needs to be answered. If winter events followed a pattern similar to the summer events, chloride levels could be extremely high at both inlet and outlet if a rainfall event occurred shortly after a snowfall and subsequent deicing. For this system, the event mean concentrations of summer and fall storms average 30 mg/L, not a significantly high value. High values would not be expected, as the majority of the chlorides should have been passed through the system in early spring and summer. Future chloride studies of this system should target snowmelt events, winter rainfall events, and early spring events to get a better idea of the yearly cycle of chloride in the wetland system.

5.2.7 Suspended Solids

Suspended solids removal is generally the most beneficial water quality treatment a stormwater wetland can make. Values of wetland solids removal of 75-90 percent are common in literature. For this site, it was assumed that overall removal values would be in this range, when factoring in baseflow. Actual values of removal were seen in a range from 50 to 95 percent. This amount of removal will decrease turbidity significantly, as well as removing any harmful pollutants sorbed to those sediments that are filtered out. The density of the plant material in the wetland is probably the driving factor for suspended solids removal. Impact of suspended solids on plant stalks and stems decreases their velocity to an extent that allows for settling to occur. The construction of the wetlands placed the sediment forebay offline from the inflow pipes. The reasoning behind this was to prevent resedimentation during high velocity storm events. In the past year, this forebay was drained after four years of performance. Sediment levels were much less than expected, and in conjunction with our results showing high amounts of removal during storms and lack of solids in baseflow, led to the conclusion that the majority of the sediment was being removed prior to reaching the sediment forebay. The area between the inlet pipe and sediment forebay is one of the most densely vegetated areas of the wetlands. On site inspections show that large amounts of sediment buildup have occurred soon after the inlet points. Whether this affects the flow path or detention volume of the wetlands is not known. During larger storms, this sediment is likely distributed more evenly throughout the wetland. It is of interest to look at the storm of August 30th, 2003 to illustrate the effects that construction can have on suspended solids pollution. During the middle of August, 2003, a flow path compromise was noticed. Water was seeping between two gabions and was bypassing the final meander to the low flow weir. This seepage caused the bank and parts of the existing berm to erode away. To remedy this situation, a replacement berm was installed, covered in geotextile and seeded for grass. The grass took a period of time to establish, therefore during storm events for the better part of a month, maximum concentrations of suspended solids at the outflow were considerably higher than the inflow, although the event mean concentrations were higher at the inflow. One explanation for this could be that the sediment of the berm had been loosened or cleaved by the standing water of the wetlands, and during storm flow this flush of suspended solids was washed away. The grass took seed quickly and no other fluctuations were noticed once the berm was reestablished. This just reiterates the need for erosion control and silt fence construction during any kind of heavy earth moving or landscaping.

5.2.8 Dissolved Solids

Theoretically, dissolved solids should show trends similar to those of chloride and nitrate. Dissolved particles simply do not have enough residency time during a storm event for conversion or uptake to occur. This is what was observed for dissolved solids for this site. In all storms but one, an increase of dissolved solids was shown at the outlet compared with the inlet. Again, this follows the pattern of the chloride movement through the site. Rainfall is extremely low in dissolved solids. The water that is maintained in the wetlands during baseflow is high in dissolved solids. When the rain first falls, these high levels of dissolved solids already in the basin are flushed through the system, and are only recorded at the outlet. With no dissolved solids coming into the inlet, the resultant averages are much greater for the outflow than the inflow for dissolved solids. This is not an unexpected result, in fact dissolved solids testing is not often performed on wetlands for this very reason. What can not be determined, however, is the portion of dissolved solids that is available for use by the wetlands plants. This will be discussed further in the section dealing with baseflow dissolved solids.

5.3 Baseflow Events

The major different between the wetland’s performance during storm events and during baseflow is the residency time of the water. During heavy storms, inflow stormwater can pass through the system in less than 30 minutes. While the exact residency time of baseflow is not known, it is probably 10 to 20 times that of storm events. During this slow flow, one would expect suspended solids to precipitate, and nutrient uptake by plants to occur. While the performance of stormwater wetlands during storm events is of great concern, performance during baseflow is equally important as baseflow represents much more yearly flow than storm events. Similarly to the storm event discussion, this section will be categorized by pollutant type.

5.3.1 Reactive Phosphorus

Of all the dissolved components in the wetlands, reactive phosphorus is the easiest for plants to take up and use. Due to the heavy plant density during our baseflow sampling times, the wetlands should show a great decrease in reactive phosphorus from inlet to outlet. This is exactly what has been observed. Removal rates were observed from 43 percent to 75 percent, with an average removal of 60 percent. All baseflow samples were taken in the summer, June through October. The behavior of this wetland system is not known for the spring, late fall and winter. It is highly possible that plant decay during late fall and winter could add reactive phosphorus to the outflow of this system. It could be hypothesized that removal rates could be even greater in the early spring, during initial plant growth. Year-round baseflow conditions are currently being studied. The results from these studies should expand our knowledge of the nutrient cycle for stormwater wetlands.

5.3.2 Total Phosphorus

Unlike storm events, removal rates of total phosphorus during baseflow does not include removal of phosphorus forms sorbed to solids, as no suspended solids were ever detected. It is possible that some solid forms of phosphorus were present in colloidal matter, smaller than the parameters defining suspended solids and in undissolved form. Supporting the idea that the majority of phosphorus entering the site is of solid form, the magnitude of baseflow total phosphorus is considerably less than during storm events. The average value for baseflow inflow was .39 mg/L compared with .91 mg/L for storm events. It can then be reasoned that a large portion of the observed total phosphorus removal is due to removal of reactive phosphorus, which differs from storm events where a majority of the removal comes in the form of sediment removal. Again, levels are such that no downstream problems would be anticipated.

5.3.3 Total Nitrogen

The removal of total nitrogen during baseflow conditions is very similar to that of reactive phosphorus. A nutrient component that is not significantly affected during storm events is efficiently removed during baseflow. Total nitrogen was removed from the wetlands with 70 to 100 percent efficiency. This suggests two things, plants during the summer months use nitrogen quite efficiently and nitrogen seems to be more readily used than reactive phosphorus. It could be that nitrogen levels are significantly lower, respective to need, than reactive phosphorus, and therefore are taken up rapidly. A second possibility would be that during this part of the nutrient cycle, nitrogen is needed more than phosphorus. It is generally known that different plants require different amounts of nitrogen and phosphorus. In general, established vegetation and shade trees require more nitrogen than phosphorus. Nitrogen is responsible for growth and greenness of plants. The baseflow sampling was done during the growing season; and resulting concentrations may have been significantly different if sampling was done during another part of the year. Dead and decaying plants, such as those found in November through February, release nitrogen and phosphorus back into the system. It is the recommendation that the current winter baseflow research compare concentrations from those months in an attempt to get an idea of the full year removal efficiency of the wetland, if any.

5.3.4 Chloride

Plants do not use chloride for any function of growth or maintenance. It is for this reason that no removal of chlorides was expected. Similar studies have suggested using chloride as a tracer element, due to its ability to move through a system unchanged (Masson et al. 1999). The results support that theory. In six baseflow samples taken over the course of two summers, no observable change in chloride concentration from inlet to outlet was ever observed. Concentration differences could be attributed to randomness of sample; no removal of greater than 5 percent was ever observed. Chloride concentrations showed little change throughout the course of the summer months. A concentration of approximately 200 mg/L was observed at both the inlet and the outlet. This abnormally high number is most likely the result of deicing practices on Villanova's campus. Studies done by Road Transport Research, 1991, have shown that natural levels of chlorides can be increased by greater than 100 mg/L due to infiltrated road salts. Road salts that have dissolved may be splashed or melted into ditches or swales and later infiltrate into the groundwater.

It is the chloride found in the system that actually controls the vegetation. Many plants are not able to survive in high chloride environments. Chloride can effect leaf tips and cause scorching. One species that is highly adaptable to high levels of chlorides is *Phragmites australis*, which happens to be the dominant species of plant within the wetland. Due to the high levels of chloride, no attempt to alter the plant composition of the wetlands is being considered, as *Phragmites* are capable of using large amounts of nutrients for growth. Chloride testing during winter months should prove interesting to check the maximum concentrations that flow into the wetland due to deicing events, and to see if any storage of these high concentrations is taking place.

5.3.5 Total Dissolved Solids

Dissolved solids data show no net decrease through the wetland system. It has already been shown that dissolved components of phosphorus and nitrogen have been removed, so it raises the question as to why dissolved solids show no decrease. In short, the chloride concentrations of the wetland are so high, all removal of small components of nitrogen and phosphorus are masked. A removal of .6 mg/L of phosphorus will not be evident when included with concentrations of 250 mg/L of chloride. This is important for research and studies that fail to consider phosphorus and nitrogen individually, as a site that is performing quite well for removal of those nutrients will show no significant removal for dissolved solids alone..

Chapter 6: Conclusions

6.1 Storm Events

The Villanova Stormwater wetland, due to its large area and high plant density, is excellent in removing suspended solids during storm events. On a non-industrial site, often suspended solids removal is the most important factor for water quality improvement. The wetland's removal efficiency during storm events was as high as expected, reducing the amount of solids that passed along into the receiving waters by approximately 60%. Due to the removal of suspended solids, a reduction in the mass of total phosphorus followed, averaging 50%. Dissolved components, such as reactive phosphorus and chloride, did not show significant removals during the course of storm events. The positive function of the wetland on these components is a great reduction in the maximum concentration. While overall mass may not have been removed, often harmful levels of pollutants were reduced to levels within water quality standards. This was most likely due to dilution of the "first flush" entering the site during the initial phases of a storm. This dilution effect was evident for all monitored pollutants; no "first flush" concentration spikes were ever observed at the outlet. During this study, the wetland had no outflow that violated the federal drinking water standards, although certain inflow concentrations were above these limits. In both appearance and actual quality, the outflow from the wetland is significantly better than the inflow.

6.2 Baseflow

Due to high residency times of inflow and high vegetation density, the wetland removed a substantial portion of the nutrients and pollutants that entered the site. The dissolved nutrient components, such as reactive phosphorus and dissolved nitrogen, show significant removal. Removal rates were 50 to 70 percent greater than during storm events. Chlorides were the exception to this trend. Chlorides were found to pass directly through the system and at high concentrations due to de-icing processes and infiltration of dissolved salts into the groundwater. Sites with high levels of chloride concentrations have dissolved solids concentrations that are primarily composed of chlorides, masking the sites effectiveness in removing other dissolved components. Due to the time constraints on this study, these results and conclusions are only applicable for summer and early fall. The effectiveness of the site during other seasons is not known at this time. Overall, the quality of the baseflow leaving the stormwater wetland to receiving waters contained no harmful or significantly high levels of any of the nutrients or parameters monitored. Chloride levels, although high, are not harmful for human consumption, but may have a detrimental effect on water taste. Although baseflow into the wetlands is generally clean, the wetland acts to further enhance the quality of the groundwater flow for receiving waters.

6.3 Recommendations for Future Research

This study focused on one time frame during the year. It will be interesting to compare the results of this study with similar studies done on a year round basis. Studies are currently underway for baseflow, but winter storm studies could also add greatly to this research. The effect of chlorides during winter months would be of great interest, to evaluate the effectiveness of the wetlands to dilute massive concentrations due to snowmelt events.

During the course of the study on storm events, there was a trend for outflow concentrations to remain high when sampling ended. The pollutant mass during the return to baseflow levels was lost. If similar studies were to be done using similar protocols, it is recommended that outflow sampling times be adjusted to collect an addition number of samples after inflow samplers have ceased. This would solve the problem of missing the end of the storm passing through the outlet.

A good portion of the impervious area of the wetland watershed is composed of parking lots. Trucks and automobiles are responsible for an entirely different kind of pollution than that studied here. On more than one occasion an oily sheen was noticed at one of the inflow points. The wetlands should be monitored for a variety of automobile related pollutants, such as oils, greases, polycyclic aromatic hydrocarbons, and certain metals. The Villanova water laboratory has been recently equipped to test multiple metal concentrations. An in-depth study of metals and other industrial type pollutants would be of great interest.

The health of a system can often be determined by the species richness that inhabits it. A comprehensive species diversity study, perhaps in conjunction with a biologist, could shed some light onto the health of this wetland system. This could be accomplished by seasonal species counts. Each species that inhabits wetlands has a specific tolerance to pollution. Identifying the species that inhabit the wetland can give a non-quantitative view to the cleanliness of the wetland.

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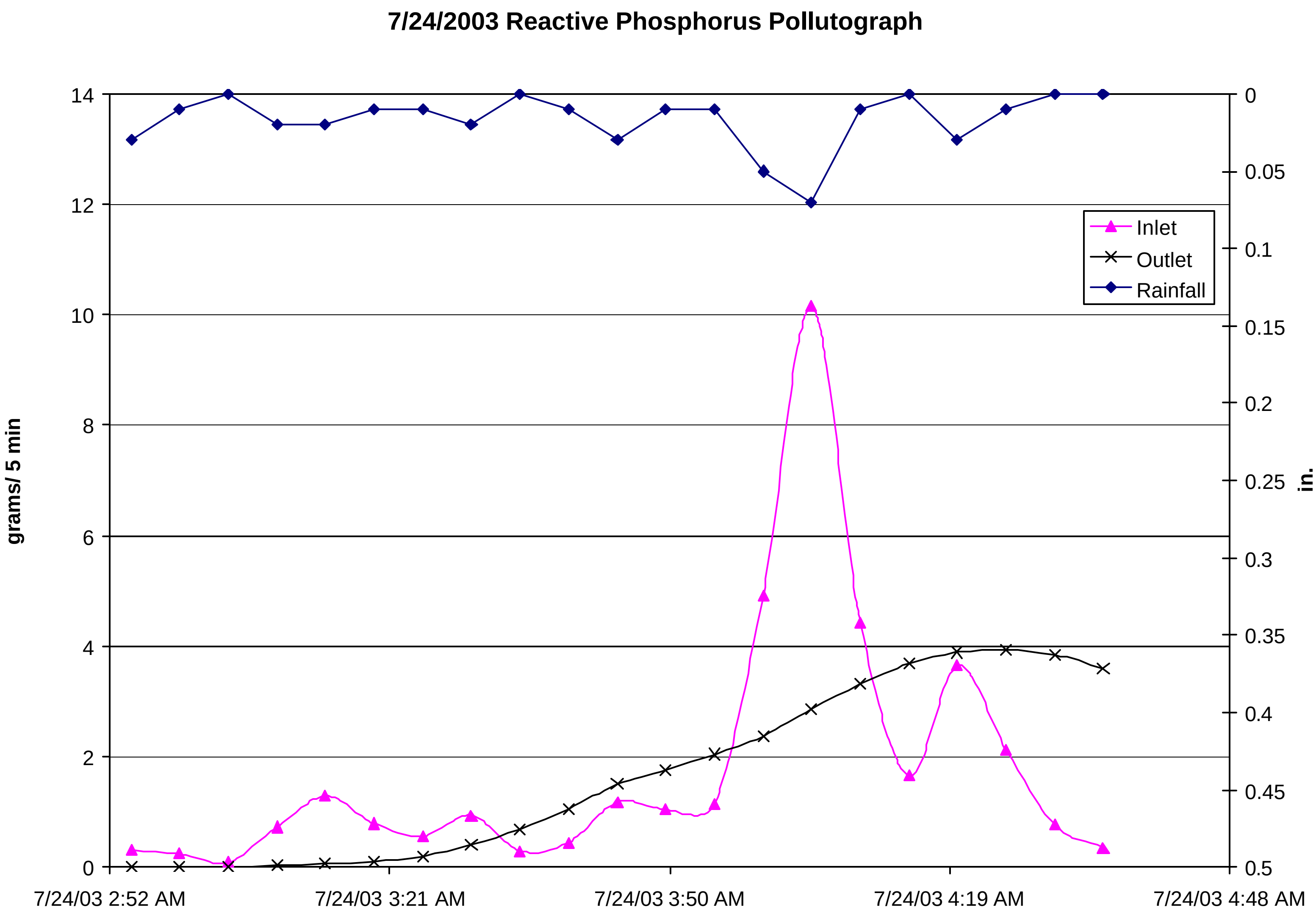
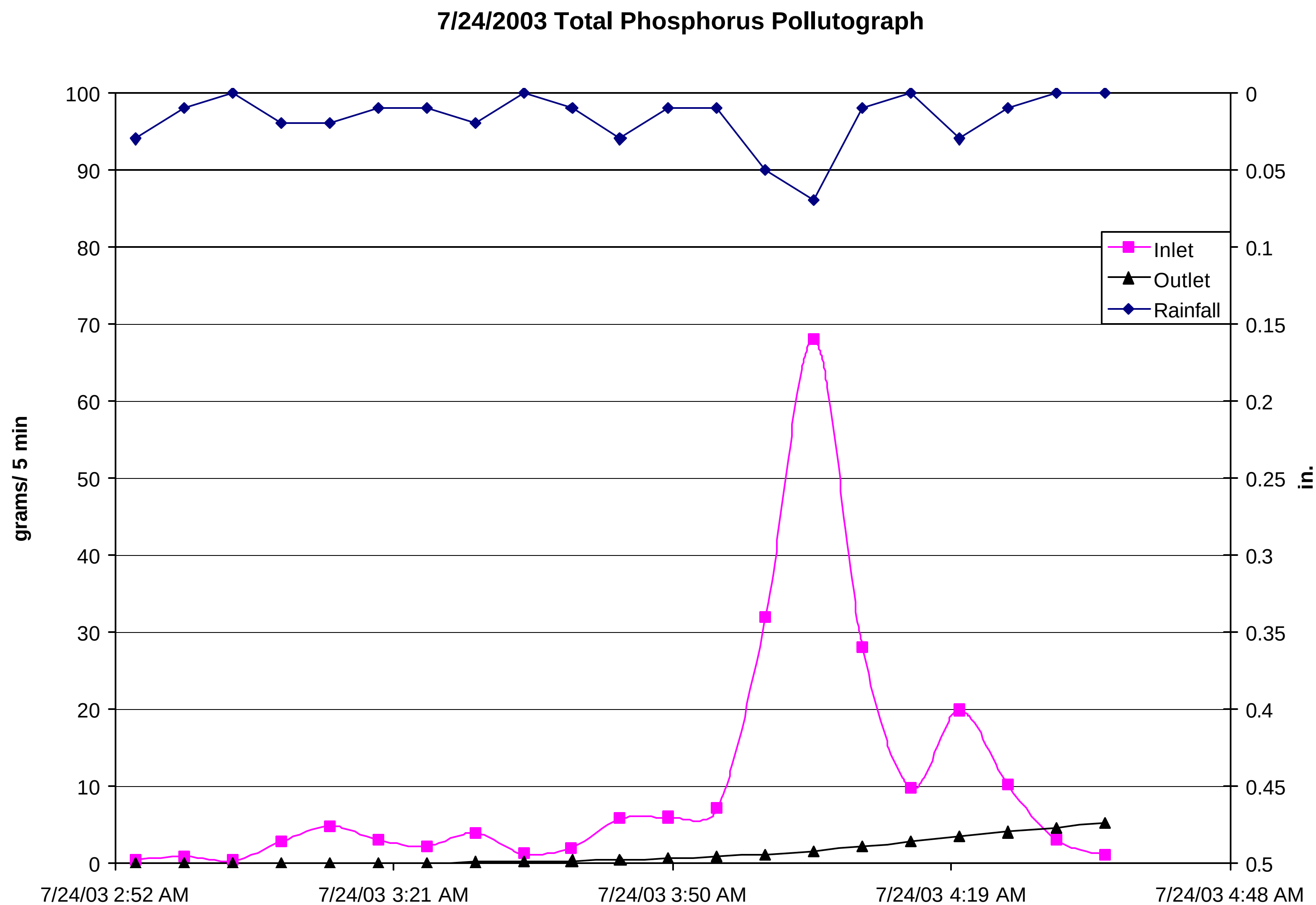
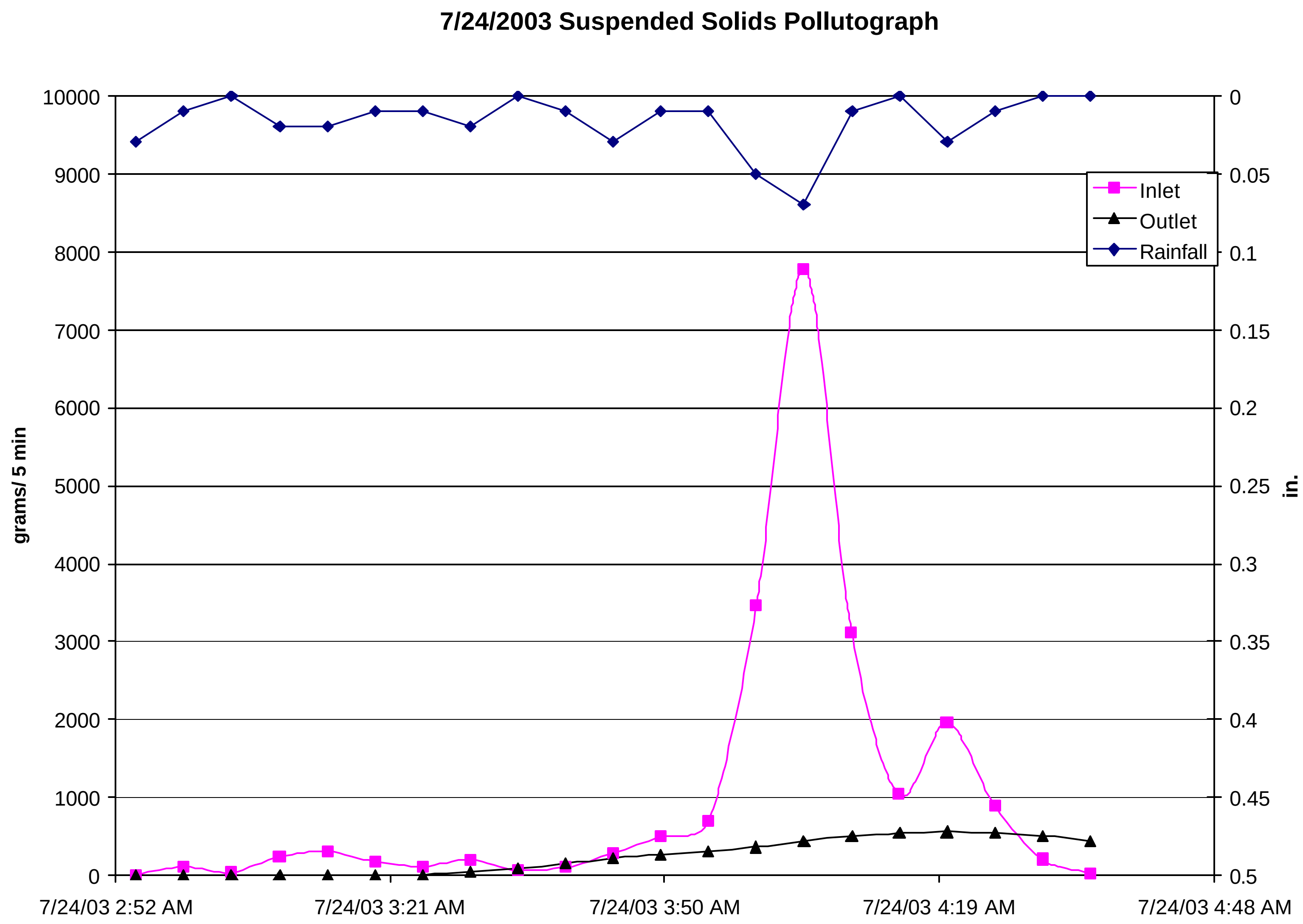
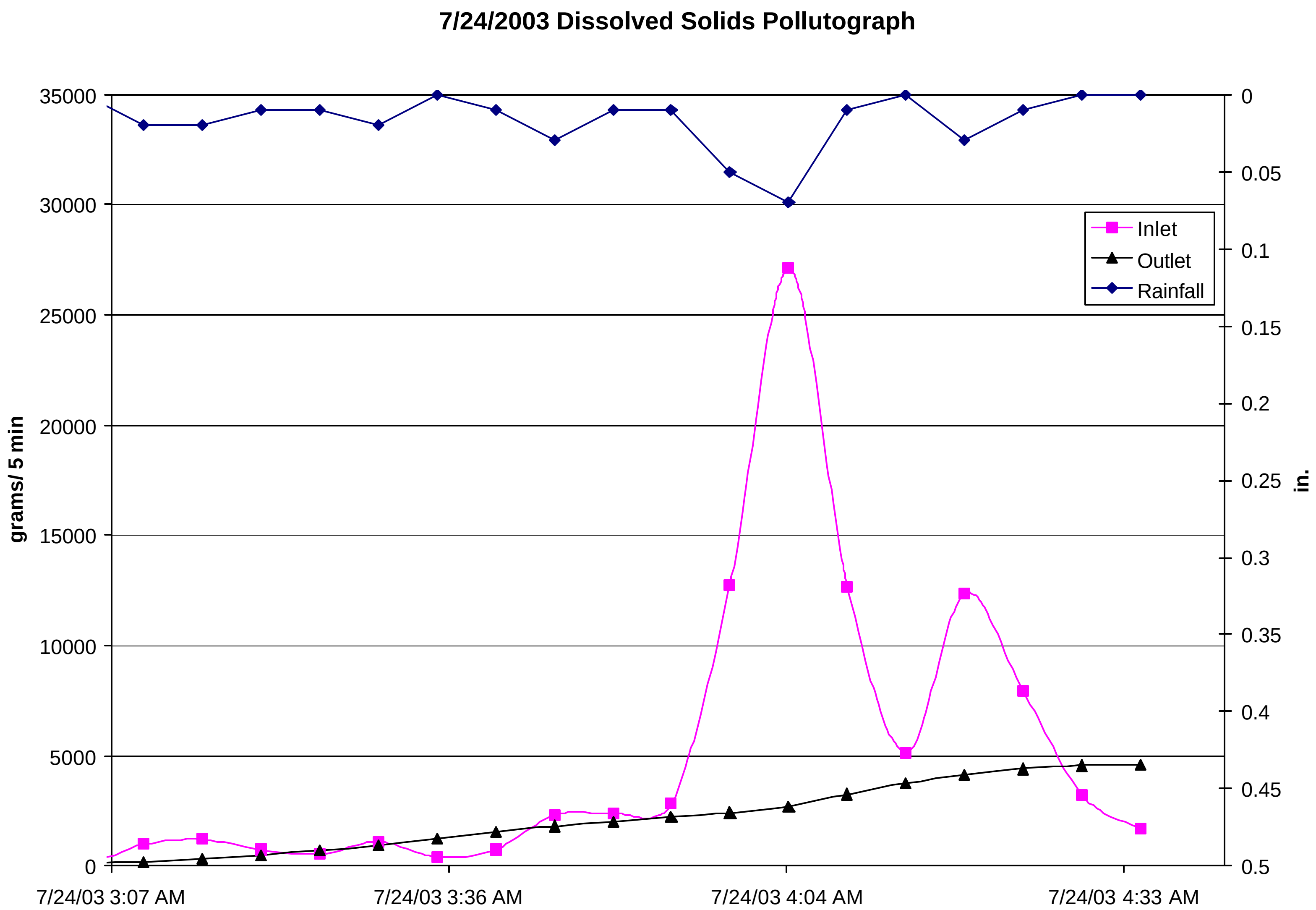
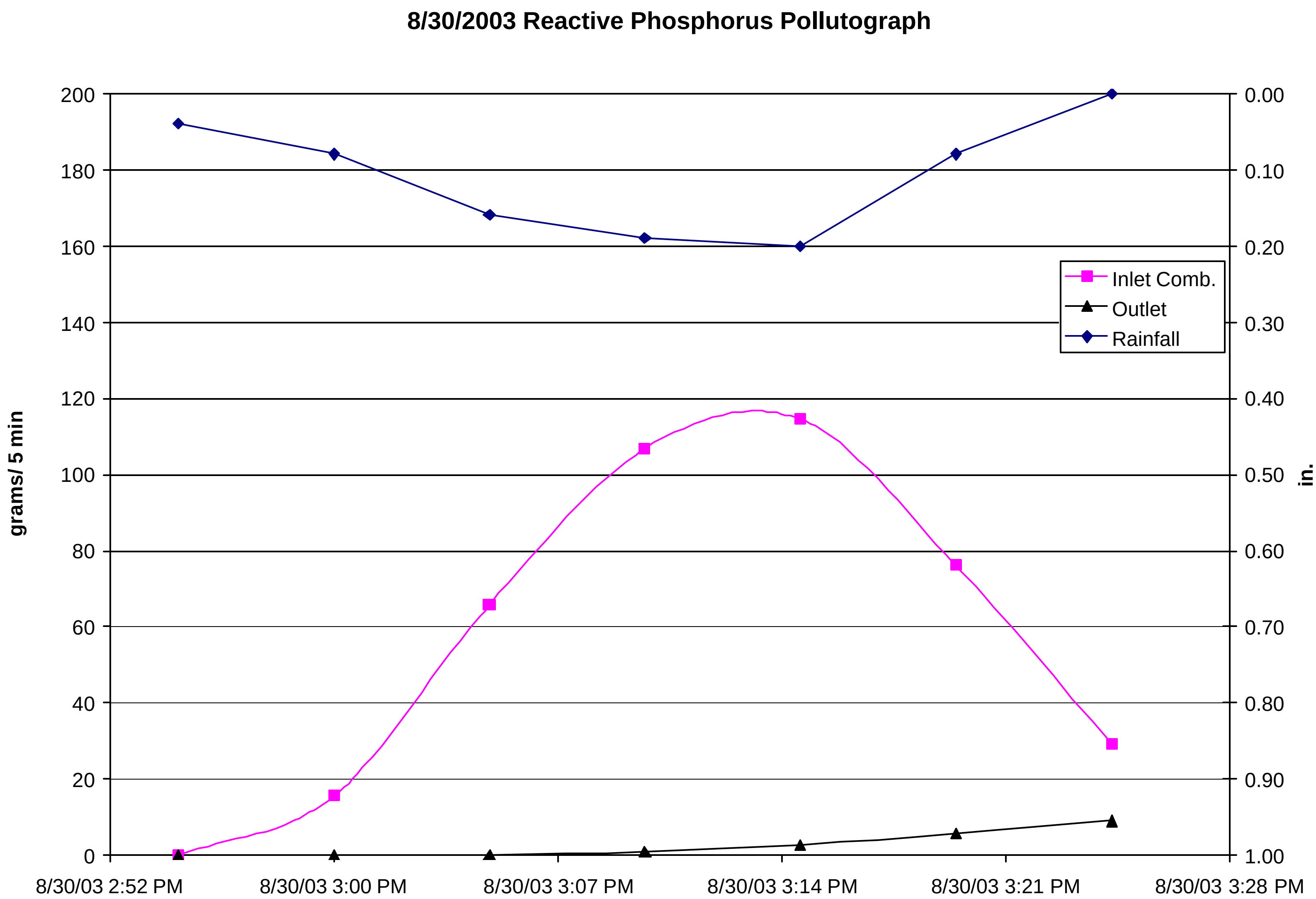
Appendix I

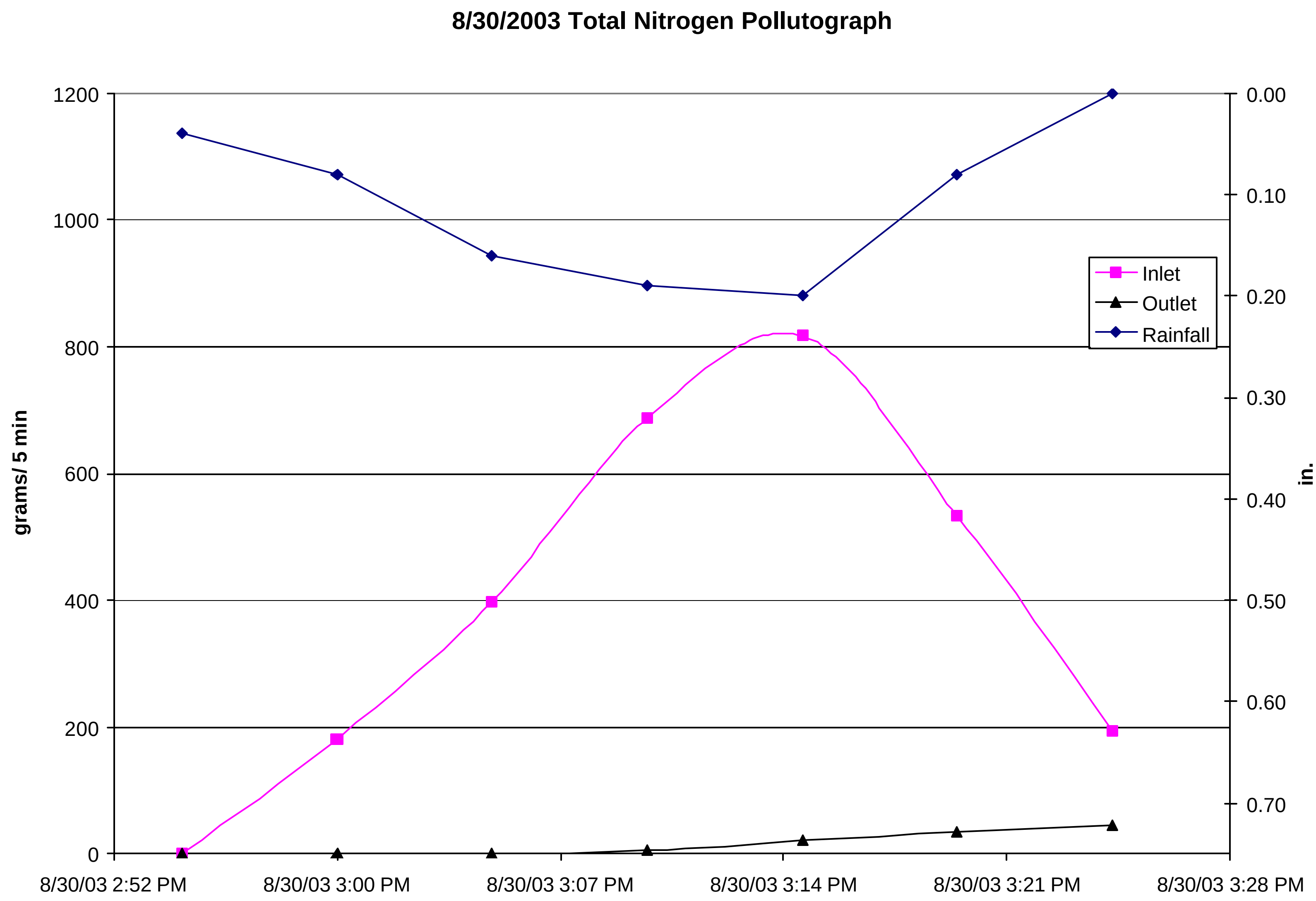

7/24/2003 Reactive Phosphorus Pollutograph
grams/ 5 min
in.
0
2
4
6
8
10
12
14
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
7/24/03 2:52 AM
7/24/03 3:21 AM
7/24/03 3:50 AM
7/24/03 4:19 AM
7/24/03 4:48 AM
Inlet
Outlet
Rainfall

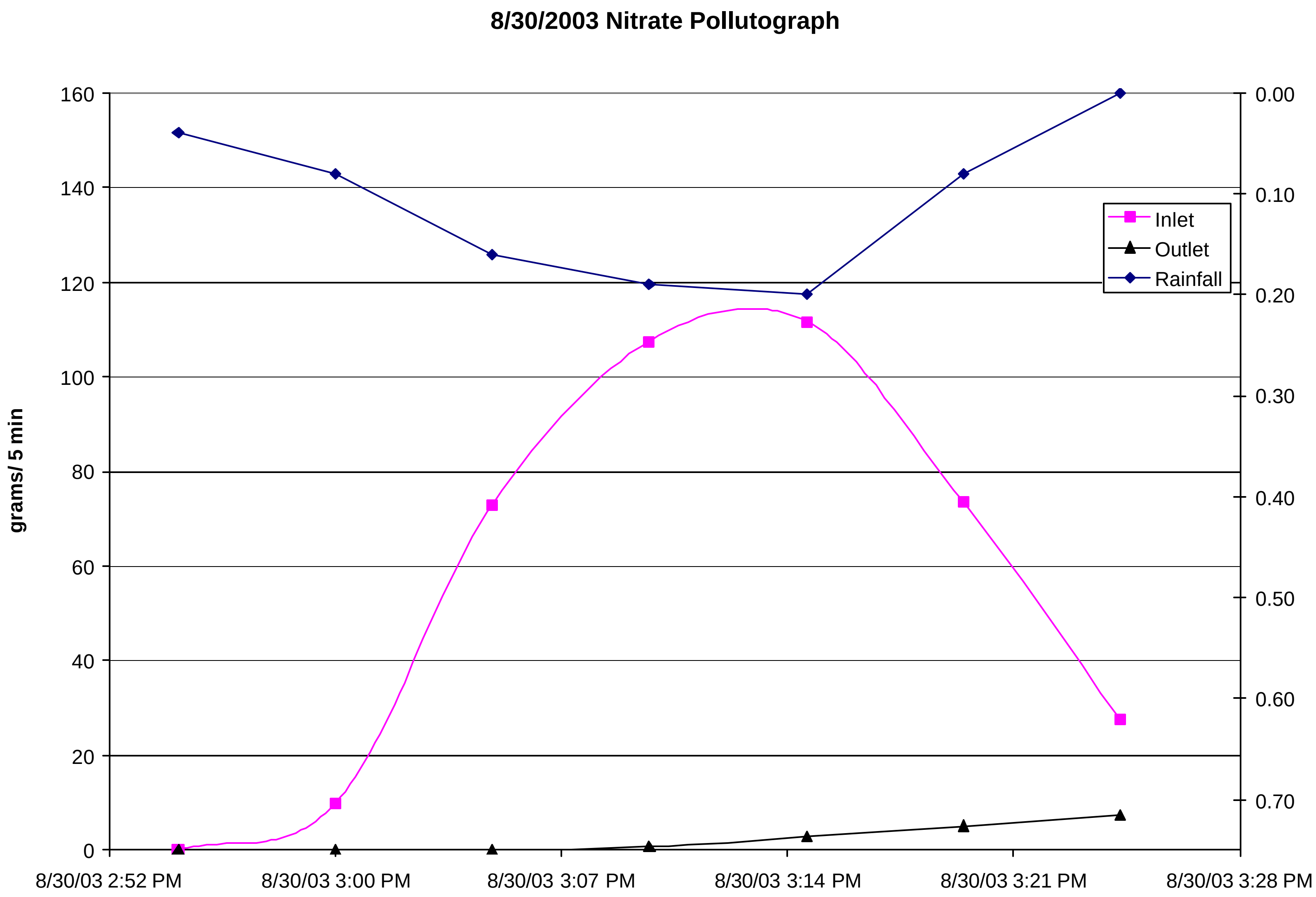

7/24/2003 Total Phosphorus Pollutograph
grams/ 5 min
in.
100
90
80
70
60
50
40
30
20
10
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
7/24/03 2:52 AM
7/24/03 3:21 AM
7/24/03 3:50 AM
7/24/03 4:19 AM
7/24/03 4:48 AM
Inlet
Outlet
Rainfall

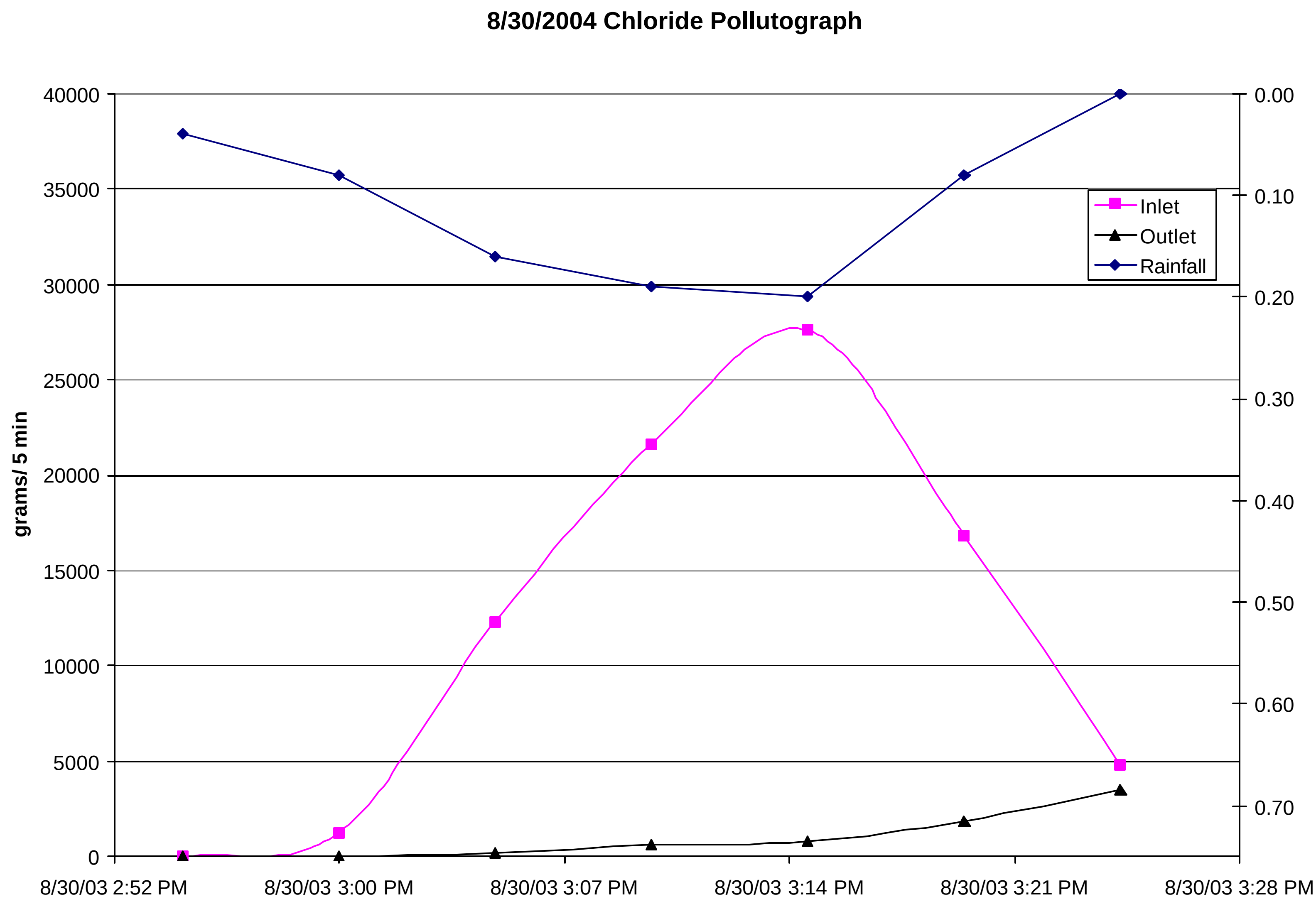

7/24/2003 Suspended Solids Pollutograph
grams/ 5 min
in.
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Inlet
Outlet
Rainfall
7/24/03 2:52 AM
7/24/03 3:21 AM
7/24/03 3:50 AM
7/24/03 4:19 AM
7/24/03 4:48 AM

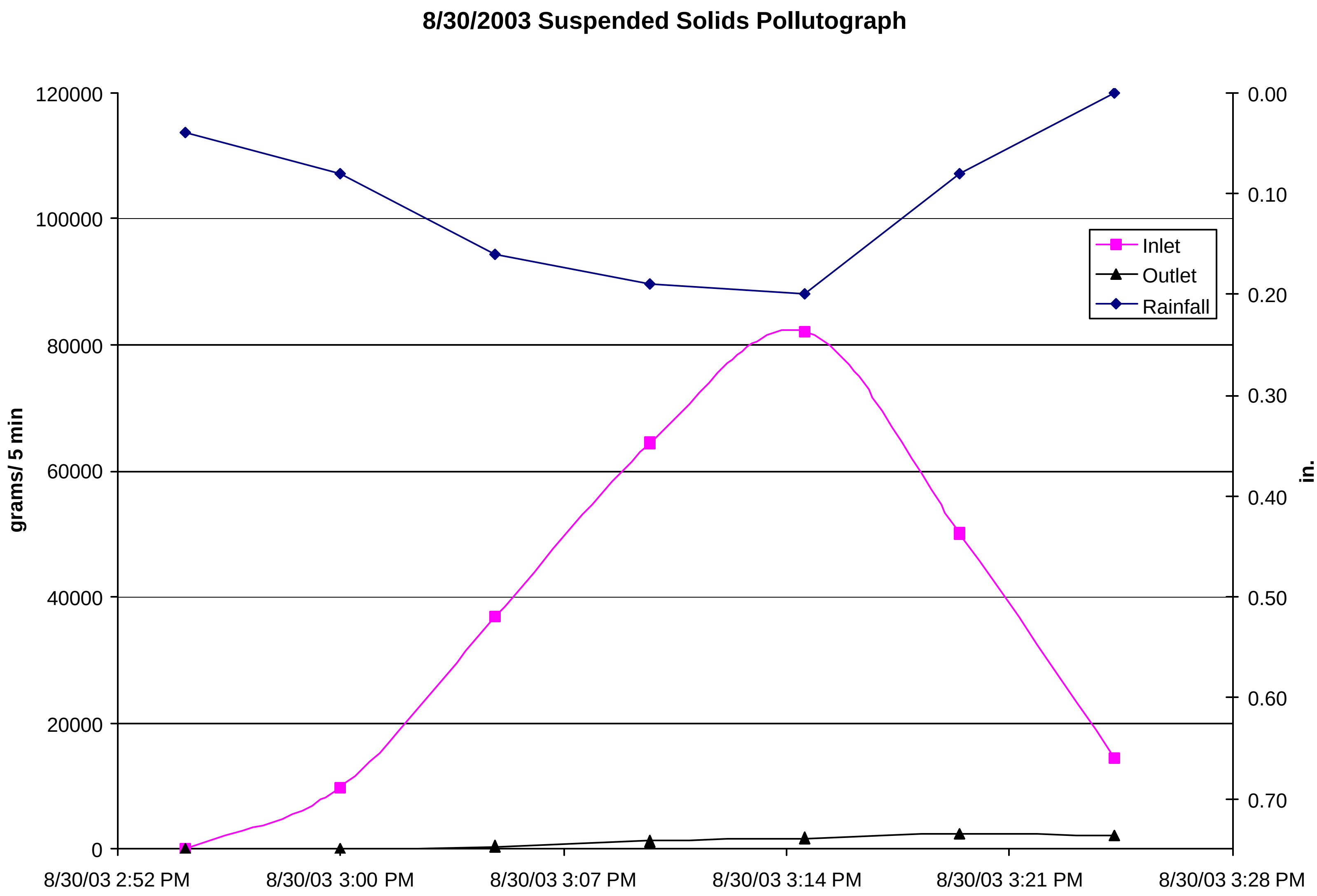

7/24/2003 Dissolved Solids Pollutograph
grams/ 5 min
in.
35000
30000
25000
20000
15000
10000
5000
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
7/24/03 3:07 AM
7/24/03 3:36 AM
7/24/03 4:04 AM
7/24/03 4:33 AM
Inlet
Outlet
Rainfall

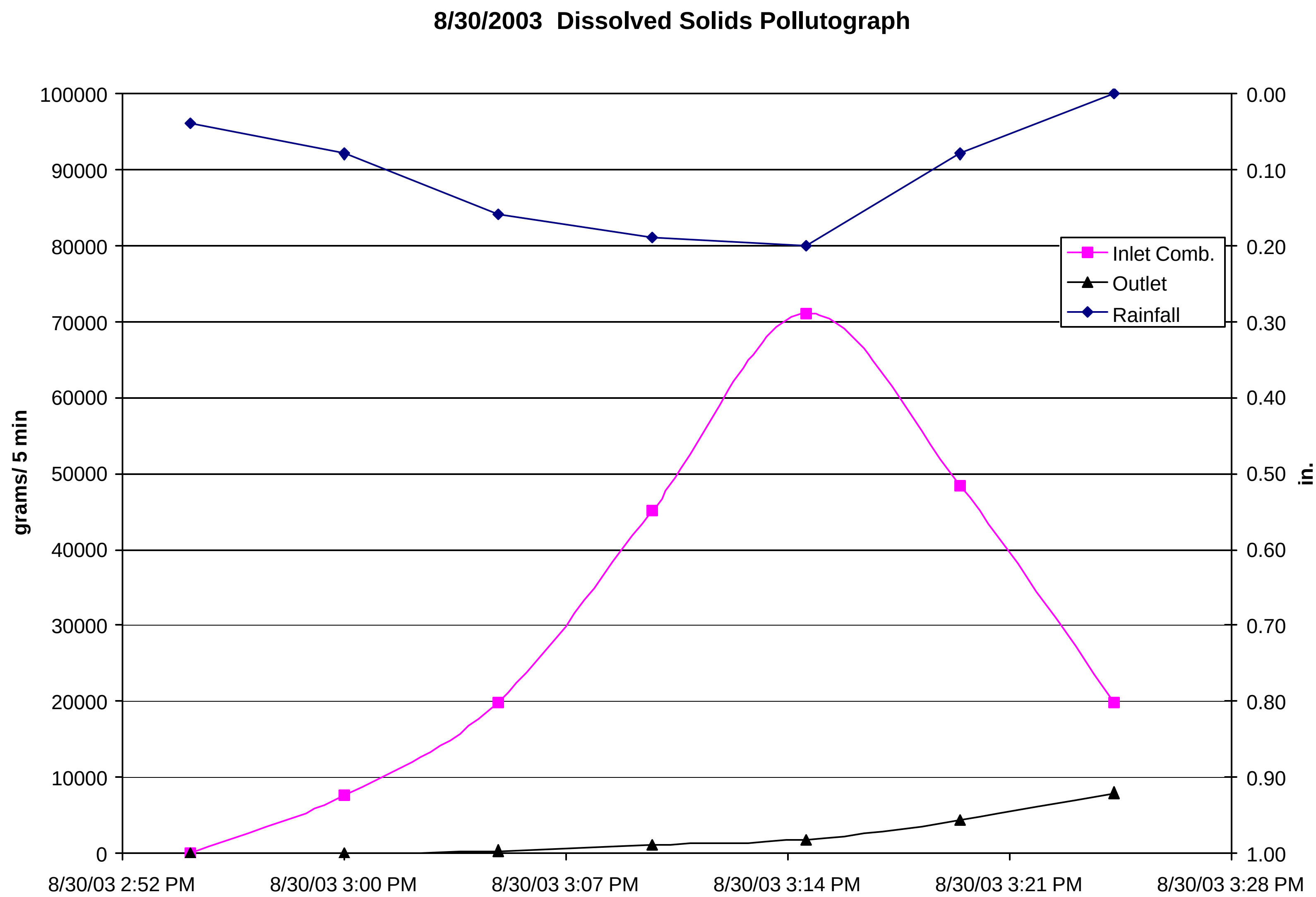

8/30/2003 Reactive Phosphorus Pollutograph
grams/ 5 min
in.
200
180
160
140
120
100
80
60
40
20
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
8/30/03 2:52 PM
8/30/03 3:00 PM
8/30/03 3:07 PM
8/30/03 3:14 PM
8/30/03 3:21 PM
8/30/03 3:28 PM
Inlet Comb.
Outlet
Rainfall

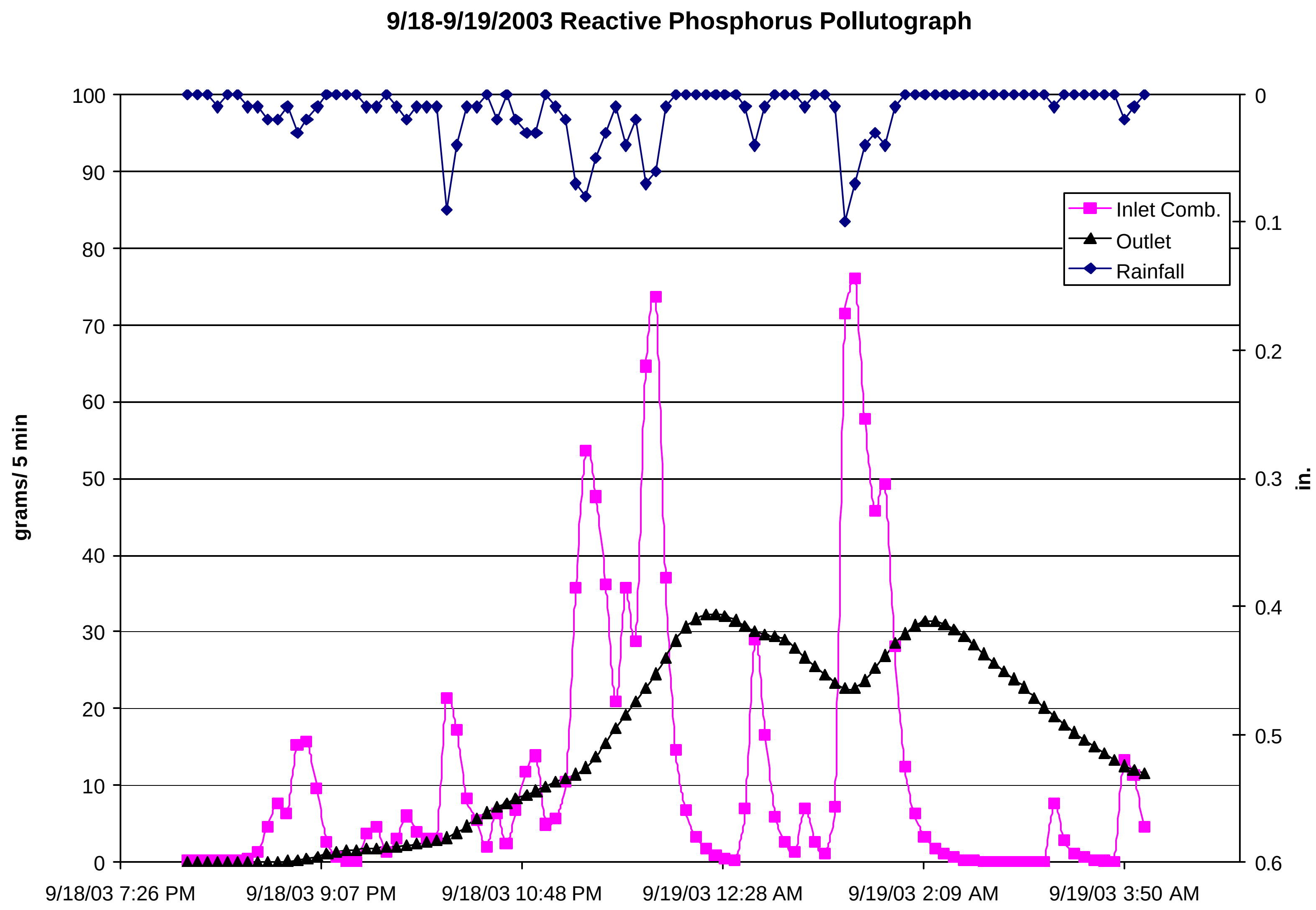

8/30/2003 Total Nitrogen Pollutograph
grams/ 5 min
in.
1200
1000
800
600
400
200
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
8/30/03 2:52 PM
8/30/03 3:00 PM
8/30/03 3:07 PM
8/30/03 3:14 PM
8/30/03 3:21 PM
8/30/03 3:28 PM
Inlet
Outlet
Rainfall

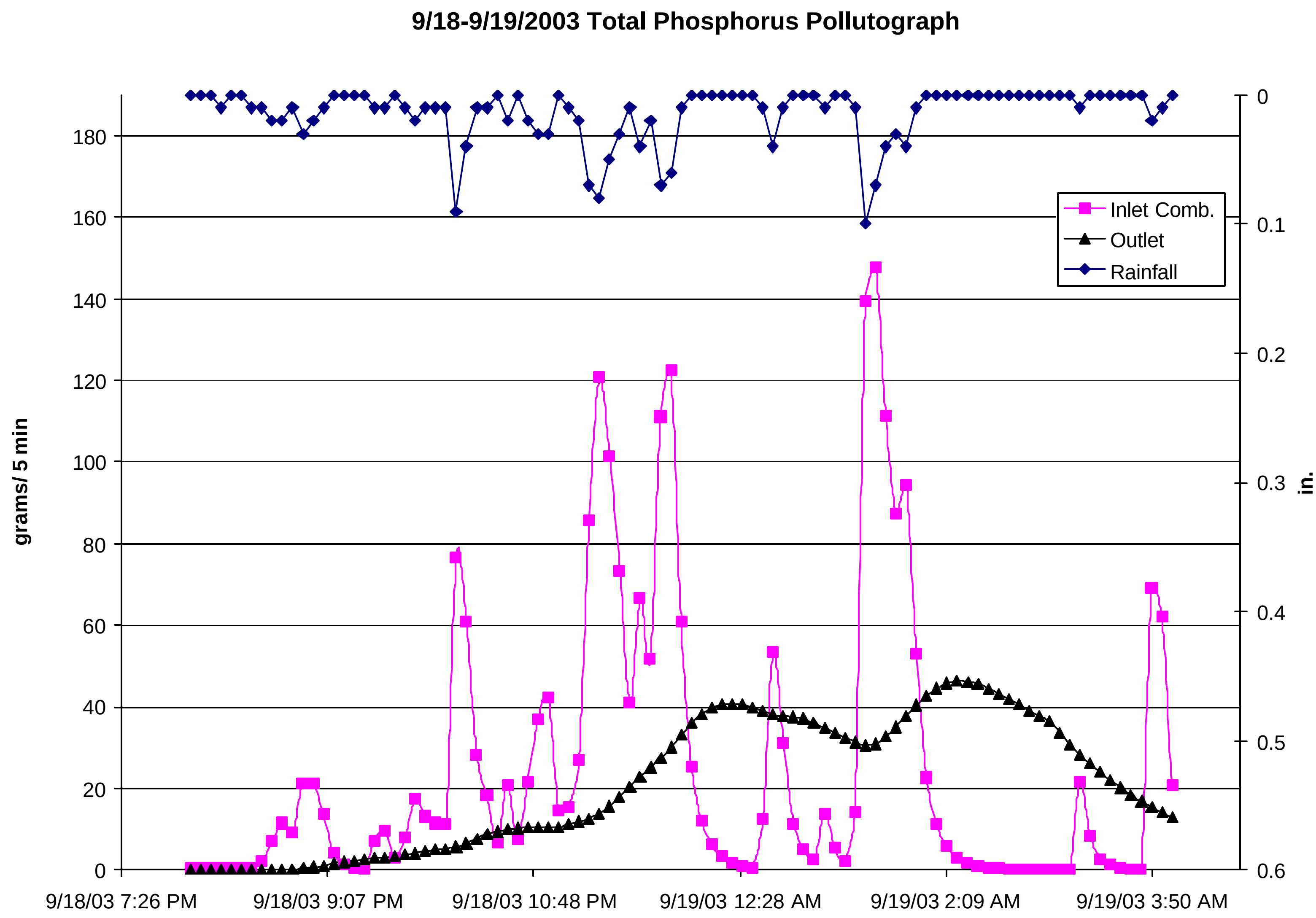

8/30/2003 Nitrate Pollutograph
grams/ 5 min
160
140
120
100
80
60
40
20
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
Inlet
Outlet
Rainfall
8/30/03 2:52 PM
8/30/03 3:00 PM
8/30/03 3:07 PM
8/30/03 3:14 PM
8/30/03 3:21 PM
8/30/03 3:28 PM

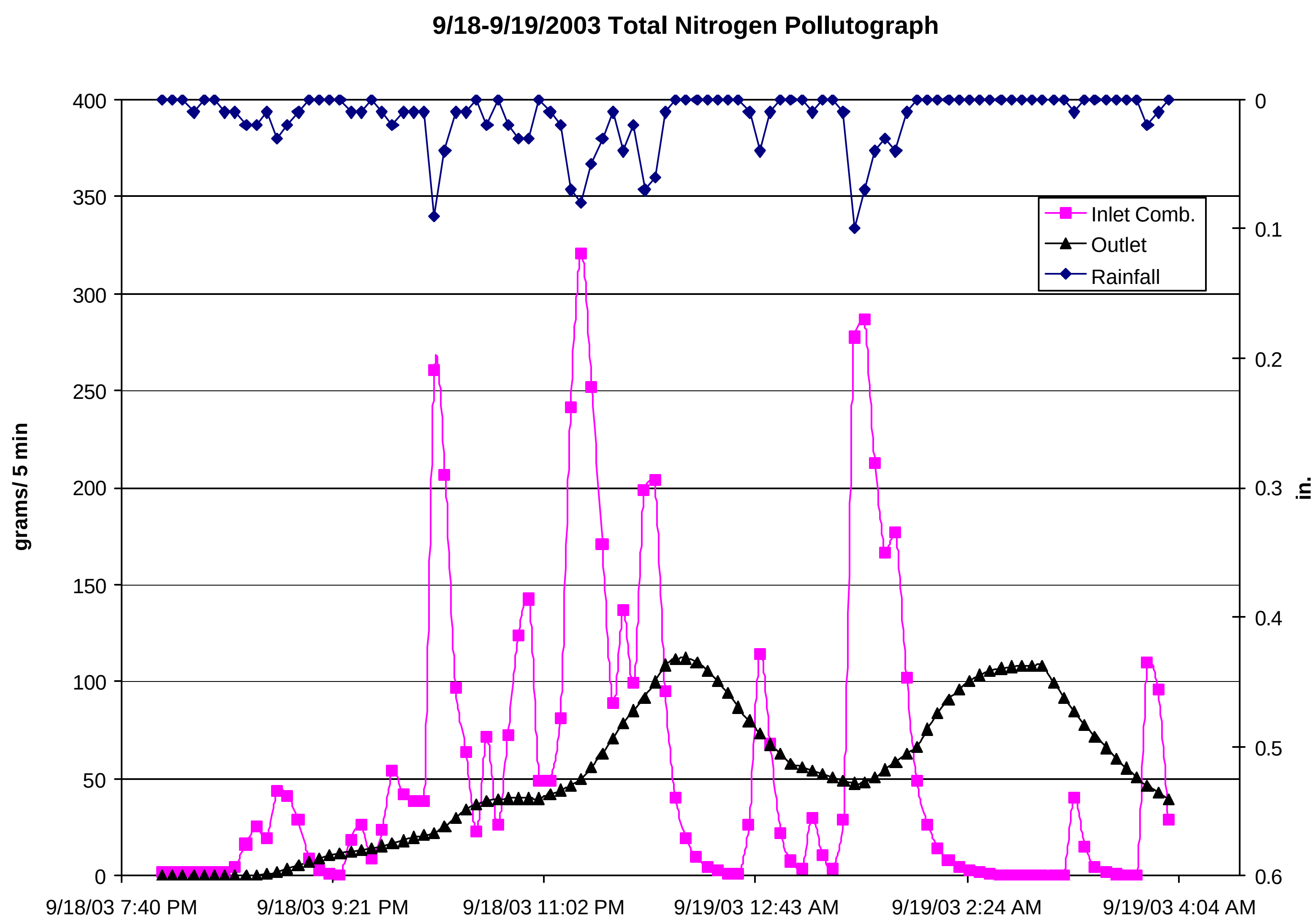

8/30/2004 Chloride Pollutograph
grams/ 5 min
40000
35000
30000
25000
20000
15000
10000
5000
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
Inlet
Outlet
Rainfall
8/30/03 2:52 PM
8/30/03 3:00 PM
8/30/03 3:07 PM
8/30/03 3:14 PM
8/30/03 3:21 PM
8/30/03 3:28 PM


8/30/2003 Suspended Solids Pollutograph
grams/ 5 min
in.
120000
100000
80000
60000
40000
20000
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
Inlet
Outlet
Rainfall
8/30/03 2:52 PM
8/30/03 3:00 PM
8/30/03 3:07 PM
8/30/03 3:14 PM
8/30/03 3:21 PM
8/30/03 3:28 PM

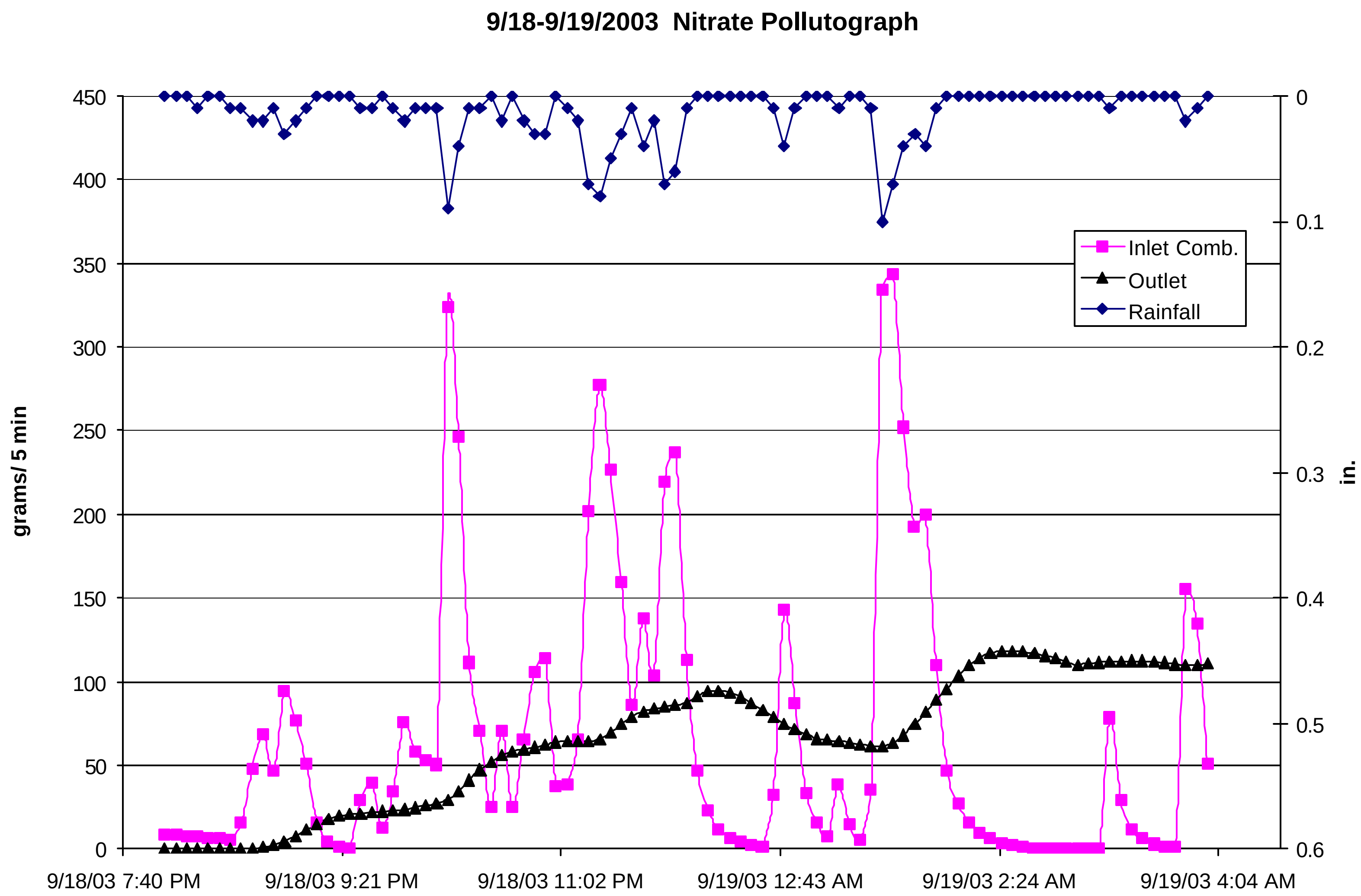

8/30/2003 Dissolved Solids Pollutograph
grams/ 5 min
in.
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
8/30/03 2:52 PM
8/30/03 3:00 PM
8/30/03 3:07 PM
8/30/03 3:14 PM
8/30/03 3:21 PM
8/30/03 3:28 PM
Inlet Comb.
Outlet
Rainfall

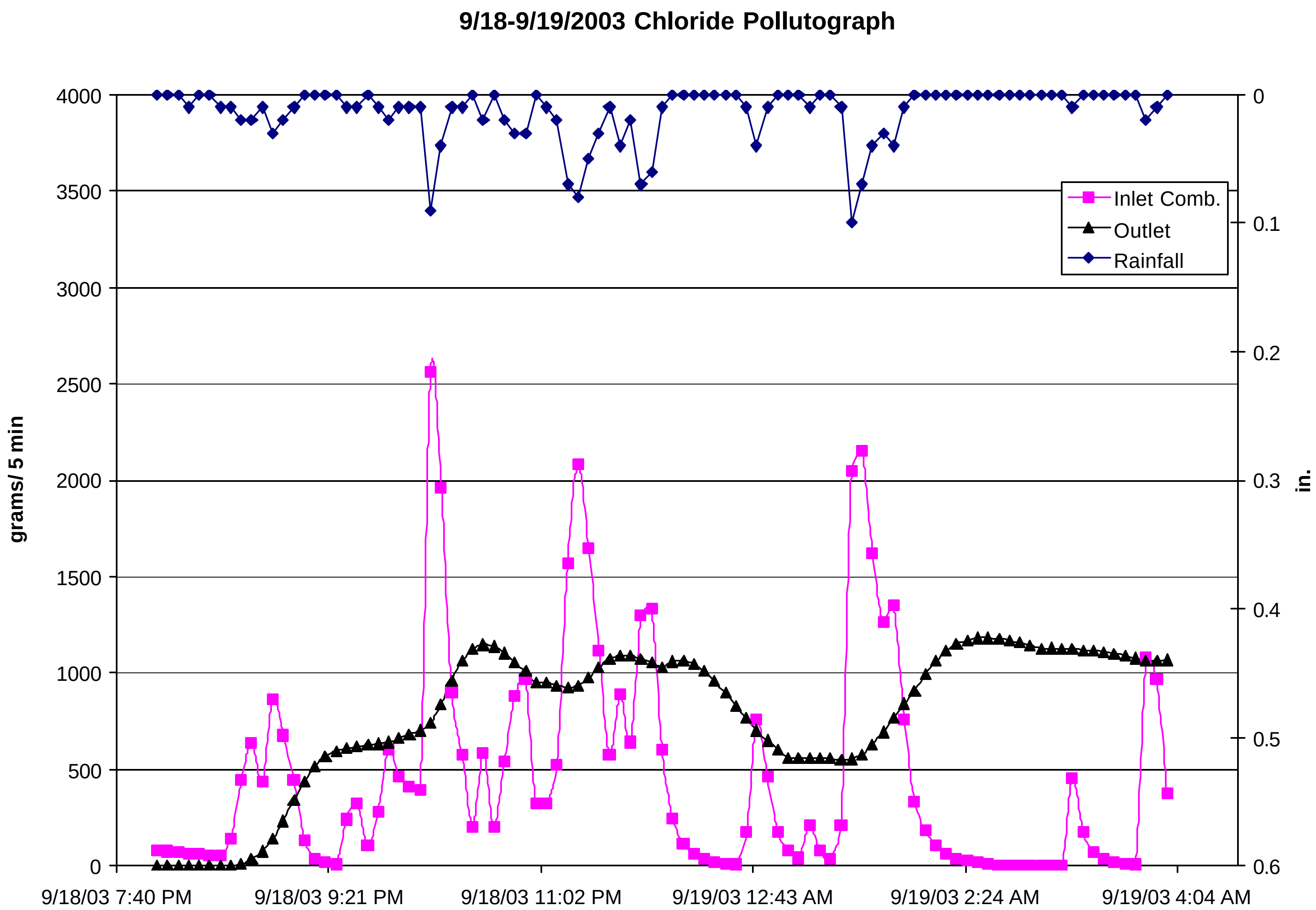

9/18-9/19/2003 Reactive Phosphorus Pollutograph
grams/ 5 min
in.
Inlet Comb.
Outlet
Rainfall
100
90
80
70
60
50
40
30
20
10
0
0.1
0.2
0.3
0.4
0.5
0.6
9/18/03 7:26 PM
9/18/03 9:07 PM
9/18/03 10:48 PM
9/19/03 12:28 AM
9/19/03 2:09 AM
9/19/03 3:50 AM


9/18-9/19/2003 Total Phosphorus Pollutograph
grams/ 5 min
in.
0
20
40
60
80
100
120
140
160
180
0
0.1
0.2
0.3
0.4
0.5
0.6
9/18/03 7:26 PM
9/18/03 9:07 PM
9/18/03 10:48 PM
9/19/03 12:28 AM
9/19/03 2:09 AM
9/19/03 3:50 AM
Inlet Comb.
Outlet
Rainfall

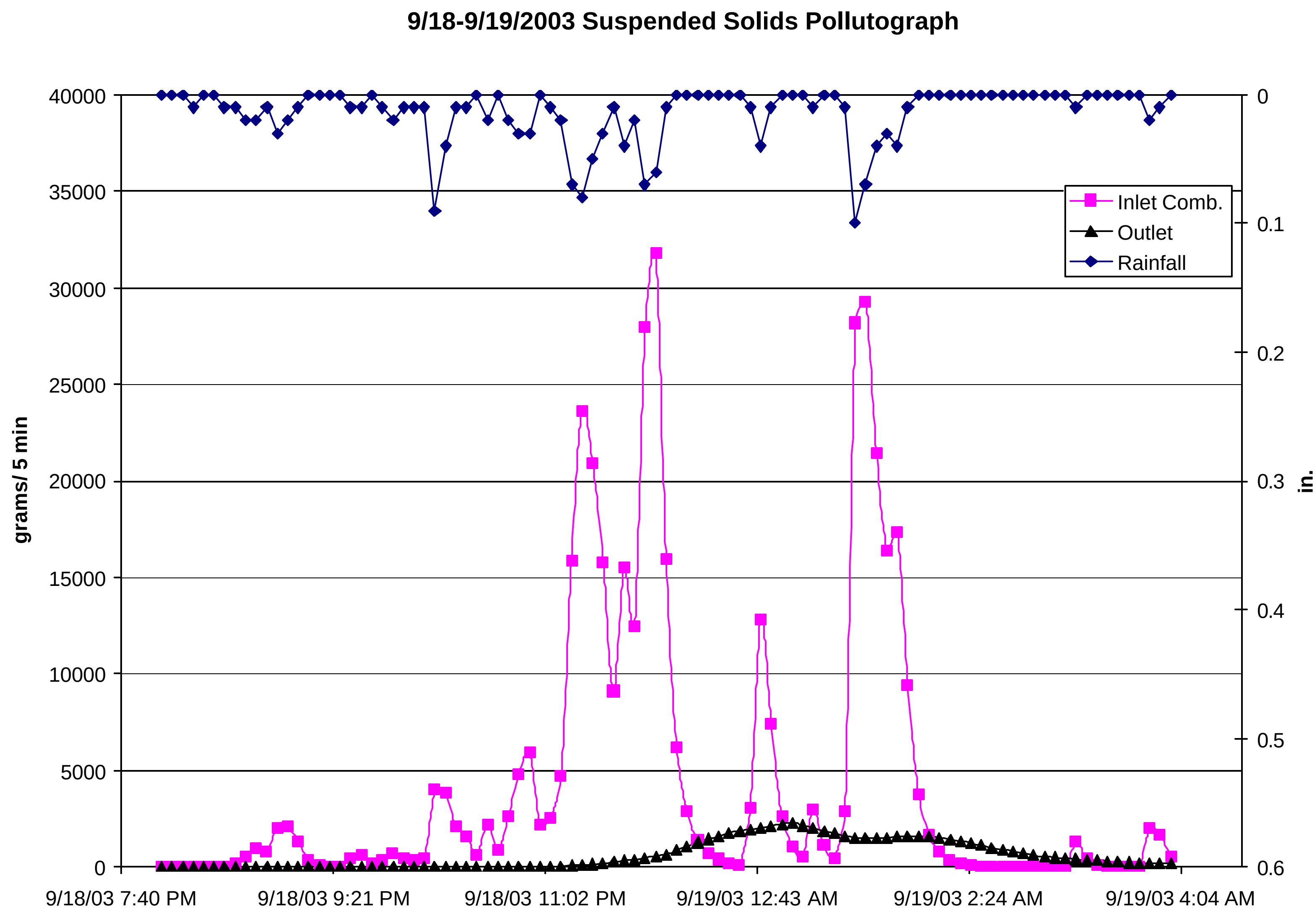


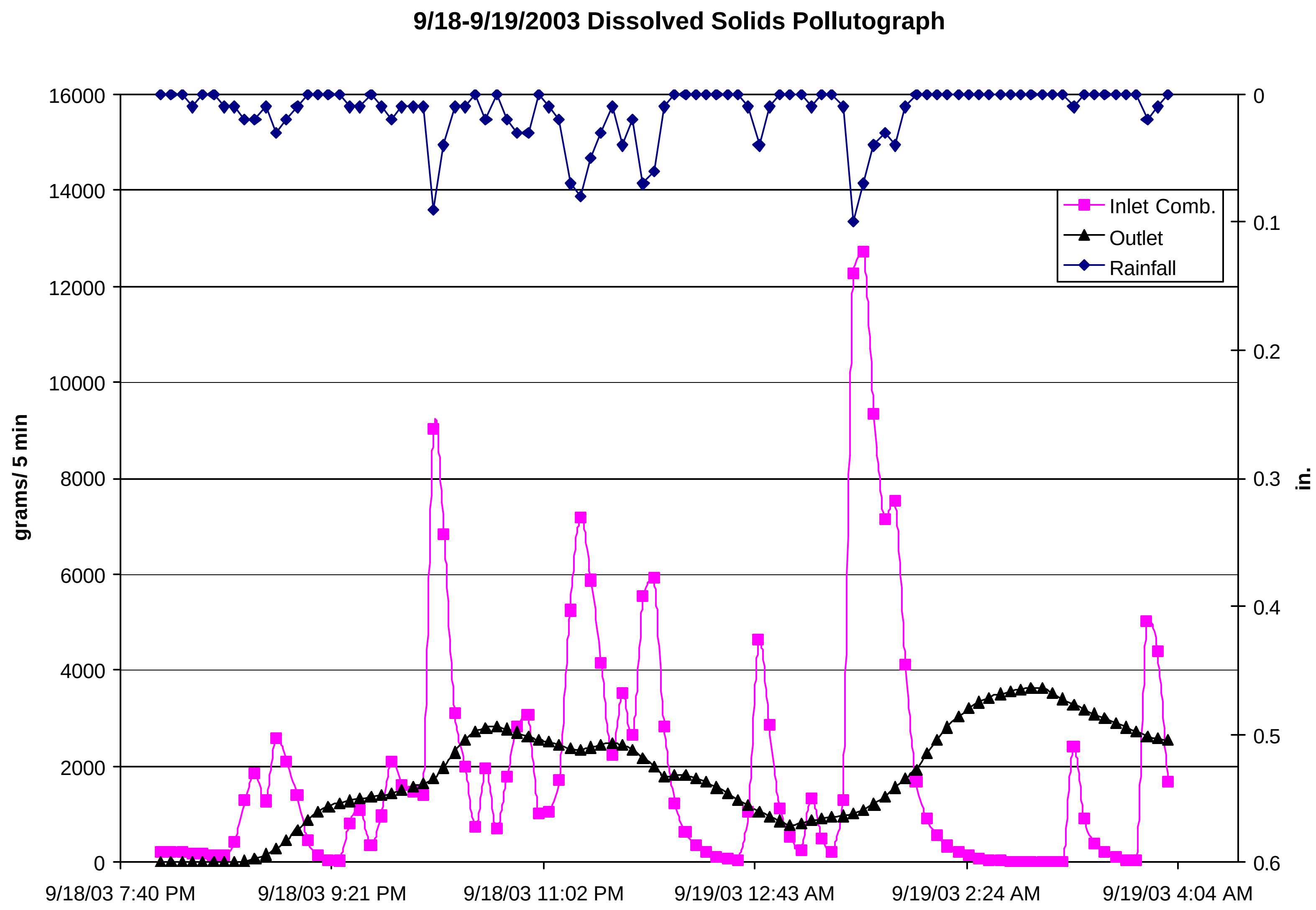
9/18-9/19/2003 Total Nitrogen Pollutograph
grams/ 5 min
in.
400
350
300
250
200
150
100
50
0
0
0.1
0.2
0.3
0.4
0.5
0.6
9/18/03 7:40 PM
9/18/03 9:21 PM
9/18/03 11:02 PM
9/19/03 12:43 AM
9/19/03 2:24 AM
9/19/03 4:04 AM
Inlet Comb.
Outlet
Rainfall


9/18-9/19/2003 Nitrate Pollutograph
grams/ 5 min
450
400
350
300
250
200
150
100
50
0
in.
0
0.1
0.2
0.3
0.4
0.5
0.6
9/18/03 7:40 PM
9/18/03 9:21 PM
9/18/03 11:02 PM
9/19/03 12:43 AM
9/19/03 2:24 AM
9/19/03 4:04 AM
Inlet Comb.
Outlet
Rainfall

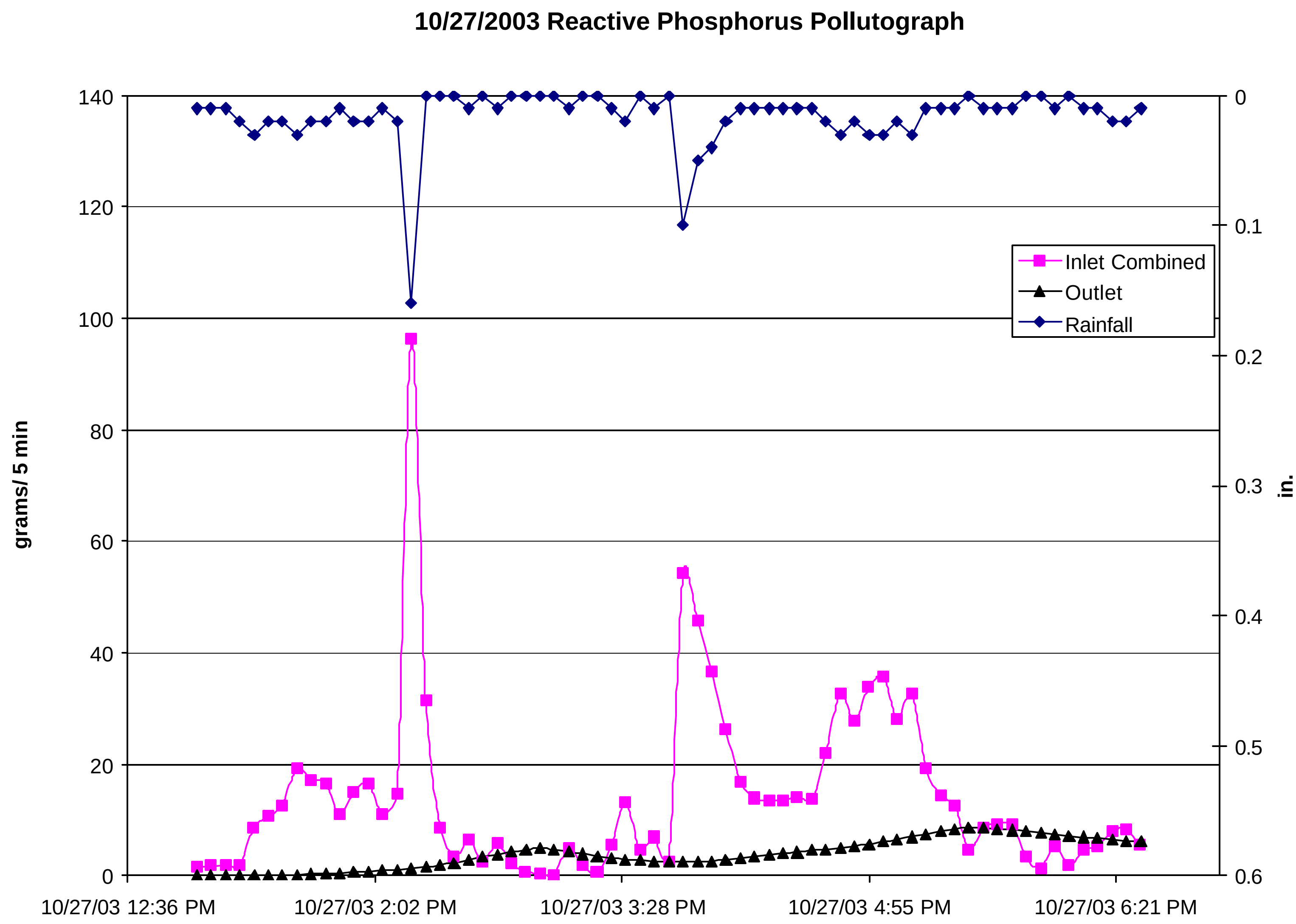


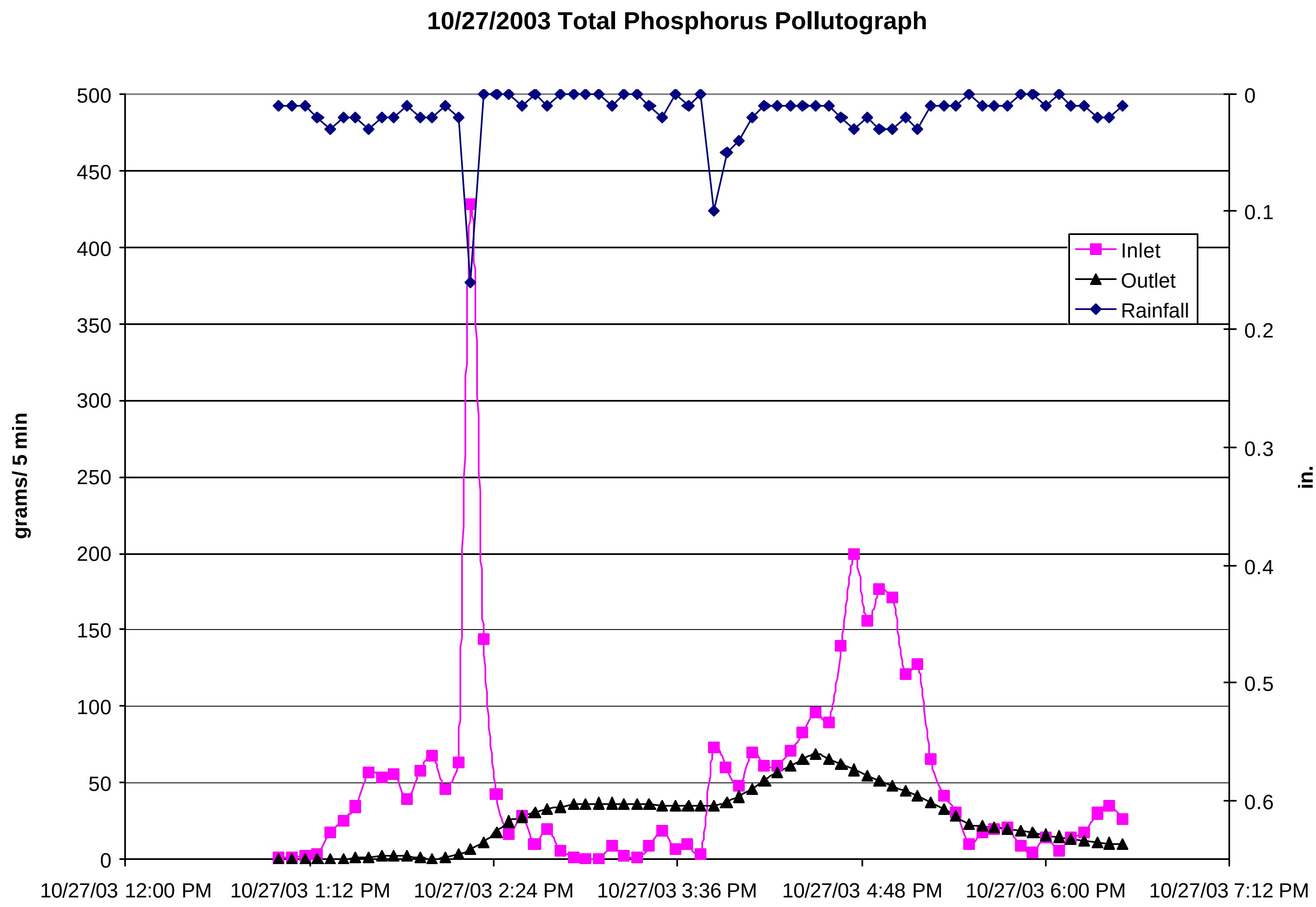
9/18-9/19/2003 Chloride Pollutograph
grams/ 5 min
in.
4000
3500
3000
2500
2000
1500
1000
500
0
0
0.1
0.2
0.3
0.4
0.5
0.6
9/18/03 7:40 PM
9/18/03 9:21 PM
9/18/03 11:02 PM
9/19/03 12:43 AM
9/19/03 2:24 AM
9/19/03 4:04 AM
Inlet Comb.
Outlet
Rainfall


9/18-9/19/2003 Suspended Solids Pollutograph
grams/ 5 min
in.
40000
35000
30000
25000
20000
15000
10000
5000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
9/18/03 7:40 PM
9/18/03 9:21 PM
9/18/03 11:02 PM
9/19/03 12:43 AM
9/19/03 2:24 AM
9/19/03 4:04 AM
Inlet Comb.
Outlet
Rainfall

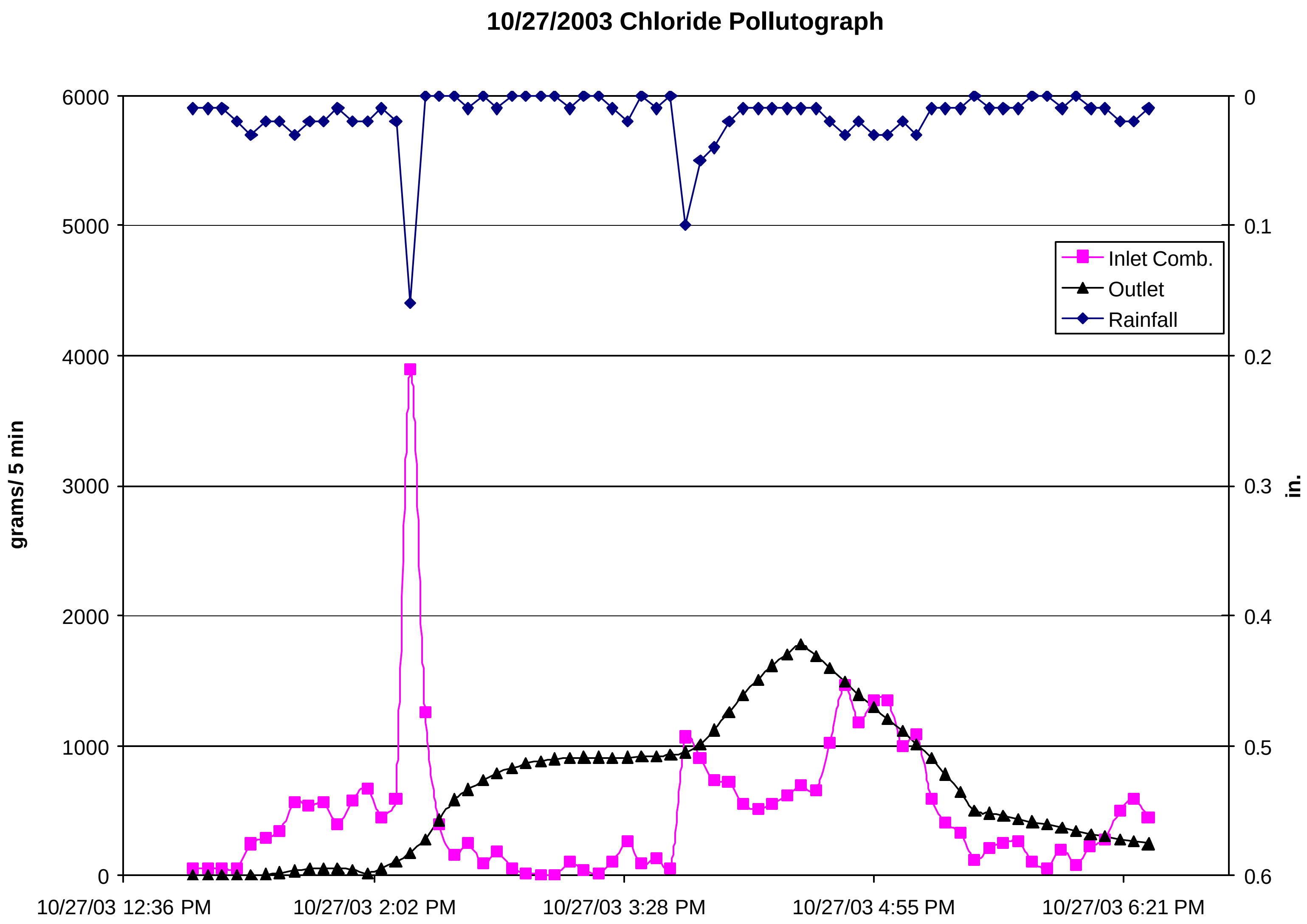


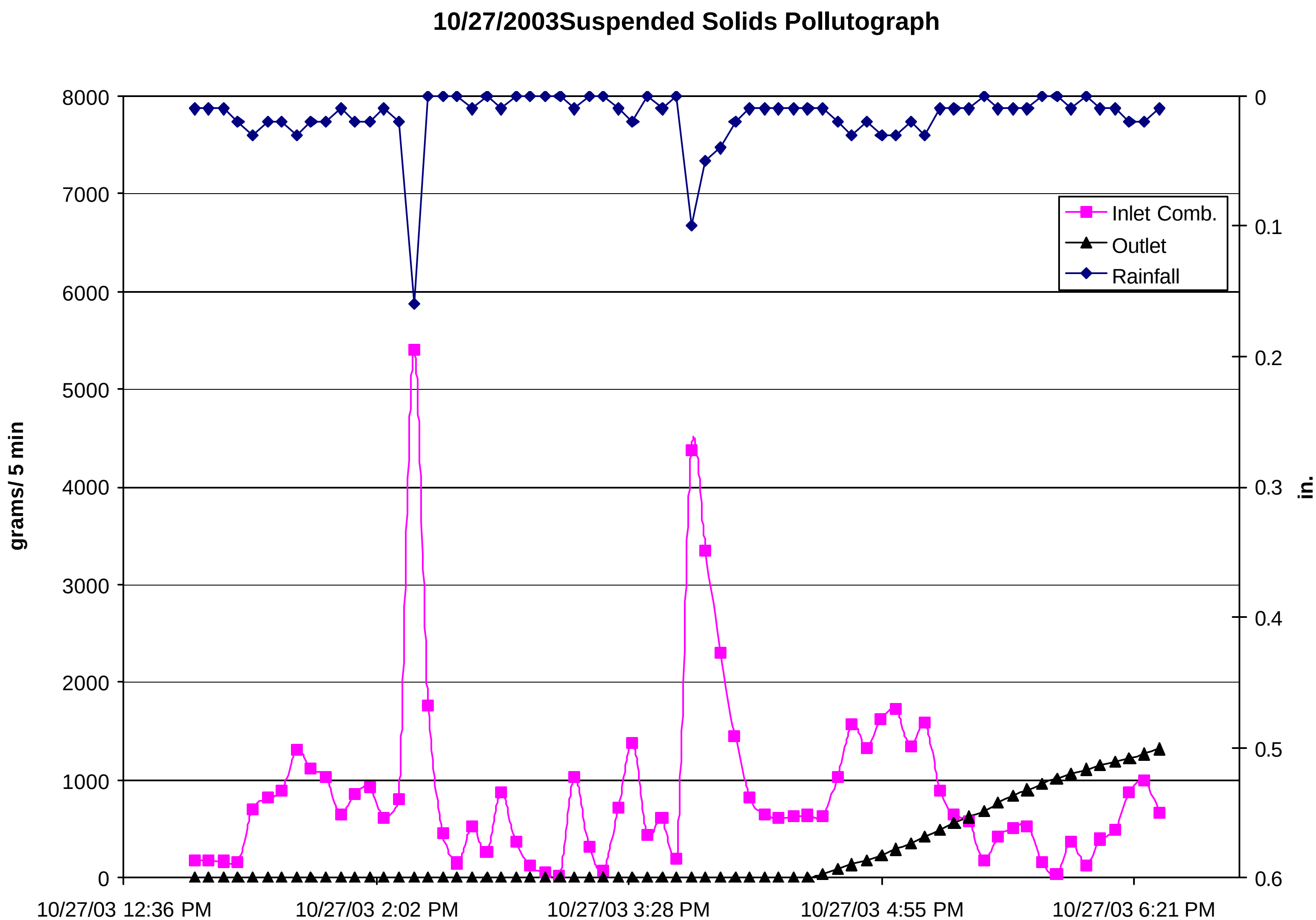
9/18-9/19/2003 Dissolved Solids Pollutograph
grams/ 5 min
in.
16000
14000
12000
10000
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
9/18/03 7:40 PM
9/18/03 9:21 PM
9/18/03 11:02 PM
9/19/03 12:43 AM
9/19/03 2:24 AM
9/19/03 4:04 AM
Inlet Comb.
Outlet
Rainfall

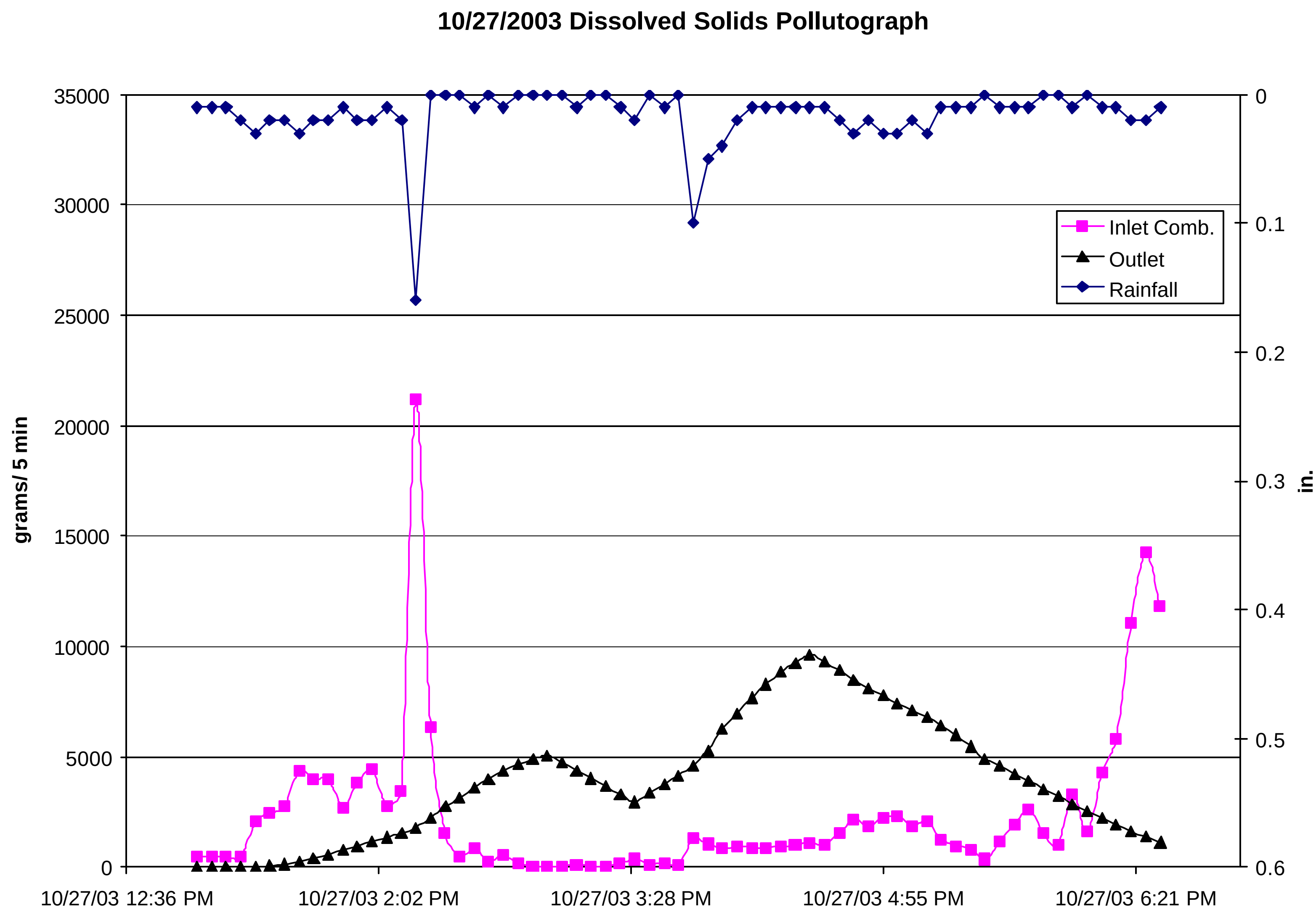

10/27/2003 Reactive Phosphorus Pollutograph
grams/ 5 min
in.
0
20
40
60
80
100
120
140
0
0.1
0.2
0.3
0.4
0.5
0.6
10/27/03 12:36 PM
10/27/03 2:02 PM
10/27/03 3:28 PM
10/27/03 4:55 PM
10/27/03 6:21 PM
Inlet Combined
Outlet
Rainfall

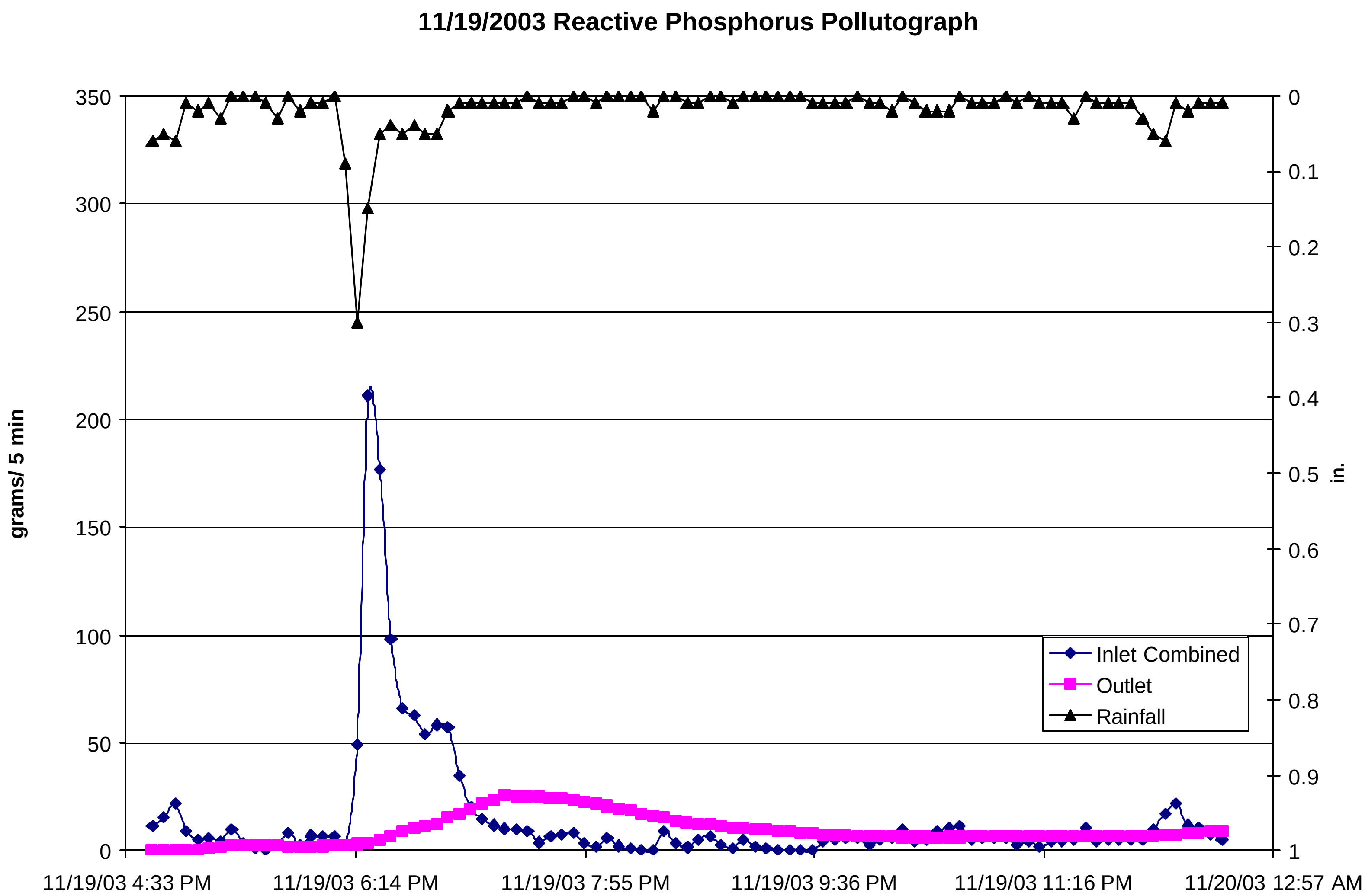


10/27/2003 Total Phosphorus Pollutograph
grams/ 5 min
in.
500
450
400
350
300
250
200
150
100
50
0
0
0.1
0.2
0.3
0.4
0.5
0.6
Inlet
Outlet
Rainfall
10/27/03 12:00 PM
10/27/03 1:12 PM
10/27/03 2:24 PM
10/27/03 3:36 PM
10/27/03 4:48 PM
10/27/03 6:00 PM
10/27/03 7:12 PM


10/27/2003 Chloride Pollutograph
grams/ 5 min
in.
6000
5000
4000
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
10/27/03 12:36 PM
10/27/03 2:02 PM
10/27/03 3:28 PM
10/27/03 4:55 PM
10/27/03 6:21 PM
Inlet Comb.
Outlet
Rainfall


10/27/2003Suspended Solids Pollutograph
grams/ 5 min
in.
8000
7000
6000
5000
4000
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
10/27/03 12:36 PM
10/27/03 2:02 PM
10/27/03 3:28 PM
10/27/03 4:55 PM
10/27/03 6:21 PM
Inlet Comb.
Outlet
Rainfall


10/27/2003 Dissolved Solids Pollutograph
grams/ 5 min
in.
35000
30000
25000
20000
15000
10000
5000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
10/27/03 12:36 PM
10/27/03 2:02 PM
10/27/03 3:28 PM
10/27/03 4:55 PM
10/27/03 6:21 PM
Inlet Comb.
Outlet
Rainfall


11/19/2003 Reactive Phosphorus Pollutograph
grams/ 5 min
350
300
250
200
150
100
50
0
in.
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
11/19/03 4:33 PM
11/19/03 6:14 PM
11/19/03 7:55 PM
11/19/03 9:36 PM
11/19/03 11:16 PM
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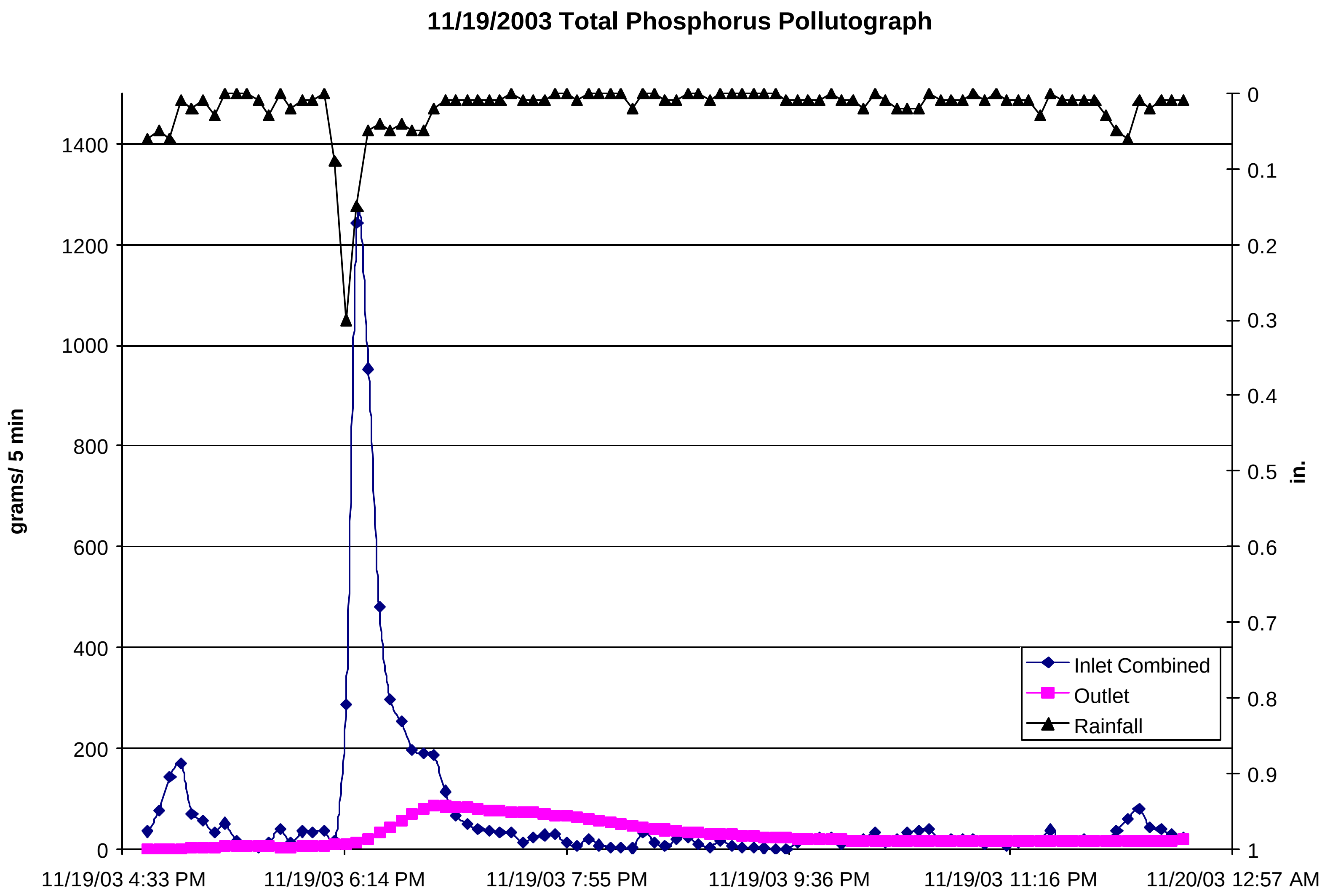
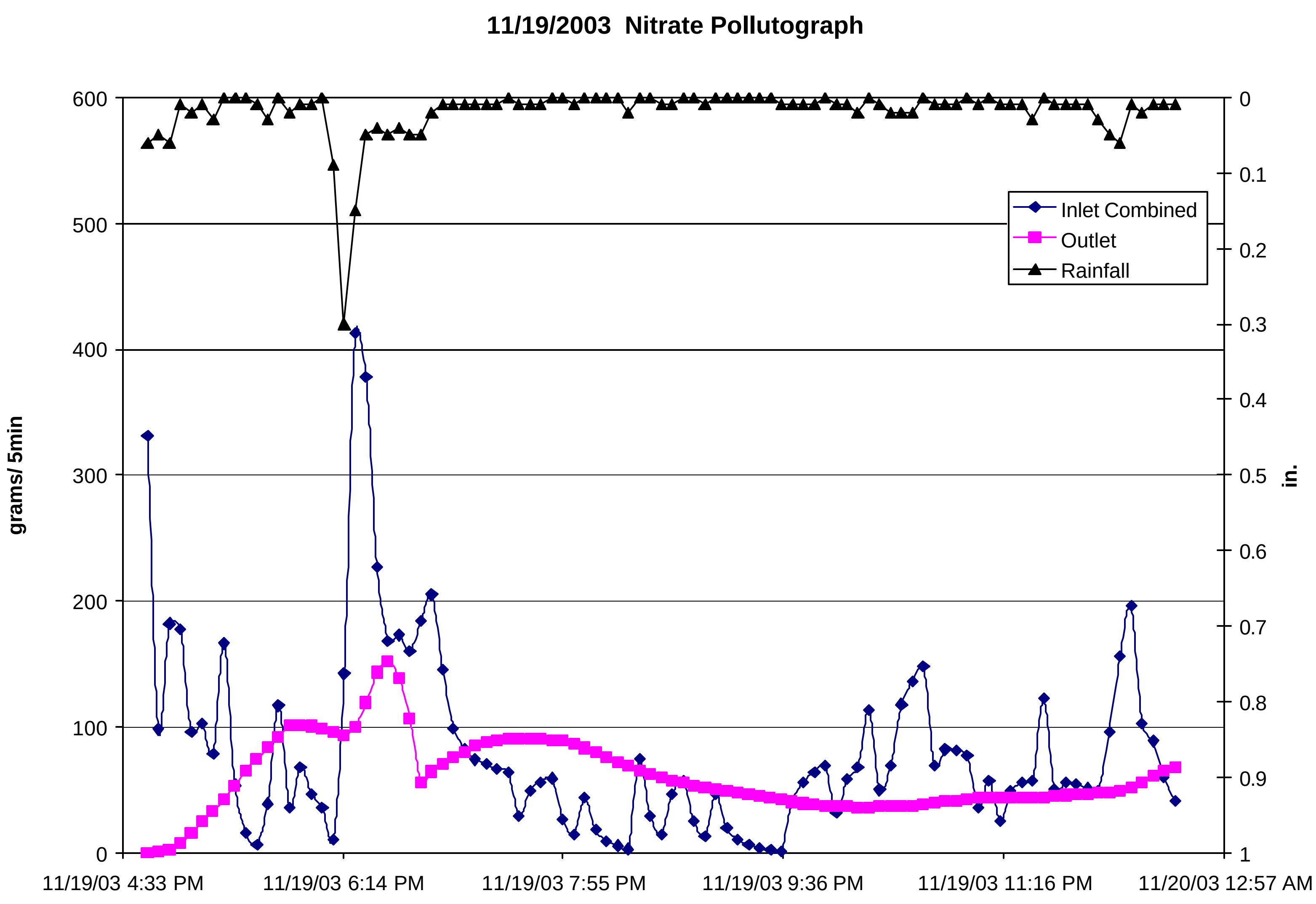
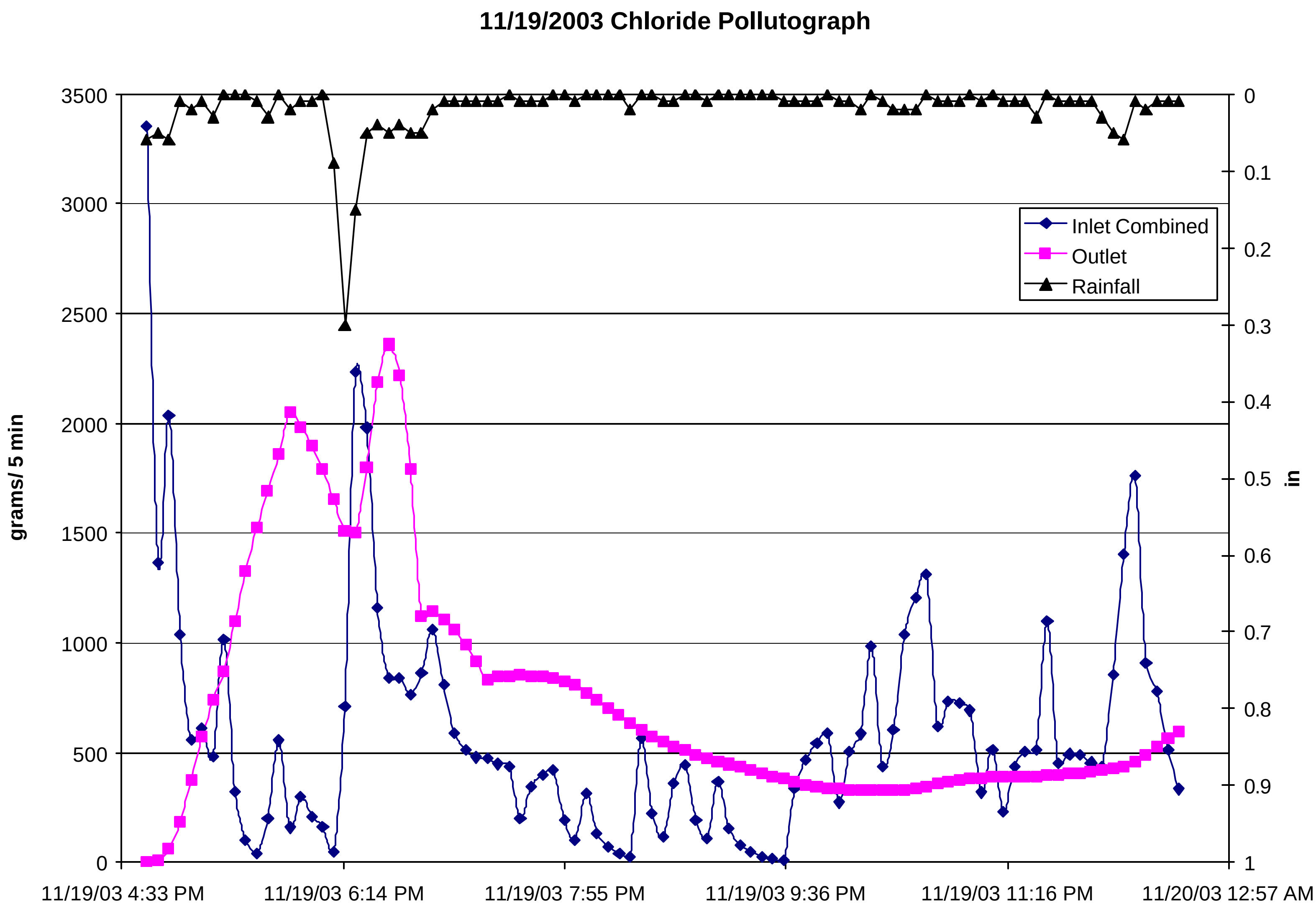
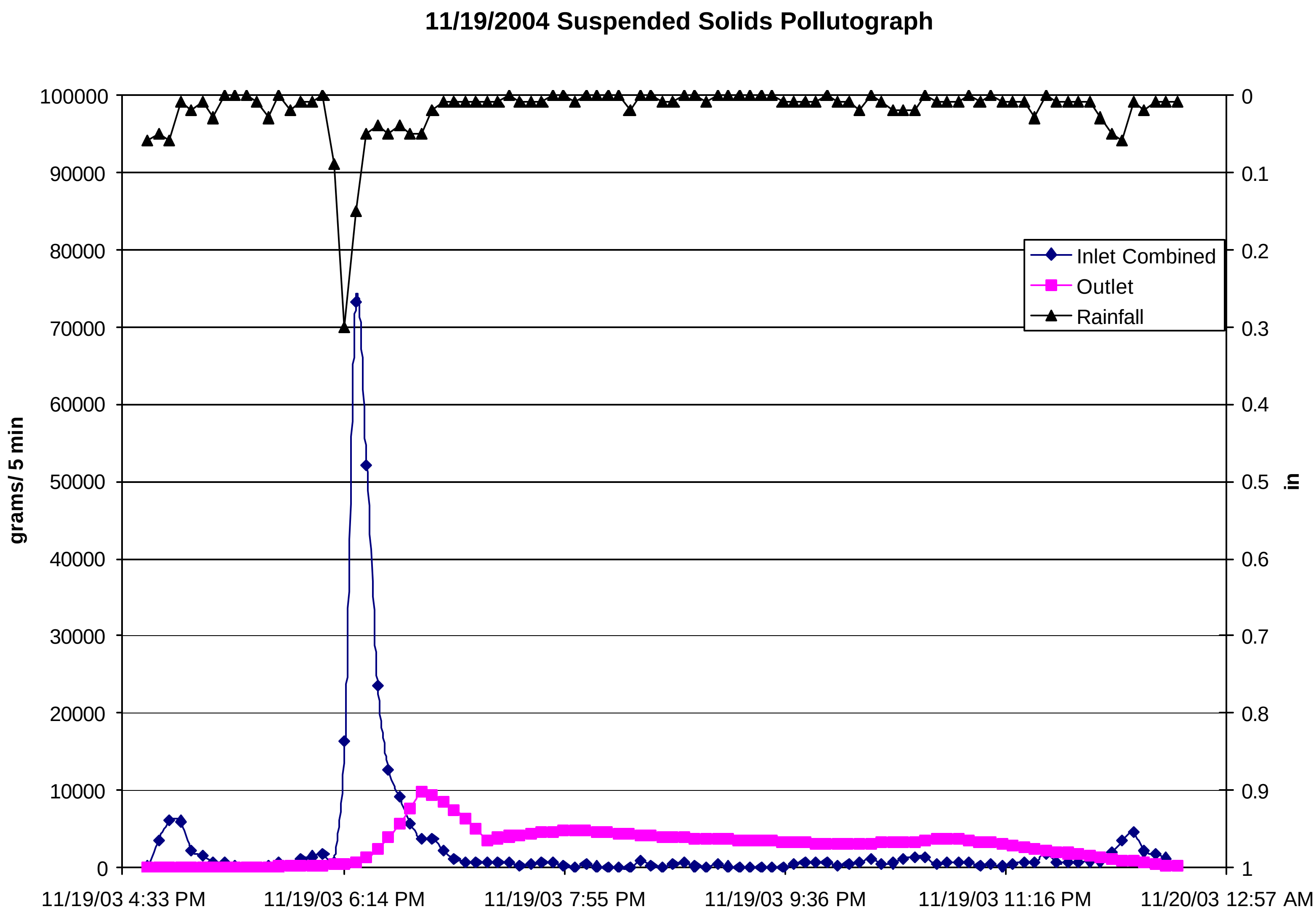
Inlet Combined
Outlet
Rainfall

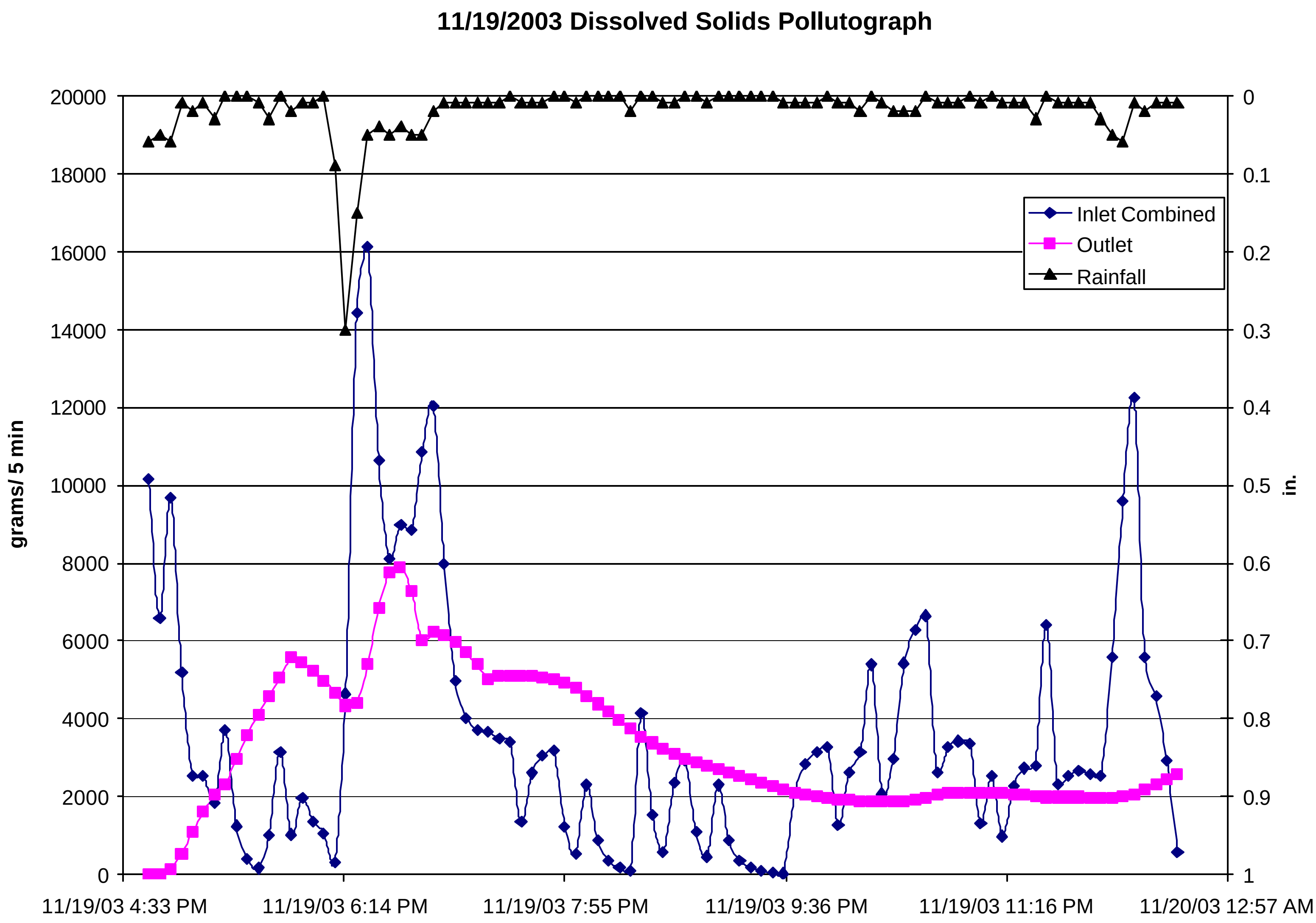


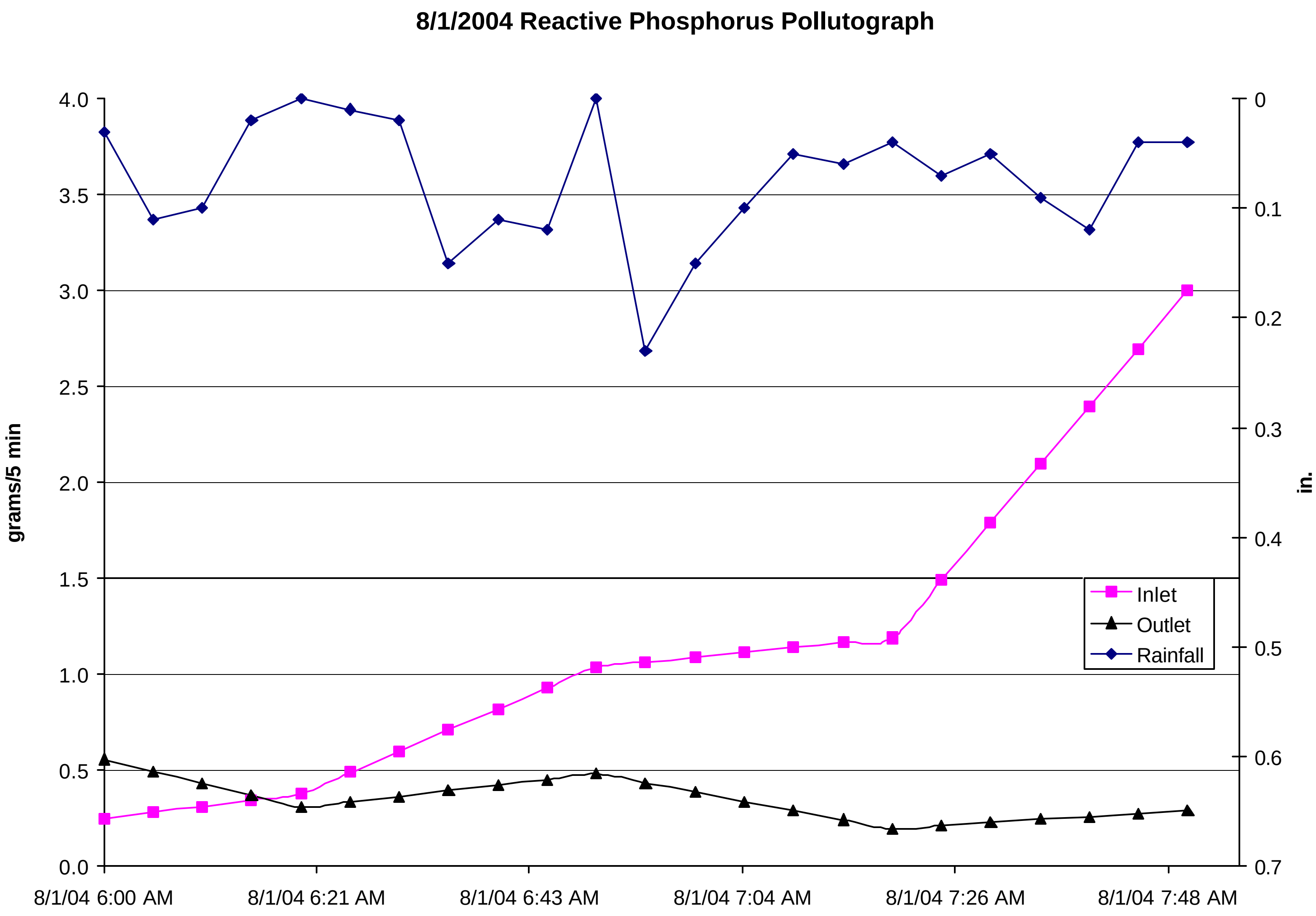
11/19/2003 Total Phosphorus Pollutograph
grams/ 5 min
in.
0
200
400
600
800
1000
1200
1400
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
11/19/03 4:33 PM
11/19/03 6:14 PM
11/19/03 7:55 PM
11/19/03 9:36 PM
11/19/03 11:16 PM
11/20/03 12:57 AM
Inlet Combined
Outlet
Rainfall

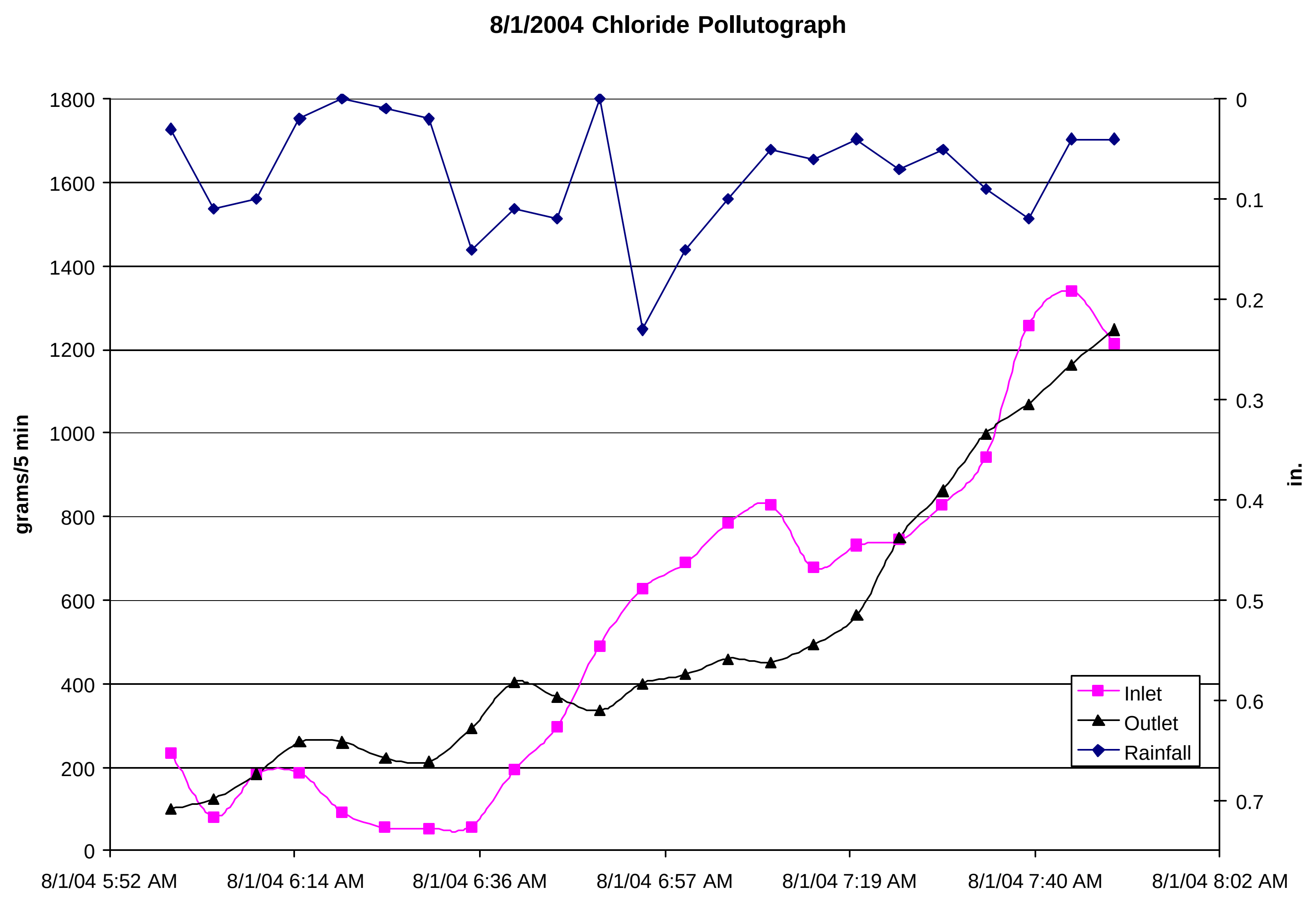

11/19/2003 Nitrate Pollutograph
grams/ 5min
in.
0
100
200
300
400
500
600
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
11/19/03 4:33 PM
11/19/03 6:14 PM
11/19/03 7:55 PM
11/19/03 9:36 PM
11/19/03 11:16 PM
11/20/03 12:57 AM
Inlet Combined
Outlet
Rainfall

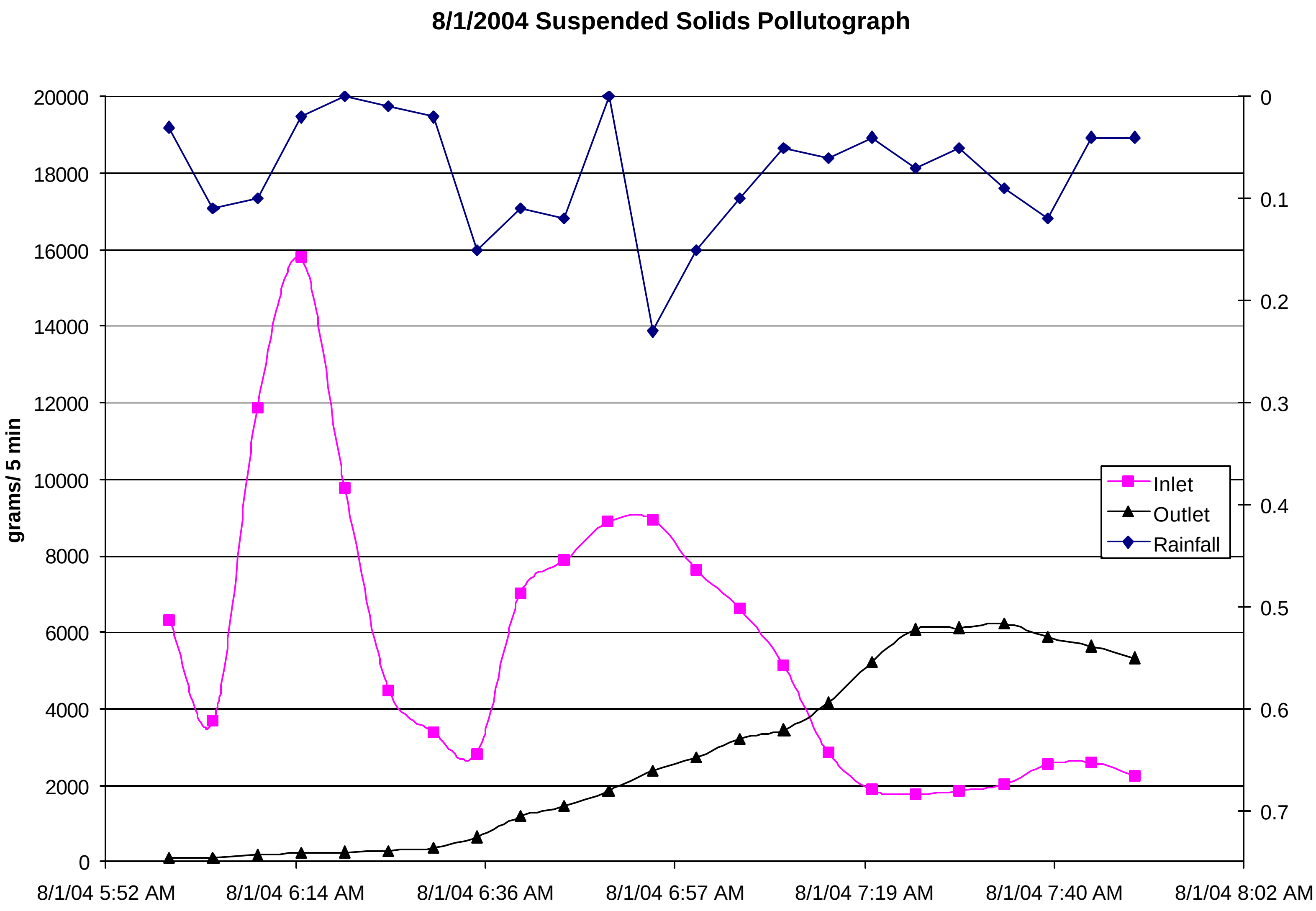

11/19/2003 Chloride Pollutograph
grams/ 5 min
in
3500
3000
2500
2000
1500
1000
500
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
11/19/03 4:33 PM
11/19/03 6:14 PM
11/19/03 7:55 PM
11/19/03 9:36 PM
11/19/03 11:16 PM
11/20/03 12:57 AM
Inlet Combined
Outlet
Rainfall

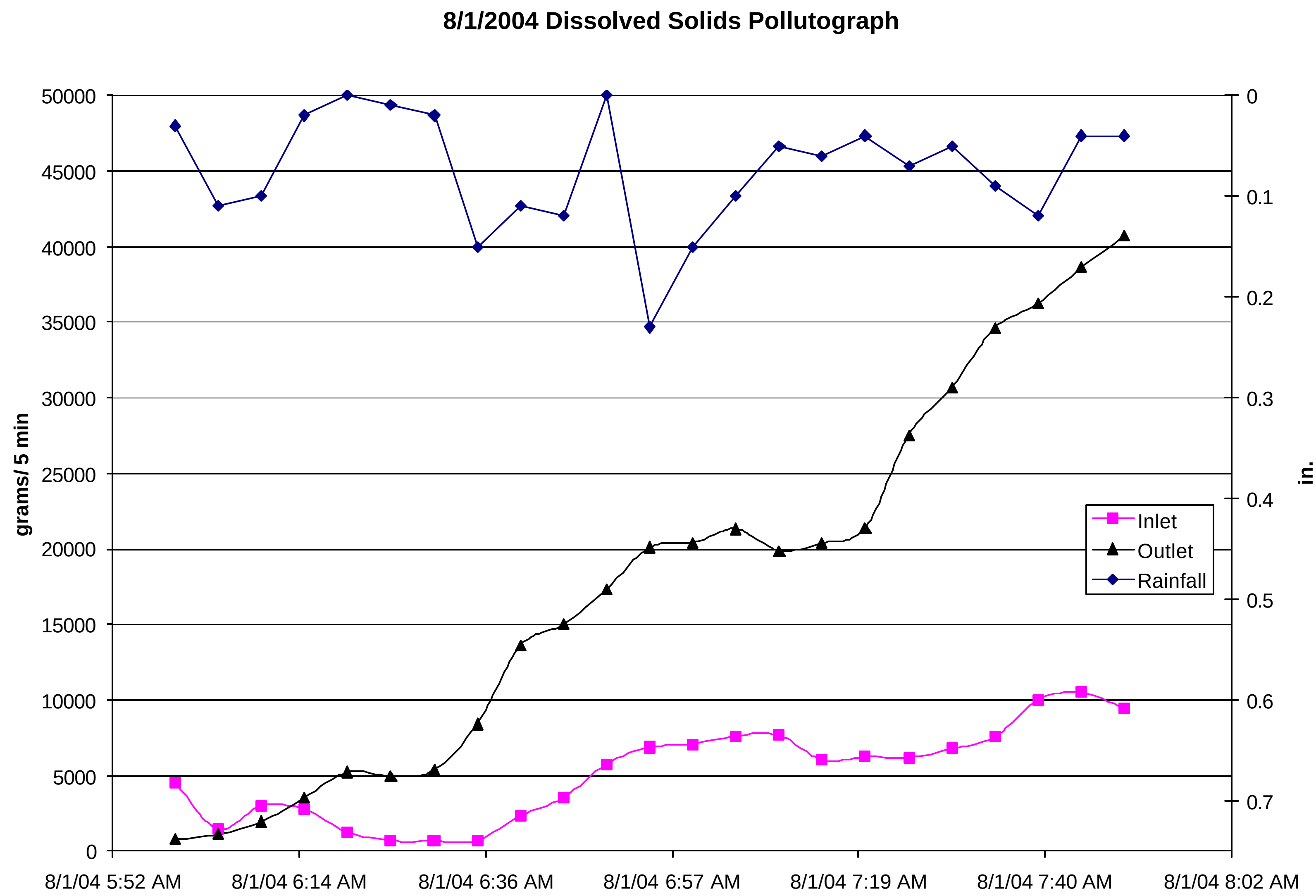

11/19/2004 Suspended Solids Pollutograph
grams/ 5 min
in
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
11/19/03 4:33 PM
11/19/03 6:14 PM
11/19/03 7:55 PM
11/19/03 9:36 PM
11/19/03 11:16 PM
11/20/03 12:57 AM
Inlet Combined
Outlet
Rainfall


11/19/2003 Dissolved Solids Pollutograph
grams/ 5 min
in.
Inlet Combined
Outlet
Rainfall
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
11/19/03 4:33 PM
11/19/03 6:14 PM
11/19/03 7:55 PM
11/19/03 9:36 PM
11/19/03 11:16 PM
11/20/03 12:57 AM


8/1/2004 Reactive Phosphorus Pollutograph
grams/5 min
in.
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
8/1/04 6:00 AM
8/1/04 6:21 AM
8/1/04 6:43 AM
8/1/04 7:04 AM
8/1/04 7:26 AM
8/1/04 7:48 AM
Inlet
Outlet
Rainfall


8/1/2004 Chloride Pollutograph
grams/5 min
in.
1800
1600
1400
1200
1000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
8/1/04 5:52 AM
8/1/04 6:14 AM
8/1/04 6:36 AM
8/1/04 6:57 AM
8/1/04 7:19 AM
8/1/04 7:40 AM
8/1/04 8:02 AM
Inlet
Outlet
Rainfall


8/1/2004 Suspended Solids Pollutograph
grams/ 5 min
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
8/1/04 5:52 AM
8/1/04 6:14 AM
8/1/04 6:36 AM
8/1/04 6:57 AM
8/1/04 7:19 AM
8/1/04 7:40 AM
8/1/04 8:02 AM
Inlet
Outlet
Rainfall


8/1/2004 Dissolved Solids Pollutograph
grams/ 5 min
in.
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
8/1/04 5:52 AM
8/1/04 6:14 AM
8/1/04 6:36 AM
8/1/04 6:57 AM
8/1/04 7:19 AM
8/1/04 7:40 AM
8/1/04 8:02 AM
Inlet
Outlet
Rainfall